

C S A

**Scientific Council for Africa South of the Sahara
Conseil Scientifique pour l'Afrique au Sud du Sahara**

**CSA SPECIALIST MEETING ON
WATER TREATMENT**

**REUNION DE SPECIALISTES CSA SUR
LE TRAITEMENT DES EAUX**

PRETORIA

1960

C C T A

**Commission for Technical Co-operation in Africa South of the Sahara
Commission de Coopération Technique en Afrique au Sud du Sahara**

COMMISSION DE COOPERATION TECHNIQUE EN AFRIQUE AU SUD DU SAHARA

Créée en janvier 1950, la Commission de Coopération Technique en Afrique au Sud du Sahara (CCTA) a fait l'objet d'une convention intergouvernementale signée à Londres le 18 janvier 1954. Elle se compose, à l'heure actuelle, des Gouvernements suivants : Afrique du Sud, Belgique, Cameroun, Congo (Brazzaville), Congo (Leopoldville), Côte d'Ivoire, Dahomey, Fédération de la Rhodésie et du Nyassaland, France, Gabon, Ghana, Guinée, Haute-Volta, Libéria, Madagascar, Mali, Mauritanie, Niger, Nigéria, Portugal, République Centre-Africaine, Royaume-Uni, Sénégal, Somalie, Tchad.

OBJECTIF

Assurer la coopération technique entre les territoires dont les Gouvernements Membres sont responsables en Afrique au Sud du Sahara.

20°

ATTRIBUTIONS

- 1) Traiter de tout sujet concernant la coopération technique entre les Gouvernements Membres et leurs territoires dans le cadre de la compétence territoriale de la CCTA.
- 2) Recommander aux Gouvernements Membres toutes mesures tendant à la mise en œuvre de cette coopération.
- 3) Convoquer les conférences techniques que les Gouvernements Membres ont décidé de tenir.
- 4) Contrôler du point de vue général et du point de vue financier l'activité des organismes placés sous son égide et présenter aux Gouvernements Membres toutes recommandations y afférentes.
- 5) Présenter des recommandations aux Gouvernements Membres en vue de la création de nouveaux organismes ou la révision des dispositions existantes pour la coopération technique, dans le cadre de la compétence territoriale de la CCTA.
- 6) Présenter des recommandations aux Gouvernements Membres en vue de formuler des demandes conjointes d'assistance technique aux Organisations internationales.
- 7) Présenter des avis sur toutes questions concernant la coopération technique que lui soumettront les Gouvernements Membres.
- 8) Administrer le Fonds Interafricain de la Recherche et la Fondation pour l'Assistance Mutuelle en Afrique au Sud du Sahara.

BUDGET

Alimenté par les contributions des Gouvernements Membres.

ORGANISATION

- 1) La CCTA se réunit au moins une fois chaque année. Ses recommandations et conclusions sont portées à la connaissance des Gouvernements Membres en vue de leur adoption à l'unanimité ainsi que de leur mise en œuvre dans les territoires intéressés.
- 2) Le Conseil Scientifique pour l'Afrique au Sud du Sahara (CSA), conseiller scientifique de la CCTA, a été créé en novembre 1950, comme suite à la Conférence Scientifique de Johannesburg (1949), en vue de favoriser l'application de la science à la solution des problèmes africains. Il est composé de personnalités éminentes, choisies de telle sorte que les principales disciplines scientifiques importantes au stade actuel du développement de l'Afrique soient représentées. En tant que membres du Conseil ces personnalités n'agissent pas sur instructions de leurs Gouvernements respectifs mais sont responsables individuellement devant le Conseil.
- 3) Des Bureaux et Comités techniques traitent chacun un aspect particulier de la coopération régionale et interterritoriale en Afrique au Sud du Sahara.
- 4) Le Secrétariat de la CCTA et du CSA comprend deux sièges : l'un à Lagos, l'autre à Nairobi. Il est dirigé par un Secrétaire Général assisté de deux Secrétaires Généraux Adjointes et, à Nairobi, d'un Secrétaire Scientifique et d'un Secrétaire Scientifique Adjoint. Le Secrétaire de la FAMA est également adjoint au Secrétaire Général.

PUBLICATIONS

Des brochures traitant de problèmes scientifiques et techniques, dont les données sont habituellement rassemblées en Afrique par le CSA, sont publiées à Londres. Toute demande d'information devra être adressée au Bureau des Publications, Watergate House, York Buildings, Londres W.C. 2.

COMMISSION FOR TECHNICAL CO-OPERATION IN AFRICA SOUTH OF THE SAHARA

Established in January 1950, the Commission for Technical Co-operation in Africa South of the Sahara (CCTA) was the subject of an Intergovernmental Agreement signed in London on 18 January 1954. It consists now of the following Governments: Belgium, Cameroon, Central-African Republic, Chad, Congo (Brazzaville), Congo (Leopoldville), Dahomey, Federation of Rhodesia and Nyasaland, France, Gabon, Ghana, Guinea, Ivory Coast, Liberia, Madagascar, Mali, Mauritania, Niger, Nigeria, Portugal, Senegal, Somalia, South Africa, United Kingdom, Upper Volta.

OBJECT

To ensure technical co-operation between territories for which Member Governments are responsible in Africa South of the Sahara.

FUNCTIONS

- (1) To concern itself with all matters affecting technical co-operation between the Member Governments and their territories within the territorial scope of CCTA.
- (2) To recommend to Member Governments measures for achieving such co-operation.
- (3) To convene technical conferences as agreed by Member Governments.
- (4) To supervise, from the financial and general points of view, the work of the organisations placed under its aegis and make recommendations thereon to the Member Governments.
- (5) To make recommendations to the Member Governments for the setting up of new organisations or the revision of existing arrangements for securing technical co-operation within the territorial scope of CCTA.
- (6) To make recommendations to the Member Governments with a view to the formulation of joint requests for technical assistance from international organisations.
- (7) To advise Member Governments on any other subject in the field of technical co-operation which the Member Governments may bring to its notice.
- (8) To administer the Inter-African Research Fund and the Foundation for Mutual Assistance in Africa South of the Sahara.

FINANCE

Contributions from Member Governments.

ORGANISATION

- (1) CCTA meets at least once a year. Its recommendations and conclusions are submitted to Member Governments for unanimous approval and for implementation in the territories concerned.
- (2) The Scientific Council for Africa South of the Sahara (CSA) Scientific Adviser to CCTA, was established in November 1950 following the Johannesburg Scientific Conference (1949), to further the application of science to the solution of African problems. Its members are eminent scientists chosen in such a manner that the main scientific disciplines important at the present stage of the development of Africa shall be represented. As members of the Council they do not receive instructions from Governments but are responsible individually to the Council.
- (3) Technical Bureaux and Committees deal with specific aspects of regional and inter-territorial co-operation in Africa South of the Sahara.
- (4) The CCTA CSA Secretariat has two offices, one in Lagos and one in Nairobi. The Secretariat has at its head a Secretary-General, who is aided in his work by two Assistant Secretaries-General and, at Nairobi, by a Scientific Secretary and an Assistant Scientific Secretary. The Secretary-General is also assisted by the Secretary of FAMA.

PUBLICATIONS

Publications dealing with scientific and technical problems, the data for which are usually collected in Africa by CSA, are issued in London. Enquiries should be addressed to the Publications Bureau, Watergate House, York Buildings, London, W.C. 2.

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*Abstract

CSA

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SUR LE TRAITEMENT DES EAUX

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AGENDA

- I. Water demineralisation
- II. Surface water supplies—some hydrobiological aspects
- III. Control and prevention of pollution
- IV. Treatment of sewage and effluents

ORDRE DU JOUR

- I. Déminéralisation des eaux
- II. Utilisation des eaux de surface — quelques aspects de l'hydrobiologie
- III. Méthodes de prévention et de lutte
- IV. Traitement et évacuation des eaux d'égouts et des eaux vannes

LIST OF TECHNICAL DOCUMENTS

LISTE DES DOCUMENTS TECHNIQUES

The following technical documents were issued for this meeting :

Les documents techniques dont les titres sont donnés ci-dessous ont été diffusés pour cette réunion :

<i>CSA W.T. (60) No.</i>	<i>Author/Auteur.</i>	<i>Title/Titre.</i>
2 ¹	CCTA/CSA Secretariat Secrétariat CCTA/CSA	Abstract of papers submitted. Résumé des papiers soumis.
3 ²	M. C. GOMELLA M. G. DROUHIN	Electrodialysis—research and work carried out in North Africa. Recherche et perfectionnements concernant l'électrodialyse — résultats obtenus en Afrique du Nord.
4 ³	M. C. GOMELLA	Solar distillation—an account of recent operation experiences in North Africa. Distillation solaire — recherche et travaux effectués en Afrique du Nord.
5 ³	Dr. B. A. SOUTHGATE	Treatment and disposal of industrial waste waters in Great Britain. Traitement et élimination des eaux industrielles en Grande Bretagne.
6 ³	Mr. T. A. MACLACHLAN	Recent progress in the development of water supplies in the Western region of Nigeria. Progrès récents dans le développement de l'approvisionnement en eau dans la Nigéria de l'Ouest.
7 ⁴	Dr. O. B. VOLCKMAN	Electrodialysis—research and development in South Africa. Electrodialyse — recherche et développement en Afrique du Sud.
8 ³	Mr. L. A. JOB	The effluent problems of the pulp and paper industry. Les problèmes des effluents de l'industrie de la pâte à papier.
9 ³	Mr. B. R. ALLANSON	The techniques and objectives of stream surveys. Techniques et buts des études de cours d'eau.
10 ⁴	Dr. E. WHITE	The industrial effluent policy of the local authority with reference to the control of pollution. Réglementation de la pollution par les autorités locales.
11 ⁴	Dr. G. J. STANDER	Surface water supplies. Eaux de surface.
12 ³	M. G. DROUHIN	Water demineralisation—a review of existing techniques. Désalinisation des eaux — revue des techniques existantes.
13 ³	Dr. O. B. VOLCKMAN	Treatment of brack water supplies for farm stock. Traitement des eaux saumâtres pour le bétail.
14 ³	M. C. GOMELLA	General problems of demineralisation of water by distillation. Des problèmes généraux de la déminéralisation des eaux par distillation.
15 ⁴	Mr. N. NICOLLE	The re-use of sewage effluents in South Africa. Réutilisation des eaux d'égouts en Afrique du Sud.

¹ Bilingual/bilingue.

² Original language English.

³ Langue originale français.

⁴ English only.

⁵ Français seulement.

<i>CSA W.T. (60) No.</i>	<i>Author/Auteur.</i>	<i>Title/Titre.</i>
16 ⁴	Mr. C. P. ROBINSON	The water purification system of the Rand Water Board. Système de purification des eaux du Rand Water Board.
17 ⁴	Dr. E. O. SEIPOLD	The rate of sulphate removal in sodium chloride containing feed waters using a simplified type of electro-dialytic water demineralisation apparatus. Etude sur l'élimination du sulfate dans des solutions de chlorure de sodium grâce à un appareil d'électro-dialyse simplifié.
18 ⁴	Dr. B. J. CHOLNOKY	The relationship between algae and the chemistry of natural waters. Le rapport entre les algues et la composition chimique des eaux naturelles.
19 ⁴	Mr. P. R. LOEWENSTEIN	By-product recovery and the effluent problem of the oil from coal industry. Récupération des sous-produits et problèmes du déversement dans l'industrie de l'extraction de l'huile de charbon.
20 ⁴	Dr. A. D. HARRISON	The role of river fauna in the assessment of pollution. Le rôle de la faune de rivière dans l'évaluation de la pollution.
21 ⁴	Mr. C. C. VAN DER MERWE. Mr. G. P. VERSTER Mr. W. N. VAN EEDEN	Important considerations in the specification of standards for effluents discharged into water courses. Facteurs à considérer dans l'établissement de normes en ce qui concerne le déversement d'eaux polluées dans les cours d'eau.
22 ⁴	Mr. A. ABBOTT	Treatment of raw sewage by means of oxidation ponds. Traitement des eaux d'égouts au moyen de fosses d'oxydation.
23 ⁴	Mr. G. A. R. DOWLING Mr. J. L. STALLEBRAS	The administration and enforcement of the laws relating to the use of water for industrial purposes and to the prevention of water pollution in the Union of South Africa. Administration et application des lois pour des buts industriels et la prévention de la pollution en Union Sud-africaine.
24 ⁴	Mr. H. VAN ECK	Theory of stabilisation ponds and its implication on their design and operation. Théorie des fosses de stabilisation et son influence sur leur dessin et leur fonctionnement.

DEMINERALISATION DES EAUX

Rapporteur : Dr O. B. Volckman

La définition de la qualité recherchée pour l'eau déminéralisée a été soulignée comme étant d'un grand intérêt, particulièrement en ce qui concerne l'effet physiologique des sels.

Quel que soit le procédé de déminéralisation utilisé, distillation d'un type quelconque ou électrodialyse, la lutte contre l'incrustation a été considérée comme fondamentale.

Il a été admis que la distillation (à l'exclusion de la distillation solaire) est un procédé techniquement bien au point. Des progrès fondamentaux seront vraisemblablement lents. L'électrodialyse constitue l'autre moyen d'envergure pour déminéraliser les eaux salines. Pour ce procédé, les perspectives d'amélioration sont considérables et il est recommandé d'en poursuivre l'étude avec vigueur.

La distillation solaire semble peu prometteuse sur le plan économique avec des appareils de type " serre " de quelque dimension que ce soit. Elle permet cependant des applications limitées dans les cas où la simplicité de l'exploitation est requise. Un appareil répondant à ces conditions a été réalisé commercialement en Algérie. La difficulté majeure pour trouver de nouvelles voies de recherche réside dans le prix élevé de la captation de la radiation solaire à un haut niveau énergétique.

Eu égard aux travaux effectués sur l'électrodialyse en Afrique du Sud et en Algérie, on a souligné la différence suivante : en Afrique du Nord, l'effort a surtout porté sur le perfectionnement technologique de prototypes existants et sur la commercialisation alors que les réalisations en Afrique du Sud ont couvert un domaine plus vaste, comprenant à la fois la construction de puissantes installations et de petits appareils simples, ainsi que la fabrication des membranes.

Les travaux accomplis dans les deux pays sont par nature complémentaires. Les chercheurs algériens ont acquis une expérience plus complète dans le traitement des eaux dures. Ce sont probablement ces types d'eaux que l'on rencontrera le plus souvent dans les applications de l'électrodialyse.

Il a été considéré comme très souhaitable que des recherches soient entreprises en vue d'obtenir des membranes présentant des propriétés de sélectivité ionique. Ceci pourrait constituer la clef d'un développement commercial considérable de l'électrodialyse.

REPORTS/RAPPORTS

Original : English

DEMINERALISATION OF WATER

Rapporteur : Dr. O. B. Volckman

The necessity of deciding the quality of water required for particular applications was stressed as being most important, particularly in view of the physiological effects of saline waters.

In all demineralisation processes the control of scaling is of vital importance, whether the process be one of distillation or of electro dialysis. Further study on the control of scaling, particularly in electro dialysis, was therefore regarded as essential.

It was considered that distillation (excluding solar distillation) is a well worked out engineering process. Fundamental improvements are likely to be slow. In the case of electro dialysis, the other major process for demineralising saline waters, the possibility of improvement is considerable and further intensive study of the process is justified.

Solar distillation shows little economic promise with plants of the "glass house" type, whatever their dimensions. It has, however, limited applications where very small quantities of water are required, and a simple process is needed. A plant complying with these conditions has been commercially developed in Algeria.

The main difficulty in finding new fields of research resides in the high cost of harnessing solar radiation at a high energy level.

In considering the work on electro dialysis in South Africa, and in Algeria, it was emphasised that the difference has been that the work in North Africa has been largely on technological improvements and the commercialisation of existing plant designs, while the work in South Africa has been more fundamental and has covered a wider range, with the development of both very large plants and very small simple plants and research on membranes. The work of the two countries is essentially complementary. The Algerian workers have had much greater experience in the treatment of high hardness waters. These are probably the chief types of waters that will be encountered in electro dialytic applications.

It was considered important that work should be carried out to develop membranes having selective ion removal properties. This could be the key to large commercial developments in electro dialysis.

Original : English

SURFACE WATER SUPPLIES AND SOME ASPECTS OF HYDROBIOLOGY

Rapporteur : Dr. G. J. Stander

The papers under this heading dealt with Surface Water supplies, the role of fauna in the assessment of pollution, the relationship between algae and the chemistry of the water, and the techniques and objectives of stream surveys.

On the question of treated sewage effluent the discussion centred on the problems caused by the presence of synthetic detergents. In treated sewage effluent in the United Kingdom the concentration of surface active agents not infrequently reached 4 ppm or higher. The discharge of sewage effluent into streams draining into the Vaal barrage has resulted in South Africa in concentrations of 0.5 ppm being observed, while in the Jukskei a concentration of 1.5 ppm has been recorded. The solution seemed to be in the preparation of new detergents which could easily be broken down under conventional sewage works processes.

In regard to surface water supplies the occurrence of ammonia as a result of agricultural activities was also raised. Concern was expressed over the possibility of introduction of insecticides into water supplies, although no evidence was thus far available on this subject. An exchange of ideas and results between workers engaged in water research would be desirable.

With regard to the other papers the discussion firstly bore on the possible practical information which could be deduced from the biota of streams and this led to consideration of whether for instance such data could reveal the presence or absence of trace elements or other substances. The effect of small quantities of nitrate, nitrite and phosphate was mentioned as well as the possible relationship between the absence of bilharzia vectors in the Highveld and Transvaal and the presence of trace elements.

Attention was paid to the occurrence of algal blooms in large dams in the Federation and South Africa, which resulted from organic pollution. The particular case of an initial population of *Anabaena* being followed by *Microcystis* was mentioned. Reference was also made to the possible effect on algal bloom of phosphates due to increasing use of synthetic detergents. The lack of information of the effects of phosphate on the development of algal bloom was noted.

The participants discussed the use of algae to effect a reduction of nutrient salts in natural waters. It was claimed that this could be done.

An interesting change in algal and diatom associations following deterioration in the quality of sewage effluent supplied to maturation ponds was reported. *Euglena* and *Phacus* occurred under highly saline conditions, but when the chloride concentration fell below 1,000 ppm Chlorococcales were established.

The importance of long-term biological research was stressed, particularly as biological sampling methods could, in the hands of a trained biologist, give information on pollution in a relatively short time. The application of this type of research was essential for a better control of pollution.

UTILISATION DES EAUX DE SURFACE: QUELQUES ASPECTS DE L'HYDROBIOLOGIE

Rapporteur : Dr G. J. Stander

Les communications présentées dans cette section ont traité : de l'utilisation des eaux de surface, du rôle de la faune aquatique dans l'évaluation de la pollution, de l'interdépendance du développement des algues et des conditions chimiques régnant dans l'eau, des techniques du contrôle de la qualité des eaux de surface et des objectifs assignés à ce contrôle.

En ce qui concerne les eaux d'égout traitées, la discussion a porté surtout sur les problèmes liés à la présence de détergents synthétiques. En Angleterre, il n'est pas rare que les effluents traités contiennent 4 mg/l et plus de corps tensio-actifs. Le rejet des effluents d'égouts dans le bassin alimentaire du réservoir du Vaal a eu pour conséquence que des teneurs de 0,5 mg/l ont pu être observées ; des concentrations de 1,5 mg/l ont été relevées dans le réservoir de Jukskei.

La préparation de nouveaux détergents susceptibles de se dégrader aisément sous l'effet de traitements classiques des eaux d'égout semble devoir apporter la solution. S'agissant des eaux de surface, on a mis en évidence la présence occasionnelle d'ammoniaque résultant d'activités agricoles.

Une mise en garde a été élevée contre la possibilité d'une contamination des eaux d'alimentation par les insecticides. Cependant de telles pollutions n'ont pas encore été démontrées. Un échange d'idées et d'informations entre les chercheurs intéressés paraît souhaitable.

A propos des autres communications, on a d'abord traité de la possibilité d'obtenir des renseignements pratiques à partir des biotopes des cours d'eau. Ceci a conduit à examiner dans quelle mesure, par exemple, des données biologiques pourraient révéler la présence ou l'absence

d'oligo-éléments ou de toute autre substance. L'action de faibles quantités de nitrate, nitrite et phosphate a été mentionnée, ainsi que la relation qui pourrait exister entre la présence d'oligo-éléments dans le Highveld et le Transvaal et l'absence concomittante des agents vecteurs de la bilharziose.

Il a été discuté de proliférations d'algues dans les grandes retenues de la Fédération et de l'Afrique du Sud, à la suite de pollutions organiques. Le cas particulier d'un peuplement initial d'*Anabaena*, suivi d'un peuplement de *Microcytes* a été signalé ainsi que l'effet essentiel sur les proliférations d'algues d'un accroissement des teneurs en phosphate dû à la généralisation de l'emploi de détergents synthétiques. Le manque d'information sur les effets de phosphates sur la prolifération des algues a été noté.

L'emploi des algues comme moyen de traitement en vue de la réduction des teneurs en sels nutritifs des eaux naturelles a été discuté. Certains pensent que cela est possible. Une intéressante modification dans l'association "algues-diatomées" a été constatée à la suite d'une détérioration de la qualité d'une eau d'égout admise dans un étang de maturation. Les *Euglus* et *Phacus* se rencontraient dans des conditions de haute salinité, par contre les *Chlorococcales* apparurent quand la teneur en chlorure tomba au-dessous de 1.000 mg/l.

L'importance des recherches biologiques à long terme a été soulignée : d'une part, un échantillonnage biologique méthodiquement effectué par des opérateurs entraînés permet d'obtenir en un délai relativement bref des informations sur la pollution, d'autre part ce type de recherche est essentiel dans la détermination de méthodes nouvelles et meilleures de lutte contre la pollution.

Original : English

CONTROL METHODS

Rapporteur : Dr. G. J. Stander

The discussion following on the papers given in this section revealed the inherent difficulties experienced in drawing up any overall legislation to deal with water pollution problems. Besides the purely legal difficulties there were technical problems as, for instance, that presented in certain regions of Africa by large and less developed communities.

METHODES DE PREVENTION ET DE LUTTE

Rapporteur : Dr G. J. Stander

Les discussions qui ont suivi la présentation des communications ont mis en évidence les difficultés fondamentales que l'on rencontre lorsqu'on cherche à établir une législation d'application générale. A côté des difficultés purement juridiques, il existe des problèmes techniques, par exemple celui de l'assainissement, en certains points de l'Afrique, d'agglomérations vastes mais n'ayant pas encore atteint un haut degré de développement.

Original : English

TREATMENT AND DISPOSAL OF SEWAGE AND INDUSTRIAL WASTES

Rapporteur : Dr. B. A. Southgate

In Great Britain, since 1951 when River Boards had been empowered to fix standards of quality of effluents, there had been much discussion on the form which these standards might take ; it was now generally agreed to be impracticable, to fix general standards covering the whole area of a River Board and it was thought that it would be necessary to consider each effluent separately.

A manufacturer in England or Wales has a legal right to discharge trade effluent to the sewers of his Local Authority, subject to certain conditions ; the Local Authority could not avoid the obligation of treating these wastes, whatever standard of quality of sewage effluent had to be attained.

It was pointed out that in Great Britain a riparian owner could bring a common law action against anybody who damaged his interests by polluting a river flowing through his property. This check on pollution operated independently from the control, under statute law, imposed by River Boards.

Effluent disposal at a large oil from coal plant (Sasol) was an integral, and considerable, part of the manufacturing process. In the pulp and paper industry it was very important to reduce the volume of effluent finally to be disposed of, by such measures as counter-current washing of pulp. There was a marked trend towards the manufacture of pulp from wood by the sulphate process. In this it is normal practice to concentrate and incinerate liquor from the digesters to recover chemicals for re-use ; this could not normally be done in the sulphite process, where consequently the problem of disposal of waste waters was much more difficult.

Marked success was reported, at low cost, in treating sewage from aqua-privies, at a native village in Northern Rhodesia by passage through a series of oxidation ponds. At Welkom, satisfactory results had been obtained from the storage of settled sewage for four to five days in ponds and success was reported also from Nairobi, where for the past eighteen months crude sewage had been treated in lagoons at about one-eighth the cost of conventional treatment.

Attention was also drawn to large-scale experiments being carried out at present by the Cape Town Municipality.

There was general agreement that recirculation of effluent from oxidation ponds was beneficial; one result of using this method was to assist in counteracting the effects of fluctuation in the strength of the incoming sewage. Circulation, however, requires pumping equipment, which might not always be available under African conditions.

It was suggested that for the treatment of water from which compounds containing manganese were deposited in pipe systems, sodium aluminate might be used as coagulant instead of aluminium sulphate; this treatment, which is applied under alkaline conditions, had been found to be effective, especially if the water were pre-chlorinated.

In Nigeria, it was important that water treatment plants should be of simple design, since they were operated by relatively unskilled labour. The opinion was expressed, however, that it might be particularly beneficial to make plants of this kind as automatic as possible in operation, though it was appreciated that they would then require attention periodically from trained mechanics. It was suggested indeed that automation might be more appropriate for small plants than for a large water treatment works such as that of the Rand Water Board, where operators were always available.

Although the use of activated silica offered many advantages in the treatment of certain waters, the preparation of the reagent required skilled supervision and it was suitable for use therefore only in plants where this was available.

There was general agreement that sewage effluents, after thorough treatment, should be re-used as far as possible, for example as cooling water, and for irrigation; and it was stressed that if this could be done near the point at which the sewage effluent became available, the loss of water by evaporation which would occur if the effluent were discharged to a stream would be avoided.

TRAITEMENT ET EVACUATION DES EAUX D'EGOUTS ET DES EAUX VANNES

Rapporteur : Dr B. A. Southgate

En Grande-Bretagne depuis 1951, lorsque les "river boards" ont été chargés de fixer des normes de qualité des effluents, la forme que pourraient prendre ces normes a donné lieu à de nombreuses discussions: il est maintenant généralement reconnu qu'il est impossible de fixer des normes générales couvrant toute la région du ressort d'un "river board" et il a été reconnu qu'il fallait envisager chaque effluent séparément.

Un industriel en Angleterre ou dans le pays de Galles a légalement le droit de déverser ses eaux vannes dans les égouts de la municipalité, sous certaines réserves; la municipalité ne peut pas se dérober à l'obligation

de traiter ces eaux, quelle que soit la norme de qualité imposée aux eaux d'égouts.

Il a été indiqué qu'en Grande-Bretagne, un propriétaire riverain peut intenter un procès contre quiconque porte atteinte à ses intérêts en polluant une rivière qui traverse sa propriété. Ce contrôle de la pollution s'exerce indépendamment de toutes mesures restrictives légalement imposées par les " river boards ".

Dans une importante usine de fabrication d'hydrocarbures à partir de la houille (SASOL), le traitement des eaux résiduaires représente une part considérable du processus de fabrication dans lequel il est intégré. L'importance est reconnue de la récupération de produits commercialisables ainsi que de la séparation des différents types d'effluents et de leur réutilisation dans le cycle de fabrication. Dans l'industrie de la pâte à papier et de la papeterie, il est très important de réduire au minimum les effluents à neutraliser éventuellement, en appliquant des méthodes telles que le lavage de la pâte à contre-courant. Il y a une tendance marquée à fabriquer la pâte à papier à partir du bois, par le procédé au sulfate. Dans cette méthode, la pratique courante consiste à concentrer et à incinérer la liqueur provenant des digesteurs en vue de récupérer et de réutiliser les produits chimiques ; cette méthode ne pourrait pas normalement être appliquée dans le procédé au sulfite, le problème d'élimination des eaux vannes présentant dans ce cas beaucoup plus de difficulté. L'attention a également été attirée sur des expériences à grande échelle que poursuit en ce moment la municipalité du Cap.

Des succès intéressants ont été signalés dans le traitement, à peu de frais, des eaux provenant des fosses d'aisance dans un village indigène, en Rhodésie du Nord, en faisant passer ces eaux dans une série d'étangs d'oxydation. A Welkom, de bons résultats ont été obtenus en retenant et en faisant déposer les eaux vannes dans des étangs d'oxydation pendant quatre à cinq jours ; des résultats intéressants ont également été signalés à Nairobi où, depuis dix-huit mois, les eaux brutes ont été traitées dans des lagunes, le coût de l'opération s'élevant à 1/8 du coût des procédés habituels.

La Réunion est unanime à reconnaître qu'il y a intérêt à recycler les eaux provenant des étangs d'oxydation ; cette méthode contribue en particulier à contrecarrer les effets des fluctuations dans la composition des eaux vannes à l'entrée. Ce recyclage exige toutefois un matériel de pompage dont on ne saurait toujours disposer dans les conditions régnant en Afrique. Il a été suggéré que, pour le traitement des eaux qui déposent dans les conduits des composés de manganèse, il pourrait y avoir intérêt à employer de l'aluminate de soude comme coagulant au lieu du sulfate d'alumine ; ce traitement appliqué en milieu alcalin a donné de bons résultats, particulièrement lorsque l'eau est préalablement traitée au chlore.

En Nigéria, il est important d'utiliser des installations de traitement

des eaux d'un modèle simple, car leur fonctionnement est assuré par un personnel relativement peu compétent. On estime toutefois qu'il pourrait être particulièrement avantageux d'utiliser, dans ces installations, des dispositifs de commande aussi automatiques que possible, bien qu'il soit reconnu que les appareils automatiques exigent un entretien périodique assuré par des mécaniciens spécialistes. Il a même été indiqué que l'automatisme conviendrait peut-être mieux à de petites installations qu'à de grandes usines de traitement des eaux vannes telles que celles du Rand Water Board, qui disposent toujours d'un personnel compétent.

Bien que l'emploi de la silice activée présente de nombreux avantages pour le traitement de certaines eaux, la préparation du réactif exige la surveillance d'un personnel spécialisé et ne convient donc qu'aux installations qui possèdent un tel personnel.

La Réunion est unanime à reconnaître qu'après traitement complet les eaux vannes devraient être réutilisées dans la mesure du possible, par exemple, pour le refroidissement et pour l'irrigation; il est souligné que si cette opération peut s'effectuer à proximité de l'endroit où débouchent les eaux vannes, on éviterait les pertes d'eaux importantes résultant de l'évaporation qui se produirait si ces eaux étaient déversées dans une rivière.

RECOMMENDATIONS

I. The Meeting EXPRESSES its deep gratitude to the Government of the Union of South Africa for the facilities provided and to the South African Council for Scientific and Industrial Research for its hospitality and most efficient organisation of the meeting. It REQUESTS the Secretary-General of CCTA/CSA to convey to them a message of thanks in this respect.

II. Considering that before undertaking any water demineralisation project the first and main factor which should be taken into account is the particular use which will be made of the water, and in view of the scarcity of information in this field, the Meeting STRESSES the need for more research on the physiological effects on men, animals and plants, of waters containing varying quantities of different mineral constituents.

III. In view of the need to find solutions, which are specifically adapted to African conditions, to problems of the treatment of water, sewage and industrial effluents in the Continent, and considering the scarcity of qualified workers and facilities in this field, the Meeting SUGGESTS that every effort should be made to establish a closer measure of co-operation between existing workers and institutes in Africa.

It therefore RECOMMENDS that CCTA/CSA should appoint a specialised correspondent in this field whose duty it would be to keep in touch with other workers and also to advise and make suggestions to the Secretariat

concerning any possible action to be undertaken in this sphere. In making this recommendation, the Meeting SUGGESTS that Dr. G. J. Stander, Director, National Institute for Water Research, of the South African Council for Scientific and Industrial Research, would be eminently qualified for such an appointment.

RECOMMANDATIONS

I. La Réunion tient à **EXPRIMER** au Gouvernement de l'Union de l'Afrique du Sud sa très vive reconnaissance pour les facilités qui ont été mises à sa disposition et au Conseil Sud-Africain pour la Recherche Scientifique et Industrielle, ses remerciements pour son hospitalité et l'excellente organisation de la présente manifestation. Elle **PRIE** le Secrétaire Général de la CCTA/CSA de leur transmettre un message de gratitude à cet effet.

II. La Réunion, considérant que, avant d'entreprendre un projet de déminéralisation de l'eau, il importe, en premier lieu, de tenir compte de l'usage auquel cette eau est destinée, considérant en outre la pénurie d'informations en ce domaine, **SOULIGNE** la nécessité de procéder à de plus amples recherches sur les effets physiologiques sur l'homme, les animaux et les végétaux, d'eaux contenant des quantités différentes de divers sels minéraux.

III. Considérant qu'il est nécessaire de trouver des solutions spécifiquement adaptées aux conditions africaines pour les problèmes de traitement des eaux et d'épuration des effluents urbains et industriels dans ce continent, considérant en outre qu'il y a pénurie de personnel spécialisé et de moyens d'action dans ce domaine, la Réunion suggère que tous efforts soient faits pour obtenir une collaboration plus étroite entre les spécialistes de ces problèmes et les divers instituts existant en Afrique.

Elle **RECOMMANDE** en conséquence que la CCTA/CSA désigne un Correspondant spécialisé dans ce domaine, chargé d'entretenir des contacts avec les autres spécialistes ainsi que de formuler des conseils et de présenter des suggestions au Secrétariat en ce qui concerne les activités qu'il serait possible d'entreprendre. En formulant cette recommandation, la Réunion suggère que le Dr G. J. Stander, Directeur de l'Institut National pour la Recherche sur les eaux du Conseil pour la Recherche Scientifique et Industrielle, serait éminemment qualifié pour remplir ces fonctions.

**I. WATER DEMINERALISATION — DEMINERALISATION
DES EAUX**

DEMINERALISATION DES EAUX. — REVUE DES PROCÉDES EXISTANTS

G. DROUHIN

*Ingénieur Général des Ponts et Chaussées,
Directeur de l'Hydraulique et de l'Équipement Rural en Algérie*

AVANT-PROPOS

En demandant un exposé sur les procédés de déminéralisation des eaux, les organisateurs de cette réunion n'ont certainement pas eu en vue une étude exhaustive des procédés possibles, de l'état des études théoriques ou pratiques auxquelles ils ont déjà donné lieu, ni des espoirs que l'on peut mettre en eux à plus ou moins longue échéance. Il y faudrait un gros livre, qui ne pourrait d'ailleurs être qu'une compilation d'une très abondante littérature, laquelle ne saurait intéresser véritablement que les spécialistes de tel ou tel procédé.

Le titre qui a été choisi par le Comité pour cette communication nous a paru constituer une invitation à présenter une idée assez claire des procédés exploitables actuellement, de montrer leurs avantages et leurs faiblesses, bref de donner dans une large mesure ce que l'on pourrait appeler le point de vue de l'utilisateur, sans toutefois attacher à cette expression un sens trop strict.

On peut estimer du reste que la situation n'évoluera pas très vite et que ce que l'on peut penser aujourd'hui a des chances de rester vrai pendant un certain nombre d'années. L'expérience montre, en effet, qu'entre la naissance d'une idée et sa réalisation industrielle il s'écoule toujours un temps très long, même à partir du moment où cette idée a déjà donné lieu à un certain nombre d'essais. Quel que soit le domaine considéré, les exigences technologiques sont tellement nombreuses et tellement complexes qu'on ne peut progresser que pas à pas et très lentement.

Si l'on a résolu de procéder à cet exposé dans l'esprit assez pragmatique que l'on a défini plus haut, cela ne signifie pas qu'il faille renoncer à toute clarté d'ensemble. Il n'est pas sans intérêt, semble-t-il, de citer au moins pour mémoire, en les classant d'une manière aussi rationnelle que possible, les différents processus auxquels il est permis de faire appel pour dessaler de l'eau. Cela nous aidera à situer les procédés actuellement exploitables dans un ensemble cohérent et à comprendre mieux les raisons profondes de certaines de leurs vertus et de certains de leurs défauts. C'est donc par là que nous commencerons.

LES PROCÉDES CONSIDÉRÉS COMME POSSIBLES

Quand on pense à séparer l'eau des sels — ou au moins d'une partie des sels — qu'elle contient en solution, on peut *a priori* imaginer d'utiliser un grand nombre de phénomènes.

On peut songer à des cycles thermodynamiques divers, à des processus chimiques, physiques ou plutôt physico-chimiques, électriques et même biologiques, sans parler des combinaisons possibles entre tel ou tel groupe de procédé.

Dans un très beau travail présenté à un récent colloque de l'UNESCO sur les zones arides, tenu à Paris en mai dernier, le Professeur E. D. Howe, de l'Université de Berkeley en Californie, a exposé un mode de classement des différents procédés actuellement en exploitation ou simplement à l'étude, qui paraît clair et rationnel, et que l'on prendra la liberté de reproduire ici avec quelques variantes de forme.

1. Procédés utilisant de l'énergie thermique (l'énergie mécanique étant limitée au fonctionnement des auxiliaires), comportant un changement de phase de l'eau, avec une dépense d'énergie pratiquement indépendante de la salure.

Distillation simple, réduite aujourd'hui à la distillation solaire.

Distillation à effets multiples.

Distillation à vaporisation instantanée en étages multiples ou sous vide poussé.

Distillation au voisinage du point critique.

Extraction de l'eau par formation d'hydrates.

2. Procédés utilisant l'énergie mécanique, comportant généralement (mais pas toujours) un changement de phase, et nécessitant une dépense d'énergie pratiquement indépendante de la salure.

Distillation à compression de vapeur.

Séparation par congélation.

Osmose inversée.

3. Procédés n'exigeant jamais de changement de phase, l'énergie à fournir diminuant avec la teneur en sels.

Electrolyse.

Electrodialyse à membranes sélectives.

Séparation osmionique.

4. Procédés chimiques, dans lesquels la quantité de produits à fournir diminue avec la teneur en sels.

Précipitation.

Echange d'ions.

Extraction par solvants des sels dissous.

Sans être exhaustive, la liste qui fait l'objet de ce classement comprend, à part ceux qui ont déjà débouché sur des applications réelles, les processus

qui paraissent suffisamment prometteurs pour qu'il semble utile d'en poursuivre l'étude, encore que ceci soit discutable dans bien des cas.

En se plaçant au point de vue défini plus haut, qui est celui de l'utilisateur en puissance, on peut classer tous ces procédés en trois groupes :

A. — Ceux qui se révèlent comme si difficiles à mettre en œuvre, nonobstant des apparences parfois séduisantes *a priori*, qu'on peut les négliger pour le moment car, ou bien les études ultérieures les condamneront, ou bien ils ne sauraient donner lieu à réalisation avant un temps très long. On peut citer dans cette catégorie :

- La distillation au voisinage du point critique, qui fait intervenir des problèmes de corrosion et d'incrustation insurmontables en l'état actuel de la technique.
- L'osmose inversée (le terme n'est d'ailleurs pas parfaitement adéquat). Il s'agit de faire passer l'eau pure, grâce à l'emploi de pressions élevées, à travers une membrane qui retient les ions. En fait, il ne semble pas qu'il s'agisse d'une sorte d'ultra-filtration, mais bien, pour le cheminement de l'eau à travers la membrane, d'un processus physico-chimique complexe et encore mal connu. On ne voit pas pour l'instant de possibilité pratique d'emploi.
- L'électrolyse, dont les processus sont extrêmement médiocres en ce qui concerne le rendement énergétique.
- L'extraction des sels par solvant, pour laquelle on ne trouve pas de solvants d'une efficacité assez générale. Ce procédé serait séduisant en ce qu'il permettrait d'aligner la dépense sur la teneur en sels, mais il ne semble pas y avoir de ce côté d'espoir sérieux.
- Le procédé par précipitation chimique a déjà des emplois industriels. Il est bien connu et il n'est pas utile d'en parler. Il ne se suffit pas à lui-même quand il s'agit de faire de l'eau potable. Il faudrait pour cela ne pas hésiter à employer des réactifs d'un coût prohibitif, avec parfois un danger de toxicité. Tout au plus pourrait-on penser à l'employer dans certains cas comme pré-traitement.
- La séparation osmionique, qui serait la mise en œuvre d'une idée élégante et originale. On ne voit pas bien encore comment ce procédé pourrait donner des débits appréciables à moins d'installations démesurées, et sans l'emploi de surfaces énormes de membranes sélectives. Ces membranes seront probablement toujours employées plus économiquement en électrodialyse.

B. — Ceux qui, sans être actuellement à l'état des réalisations, ne semblent pas présenter d'obstacles majeurs et ont des chances de déboucher dans peu d'années sur des applications.

Ce sont essentiellement :

- la séparation par congélation ;
- peut-être la séparation par formation d'hydrates solides.

Le procédé de séparation par congélation, le plus avancé des deux, repose sur le fait bien connu que les cristaux de glace qui se forment au sein d'une eau saline sont constitués par de l'eau pure. Il fait appel à un cycle thermodynamique alimenté par de l'énergie mécanique, et qui n'est pas sans analogie avec la distillation par thermo-compression, avec les avantages suivants :

- quantité d'énergie à mettre en œuvre plus faible dans le changement de phase eau-glace que dans le changement eau-vapeur (de l'ordre de 1/7 par unité de poids dans des conditions moyennes) ;
- conditions de température telles que les dangers de corrosion ou d'incrustation sont pratiquement annulés ;
- enfin, possibilité de fonctionner au voisinage de la pression atmosphérique, ce qui simplifie grandement l'appareillage. En fait, les spécialistes tendent aujourd'hui à abandonner cet avantage en faisant de la congélation directe et quasi instantanée sous vide poussé, parfois sans fluide intermédiaire, afin d'éviter les effets de parois.

L'analogie avec la thermo-compression ne peut en fait être poussée très loin. En effet :

- d'une part, l'appareillage indispensable pour obtenir une source de frigories est obligatoirement plus compliqué que celui qui est nécessaire pour comprimer de la vapeur, et son fonctionnement est sous une dépendance beaucoup plus complète des conditions locales ;
- d'autre part, lorsque l'on vaporise, la phase gazeuse est extérieure à la phase liquide et peut être extraite sans difficulté pour condensation. Quand on congèle, les cristaux restent dans la saumure, c'est bien de là que provient la principale difficulté du procédé. La séparation se fait par différence de densité, mais les cristaux retiennent énergiquement, par effet de surface, une certaine quantité de saumure dont il est difficile de les séparer avant fusion de la glace propre sans une dépense considérable d'énergie ou sans que l'on perde au lavage une proportion importante de l'eau pure produite.

Des recherches sur prototypes expérimentaux sont en cours aux États-Unis, en Israël (procédé Zarchin) et également en France. Elles montreront à quelles conditions le procédé est susceptible d'entrer dans la pratique industrielle.

A noter que l'on rencontre la même difficulté dans les tentatives de séparation par formation d'hydrates solides, qui ne sont cependant pas sans espoir.

C. — Enfin ceux qui sont déjà entrés dans la pratique et ont permis de réaliser des installations actuellement en service :

- la distillation solaire ;
- les échangeurs d'ions ;
- les distillations avec apport d'énergie non gratuite (à effets multiples, à vaporisation instantanée, à thermo-compression, avec leurs variantes et leurs combinaisons) ;
- l'électrodialyse à membranes sélectives.

On se trouve donc finalement en présence d'un très petit nombre de techniques disponibles, quatre groupes en tout, cinq si l'on distingue la distillation par apport d'énergie thermique et la distillation par thermo-compression, dont les caractéristiques sont d'ailleurs bien différentes.

Disons tout de suite, parce que ceci résulte d'une expérience déjà longue en Afrique du Nord, et on s'expliquera plus longuement sur ce point dans ce qui va suivre, que les deux premiers procédés comportent des limitations techniques et économiques qui ne permettent guère de résoudre que des problèmes assez particuliers et d'assez faible importance en quantité. Les deux derniers, au contraire, ont d'ores et déjà un caractère véritablement industriel et sont susceptibles d'apporter des solutions à l'échelle de groupements importants. On ne peut, en effet, parler pour l'heure que d'eau pour consommation humaine, pour l'abreuvement des animaux, ou pour la satisfaction de certains besoins industriels, car on est encore loin d'entrevoir le jour où les prix de revient effectifs baisseront assez pour qu'on puisse penser à des utilisations agricoles, sauf peut-être les cas limités de cultures hydroponiques ou de recherche d'une nourriture humaine ou animale dans la production d'algues microscopiques d'eau douce.

En se reportant à la tentative ci-dessus de classification générale, on constatera immédiatement une différence essentielle entre les deux procédés dits " industriels ".

Les distillations font partie de ce groupe dans lequel la dépense d'énergie ne dépend pas, en première approximation, de la salure. Elles sont telles qu'il est aussi cher de traiter des eaux saumâtres à quelques grammes par litre que de l'eau de mer. Par contre elles permettent si les circonstances s'y prêtent, d'utiliser des énergies de faible valeur marchande : gaz naturel sur les lieux de production, résidus de fuel intransportables, chaleur perdue dans des installations industrielles, etc.

L'électrodialyse, à l'inverse, permet de proportionner sensiblement, à un terme constant près, l'énergie à la teneur en sel de l'eau à déminéraliser. Encore qu'il entre dans le prix de revient de l'eau épurée produite bien autre chose que le coût de l'énergie, on peut dès maintenant concevoir que ce procédé a toutes chances d'être avantageux quand il s'agit non d'eau de mer, mais d'eau simplement saumâtre. Par contre, il faut toujours passer

par le truchement de cette énergie de haute qualité qu'est l'énergie électrique.

Ceci doit nous rendre prudent dans les comparaisons énergétiques, et il sera bon de savoir bien toujours de quoi l'on parle.

On passera maintenant en revue, toujours dans le même esprit, c'est-à-dire sans souci didactique, les méthodes de déminéralisation entrées dès à présent dans la pratique ou vraiment sur le point d'y entrer.

LA DISTILLATION SOLAIRE

La distillation solaire est une distillation à simple effet, réalisée jusqu'ici dans de petits appareils de conception élémentaire, et utilisant une énergie thermique gratuite, celle du soleil.

Il y a bien longtemps que ce procédé a été employé en pratique. Actuellement de nombreuses études expérimentales sont en cours notamment au Maroc, en Australie, en U.R.S.S., aux Etats-Unis, en Italie et en Algérie. Elles sont dirigées dans deux voies :

- perfectionnement des petits appareils à faible débit unitaire ;
- tentatives de construction de vastes installations susceptibles de produire des débits importants.

La communication que fera M. Gomella au cours du présent colloque me permet de me limiter ici aux considérations essentielles.

En Afrique du Nord, et notamment dans les régions sahariennes, l'emploi de ce procédé pour de petites installations répondait à une véritable nécessité, à cause du caractère généralement saumâtre des eaux qu'on y rencontre, souvent impropres à tout usage, et de la dispersion sur un territoire immense de nombreux besoins de faible importance. La générosité de la nature en chaleur solaire y est d'autre part bien connue.

Aussi les études expérimentales et la mise au point d'une technologie adéquate, qui n'est pas aussi simple que pourrait le laisser prévoir la simplicité de la conception, ont-elles été poussées avec vigueur. On en est arrivé à un point où l'on peut considérer que les appareils du type serre ne sont pratiquement plus susceptibles de perfectionnements notables si l'on considère le prix réel de l'eau potable. En fait, si le marché de ces appareils n'est pas bien considérable, il faut tout de même observer que plus de 250 unités ont été acquises par une certaine clientèle non subventionnée à qui ils rendent de bons services (en Algérie, au Maroc, dans les Territoires sahariens, au Tchad, au Sénégal ; il y en a même dans l'île de Malte).

L'appareil comporte une coque en amiante-ciment de forme telle que les coques puissent s'emboîter l'une dans l'autre pour en faciliter le transport, tout en permettant l'emploi de surfaces transparentes rectangulaires. Cette couverture, qui sert de surface de condensation, est formée de verre à vitre : de multiples essais ont montré qu'il était encore impossible, dans nos territoires, de trouver des matières de remplacement (plastiques)

d'un prix acceptable et ayant une tenue suffisante aux très dures conditions sahariennes (ultra-violet, vents de sable, etc.). D'importantes recherches sont en cours dans ce domaine : elles sont encourageantes. Bien entendu le fond intérieur de la cuve est peint en noir. Le toit est à double pente faible (10°). La cuve est isolée à sa partie inférieure par de la laine de roche. La surface insolée est de $1,25 \text{ m}^2$. La production effective, suivant la latitude, varie entre $1,9$ et $2,5 \text{ m}^3$ par appareil et par an, ce qui correspond à $1,5$ et 2 m^3 par m^2 et par an. Le rendement par rapport à l'énergie solaire effectivement reçue par mètre carré horizontal va de 49 à 61% .

Les deux sujétions essentielles, si l'on veut arriver à un rendement convenable, consistent (les études théoriques faites un peu partout et les constatations expérimentales le confirment) à avoir une lame d'eau très peu épaisse et une distance moyenne aussi faible que possible entre la surface de l'eau et la vitre. Il y a à cela des limitations technologiques, et l'on estime impossible de faire mieux que ce qui existe : 2 cm de lame d'eau en moyenne, distance moyenne entre la surface de l'eau et la vitre : 10 cm .

En Algérie, des expérimentations se poursuivent cependant dans le cadre du Groupement de Recherches pour les Applications de la Chimie des Eaux (GRACE), et des chercheurs divers se partagent la besogne sur des prototypes plus ou moins compliqués (appareils à gradins, à fonctions évaporation et condensation séparées, etc.). Prises sur le plan du prix de revient effectif de l'eau, ces expériences ne paraissent conduire qu'à des résultats décevants. Le seul perfectionnement qui paraisse avoir une valeur est l'emploi de réflecteurs plans à surface aluminée, qui augmentent le rendement. Encore faut-il attendre que l'expérience fasse connaître l'augmentation de prix qu'entraînera la détérioration des surfaces réfléchissantes par les vents abrasifs du Sahara.

Le problème qui se pose en matière de distillation solaire est de savoir si l'on peut songer à construire des installations de grande superficie, susceptibles de fournir des débits importants. Les groupes expérimentaux les plus grands construits ces dernières années se trouvent à Port-Orange en Floride et sont à l'essai pour le compte de l'Office of Saline Water de l'U.S.D.I.

Des essais systématiques sont poursuivis à la station expérimentale de Touggourt par M. Gomella et son équipe, pour le compte de la Direction de l'Hydraulique et de l'Équipement rural de l'Algérie et de l'Organisation Commune des Régions Sahariennes. Ils ont pour but d'analyser le phénomène et l'effet des différentes variables ainsi que leur interaction.

La conclusion paraît hélas ! claire et assez décevante. La notion d'une station du type " serre " comportant de grandes superficies évaporatoires d'un seul tenant conduira probablement à des prix de revient plus élevés qu'en réalisant une telle station par un " pavage " de petits appareils.

Il semble bien que la réalisation de grosses stations solaires devra être cherchée dans des voies nouvelles, qui supposeront la séparation entre

la captation de l'énergie d'une part, et son utilisation à la distillation d'autre part.

En ce qui concerne la captation de l'énergie, on peut envisager deux possibilités :

- ou bien utiliser des niveaux élevés de température en acceptant les sujétions astronomiques et optiques que cela suppose ;
- ou bien se contenter de niveaux bas, ne nécessitant qu'un appareillage relativement simple et moins délicat, mais au prix d'un encombrement considérable.

Il est vraisemblable qu'on arrivera un jour à des réalisations intéressantes. Ce n'est pas hélas! encore pour demain, et la sagesse consiste pour l'instant à prendre la distillation solaire pour ce qu'elle est : un intéressant moyen de résoudre dans des pays difficiles des problèmes minuscules, à raison d'un petit nombre de litres par jour et par appareil. C'est parfois très intéressant, qu'il s'agisse d'eau de boisson ou parfois d'eau pour les batteries d'accumulateurs et les radiateurs des véhicules automobiles. Ce problème est actuellement résolu dans des conditions satisfaisantes.

Indiquons en terminant ce chapitre que, compte tenu de l'amortissement qui est la part importante du prix et de frais d'entretien très peu élevé, le prix de revient actuel de l'eau " solaire " peut être estimé à 10 NF par m³ (environ \$8,30 pour 1.000 gallons américains).

Il est à noter que s'il s'agit d'eau de mer, ce prix n'est pas aberrant par rapport à ceux d'autres procédés.

UTILISATION DES ECHANGEURS D'IONS

Les résines échangeuses d'ions peuvent techniquement être employées à la déminéralisation d'eaux titrant jusqu'à 8.000 et même 10.000 ppm suivant composition ionique. Pour des concentrations supérieures, le procédé est " autophage ", en ce sens qu'il faut employer au rinçage lors de la régénération toute l'eau épurée produite. La limite d'utilisation pratique se situe bien en-dessous de ces chiffres.

De toutes manières, le procédé est coûteux. Il faut compter 10 NF par kg de sel enlevé (rapporté au m³ d'eau dessalée). Avec une eau saharienne typique, celle de Touggourt (4.600 p.p.m. de résidu sec), le prix approximatif est de près de 50 NF par m³ (ordre de grandeur \$41,5 pour 1.000 gallons américains.)

C'est un fait bien connu que l'utilisation de choix des résines échangeuses n'a que peu de rapport avec la production d'eau alimentaire. Elle réside, pour certains usages industriels, dans la possibilité d'obtenir aisément, et à prix abordables, une déminéralisation très poussée (eau à très haute résistivité) en partant d'une eau naturellement potable, ou sinon préalablement traitée par d'autres procédés. C'est un procédé de finition.

On citera cependant, presque à titre de curiosité, une application

intéressante mise au point en Algérie pour les besoins sahariens et se rapportant à l'eau potable. Quand une équipe itinérante se déplace dans le désert, elle ne trouve souvent que de l'eau très saumâtre et quasi imbuvable. Elle est donc obligée d'emporter son eau, ce qui occasionne une surcharge et un encombrement considérables. L'emploi de deux containers en polyéthylène, l'un chargé d'une résine anionique, l'autre d'une résine cationique, et servant de bacs d'échange, permet, pour un volume d'eau donné, de diviser poids et volume par un coefficient très important. Les résines sont régénérées en fin de tournée, en un endroit où le coût des produits de régénération n'est pas trop handicapé par les transports, et où l'eau de rinçage peut être obtenue à faible prix. C'est, on le voit, une petite chose, mais qui en pratique rend des services fort appréciés, et dont l'emploi tend à se généraliser.

Le simple adoucissement de l'eau par permutation des ions alcalino-terreux en ions alcalins, que l'on peut opérer avantageusement avec des résines échangeuses, peut présenter un gros intérêt dans deux cas :

- Les eaux très minéralisées sont souvent des eaux très dures, dont l'utilisation aux lavages, à la cuisson des aliments, etc. est souvent impossible. On peut avoir intérêt, dans certains cas, à traiter à part le problème de l'eau potable et celui de l'eau ménagère simplement adoucie par permutation. Dans certains cas, l'opération pourrait ne pas être très coûteuse, notamment quand on dispose d'un agent naturel de régénération des résines (par exemple eau de drainage de certaines palmeraies sahariennes).
- On peut aussi penser à utiliser l'adoucissement à titre de prétraitement de l'eau qui doit passer dans des appareils de déminéralisation, quand la composition ionique rend les phénomènes d'incrustation très redoutables. On reviendra plus loin sur ce point.

Dans ces cas on sera conduit à l'emploi d'appareils à résines à fonctionnement continu. Le prototype d'un tel appareil est en cours d'expérimentation en Algérie, et les essais conduisent à des résultats fort encourageants.

LES DISTILLATIONS

Il n'entre pas dans notre propos de décrire des appareils ni même des schémas. On voudrait simplement situer les procédés en question dans un ensemble, de manière à suggérer quelques éléments de comparaison.

Les procédés de distillation comportent tous le passage par la phase vapeur. On a vu plus haut qu'il y avait deux cycles très différents dans leur principe :

- celui qui n'exige que de l'énergie thermique (distillation thermique) ;
- celui qui n'exige que de l'énergie mécanique (distillation par thermo-compression).

Dans la pratique les choses ne sont pas aussi simples que l'indique cette distinction théorique. En fait, les différentes méthodes de distillation thermique requièrent de l'énergie mécanique pour le fonctionnement d'auxiliaires fondamentaux, et il est difficile d'imaginer des procédés par thermo-compression qui n'exigent pas un chauffage préalable pour partir d'un niveau d'énergie assez élevé. De plus, dans la course à l'économie énergétique, bien des constructeurs ont pensé à combiner les deux formules.

A. Distillation thermique

La distillation thermique simple est connue depuis des siècles. Elle est extrêmement coûteuse en énergie, et coûteuse tout court, à cause de la valeur très élevée de la chaleur latente de vaporisation de l'eau (près de 540 kilocalories par kg à 100° C). Si l'on ne fait aucune récupération, il faut, au voisinage de 100° C, dans des conditions de rendement raisonnables :

1.000 kWh par m³ si l'on ne fait aucune récupération

et environ 850 kWh par m³ si on prend la précaution de faire un préchauffage de l'eau qui entre dans le circuit par récupération de calories provenant de la vapeur sortant du bouilleur.

Le vieil alambic à simple effet conduit donc à des dépenses d'énergie absolument prohibitives. Il a cependant pour lui le mérite de la rusticité, et permet parfois de résoudre certains problèmes de détail grâce à une grande simplicité de construction et à sa faculté de se contenter de combustibles qui ne sont souvent que des déchets. On a vu plus haut ce qu'il fallait penser de la distillation solaire, qui consiste en une distillation à simple effet particulièrement rudimentaire, sans même le moindre préchauffage, et qui n'a pour elle que la gratuité des calories naturelles.

Le seul moyen de rendre la distillation payante, à l'échelle d'installations de puissance notable, est de faire "travailler" cette chaleur latente de vaporisation plusieurs fois, à des niveaux de température de plus en plus bas et par conséquent à des pressions elles-mêmes de plus en plus basses. C'est ainsi qu'on arrive à la notion de distillation à effets multiples dans laquelle la part de l'enthalpie correspondant à la chaleur latente est recyclée un certain nombre de fois, pour le plus grand bien de l'économie énergétique, mais au prix d'une augmentation sans cesse croissante des investissements pour un débit donné.

On peut calculer le nombre d'"effets" théoriquement possibles entre deux niveaux de température (166 entre 100° C et 25° C). Il reste en nombre fini, à cause de la différence de pression de vapeur saturante entre l'eau salée et l'eau pure. Le "gained output ratio" (GOR), rapport entre le poids total du distillat et le poids de la vapeur introduite en tête, même en l'absence de toute perte, ne peut être qu'inférieur au nombre d'effets.

En pratique, il est impossible de multiplier les effets au-delà de toute

mesure, à cause des problèmes technologiques que cela poserait (notamment celui d'un vide très poussé dans les derniers étages, sans parler de l'énormité des surfaces de contact nécessaires). Il ne semble pas, d'après l'enquête du Prof. Howe (rapport précité), que les groupes en service présentent plus de douze effets, sauf dans des installations prototypes destinées à une expérimentation en vraie grandeur.

B. Distillation par thermo-compression

L'idée de base est simple. La pression de vapeur saturante en présence d'une eau salée étant inférieure à la pression de vapeur en présence de l'eau pure à la même température T , il est impossible de se servir de l'eau salée pour condenser la vapeur produite, qui ne pourrait redonner de l'eau qu'à une température inférieure à T . Mais si l'on comprime par un moyen mécanique la vapeur extraite de l'eau salée, l'énergie ainsi introduite permettra la condensation de l'eau distillée dans un condenseur situé au sein de l'eau salée (disons de l'autre côté d'une paroi d'échange). C'est tout le principe de l'opération.

Ce genre de cycle se prête à des montages en étages successifs, qui permettent de se rapprocher peu ou prou des conditions idéales de réversibilité.

C. Problèmes techniques communs aux procédés de distillation — Influence sur les prix de revient

L'ennemi public n° 1 de tous les procédés de distillation, si l'on ose s'exprimer ainsi, est le coefficient global de transmission calorifique pratique, soit dans les échangeurs divers de récupération de liquide à liquide, soit surtout à la traversée des discontinuités qui séparent un liquide en cours d'évaporation d'une vapeur en cours de condensation.

Tous les progrès déjà acquis, tous ceux qu'on espère, n'ont pu provenir et ne proviendront que de la lutte contre cette influence.

Observons tout d'abord que l'on n'obtient de bons coefficients, en l'état actuel de la technique, qu'avec le cuivre, métal cher, et que ceci donne dans le prix de revient un poids considérable aux amortissements, surtout si l'on veut économiser sur l'énergie en travaillant sur chaque effet ou chaque étage avec des différences faibles de température et de pression, les deux étant liées.

Remarquons ensuite que les coefficients d'origine ont une fâcheuse tendance à se détériorer, à cause des dépôts et des incrustations de sels mauvais conducteurs de la chaleur.

Ce sont ces moyens de lutte qui introduisent le plus de variétés dans les réalisations pratiques. Deux voies principales ont eu la faveur des chercheurs :

- L'une consiste à employer la vaporisation dite "instantanée", que l'on ferait mieux de qualifier de "rapide". L'utilisation de

vides convenablement adaptés aux températures en cause provoquent la vaporisation au sein du liquide, et non au contact d'une paroi, ce qui a pour effet de limiter la surface nécessaire de la paroi (économie d'investissement) et surtout de réduire grandement le danger d'incrustation.

- L'autre a pour but de répartir l'eau à évaporer en film mince et régulier sur la paroi d'échange, grâce dans certains cas à des dispositifs de distribution situés à l'intérieur de tubes évaporatoires, le plus souvent par une mise en rotation rapide de l'ensemble des surfaces d'échange montées sur une sorte de tambour, l'agent de bonne répartition étant la force centrifuge.

Ceci se combine plus ou moins avec :

- la recherche de la condensation en gouttelettes, et non en film, grâce à un traitement des parois côté vapeur (cannelures très étudiées, revêtements spéciaux, etc.) ;
- l'utilisation de cycles à température supérieure suffisamment basse pour que les incrustations soient plus faciles à éliminer (carbonates au lieu de sulfates de cations divalents) ;
- la disposition en "effets" ou "étages" superposés dans des colonnes, avec utilisation des échanges thermiques à contre-courant, et avec le minimum de tubulures extérieures de manière à limiter les pertes thermiques.

Dans ce domaine des distillations, si simple en apparence mais fort complexe en pratique, le type des réalisations et la nature des développements dépend étroitement de l'idée que chaque constructeur se fait de l'équilibre le plus judicieux entre investissements et par conséquent frais d'amortissements, frais d'exploitation et d'entretien, et coût de l'énergie nécessaire.

Les résultats obtenus sont bons, et doivent s'améliorer, car il existe encore une marge énorme entre les énergies dépensées en pratique et les minima thermodynamiques requis (coefficient multiplicateur compris, pour des appareils en service, entre 80 et 30 comme ordre de grandeur).

Actuellement la technique semble en être au point suivant : ou bien on arrive à des installations énormes qui ne sauraient se concevoir que pour des productions très importantes, ou bien à des appareils très satisfaisants — à tous égards — en petites dimensions, mais dont l'extrapolation à une échelle supérieure pose des problèmes qui ne semblent pas encore avoir trouvé de solution satisfaisante (ex. : appareil rotatif à thermo-compression type Hickman).

On répètera, pour en terminer avec ce rapide examen, que tous ces procédés sont extrêmement peu sensibles à la teneur en sels de l'eau brute, et qu'ils subissent de ce fait un handicap certain pour le traitement des eaux simplement saumâtres.

L'ELECTRODIALYSE A MEMBRANES SELECTIVES

Le procédé, on le sait, repose sur le transport, au sein de l'électrolyte que constitue l'eau saline, des anions et des cations, en sens inverse, sous l'action d'une différence de potentiel établie entre deux électrodes, et sur le " piégeage " de ces ions, extraits d'un circuit de déminéralisation, dans un circuit de concentration. Cet effet est obtenu par l'emploi de membranes sélectives, imperméables à l'eau, et laissant passer respectivement et uniquement les unes les anions, les autres les cations.

Si l'on considère un paquet de membranes empilées en laissant entre elles un certain vide, membranes alternativement anionique et cationique, et comprises entre deux électrodes, le circuit de déminéralisation sera constitué par exemple des compartiments pairs avec des arrivées et des départs disposés en parallèle, les compartiments impairs, également équipés en parallèle, constituant le circuit de concentration.

L'énergie nécessaire au dessalement, sans parler du fonctionnement des auxiliaires, est représentée par le travail de transport des ions sous l'action de la différence de potentiel, et par les pertes ohmiques à travers le dispositif et surtout à travers les membranes.

On a donc tout intérêt à rechercher des membranes à faible résistivité électrique, et à faire en sorte que le cheminement électrique des ions soit très court. Cette dernière condition impose un rapprochement des membranes aussi poussé que possible compte tenu des nécessités hydrauliques.

A condition de disposer de membranes sélectives, et il en existe dès maintenant de types variés dans le commerce, l'idée de base est simple, mais, comme en tout domaine industriel, la technologie est assez complexe.

En ce qui concerne la circulation de l'eau entre membranes, les constructeurs se sont orientés dans deux voies différentes :

- circulation dans un canal sinueux ménagé dans l'épaisseur de deux membranes voisines ;
- circulation entre deux membranes parallèles dont l'écartement est maintenu par un séparateur de type approprié.

Une des difficultés contre lesquelles on a à lutter est le danger de polarisation des électrodes et des membranes, au niveau d'une couche laminaire qui freine l'arrivée des anions ou des cations des sels de l'eau. Ce phénomène est pour beaucoup sous la dépendance des problèmes de turbulence. C'est pourquoi, dans les appareils à membranes lisses parallèles, le séparateur n'est pas seulement destiné à maintenir l'écartement, mais il joue un rôle important dans la bonne répartition du courant d'eau et dans la provocation des phénomènes de turbulence aux parois des membranes (et des électrodes). On arrive également très vite à la notion de vitesse moyenne critique, et l'on est souvent amené, au moins dans les appareils à passage direct, à prévoir des recirculations provoquées par des pompes

spéciales, de manière que le débit de passage dans les compartiments soit supérieur au débit qui entre dans l'appareil et qui en sort.

L'autre danger est celui de l'incrustation entre les membranes, et, ce qui est encore plus grave, parfois au sein de celles-ci. Il est aisé de concevoir que les phénomènes en cause sont étroitement liés à ceux que l'on vient d'évoquer. La caractéristique de ces incrustations, en électrodialyse, est qu'une fois déclenchées elles progressent à grande vitesse à cause d'un ensemble de processus qui ont un effet quasi-exponentiel. Il faut donc, à tout prix, en éviter l'apparition, grâce à une étude attentive de chaque problème posé, et grâce à des précautions adéquates : correction du pH, inversion des flux hydraulique et électrique, rinçage; etc., qui commencent à être bien au point.

Les membranes peuvent être à support cellulosique ou plastique à longues chaînes avec liaisons dans le sens latéral. Il en existe, on le sait, deux types : les membranes hétérogènes formées d'un support plastique dans lequel sont incorporées des poudres fines de résines échangeuses, les homogènes, où un traitement approprié fixe sur le support les fonctions chimiques destinées à donner la perm-sélectivité. Il semble que l'orientation aille vers ces membranes homogènes, encore que certains types de membranes hétérogènes semblent présenter pratiquement certains avantages à l'égard des incrustations, pour des raisons encore mal connues mais qui tiennent peut-être à des actions de micro-turbulence à la surface.

On a mis au point, concernant ces membranes, un certain nombre de tests qui permettent d'en apprécier les mérites sur échantillons. Les principales qualités que l'on recherche sont les suivantes :

- imperméabilité à l'eau ;
- sélectivité très élevée ;
- faible résistivité électrique (sous la dépendance de la nature du support et de son épaisseur) ;
- résistance mécanique aussi élevée que possible ;
- bonne réversibilité entre état sec et état humide.

Mais ces tests ne sauraient remplacer intégralement des essais prolongés dans une petite cellule de déminéralisation avec des eaux réelles et variées. C'est cet essai seulement qui notamment peut donner une idée de la durée de vie pratique des membranes pour un affaiblissement donné de leurs caractéristiques. Si le coût initial des membranes a une grande importance sur le prix de revient de l'eau traitée, la durée de vie a des conséquences aussi fondamentales, et souvent plus grandes si les appareils doivent être exploités dans des régions reculées et difficiles.

Les progrès de l'industrie chimique sont tels que les caractéristiques des membranes ne cessent de s'améliorer, mais on se heurte à une difficulté, bien connue dans toute commercialisation de procédés nouveaux, qui peut se résumer par les deux propositions contradictoires suivantes :

- le marché des appareils de déminéralisation par électrodialyse ne se développera bien que si l'on trouve aisément et à bas prix des membranes de caractéristiques élevées ;
- les firmes qui pourraient mettre au point et fournir ces produits ont tendance à attendre que le marché se soit développé avant de lancer des fabrications suffisamment industrielles pour que les prix de revient baissent substantiellement.

Il n'y a toutefois pas lieu de désespérer : la solution sera acquise par paliers successifs, mais il y a là une cause de ralentissement indiscutable dans le développement.

Les principales vertus du procédé de dessalement par électrodialyse sont les suivantes :

1°) Si l'on considère le processus physico-chimique proprement dit, la dépense d'énergie, aux pertes ohmiques près, est proportionnelle au poids de sels extraits, ce qui le rend avantageux par rapport à ceux qui font appel à un changement de phase.

Si l'on fait intervenir les rendements et la fourniture d'énergie aux auxiliaires (pompes de circulation et de recyclage), l'expérience montre que cette proportionnalité se maintient à peu de chose près. Avec les appareils construits en Algérie, on arrive à des chiffres de l'ordre de 1,2 à 1,4 kWh par kg de sel extrait pour passer d'un volume donné d'eau brute au même volume d'eau déminéralisée à 300 ou 500 ppm.

Si l'on considère enfin les autres éléments du prix de revient (amortissement, remplacement des membranes, frais d'entretien et d'exploitation), on constate finalement que le procédé, qui n'est probablement pas bien loin, pour l'eau de mer, d'être compétitif avec les distillations à prix d'énergie égal, est imbattable quand il s'agit d'eau simplement saumâtre (jusqu'à 15.000 et même 20.000 ppm).

2°) Le procédé est extrêmement " plastique " en ce sens qu'il permet des réalisations de toutes importances et adaptées à tous les cas de la pratique.

Il peut permettre la construction de très grosses installations par juxtaposition de cellules unitaires, avec toutes les combinaisons possibles de montage en parallèle et en série. Il est vraisemblable qu'il sera peu indiqué même dans ce cas d'augmenter considérablement les dimensions de la cellule élémentaire (notamment à cause des difficultés technologiques qu'introduirait l'emploi de membranes de très grandes dimensions). En Algérie (SODEMI) nous considérons que la bonne dimension est celle de l'appareil DE 1410-1 dérivé de l'appareil TNOWD 10-4, avec des membranes de 1 m x 0 m, 40 et dont la puissance moyenne d'extraction est de 600 à 700 kgs de sels par jour.

Grâce au montage par paquets partiels, l'introduction d'électrodes et de circuits supplémentaires et l'emploi de recyclages, chaque cellule peut

constituer une petite usine complète susceptible de résoudre à elle seule le problème du dessalement par passage direct quand le débit demandé n'est pas trop élevé (par exemple 130 m³ par jour avec une eau sulfatée calcique et magnésienne à 5.000 ppm).

On peut aussi, quand les débits requis sont plus faibles, fabriquer des appareils montés sur skid et facilement transportables en bloc. Ceci résoud bien le problème de l'obtention de quelques m³ par jour d'eau potable dans les conditions moyennes de salinité. On a intérêt dans ce cas à exploiter par "cuvées" (batches).

On peut même aller plus loin dans la voie des petits débits. La SODEMI a en essai un prototype d'appareil ménager, à brancher sur un robinet, et susceptible de fournir par exemple à une famille saharienne, à partir d'eau à 3.000 ou 5.000 ppm, quelques centaines de litres par jour d'une eau titrant 300 ou 500 ppm.

Ces deux groupes d'avantages sont importants. Il ne faut toutefois pas perdre de vue que l'électrodialyse n'est pas un procédé qui permette d'obtenir de l'eau distillée. Il est théoriquement possible d'aller très loin dans la voie du dessalement, mais les prix de revient deviendraient extrêmement élevés si l'on voulait franchir vers le bas le seuil de 100 ppm. Cela ne présente d'ailleurs aucun intérêt quand il s'agit des utilisations alimentaires. Pour ces usages, une eau distillée doit être rechargée en sels. On peut rappeler à titre de comparaison que l'eau minérale d'Evian, qui est sur le marché français, et d'après les médecins, la meilleure eau de boisson qu'on puisse trouver, titre 300 ppm.

REMARQUES GENERALES ET CONCLUSIONS

Le problème des dépôts salés et des incrustations

Il est assez curieux de constater que quel que soit le procédé choisi, la cause fondamentale des principaux ennuis techniques et d'une augmentation du prix de revient réside dans les dépôts solides ou incrustations dont les grands responsables sont les ions bivalents, c'est-à-dire essentiellement le calcium et le magnésium d'une part, les radicaux sulfurique et carbonique d'autre part.

S'agit-il de distillation solaire? Avec des eaux séléniteuses et magnésiennes, des eaux sahariennes par exemple, il se forme rapidement sur la cuve d'évaporation une couche cristalline qui, sans précautions, fait tomber rapidement le débit de l'appareil. Une des voies de perfectionnement les plus intéressantes pour cette application consiste à chercher à faire en sorte que ces cristaux se produisent sous une forme moins gênante et coulent au fond du bac : encore le problème de leur extraction périodique n'est-il pas tellement simple.

L'emploi des résines échangeuses d'ions n'est pas à l'abri d'un

inconvenient du même ordre, soit que la captation de certains ions au moment de l'épuration déséquilibre l'eau dans des conditions telles que certains sels puissent se précipiter, soit que le phénomène se produise, et le cas est plus fréquent, au moment de la régénération.

Si l'on considère les distillations, le prix de revient de l'eau épurée est sous la dépendance étroite des coefficients de transmission de la chaleur à travers des parois solides, coefficient auquel les incrustations portent un coup très dur. De plus, si l'on veut éviter des inconvenients techniques graves pouvant conduire à des arrêts prolongés et à des dégâts sérieux, il faut porter la plus grande attention à l'entretien de ces surfaces, et cela coûte cher. Quand on examine les efforts des scientifiques et des ingénieurs pour valoriser ce groupe de procédés, on constate que ceux-ci sont essentiellement commandés par le souci d'éviter ces phénomènes gênants, coûteux et parfois dangereux.

On a vu qu'en matière d'électrodialyse, avec certains types d'eau tout au moins, l'inconvenient n'est pas moindre. Là, on ne peut pas parler d'une augmentation lente du prix de revient énergétique, mais d'un phénomène qui une fois amorcé progresse à une vitesse telle qu'il faut arrêter l'appareil à un moment où les cellules et souvent les membranes elles-mêmes, dans leur structure, ont déjà malheureusement subi des dégâts importants.

La difficulté réside dans le fait que le danger est difficile à prévoir, que c'est une question de seuil de démarrage, et que dans les cas limites la moindre erreur d'appréciation, le moindre défaut de montage peut suffire à le provoquer. Les précautions à prendre dans le domaine technique et dans celui de l'exploitation ne sont pas gratuites.

On a pu constater qu'en électrodialyse il était parfois beaucoup plus aisé de traiter de l'eau de mer que certaines eaux simplement saumâtres à moins de 5.000 ppm, mais de composition saline particulièrement fâcheuse.

On en vient à se demander s'il ne conviendra pas, au moins dans des cas particulièrement difficiles, de modifier la composition ionique de l'eau avant de l'admettre dans un appareil industriel, qu'il s'agisse d'une quelconque sorte de distillation ou d'électrodialyse. Dans cette dernière application, on a pu penser à faire précéder l'installation d'un appareil à résine à fonctionnement continu, en faisant la régénération, d'une manière également continue, en employant comme liquide régénérateur le concentrat sortant des cellules. Dans le cas des distillations, certains traitements chimiques par précipitations pourraient parfois être avantageusement préconisés.

Il n'est pas impossible qu'on arrive un jour à "piéger" les ions alcalino-terreux au sein de complexes chimiques organiques moins nuisibles par ce qu'on est convenu d'appeler des agents chélateurs. Cette voie n'est pas sans espoir, mais elle n'en est qu'au stade de la recherche fondamentale (notamment au Southern Research Institute aux U.S.A.).

Choix d'un procédé de déminéralisation

Il est encore impossible en l'état actuel de la technique, de donner une recette infailible et complète pour choisir dans chaque cas, parmi les appareils que tel ou tel constructeur peut d'ores et déjà livrer, celui qui répondra le mieux à un problème posé y compris l'énoncé des conditions locales.

Il n'est tout de même pas inutile de résumer à ce sujet quelques idées bien claires sans souci excessif de logique cartésienne.

On doit prendre en compte avant tout, semble-t-il, la dimension du problème, la nature de l'eau et les autres conditions naturelles.

S'il s'agit de tout petits débits, à l'échelle de quelques dizaines de litres par jour, et si les conditions d'insolation sont suffisantes, la distillation solaire avec des appareils standards constituera une bonne solution. Si l'on se trouve dans un pays peu lumineux, on pourra parfois faire appel au bon vieil alambic à simple effet avec ou sans réchauffeur, ce qui permettra parfois d'utiliser comme moyen de chauffe des déchets divers, minéraux ou végétaux. On n'oubliera pas que les échangeurs d'ions peuvent parfois être utilisés avec fruit, nonobstant l'importance du prix de revient.

La question devient plus sérieuse quand on passe à quelques centaines de litres, voire quelques m³ par jour. Le prix de revient et la sécurité de marche commencent généralement à prendre alors de l'importance, ainsi que parfois la nécessité de pouvoir déplacer aisément les appareils, car il s'agit souvent alors d'installations provisoires. La distillation thermique n'est pas très indiquée, car elle ne permet guère de petites réalisations si l'on veut un bon rendement, et les frais d'exploitation dépendent assez peu de la dimension. On pourra s'orienter soit vers de petits appareils à thermo-compression du type rotatif, genre Aquastill d'Hickman, soit vers l'électrodialyse. L'avantage pourra aller aux premiers s'il s'agit d'eau de mer ou d'eau extrêmement chargée en sels, disons au-delà de 20.000 ppm, à la seconde à coup sûr si l'eau est nettement moins saline.

Quand on arrive aux centaines et aux milliers de m³ par jour, on n'aura que peu de chances de se tromper si l'on applique la même discrimination en l'état actuel des choses : électrodialyse dans le cas d'eau simplement saumâtre, distillation pour l'eau de mer ou une eau de composition voisine. Remarquons, toutefois, que ceci n'est déjà plus tout à fait évident, et que l'électrodialyse a certaines chances de devenir à bref délai compétitive avec les distillations, à moins que celles-ci de leur côté ne fassent des progrès décisifs et subits.

Si c'est l'électrodialyse qui est choisie, il conviendra de se méfier des offres comportant des appareils "passe-partout" et des études insuffisantes concernant la composition ionique de l'eau. Il n'y a pas de panacée en cette matière. Il est naturel que les constructeurs, pour abaisser le prix des fabrications, limitent celles-ci à un petit nombre de standards. Mais il est indispensable que ces appareils-types présentent une plasticité suffisante

pour que le montage de détail (circuits hydrauliques, électriques, pompes, etc.) puisse être adapté étroitement à la nature de l'eau à traiter, sous peine des plus graves mécomptes. Chaque cas doit être analysé comme cas particulier. Le prix de revient réel et la régularité d'exploitation dépendent étroitement du soin apporté aux études préliminaires.

Il faudra également que le client éventuel sache demander au constructeur ce qu'il désire en matière de contrôle et d'automatisme. Dans ce domaine on peut faire pratiquement ce qu'on veut sans toucher profondément aux structures technologiques fondamentales. On ne peut qu'inciter les utilisateurs à être prudents en cette matière, et à bien réfléchir avant de payer cher des sécurités souvent plus apparentes que réelles, qui introduisent des causes de souci supplémentaires. Tel appareil qui fonctionne bien tout seul avec une surveillance épisodique pourra se trouver arrêté parce qu'un relais de contrôle se sera dérégulé sous l'action d'un vent de poussière ou d'un quelconque phénomène parasite : on peut passer des heures, voire des jours, à chercher la cause d'une telle panne, alors qu'au fond l'appareil de déminéralisation ne demande qu'à continuer à fournir de l'eau. Ce n'est pas à dire que certaines sécurités fondamentales ne doivent pas être installées (par exemple celles qui portent sur des différences de pressions dangereuses pour les membranes). Mais il ne faut pas en abuser.

S'il s'agit de distillation, quel type d'appareil choisir ? Distillation à effets multiples en longs tubes verticaux ? Distillation dite "instantanée" à étages multiples ? Distillation par thermo-compression elle-même étagée ? Combinaison de plusieurs procédés ? Il est vraiment prématuré de donner des conseils en cette matière complexe, à un moment où les meilleurs espoirs, en ce qui concerne le prix de revient, sont donnés par des appareils que l'on sait certes construire et faire fonctionner, mais qui n'ont pas encore reçu la longue sanction de l'expérience dans des conditions d'emploi réelles et parfois sévères. Pour les appareils les plus modernes, la partie "références" dans un dossier d'offres ne peut être encore qu'extrêmement légère. Le choix sera souvent guidé par le degré de confiance que l'on fait au constructeur, par le sérieux de son étude de détail et par l'importance des garanties après vente qu'il sera prêt à assumer par contrat.

Avenir de la déminéralisation

Extraire des sels de l'eau reste et restera longtemps encore une opération coûteuse, parfaitement justifiée et payante s'il s'agit d'alimentation humaine ou animale, mais d'emploi impossible pour l'usage agricole courant.

On peut avoir l'idée que la question n'est pas toujours correctement posée.

Même lorsqu'il s'agit d'alimentation humaine, on sait bien que l'eau

distillée n'est pas une eau potable, et qu'il faut y rétablir un certain pourcentage de sel pour la rendre utilisable. Ce qui tombe moins sous le sens, c'est qu'il n'est pas toujours indiqué de déminéraliser trop à fond quand le procédé, comme l'électrodialyse, permet de proportionner les frais au poids de sel enlevé. On a vu parfois commettre l'absurdité qui consiste à donner à des hommes qui évaporent énormément en travaillant (par exemple au Sahara où un travailleur manuel en été doit boire 10 à 12 litres d'eau par jour) une eau très pure et à les obliger par ailleurs à absorber des pastilles de sel. On dira qu'il y a une question de goût de l'eau, et qu'un goût agréable fait partie du confort. C'est vrai, mais bien souvent le consommateur, qui n'est pas un dégustateur spécialisé, ne fera de ce point de vue aucune différence entre une eau à 300 ppm et une eau à 700. Or la seconde sera sous certains climats mieux tolérée que la première.

Quand on dit qu'on ne pourra jamais rien faire pousser (à part du palmier-dattier) avec une eau à 6.000 ou 7.000 ppm, cela est généralement vrai, et il est non moins vrai que déminéraliser cette eau pour la transformer en eau d'irrigation est une opération non payante. Mais il est des cas limites où une transformation intéressante peut être envisagée. En biologie végétale les ions n'ont pas tous la même nocivité. Les plus dangereux sont le chlore et le sodium. Il suffit parfois de descendre pour ceux-ci au-dessous d'un certain seuil, qui reste assez élevé grâce aux progrès des techniques agricoles en pays aride, pour que l'eau soit utilisable.

Si l'on considère l'électrodialyse, on s'aperçoit que sans que le phénomène soit extrêmement marqué, il y a une certaine sélectivité ionique, et que les ions monovalents sont éliminés un peu plus vite que les autres. Il y a sans doute là une voie à exploiter, et un problème qui mériterait d'être posé aux fabricants de membranes.

En élevant un peu le débat, et c'est sur cette remarque que l'on terminera, on en arrive à l'idée suivante. Actuellement les organismes de recherche et l'ensemble des utilisateurs se contentent de poser aux chercheurs et aux industriels la question suivante : à quel prix, étant donné telles conditions, puis-je obtenir de l'eau distillée ou de l'eau à 300 ppm ? C'est peut-être "mettre la charrue devant les bœufs", comme on dit en France. Sans doute serait-il plus indiqué de demander d'abord aux spécialistes de tous ordres : médecins, hygiénistes, vétérinaires, phytobiologistes, agrologues, etc., la définition des standards minima à requérir pour telle ou telle utilisation dans tel domaine de conditions d'ambiance. On pourrait alors poser aux scientifiques et aux industriels qui s'occupent, non de distillation, mais peut-être de séparation par congélation et en tous cas d'électrodialyse, disons de modification ionique des eaux, des questions plus judicieuses. Il n'est pas impossible qu'en suivant cette voie on arrive à déboucher sur certaines applications aujourd'hui fermées en pratique, et à utiliser de manière plus féconde des investissements de tous ordres.

ELECTRODIALYSIS RESEARCH AND DEVELOPMENT IN SOUTH AFRICA

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SUMMARY

The development of electro dialysis equipment by the SACSIR, culminating in the erection and operation of a 2,400,000 gallon per day plant to desalt underground mine water, is reviewed. Also reviewed are the results of pilot plant sea water desalting experiments aimed at assessing sea water desalting costs when using large-scale equipment.

The development of simple electro dialysis equipment designed to produce stock-drinking water in arid areas is briefly reviewed.

A brief account is given of the development of parchment-based ion-selective membranes, and the performance of such membranes, commercially produced, on the mine water desalting plant.

INTRODUCTION

Throughout the world the need for water for mankind's activities is forever increasing. This is no less true for the rapidly developing areas of Africa South of the Sahara than it is for other parts of the world which have a longer history of civilisation and industrialisation.

In the more arid areas of Southern Africa many of the available water supplies are brack—often too much so for them to be used even by animals, which have a greater tolerance for dissolved salts than have humans or vegetation.

The production of fresh water from salt water by distillation has been a feasible large-scale process for over half a century ; of the newer processes to have been investigated in the last decade, the only one yet to have reached the stage of practical development is electro dialysis. South Africa, in common with other countries such as the U.S.A., Britain, Holland, France, Israel and Japan, has investigated the electro dialysis process, and during the past seven years has brought it to the stage where the only existing large-scale plant, with a designed output of 2,400,000 Imperial gallons per day, has been in continuous operation since January 1959. This plant is desalting brack mine water at the Free State Geduld gold mine in the Orange Free State goldfields.

The South African Council for Scientific and Industrial Research (SACSIR) has also been active in investigating the practical and economic possibilities of producing drinking water from sea water by electro dialysis, through actual trials at Luderitz, South West Africa, where the town's sole source of water is the sea.

Large areas in South Africa which are used for raising cattle and sheep have very limited supplies of fresh water, but have ample supplies of brack water too salt for animals to drink. The Department of Agricultural

Technical Services has for long past been interested in investigating the long-term effects of brack waters on animal health.

With electro dialysis it is possible to carry out properly controlled field tests using one or more specific brack well waters desalted to differing degrees. A research camp is being set up on the south-western fringe of the Kalahari Desert at which a CSIR desalting unit will operate. The main objective of the CSIR in this project is to see if it is technically and economically possible to develop extremely simple electro dialysis units for providing stock drinking water in such areas.

Although the electro dialytic method of desalting water can never be cheap enough under more normal circumstances for providing irrigation water, certain special cases in South Africa are warranting attention. Such cases are to be met with where large-scale citrus growing is carried out in areas subject to periodic droughts. During these periods, areas such as the Sundays River Valley then have to rely on brack borehole water. The provision of fresh water for six months or so in drought years can prevent markets from being lost and whole orchards that have taken many years to come to maturity from being totally destroyed. Where a market of somewhere near £2,000,000 is involved, the occasional provision of expensive irrigation water by electro dialysis can be regarded as commercial insurance against total financial loss. It is more than probable that other special cases will be found throughout southern Africa.

The purpose of this paper is to highlight some of the experiences met with and conclusions reached regarding the electro dialysis process, based on the past seven years' work in South Africa. It will be restricted mainly to the work concerned with the problem of disposal of brack mine water in the Orange Free State goldfields which has led to the commissioning of the 2,400,000 gallon per day Free State Geduld plant. This work has been fully reported in a recently published monograph.¹ The work on the so-called "Farm Units" is described in a companion paper to this one.²

Although it has not been possible to complete, in time for this paper, a detailed analysis on the operating costs of the Free State Geduld plant, it is hoped to present up-to-date data at the Conference for which this paper forms a technical document. Nevertheless, it can be said that this plant is proving that electro dialysis on the very large scale is a perfectly practical engineering proposition which should meet present-day price requirements for bulk water supplies in many cases where power is cheap and the desalting range is of the order of 2,500 ppm total dissolved solids (TDS).

The wide range of conditions under which the electro dialysis process may have to work, and the flexibility inherent in the process, make it almost impossible to quote typical costs for desalting water by electro dialysis. All that can be done is to show what has been achieved under actual operating conditions in South Africa.

The flexibility of the process renders it possible to design plants to make the best use of local factors such as power and labour costs, etc. In some cases the cost of membrane replacement may be considerably greater than the power costs for operating the process, or the opposite may apply. In the one case it may pay to use low current densities and a large total membrane surface, and in another case to use a smaller plant at a higher current density, and hence smaller total membrane surface. The number of parameters is very large. For large plants which can be " custom built " this is an advantage. For small units, especially where cheapness is desirable, a standard design is required which may not always be the optimum for every application.

The difficulty facing the manufacturer is to gauge the market correctly and to produce a design that best meets average needs. It is this difficult stage of commercialisation that is just being reached, and for this reason, in particular, the work in South Africa is being viewed with particular interest, since it may give definite leads as to the future lines on which the electro dialysis process can best develop.

Practical experience of the electro dialysis process in South Africa has thrown up many problems, the solving of which requires fundamental investigations in such diverse fields as electrochemistry, the physical chemistry of ion-selective membranes, fluid mechanics and corrosion. Work is being actively done in some of these fields, since it is through a better understanding of the basic principles that the real advances in technology take place.

THE BACKGROUND TO SOUTH AFRICAN WORK ON ELECTRO-DIALYSIS

The electro dialytic process for the demineralisation of saline waters has been well described in the literature.^{3,4} It will be assumed, therefore, that the reader is familiar with the principles of the process and with general progress in the field as reported in such publications as the Annual Reports of the U.S. Department of the Interior—Office of Saline Water.

South Africa started investigations into the electro dialysis process in 1953 by the establishment of a group of research workers in the National Chemical Research Laboratory of the Council for Scientific and Industrial Research.

The original intention was to investigate the potentialities of the electro dialysis process as a practical and economic method of desalting brack waters. It was hoped that from this exploratory work possible fields of desalting in South Africa, which would warrant detailed investigation, would be disclosed. In 1953 the process was hardly out of the laboratory stage and only then really entering into the development stage.

Early in 1953, however, the Anglo-American Corporation of South Africa Limited approached the CSIR to see if it would be willing to

investigate the possibility of the electro dialysis process being a practical and economic means of desalting the many millions of gallons of brack water which were beginning to be pumped up daily from the newly developed and ever expanding gold mines in the Orange Free State.

The occurrence of large quantities of underground water in these mines was entirely unexpected ; the fact that it was brack (from 3,000 to 4,000 ppm NaCl) was even more unexpected, and was a most serious matter since the surrounding country was quite unsuitable for any indiscriminate disposal of saline water and there were no large rivers, or indeed any perennial rivers nearby, into which it could be flowed. The immediate practical solution which was being used was the disposal of the water into large solar evaporation pans. Electro dialysis was, however, one of a number of other disposal methods which merited consideration. It had the attraction of rendering usable the greater part of the brack water, and hence saving an equivalent amount of water from being pumped from the limited resources of the Vaal River some distance away, while brine from the process could be sent to the existing evaporation pans and the salt eventually be recovered. This salt recovery could be by no means insignificant as salt is usually in rather short supply in South Africa.

Since almost 90% of the total dissolved solids in the mine waters are in the form of sodium chloride the amount of salt in the effluent from the Free State Geduld plant, having a total inflow of approximately 3,000,000 gallons per day of water averaging 2,800 ppm TDS, would be nearly 33 short tons per day. If all the estimated amount of water that might have to be treated eventually were treated by electro dialysis, this figure for the gold-fields could rise to as much as 200 tons of salt per day.*

The whole background to the electro dialysis investigation was, therefore, changed from a rather indeterminate long-term one into one to develop and engineer the process, against time, for multimillion gallon per day quantities. Apart from the time limit a further severe limitation was that the desalted water should not cost more than 2s. 6d. per 1,000 Imperial gallons to produce—including all operating costs, depreciation, and interest on capital invested. This was the equivalent cost of buying Vaal River water at 2s. 3d. per 1,000 gallons, plus 3d. per 1,000 gallons for disposal of brack mine water to the evaporation pans. Thus, in 1953, active steps were already being taken to develop a very large electro dialysis plant—a matter which is only now being started in the U.S.A. under the Demonstration Plant Programme of the Office of Saline Water of the Department of Interior.

It is of interest to note that the plant at the Free State Geduld (F.S.G.) mine, which started partial operation on a production basis in January 1959, is rated at 2,400,000 Imperial gallons per day output, whereas at the

* Since this report was prepared it has been reported that both the water table and water salinity are slowly falling and that the long-term disposal problem is now less urgent.

end of 1959 only sixteen other plants with a combined total of 412,000 U.S. gpd were listed by the O.S.W.⁵ as existing or under construction, although a total of about thirty to forty small plants were said to be in operation throughout the world.

As far as is known, the two largest electro-dialytic demineralisation plants outside South Africa are the Ionics Inc. 86,400 U.S. gpd plant at Monahans, Texas, and one of the same capacity at Bahrein in the Persian Gulf. The demonstration plant scheduled for operation in the U.S.A. for 1961 will produce 250,000 gpd of water of 500 ppm TDS from a water of 4,000 ppm TDS. The Free State Geduld plant in South Africa is designed to produce 2,880,000 U.S. gpd of 600 ppm TDS water from a water of 3,000 ppm TDS.

The pilot-plant work which led to the decision to erect the Free State Geduld plant was carried out on a 4,000 ppm TDS water desalted to (a) 1,000 ppm TDS, (b) 500 ppm TDS. The 1,000 ppm TDS water was intended for domestic consumption. It was later decided to place the large plant at a mine having a 3,000 ppm TDS water and to use the desalted water in the uranium plants associated with the gold mines. An upper limit of 600 ppm TDS was prescribed, giving the maximum allowable NaCl in water for the uranium plants.

The background to the early work, and the progress of the co-operative work of the CSIR and the group of gold-mining companies who largely financed this development, has been fully reported in a number of publications^{6,7,8} and it is not intended to repeat it here.

Quite early in the development work it became apparent that if a large-scale plant was to be erected the supply of membranes to operate the process would be a major difficulty. At that time no membranes had been manufactured in either the quantity or the size required for the proposed pilot-plant investigations, let alone for what would be required for the envisaged large-scale plant. An urgent programme was therefore put in hand immediately to develop membranes that could be used for the pilot-scale trials, and eventually be produced in sufficient size and quantity for any planned large-scale plant, should suitable commercially produced membranes not have become available by then. In fact, other suitable membranes did not become available in time for the 2,400,000 gpd plant and the CSIR type membranes were, therefore, manufactured under licence by the Permutit Company Limited, London, and have been operating completely successfully in the F.S.G. plant. Approximately 10,000 anionic and 10,000 cationic membranes, each of 15 sq. ft., i.e. 300,000 sq. ft. of membrane, are required annually.

The F.S.G. plant started operation slightly less than six years from the time that the electro-dialysis process was first investigated at the CSIR, and only three years after the pilot plant, which formed the basis of the design, was brought into full operation.

Considering that the F.S.G. units have membranes practically eight times the area of those of the pilot plant, packs with twice the number of membranes in them and presses with two-and-a-half times the number of packs in them, some idea of the magnitude of the step forward to the full-size plant can be formed.

It would be wrong to suggest that there have not been difficulties in getting the F.S.G. plant into production. Many of these have been purely mechanical in nature or stem from having to use materials of construction with which the designers, fabricators and plant contractors had little or no experience. Other difficulties have arisen from hydraulic causes; in particular, the problem of obtaining the rather uniform liquid distribution to packs, and to compartments of packs, that is necessary in electro dialysis equipment as at present designed, has proved considerable.

The F.S.G. plant was started up in stages in January 1959. It was regarded as an experimental plant, but has been operated as much as possible on a routine production basis so that the maximum revenue from the sale of water could be obtained.

Numerous modifications have been made as the result of experience. It is only recently that all eight presses have been in operation. For a considerable time only three-quarters of the plant was on stream as improved components for the final quarter of the plant had not been completed.

Experience with the three-quarters of the plant on stream has demonstrated the basic soundness of the engineering design. Two major problems arose which have prevented more than about 60% of the designed output being obtained so far. These problems centre around the development of intercompartmental leakage (flow of concentrating stream into diluting stream, or vice versa) under certain operating conditions, leading to loss of output, and around the rather high average electrical resistance of the packs—approximately twice that designed for. The former is an engineering and assembly problem, the solution to which lies in careful assembly of the components, and is being overcome; the second one is a hydraulic distribution problem which, although very carefully investigated in the pilot- and prototype-plant phases, is still not completely solved. Plant reliability has been very high.

The average coulomb efficiency has been within the design figure and the membranes and electrodes have exceeded by a substantial margin their designed estimated life of nine and six months respectively.

Other aspects of the electro dialysis project, such as Sea Water Desalting, Farm Units, and Membrane Development, which arose as a logical extension of this work, are mentioned later.

DESALTING OF BRACK MINE WATER

The earlier South African work has been described in a number of publications,^{7,8,9,10,11} while the whole of the CSIR work on electro-

dialysis and membranes, but excluding "farm" type electro dialysis units, is included in a recently published monograph.¹

A paper by Wilson¹² outlines important factors in the design of electro dialysis equipment with particular reference to the Free State Geduld plant.

In the following section some of the more important features of the approach to the mines' problem, the plant design, and operating experience will be outlined.

PRELIMINARY INVESTIGATIONS — LABORATORY UNIT

The first laboratory unit was based on the designs and experience of the TNO, using the full flow or "intermembrane-spacer" type of apparatus,^{1,9,10,12,13,14} which basic type has been retained throughout in the large plant designs, but not in the farmer's unit type, work on which only started in 1956 and in which a modified tortuous path design is used.

The laboratory unit is shown in Figure 1.

The unit was of the multi-compartment type, using from five to fifty cell pairs. The compartments were in the vertical position, brine (concentrating) and dialysate (diluting) streams flowing co-currently. Separate electrode rinses were used. The spacer material used was either rigid P.V.C. perforated, corrugated material giving a membrane spacing of $\frac{1}{8}$ in., or somewhat similar material fabricated at the CSIR from flat perforated sheet, to give a membrane spacing of $\frac{3}{32}$ in.¹⁰

The sealing gaskets were of relatively incompressible material (Bakelite, and later Klingerit steam jointing) as plastic materials were not favoured owing to fear of plastic flow under compression and change of thickness of the gaskets.

The electro dialysis unit had a rated production of 200 gph of desalted water when operating with fifty cell pairs and desalting through 800 ppm with a feed water in the ranges of 4,000 to 2,000 ppm TDS. Overall membrane dimensions were $29\frac{1}{8}$ in. \times $10\frac{1}{8}$ in. (700 \times 270 mm.) and the active area $16 \times 8\frac{1}{8}$ in. (406 \times 231 mm.), giving 44.5% active membrane area.

The installation was set up so that both brine and dialysate recycle could be used. Gravity flow feed systems were used. The unit was primarily used to study all design parameters such as flow, current density, hydraulic resistance, polarisation characteristics of the membranes, salt concentrations, flow ratios in concentrating and diluting compartments, pressure equalisation between compartments, power consumption, engineering design features and materials of construction, etc.

Most of the work on this laboratory unit was carried out using mains water to which sodium chloride was added, and using TNO produced cellophane-based membranes,¹⁰ although CSIR parchment-based membranes were used towards the end of the tests.

Some 2,000 hours operation were carried out on this press under a wide variety of operating conditions.

The results of work on this unit showed that electro dialysis might well be a technical and economic solution to desalting the brack mine waters in the new O.F.S. goldfields.^{9,10}

A very preliminary estimate indicated that it might be possible to desalt 3,800 ppm TDS mine water down to 1,000 ppm TDS for about 2s. 6d. per 1,000 gallons. This was based on :

- (i) A total desalting energy demand for electro dialysis of 8 to 10 kWh/1,000 gallons.
- (ii) Desalting in four stages.
- (iii) Average salt concentration ratio between concentrating and diluting streams of 4 : 1.
- (iv) Membrane spacing $\frac{1}{8}$ in.
- (v) Current densities from 4 to 8 mA/cm².
- (vi) Pumping energy 5-7% of total energy.
- (vii) Electrical energy price of 0.3d. per kWh.

On the basis of these conclusions, the mining companies decided to enter into a contract with the CSIR for the design of a pilot plant to be erected at the No. 1 Shaft of Western Holdings Mine, Welkom. This mine was in the development stage and had a water of the approximate composition shown in Table I. Owing to mining operations the composition of the water showed small variations from time to time.

Table I.—Typical analysis of water pumped from underground at No. 1 Shaft, Western Holdings Mine

Suspended solids—variable	. 1-124 ppm (average 40 ppm)
Chlorides (as NaCl)	. 3,800 ppm
Total hardness (as CaCO ₃)	. 401-415 ppm
Calcium (as CaCO ₃)	. 382 ppm
Magnesium (as MgCO ₃)	. 19-33 ppm
Sulphate (as SO ₄ ²⁻)	. 144 ppm
Carbonate (as CaCO ₃)	. Nil
Silica (as SiO ₂)	. 15-20 ppm
Fe	. 0.1 ppm
Co, Ni, Mn, Al	. Not detectable
K	. Possibly traces
Ba	. 0.3 ppm
Sr	. 0.10 ppm
pH	. 3.2 to 9.6 (depending on mining)

Pilot Plant

The pilot plant was erected by the Anglo-American Corporation of South Africa Limited and operated by their staff under the direction of the CSIR.

The plant was a four-stage one, designed for maximum flexibility.^{1,9,10} It included a raw water pretreatment section consisting of lime dosing mechanism, various types of settlement equipment, a rapid gravity sand filter and a 10,000 gallon storage tank for filtered water.

The electro dialysis units were arranged with the four stages in series so that there was co-current flow of the diluting and concentrating streams within each stage, but counter-current flow of these streams through the plant, the raw water being fed as the diluting stream to stage one and as the concentrating stream to stage four. Provision was made for recycle and gravity feed to each stage.

Experience on the small unit at Pretoria was incorporated in the electro dialysis units, or presses, in the pilot plant.

The major changes are outlined later as they are of some importance, having as they did a distinct bearing on the eventual design of the 2,400,000 gpd plant.

The purposes of the plant were :

- (i) To check the laboratory findings by extended tests on actual mine water ;
- (ii) to determine the probable lifetime and behaviour of the membranes ;
- (iii) to obtain experience on a continuously operating plant working on a mine water of variable composition, as would be met with in practice ;
- (iv) to obtain more accurate engineering design—and cost—data ;
- (v) to incorporate such mechanical or operating improvements as might be suggested during the course of the tests.

The pilot plant operated from September 1955 to the end of May 1957, for a period of well over 12,000 hours.

In designing the pilot plant the needs of large plant operation were borne in mind.

Work at Pretoria had suggested that current densities in the order of 4 to 8 mA/cm² would be best, if polarisation difficulties were to be minimised, and that the difference of salt concentration between the concentrating and diluting streams should not exceed about 4 : 1 with the membranes then available, higher concentration differences leading to excessive back-diffusion of salt from the concentrated stream into the diluted (or desalted) stream. It was also considered worth attempting to use a membrane separation distance of only $\frac{1}{2}$ in., as some savings in electrical energy (about 7-10%) could be expected in comparison with the use of a $\frac{1}{8}$ -in. distance. Arrangements were therefore made to permit stage four to be operated at this closer membrane distance once suitable membrane spacer material could be obtained : the spacer material had to be made at the CSIR.

The question uppermost in mind was whether a large plant should be designed around a considerable number of relatively small units or a few very large ones. In view of the extreme restrictions on operating costs

for any large plant for the mines, which costs included depreciation and interest on capital, the use of a few large units was considered the better approach. This, however, meant investigating at some stage the behaviour of large units, as absolutely no experience on such units was available anywhere in the world and there were no data for checking the reliability of scale-up factors. It could also raise engineering and design problems of no small magnitude, as indeed has proved to be the case. It was decided to let the final decision depend on the course of the pilot plant trials.

The pilot plant did, however, incorporate the most important features which it was felt would be most necessary in a large plant consisting of a few large units. One of these was the construction of electro-dialysis units having a large number of membranes each. This need led to the conception of the principle of multiple pack units and the so-called "intermediate plate".^{1,9,10,12,15}

It was fairly well known at this time that the uniform distribution of liquids to the compartments forming a membrane pack or "stack" becomes increasingly more difficult as the number of compartments increases. It also seemed that the problem was more acute with the intermembrane spacer type of apparatus, with its relatively low hydraulic pressure loss of the order of 1 to 2 ft. head of water per foot length, than in the tortuous path design with pressure losses under practical operating conditions of the order of 20 ft. water per foot length. The problem is primarily to control effectively the onset of polarisation at the membrane surfaces, particularly the negative membrane, and to prevent excessive desalting, either or both of which can occur if the flow to a diluting compartment is considerably reduced for otherwise steady operating conditions. The problem is of practical significance mainly in the diluting compartments. About one hundred cell pairs (200 membranes) in a pack seemed to be the maximum with which adequate distribution could be obtained. Much above this caused some compartments to have considerably less than the average flow, causing either polarising conditions to set in or, with the prevailing current density, so much desalting to occur that the electrical resistance rose excessively. In packs with very large numbers of membranes the liquid supply and removal conduits also have to be excessively large.

For the above reasons it was decided to retain the advantages of fairly small packs while minimising the number of presses, with their attendant electrodes, rinsing systems, control gear, etc., large duplication of which adds disproportionately to the capital and operating costs. The scheme adopted is shown in Figure 2. It consisted of four packs in each of the presses forming a stage, each pack consisting of fifty cell pairs or one hundred membranes.

The electrode area was the same as for the laboratory unit. Owing to the change in shape of the compartments the apparent effective area was 182 sq. in. in place of the 130 sq. in. of the rectangular compartments of

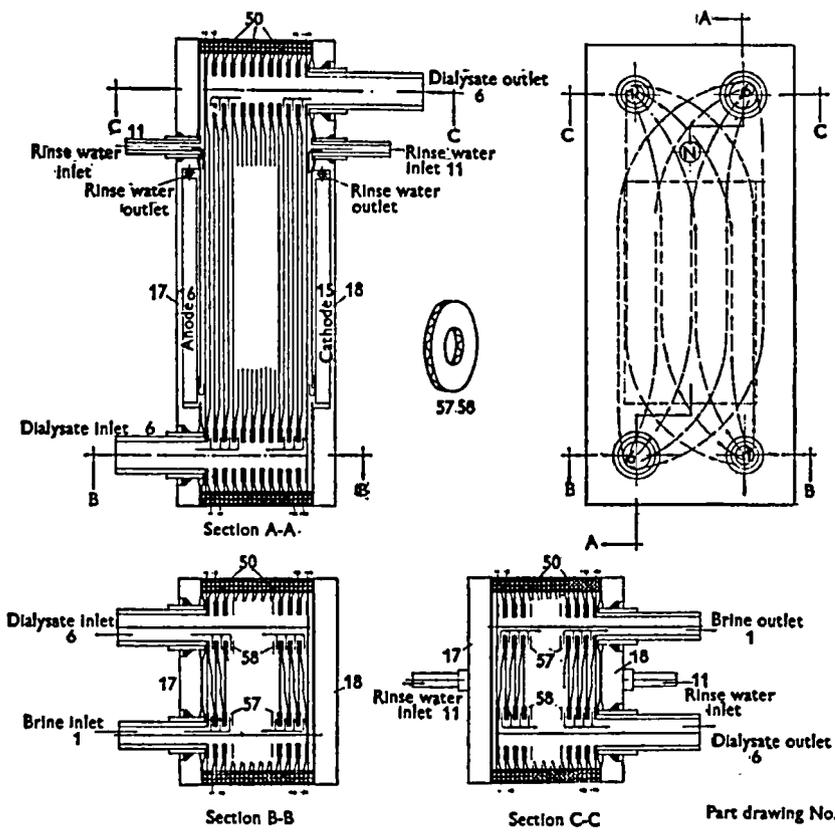


FIG. 1.

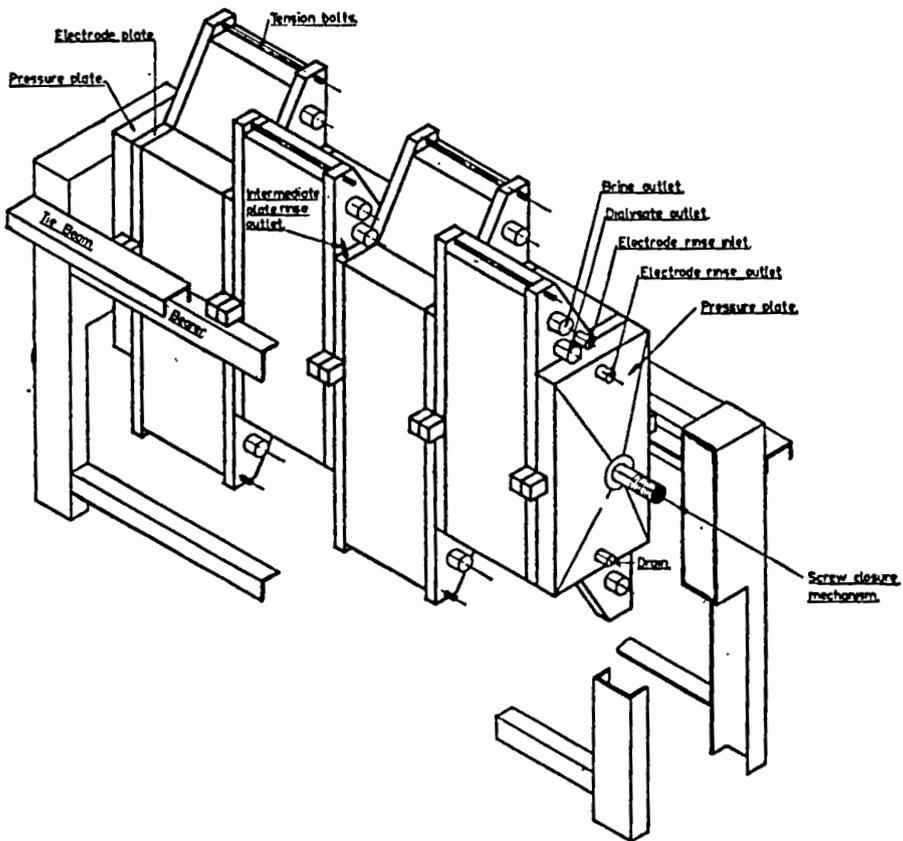


FIG. 2.—Pilot plant electro dialysis unit.

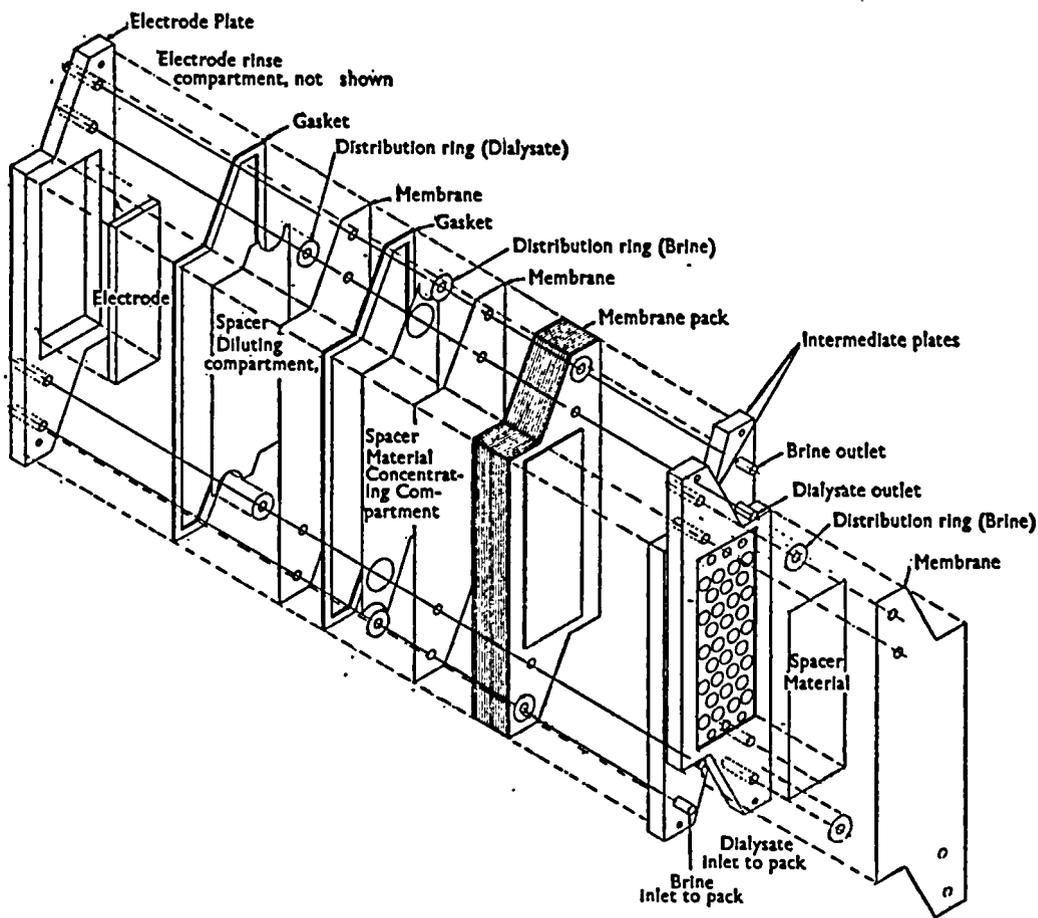


FIG. 3.

the laboratory unit. Current densities ranged from 12 mA/cm² in stage one to 8 mA/cm² in stage four, with a throughput of 1,000 gph.

The basic distribution ring system (Figs. 1 and 3) was retained, but the shape of the plates was changed so that the inlet and outlet connections could be brought in as shown in Fig. 3, and not at the sides of the plates, which would have meant using thicker plates and increasing the electrical resistance of the whole unit.

This design enables individual packs to be removed from a press by slackening off the press, and lifting a particular pack out vertically; the packs were kept together by the tie-bolts. This arrangement can be of particular value if any one pack becomes faulty as a new one can be very quickly inserted. Furthermore, packs with small numbers of membranes are easier to handle than large ones and broken membranes are easier to locate.

In practice it has been found on the F.S.G. plant that once a press is assembled and closed up it operates for many months at a time without requiring attention, and that it is rarely necessary to remove a single pack except for research or test purposes.

The chief advantages of the intermediate plate system lie in the possibility of having in effect electro dialysis units with large numbers of membranes in a single unit—2,000 in an F.S.G. unit—thus minimising the number of control valves, control gear, piping, and electrodes, the latter absorbing non-productive electrical energy. At the same time the advantages of packs with a small number of membranes are retained, leading to ease of handling, assembly, maintenance, and making a practical design possible from the engineering point of view.

With regard to membrane breakage, both on the pilot plant and the F.S.G. plant, this has, in fact, been confined almost entirely to a few end ones in the packs. Almost without exception, broken membranes are not found deep inside a pack. The main cause of breakage has been either due to out-of-balance hydraulic pressure between the rinse compartment in the plates and the end membrane compartment, or due to physical damage of the membrane at the intermediate plate, which, to provide electrical continuity, must have as large an open area as possible. In the pilot-plant design circular holes were cast in the plate which was moulded as an integral unit from glass fibre-epoxy resin impregnated material (Fig. 3). Little trouble was caused from this design. The large plates for the F.S.G. plant had, however, to be fabricated from other materials, since epoxy resin- or polyester-glass fibre plates could not economically be manufactured in the large size necessary (7 ft. by 2 ft. 2 in. by 2 in. thick). Separate inserts were used to support the membranes against the plates and yet allow adequate open area for the electrical current. These caused considerable damage to membranes as the inserts were not sufficiently rigid. A satisfactory solution to large intermediate plate design and

fabrication problems involved in the F.S.G. plant has only recently been achieved.

The so-called parallelogrammic shape of the pilot-plant plates was not altogether satisfactory. The flow distribution across compartments tended to take the form shown in Fig. 4, so that when the F.S.G. plant design was considered a rectangular shaped plate was adopted, liquid connections being at the side of the plate. With this design the percentage active membrane area was raised from 44.5 to 69.6—an important saving in membrane costs. The general type of plate design and associated gaskets is shown in Fig. 5. The reason for the slots in the gaskets is for more even distribution of liquid to the active area of the membranes, which is discussed later.

SOME FACTORS IN THE DESIGN OF THE FREE STATE GEDULD PLANT

Uniform liquid flow distribution in a multicompartiment electro-dialysis unit of the intermembrane spacer type of apparatus is a basic problem. The degree to which this problem is solved in any particular design will largely determine its practicability and the operating costs of the process.

As the matter is of such basic importance and has played a large part in the design considerations of the F.S.G. plant, it is of value to discuss it in some detail.

It is well known that in electrolysis processes involving membranes, one of the factors governing the energy requirements of the process is the development of polarised layers adjacent to the membranes. This phenomenon has been widely studied and reported, while work related directly to its significance in the electro-dialysis process has been carried out in this Laboratory over the past two years and will shortly be published.¹⁶

So far as polarisation effects concern electro-dialytic membrane cell design and operation, the following facts have to be borne in mind.

The polarised layers in the electrolyte bounding the membrane surfaces are layers of high electrical resistance and of significantly different pH to that of the adjacent bulk electrolyte. These layers arise as a result of ion depletion at the membrane-bulk electrolyte interface, due to differences in rate of ion transfer in the membrane and in the bulk electrolyte. Where the bulk electrolyte is not a flowing system these layers can become quite thick.

The degree of ion-depletion in these polarised layers, the extent of the pH changes, and the increase in electrical resistance in these layers relative to that of the bulk electrolyte, depend upon a large number of factors such as the nature of the electrolyte, the species of membrane

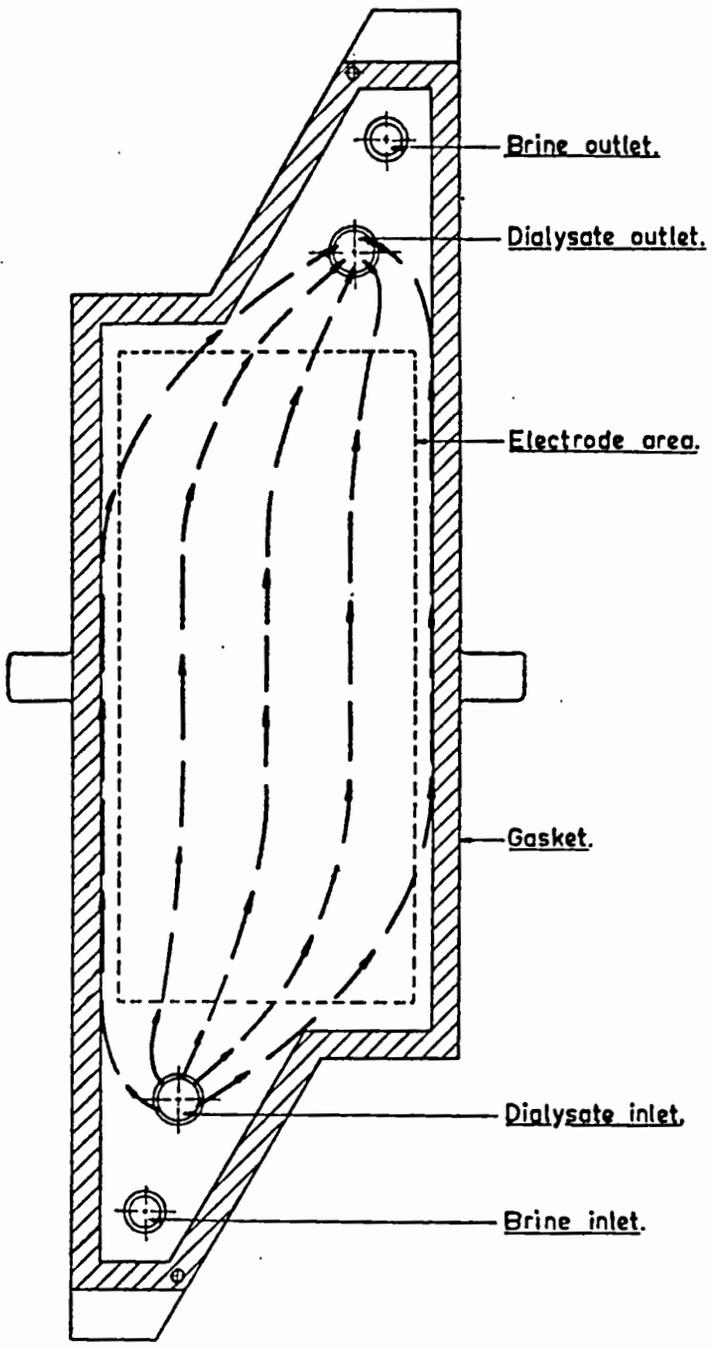
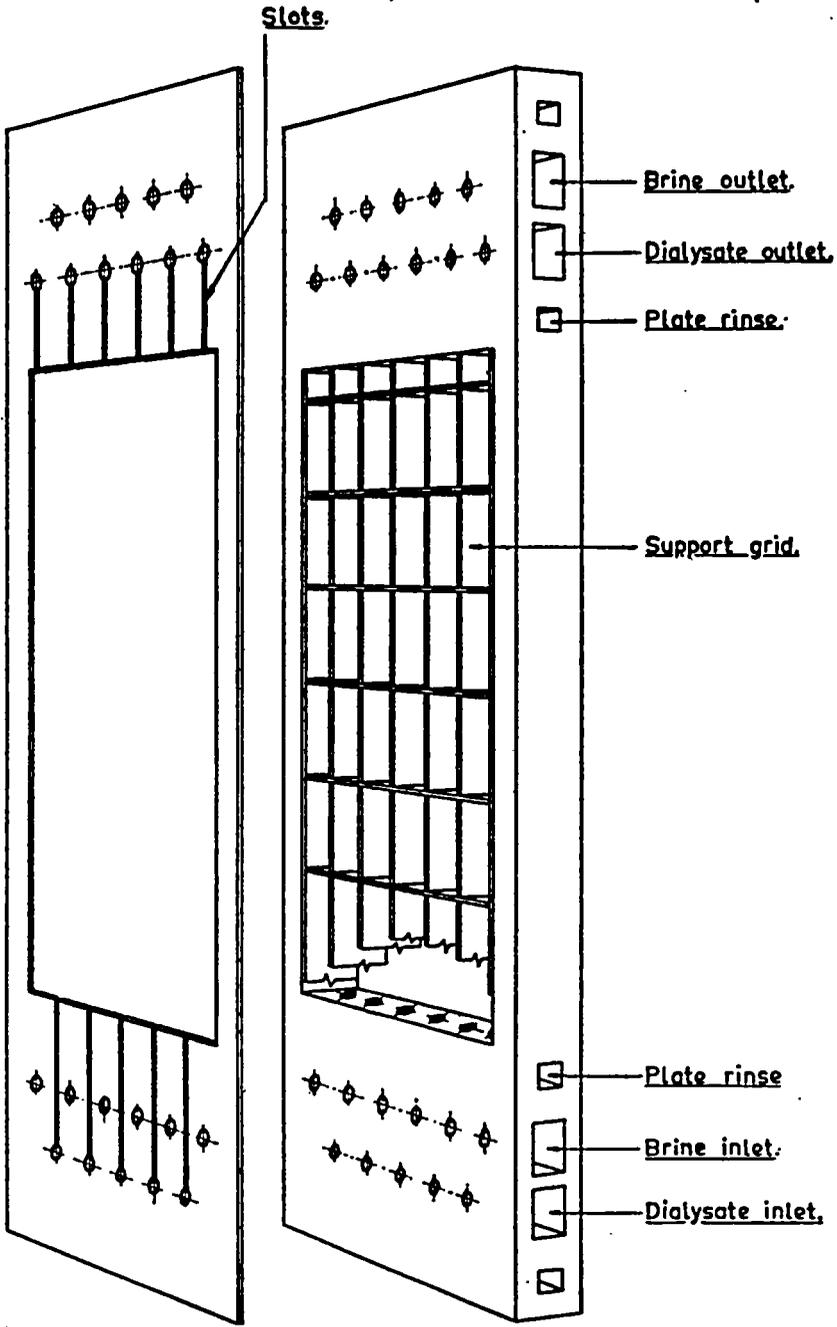


FIG. 4.



Dialysate gasket.

Intermediate plate.

FIG. 5.

(anion- or cation-selective), the electro chemical and surface properties of the membranes, the applied current density, rate of flow of bulk electrolyte, degree of "turbulence" in the flowing electrolyte, temperature of the system, etc.

The development of high or low pH conditions in, or at the surface of, the membrane can cause their rapid deterioration if their pH-stable range is limited, while deposition of scale can occur when ions such as Mg are present which are pH dependent regarding precipitation of salts such as $Mg(OH)_2$.

As mentioned above, the development of layers of low electrical conductivity can raise the energy requirements of the process very significantly. Fig. 6 shows in idealised form the typical effect of polarisation on the voltage drop across a single pack at constant applied current density.

In a practical electro dialysis apparatus polarisation is controlled by achieving in one way or another sufficient turbulence in the liquid streams to prevent the formation of extensive polarised layers of electrolyte. A certain degree of polarisation will always exist, as has been shown by work at the CSIR on "ideal" laboratory membrane-electrolyte systems.¹⁶ However, the development of significant, or practically important, amounts of polarisation, such as occur in Fig. 6 to the left of point A can be controlled. In the "tortuous path" type of apparatus this is achieved by using high linear liquid velocities, with or without some means of baffling. One disadvantage of the tortuous path system might seem to be the high energy losses in the long paths, in which liquid velocities of the order of $1\frac{1}{2}$ to 2 ft./sec. are used, and in which the dynamic pressure drop for typical apparatus can rise to as high as 20 ft. head of water per foot length of path. This leads to rather high energy demands for pumping, and high pressures at the inlet side of the apparatus. Typical inlet pressures for plant of this type are of the order of 30 psi.

Another seeming disadvantage is the rather small utilisation of membrane surface. As the initial and replacement costs of membranes are often considerable this cannot be ignored.

In the intermembrane spacer, or full flow, type of apparatus the necessary "turbulence" is effected by the material used to separate the membranes. A feature of this system is that the same degree of control of polarisation as in a tortuous path type of apparatus can be achieved at very much lower liquid velocities and hence the requirements of pumping energy are very much lower, and the inlet pressures to the system are also considerably lower. In the F.S.G. plant, flow velocities in the diluting compartments are 0.22 ft./sec., based on the open compartment, i.e., without spacer, while the dynamic pressure drop under operating conditions with spacer is about 1.6 ft. head of water per foot length of compartment in the active compartment itself, the inlet pressure to the packs being

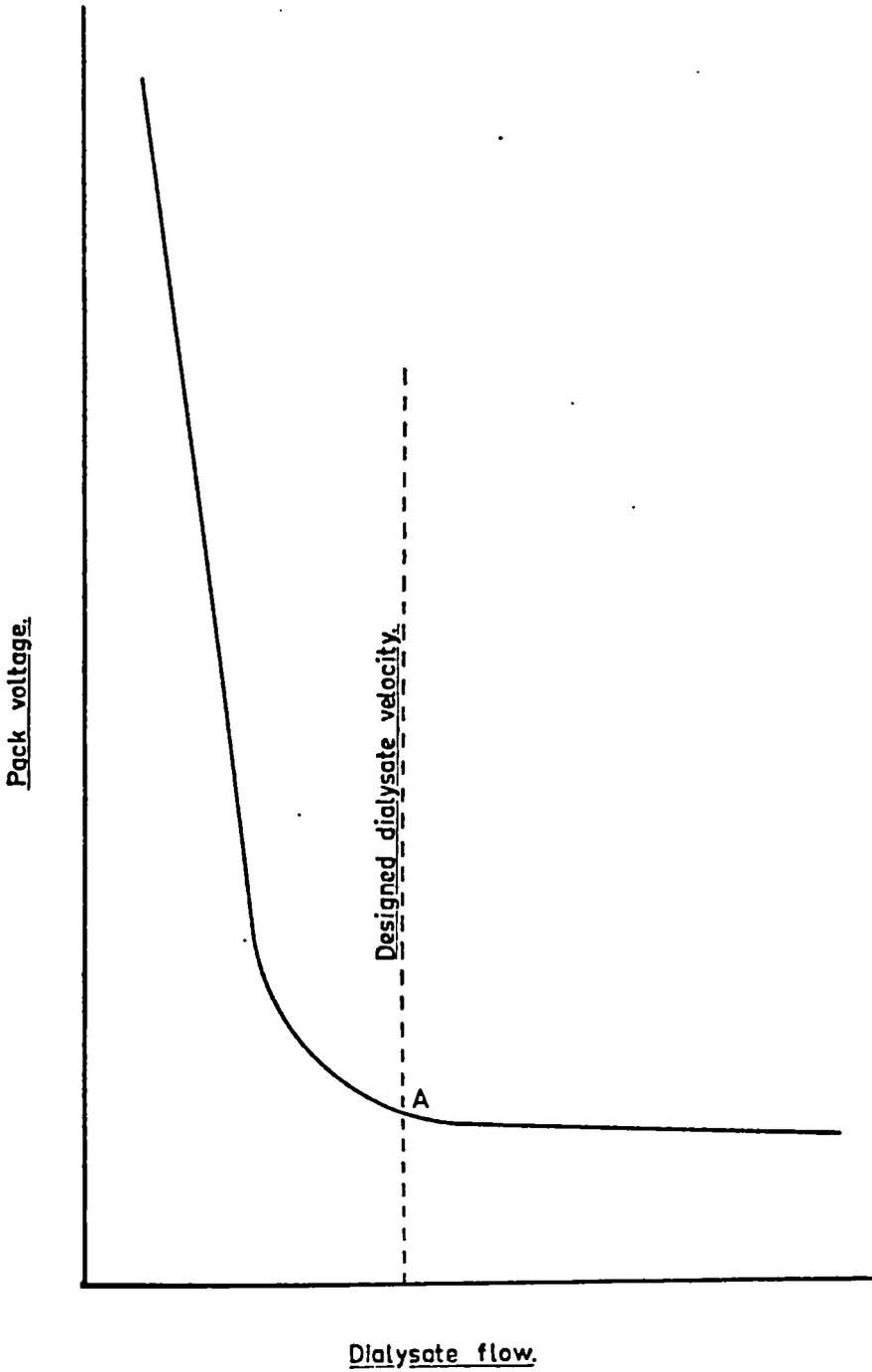


FIG. 6.

about 9 psi, about half of this being accounted for by the slots in the gaskets.

At the current densities and concentrations normally used in water desalting plant, polarisation in the brine, or concentrating, compartments is of minor importance. It is in the diluting compartments, where the electrical resistance is the greatest, that it is of practical significance.

In considering the relation between liquid velocity and degree of polarisation, a compromise must be reached between the rate of flow that is practical and the degree of polarisation. In theory it would be preferable to operate on the right of, but as near to point A on the curve in Fig. 6 as possible. This, however, would leave little margin in plant operation for fortuitous reductions in flow and consequent development of heavy polarising conditions.

Although much work is in progress in the CSIR on the correlation of the various factors affecting polarisation, so far it has not been found possible to calculate for any set of conditions what may be termed the "critical polarisation velocity", i.e., the velocity below which a rapid increase in electrical resistance occurs for otherwise constant conditions. The complex form of corrugated, perforated spacer material such as is used in the South African plants, and the obviously complicated flow patterns that arise, have so far required an empirical approach to the problem.

In the laboratory and pilot plant work critical polarisation curves were obtained experimentally for a range of operating conditions and the "critical polarisation velocity" fixed empirically as the velocity immediately below which a perceptible increase in voltage develops (A, Fig. 6).

When considering the design of the F.S.G. plant, account had to be taken of the very low price (2s. 6d. per 1,000 Imperial gallons) at which the desalted water had to be produced. This meant designing the plant for minimum costs.

A number of proposals were put forward and equations derived for the most economic number of stages, current density, etc., and cost estimates then prepared.^{1,12}

It was decided to use the largest membrane and compartment size that seemed practical, and the minimum number of individual electro-dialysis units. The ratio of brine (concentrate) to dialysate (product) was kept as low as possible to minimise disposal costs, pumping costs and size of water pretreatment plant.

For a fixed current density, the greater the liquid flow rate the less the degree of desalting in the diluting compartments per pass. As it was desired to minimise equipment and pumping costs it was decided not to use recycle but, in order to keep membrane surface and equipment sizes to the minimum, to operate at the "critical polarisation velocity" determined from tests on a prototype unit and on the pilot plant. The method

of determining the "critical polarisation velocity" was the empirical method described above. This method was never considered a really satisfactory one, but had to be used in the absence of any sounder method at that time.

It was decided to use packs of 200 membranes or a hundred cell pairs (instead of the fifty cell pairs of the pilot plant), and ten packs in a press instead of four on the pilot plant. The danger of excessively high voltages to earth was overcome by fitting a central common electrode so that there were only five packs in each electrical half press.

The main design data for the F.S.G. plant have been reported elsewhere.¹ Some basic information is given in Tables II and III.

Table II.—Basic data for 100,000 gph plant

Nominal desalting range.	3,000 to 500 ppm NaCl
Capacity	100,000 gph desalted water
Brine	20,000 gph (25,000 max.)
Number of stages	2
Number of presses per stage	4
Number of stand-by presses	1 serving either stage
Number of packs per press	10
Number of membranes per pack	100 anionic, 100 cationic
Number of membranes per press	1,000 anionic, 1,000 cationic
Size of membranes, overall	7 ft. $\frac{3}{4}$ in. by 2 ft. $1\frac{1}{4}$ in.
Total area of a membrane	15.1 sq. ft.
Effective area of a membrane	10.5 sq. ft.
Effective area—percentage	69.6%
Space between membranes	$\frac{1}{2}$ in.
Materials :	
Membranes	Parchment base
Gaskets	$\frac{1}{2}$ in. Klingerit
Spacers	Perforated corrugated P.V.C.
Electrode and intermediate plates	Wood/polyester resin
Electrodes	Graphite
Piping	Polythene or steel polythene-lined
Current density Stage 1	15.8 mA/cm ² *
Current density Stage 2	6.4 mA/cm ² *
Average overall voltage per press :	
Stage 1	1,000*
Stage 2	800*
Average voltage to ground :	
Stage 1	500*
Stage 2	400*
Coulomb efficiency over effective membrane life of nine months	87 to 60% (av. estimated at 78%)*

Takes into account minimum water temperatures (15° C.) and old membranes with 60% coulomb efficiency.

* Designed.

The design of the pilot-plant packs was not considered suitable for large-scale plant. In particular, the use of separate "distribution rings" for forming the conduits required too much time and skill in building up packs, while the distribution of liquid across a wider compartment would not be sufficiently uniform. Liquid leakage was also troublesome when using these distribution rings.

Table III

	No. 1 shaft *	No. 2 shaft *
pH	8.6	8.55
Conductivity (micromho)	5,000	4,600
Total solids, dried at 180° (ppm)	3,206	3,115
Dissolved solids dried at 180° (ppm)	3,018	2,806
Suspended solids (ppm by difference)	188	219
Total alkalinity	44	54
Total hardness	166	121
Calcium hardness } (ppm as CaCO ₃)	146	110
Magnesium hardness	20	11
Chlorides (ppm as Cl ⁻)	1,720	1,680
Chlorides (ppm as NaCl)	2,826	2,766
Sulphates (ppm as SO ₄ ²⁻)	71	38
Silica in filtered sample (ppm as SiO ₂)	27	28
Sodium (ppm as Na)	1,080	1,080
Potassium (ppm as K)	7	7
Iron in filtered sample (ppm as Fe)	0.1	0.2

* TDS are currently somewhat less—average 2,800 ppm

A considerable research and development programme was carried out to study the distribution of liquid in single compartments having various feeding arrangements, types of membranes, spacer material, compartment thickness and with various fluid velocities.

From these results came the decision to use the slot feed form of gasket shown in Fig. 5. This gave essentially uniform flow across the full width of the compartment.

Slot lengths were calculated to give acceptably small current leakage through the highly conducting brine path. On the F.S.G. plant current leakage is less than 2½%. This slot feeding system to a certain extent negated the advantage of the low pressure drop of the intermembrane spacer type of apparatus owing to increased flow resistance in the slots. On the F.S.G. plant the overall flow resistance due to the slots for a diluting compartment is about 10 ft. head of water. Advantages are, however, more even liquid distribution in compartments, ease of assembly, and better control of intercompartmental leakage. It was found that there was a critical relation between slot length, slot width, type of membrane and differential pressure between compartments, if leakage from one compartment to the other by collapse of the membrane into the slots was to be avoided, so that this system precludes the use of very flexible membranes or membranes susceptible to distortion.

The main conclusions to be arrived at from one and a half years' operation of the F.S.G. plant are that the electro dialysis process is a practical proposition on the very large scale and that it is possible to operate with very large units. Plant reliability, once the start-up difficulties were overcome, has been of a very high order.

It is not at present possible to operate at quite as low an electrical energy level as estimated. At the time of writing, the average electrical resistance of the plant is about twice as great as designed, although some individual units do operate within design specifications. The basic reasons for this are probably twofold, but interlinked. Firstly, it is not possible to guarantee that the liquid flow rate in every compartment of a pack is at or above the critical polarisation velocity. This means that in any one pack polarisation greater than designed may set in in one or more compartments, or, in an extreme case, the flow in a single diluting compartment may be so restricted that excessive desalting occurs with the prevailing current density, leading to an electrolyte of very high electrical resistance. Calculations show that such conditions occurring in only one or two compartments in a pack are sufficient to account for the present higher-than-designed electrical resistance.

Secondly, tests on the plant units have shown that the "critical polarisation velocity" is somewhat higher than allowed for in the original design, and that the average electrical resistance of a cell pair on the plant progressively decreases at the designed flow rate as the number of these in a pack decreases from the present 100 to twenty-five, this latter factor probably being the result of uneven liquid distribution.

Correlation of the F.S.G. plant data with work carried out in the laboratory has now provided the means for fixing more definitely the "critical polarisation velocity" for any given set of conditions. As a result of this recent work it appears that the "critical polarisation velocity" is higher on the F.S.G. plant than allowed for by some 15-20%. This may to some extent be related to differences between the spacer material used in the pilot plant and prototype tests, and the mass-produced commercial material in use on the large plant.

Operational and Cost Data

As explained earlier, it is difficult to give up-to-date figures in this report. Mention has been made of the higher-than-calculated electrical resistance of the plant. The very latest investigations have confirmed that the troubles are due to polarisation, and that the presently used spacer material may be a major reason for this. Bearing this in mind, the following typical operational data for periods up to early March 1960 are given in Table IV.

During periods B and C no major design changes were made on the plant, and it can be seen that the production as percentage of designed capacity remained much the same. The rise in power consumption in period C can be attributed partly to the higher current density used in stage one and partly to a slow rise in the resistance of the membranes, although the mean coulomb efficiency has remained approximately the same for stage one and has improved in stage two. A very small amount of

if full designed production could be achieved without further increases in energy consumption, i.e., by reducing the ohmic resistance of the plant to the calculated value. These costs could probably be reduced in the pretreatment section as chemical dosing is now being reduced by using improved flocculation techniques. The costs could also be reduced in the electro dialysis section if the membrane life of nine months is adjusted upwards, as further plant experience shows can be justified. The membrane cost in column 3 is based on present replacement costs.

Table V.—Estimated and actual operating costs for F.S.G. plant

		Estimate	Actual cost	Estimate
		(1957)	for F.S.G. plant operating at 56% of designed capacity	for full production (1959)
		Pence per 1,000 Imperial gallons		
		1	2	3
Pretreatment :				
Chemicals		0·46	2·66*	0·83
Power		0·13	—	—
Labour		—	—	—
Repairs and maintenance		0·42	—	—
Interest and redemption—10 years		2·04	6·90*	2·14
	15 "	1·56	5·26*	1·63
Sub-total	10 "	3·19	—	—
	15 "	2·71	—	—
Electrodialysis :				
Replacements—miscellaneous		1·45	—	1·45
Membranes (CSIR type, nine months life)		3·77	—	7·80
Electrodes (graphite)		0·30	—	0·15
Power—electrodialysis		6·06	5·93	5·93
Pumping and lighting		0·50	3·36†	1·05†
Labour and administration		4·51†	11·89†	3·69†
Repairs and maintenance		1·23	3·77†	1·17†
Royalties (3% on electro dialysis unit)		0·53	—	0·89
Interest and redemption—10 years		9·85	29·75†	9·23
	15 "	7·52	22·70†	7·04
Sub-total	10 "	28·20	64·26† ^a	—
	15 "	25·87	55·57† ^a	—
Overall total	10 years	31·39	—	34·33
	15 "	28·58	—	31·63

* Includes pretreatment plant costs.

† Costs affected by rate of production.

Note :

^a Actual costs have been given as a "sub-total" value because certain items on which no operational data are available are not included in these values.

In column 2 of Table V, no replacement costs for membranes or electrodes are shown; the first charge of membranes and electrodes was

included in the capital cost of the plant, this first charge therefore appears again in column 3 in the interest and redemption figures for the electro dialysis section.

The actual capital cost of the plant including the complete pretreatment plant, buildings, site preparation and overheads amounted to £285,000 as against an estimated figure of £324,300.

THE ELECTRODIALYTIC DESALTING OF SEA WATER

Electrodialysis has certain disadvantages over distillation processes in brackish water desalting. For instance, in electro dialysis salt removal is effected by extracting only the salt from large volumes of water, while with distillation large quantities of water as vapour are removed from small amounts of salt. Where salt concentrations are low, as with brackish waters, the energy demands are more favourable in the case of electro dialysis. Although the capital investment for small capacity plants is considerably lower in the case of electro dialysis, in the medium and large output range (say, 10,000 to 100,000 gph) the advantage is less marked. In the case of electro dialysis, the size of installation for a given production capacity increases as the salt content of the feed water increases, so that the capital investment eventually reaches the same order as that for distillation. For this reason workers in the electro dialysis field generally recognise that, for sea water desalting, distillation processes are to be preferred, except when the installation is very small and no steam is available, or in the rare situation when electric power is much cheaper than steam.

Such a situation exists in the small coastal town of Luderitz in South West Africa where the present demand for drinking water is met by a conventional multiple effect distillation plant having a capacity of approximately 40,000 gallons or 200 m³ per operating day. The average daily demand, although slowly increasing each year, could easily be met by the present installation. During a three months fishing season, with fish canning factories in full operation, the daily consumption requires, however, water production at full capacity and already for two years even this has been insufficient and additional water has been obtained from an outside source of limited capacity. The future annual increase in peak months demand was, at the time that the CSIR was requested to investigate the situation, estimated at about 10,000 gallons or 45 m³/day. Electricity could be supplied to any additional water producing plant at a locally favourable rate of 1.5d./kWh.

It seemed that the application of the electro dialysis process merited consideration in this case because of :

- (a) the comparatively low investment costs of electro dialysis compared with a small distillation plant (this was important as the plant would be idle for about nine months per year) ;

- (b) the possibility of increasing capacity stepwise (electrodialysis units of the multi-pack type had been developed which could easily be extended) ;
- (c) the existing production of 40,000 gpd of **distilled** water (electrodialytic desalting would thus not have to be carried down to drinking water concentration, the latter being obtained by mixing with the distilled water).

Laboratory experiments on sodium chloride solutions and synthetic sea water were carried out and these provided some data on energy consumption and efficiency from which preliminary cost estimates were made. These estimates showed that an electrodialysis unit should be able to produce water cheaper than with the existing installation at Luderitz (see Table VI).

Pilot plant experiments on a single unit of the F.S.G. plant design carried out with actual sea water at Luderitz confirmed this. These experiments had to be made, however, with the cheaper parchment-base membranes developed for brack water desalting, instead of the plastic-base membranes more suitable for the job which were at the time not yet available in the large size required.

Table VI.—Comparative investment costs for sea water desalting plant at Luderitz

Capacity range 40,000–120,000 gpd	Investment in £ per 1,000 gals. per calendar day (erected at Luderitz)
Electrodialysis	400 approx.
Multi-stage flash evaporation	700–900
Multi-effect distillation (submerged tube)	1,100 approx.
Vapour compression distillation	1,800–2,800 approx.

In the meantime the water requirements at Luderitz had changed because it was learned that the source of additional water for the peak season would shortly no longer be available.

A careful analysis of past seasonal water consumption and trends in increase of consumption showed that future requirements would require extra plant of larger initial capacity than originally estimated.

The particular conditions at Luderitz, with special reference to the relation between costs of steam, electricity and domestic water production, were investigated. The results showed that with the larger water desalting installation required, electrodialysis was unlikely to compete favourably with modern sea water distillation plant, particularly if these processes could use a considerable amount of electrical power to effect a favourable economic balance between high pressure steam production and electricity generation

and the use of pass-out steam for sea water distillation. Either vapour-recompression distillation plant or multi-stage flash evaporation with a large proportion of brine recirculation could be favourable.

In spite of the final decision regarding electro dialysis it may be of interest to record some of the results of the sea water desalting experiments.

SOME CONCLUSIONS FROM THE LUDERITZ SEA WATER DESALTING TESTS

Several of the results of the experiments on electro dialytic sea water desalting are of importance for the application of the same process to the demineralisation of highly brackish water as well.

The resistance of a membrane stack can be calculated from the resistances of the component parts which can be determined separately. This approach has been used by several workers to predict the energy consumption in electro dialysis. The results of the Luderitz experiments indicated, however, that the effective resistance of a membrane pack is considerably higher than that calculated from the resistances of the component parts, and that energy consumption calculations should be based upon resistance measurements under practical conditions or by using an experimentally determined correlation factor (Fig. 7).

The ionic composition of the water to be treated appeared to play an important role. The presence of a considerable amount of ions other than sodium and chloride in sea water decreased the efficiency of the process considerably (Fig. 8), while the unfavourable factor of water transport with the ions from dialysate to brine is increased by the presence of the ions Ca, Mg and SO_4 (Fig. 9). Simultaneously these ions increase the resistance of the membranes considerably. All these factors together cause a higher energy consumption for sea water desalting than for sodium chloride solutions of equivalent ionic concentration under otherwise identical circumstances of current density, temperature, flow, etc.

In a semi-batchwise process, in which a batch of dialysate is desalted by circulation through the membrane stack while the concentration of the circulating brine is kept approximately constant, a simple correlation between energy consumption and dialysate concentration was found which facilitates easy prediction of energy consumptions in a whole series of desalting ranges.

Table VII gives some data for a proposed 44,000 gpd batch operated plant based on the use of the type of equipment used in the tests at Luderitz.

These data and those in Table VIII are based on the use of membranes of the AMF (American Machine and Foundry) type assuming that laboratory data using such membranes are valid for the large plant, as was shown to be the case for the parchment type membranes actually used.

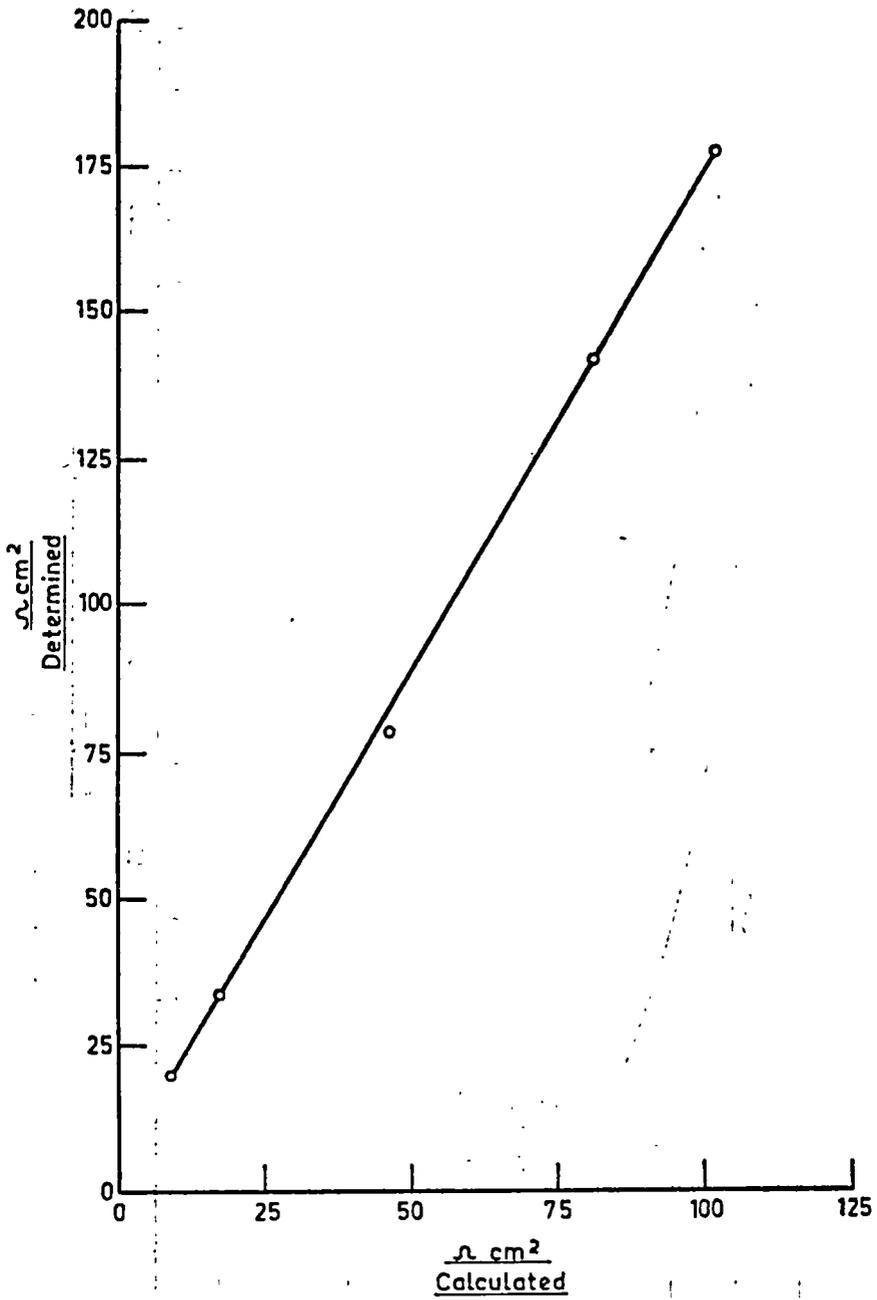


FIG. 7.—Correlation of theoretical and practical stack resistance.

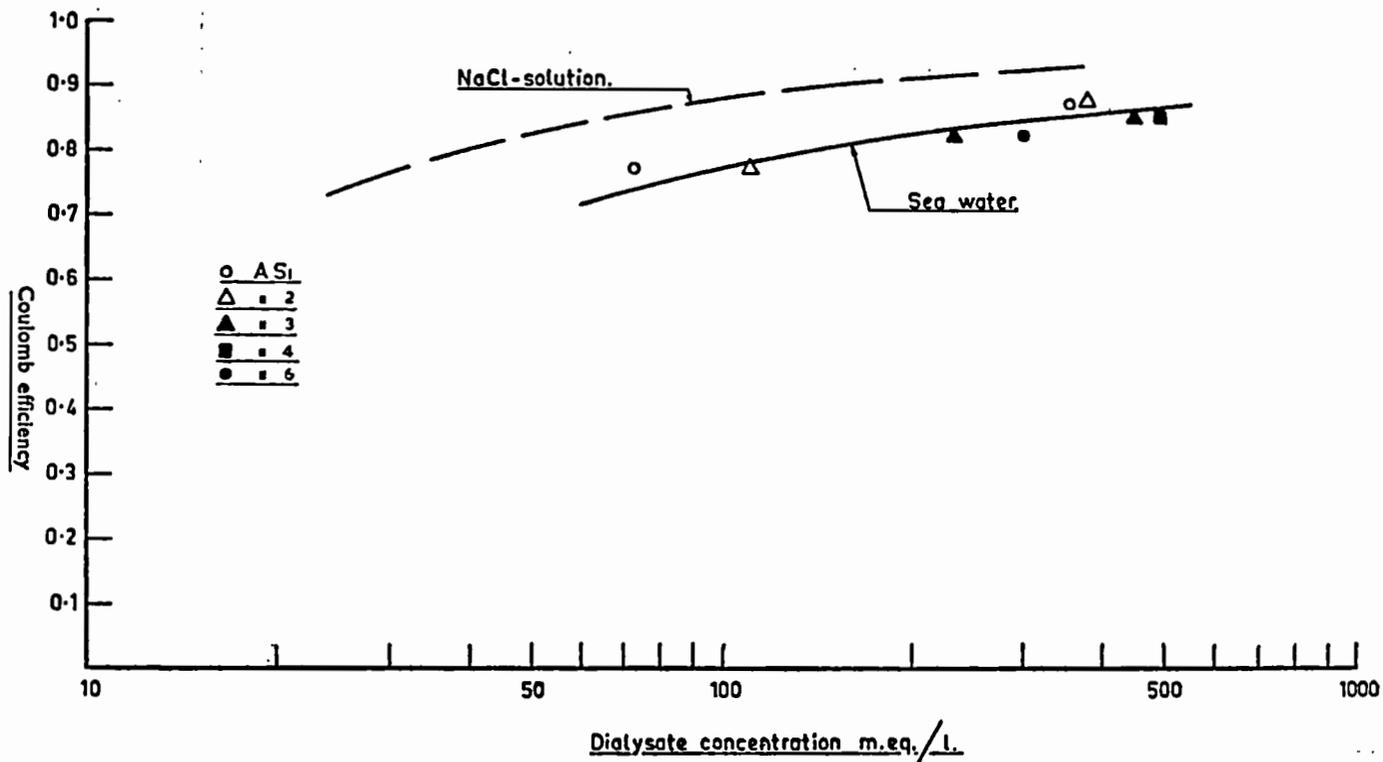


FIG. 8.—Coulomb efficiency against dialysate concentration.

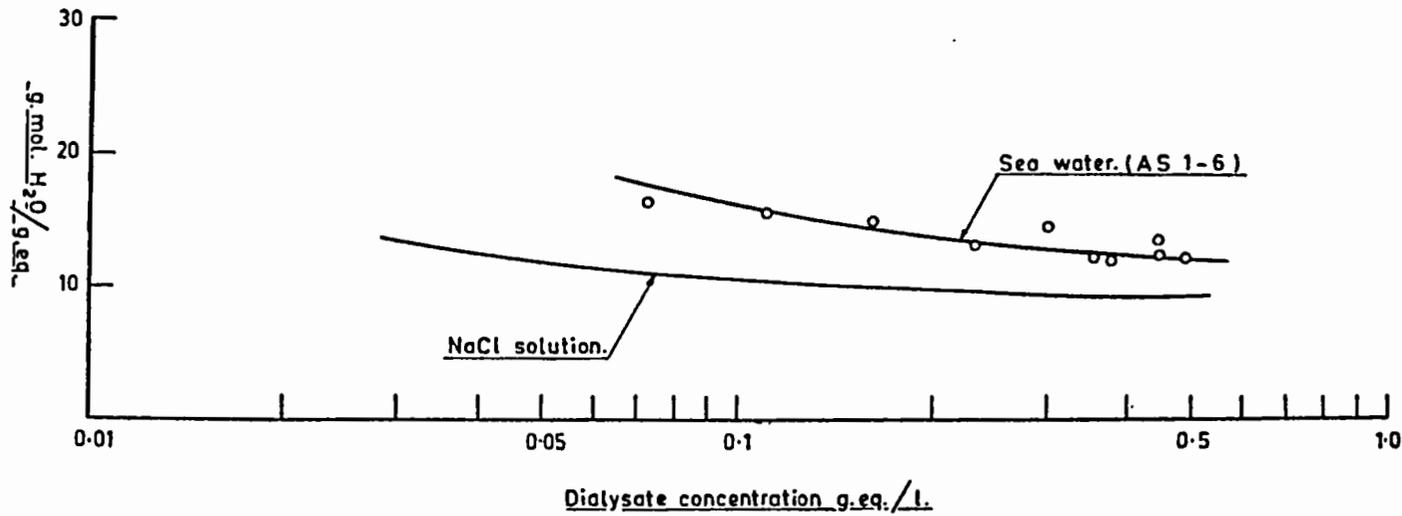


FIG. 9.—Water transport against dialysate concentration.

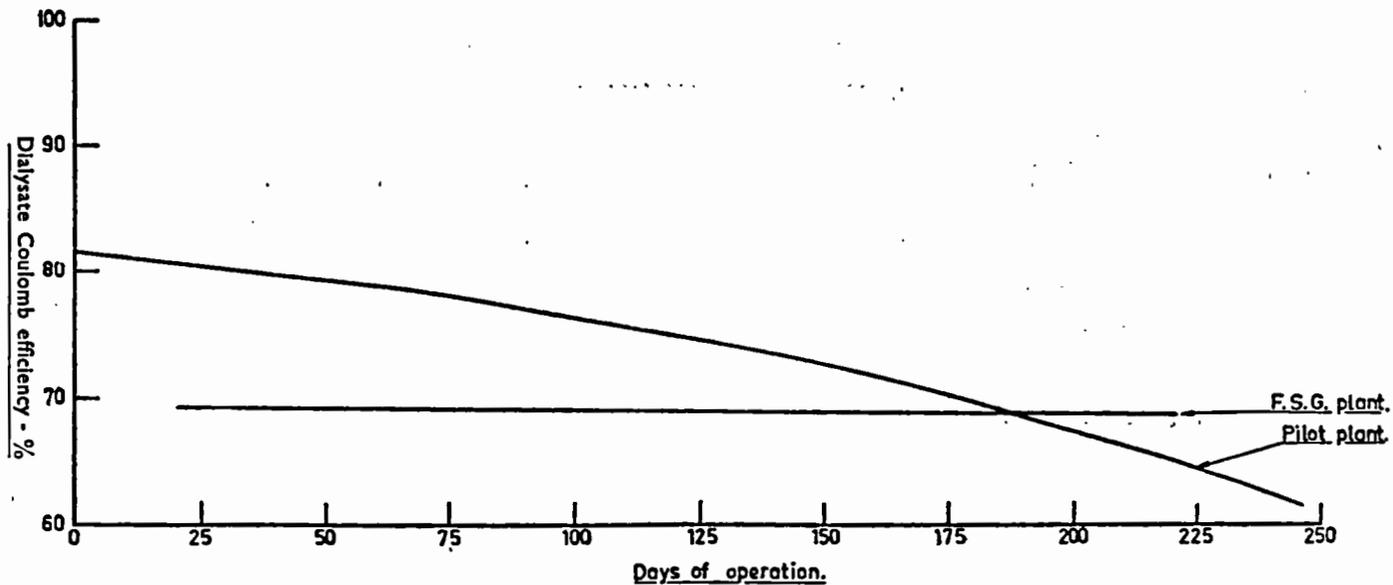


FIG. 10.—Effect of extended operation upon the overall coulomb efficiency of the F.S.G. plant (early stages of operation).

Table VII.—Data for proposed 44,000 gpd sea water desalting plant (batch operation) desalting to 1,000 ppm TDS

	Membrane life 2·5 years	Membrane life 5 years
	I	II
Total number of cell pairs	882	1,196
Number of membrane packs	8	12
Total D.C. kWh/1,000 gal.	104	77
Total D.C. kWh/1,000 gal. which is lost in electrodes and intermediate plates between packs	9	6
Total A.C. in kWh/1,000 gal.	126	92
Total capital outlay	£12,280	£18,360

Table VIII.—Estimated sea water desalting costs for proposed 44,000 gpd plant at Luderitz

	I	II
	Shillings/ 1,000 gal.	Shillings/ 1,000 gal.
Capital (Note <i>a</i>)	1·67	2·5
Membrane replacement (Note <i>b</i>)	7·7	5·2
Energy consumption (desalting) (Note <i>c</i>)	15·1	10·9
Energy consumption (pumping) (Note <i>d</i>)	2·9	3·9
Salaries (Note <i>e</i>)	3·8	3·8
Acidification (Note <i>f</i>)	0·75	0·75
Maintenance	0·94	0·94
	32·8	28·0

I. Membrane life 2·5 years. II. Membrane life 5 years.

Notes :

- a* Depreciation and interest 10% of capital outlay p.a.; buildings and services already available.
- b* Based upon a price of £8 per membrane.
- c* Electrical energy 1·44d./kWh.
- d* Conservative; corresponds to the high velocity recommended for approximately double the current density actually used.
- e* Based upon an estimated £2,700 per year for salaries and overheads.
- f* Sulphuric acid £15 per ton delivered to site.

SIMPLE ELECTRODIALYSIS EQUIPMENT FOR PROVIDING DRINKING WATER FOR STOCK IN HIGHLY BRACK WATER AREAS

By 1956 the water desalting work of the CSIR had aroused the interest of a number of farmers carrying on extensive cattle and sheep-raising activities in brack water areas such as the Gordonia and Kenhardt regions of the Cape Province.

So many requests for assistance in desalting water were being received that it was decided that the position should be investigated. Discussions with the Division of Chemical Services of the Department of Agricultural Technical Services showed that much more information was required as to the types of waters to be met with and the location and output of bore-holes in brack water areas. Similarly, discussions with the Onderstepoort Veterinary Research Laboratory of the Department of Agricultural Technical Services revealed that there was a definite need to determine accurately the upper safe limits of total dissolved solids in brack waters of various compositions, that would maintain stock in healthy condition. This problem could only be studied in the field as factors such as climate, grazing and terrain play an important part in determining practically safe watering conditions.

On the part of the CSIR, it was felt that the limitations of farming conditions would probably preclude the adoption of electrodialysis as a practical or economic method of desalting brack waters on farms, but that the possibility of developing very simple desalting units should nevertheless be investigated.

A joint steering committee was set up with the CSIR and the Department of Agricultural Technical Services. The Division of Chemical Services was to be responsible for a survey of existing brack water bore-holes and water analyses, the Onderstepoort Veterinary Research Laboratory was to plan long-term field experiments to determine the effect of brack water on animal health, and the CSIR was to analyse the water needs of typical farmers, and endeavour to develop a simple electrodialysis unit that might meet their needs, any unit first to be extensively field tested under the Veterinary Research Laboratory's brack water field testing programme.

This work is described in the companion papers "Treatment of Brack Water Supplies for Farm Stock" by O. B. Volckman, "Effects of Brack Water on Animal Health" by T. F. Adelaar, and "The Rate of Sulphate Removal in Sodium Chloride Containing Feed Waters Using a Simplified Type of Electrodialytic Water Demineralisation Apparatus" by E. O. Seipold.

ION-SELECTIVE MEMBRANES

When the CSIR started its programme on electrodialysis the only membranes available in the sizes required were cellophane-based membranes produced by TNO.

Examination of the process at that stage showed that the membrane situation was the least satisfactory factor of electrodialysis. Little was known of the true lifetime that could be expected and costs were purely speculative as production was on the very small scale, generally in research

quantities only. It is only in the past year or two that progress has been made by commercial companies and that membranes combining both large size and good electrochemical properties have become commercially available. Ionics, Inc. have had membranes operating successfully in the field for many years, but these have been restricted to sizes of the order of 20 × 20 in.

With the development of designs for the Free State Geduld plant, and even for the pilot plant, the CSIR was faced with the problem of membrane supply which looked like holding up the whole programme. It was decided to initiate immediately development of membranes which would at least meet the needs of brack water desalting for the mines, where the maximum salt concentration difference between concentrating and diluting streams was unlikely to be greater than about 12,000 ppm TDS and the back-diffusion problems would not be very severe.

It seemed that the South Africa programme would be completely held up for lack of suitable membranes. It was decided, therefore, to start at once on a programme of developing membranes that would at least meet the needs of brack water desalting on the mines.

In making cost estimates it was important to gauge the useful life of membranes, as they were at that time expensive items which could amount to some 30% of operating costs, even with an estimated three years lifetime.

It was considered that membranes could become useless, well before their electrochemical properties had deteriorated significantly, by such factors as "poisoning" by the formation in use on the membrane of undissociable compounds, attack by highly acid or alkaline conditions or by free chlorine due to plant operational faults, heavy scaling, and mechanical breakage due to factors of plant design or during routine plant maintenance or pack inspection. For these reasons a lifetime of only nine months was allowed for. This meant that a membrane would have to cost only a quarter as much as existing ones, if these actually achieved a three-year operational life, and to bring down the cost structure of the process appreciably, should preferably cost only about one-tenth of that of existing membranes. It should also be possible to make them in large sizes—up to 2 × 7 ft. was considered practical. This meant that they should be mechanically strong—also important in intermembrane spacer type of plant where the stresses on the membranes are generally greater than in the tortuous path type.

The raw materials would necessarily have to be cheap and the manufacturing process simple.

It was decided to develop a series of anion- and cation-selective membranes based on cellulose as sheet-forming material providing a polymeric structure to be activated. Kraft parchment paper was taken as the starting material from which was evolved the membrane now used on the Free State Geduld plant.^{1,10}

The negative or cation-selective membranes are prepared by introducing cation exchangeable, i.e. sulphonate, groups into the cellulosic matrix¹⁹; the positive or anion-selective membranes contain anion exchangeable, i.e. quaternised nitrogen groups, introduced by treating the cellulosic base material with guanidinium salts or other suitable nitrogen compounds.²⁰ In both cases a simple impregnation step is used followed by a polymerisation step at controlled temperature, during which the membrane is activated and crosslinked to such an extent that the desired membrane properties are achieved.

The selection of the cellulosic base material is of major importance in producing membranes of uniform quality. The weight of the paper and the degree of parchmentation have to be controlled carefully in order to obtain the required end product. Considerable difficulties were encountered in obtaining parchment paper of uniform and suitable quality. Present membrane development is, therefore, aimed at extending the membrane types to include ones that can be made from locally produced unparchmented Kraft paper.

The membranes have so far been made batchwise employing curing in a hot-air oven, but recently a satisfactory prototype for semi-continuous production using infra-red heating has been put into operation at the CSIR which could lead to reduced production costs.

The characteristics accepted as criteria for permselective membranes to be used successfully in electro dialysis are high ion-selectivity in electrolyte solutions of considerable concentrations and wide range of pH values, high electrical conductance to keep the overall resistance of the system as low as possible, a low rate of free diffusion of salt to restrict back-diffusion, and good mechanical strength. One of the chief difficulties in the preparation of ion-selective membranes is found in securing desirable values of all these properties in combination, especially if regard be paid to the production cost of the membranes.

The membranes for the F.S.G. plant have to meet the following specifications:

Free diffusion of sodium chloride at 30° C. through a membrane placed between and separating distilled water and a sodium chloride solution of 15,000 ppm NaCl should not be more than 1.3 millimicro equivalent per cm² membrane surface per second.

Conductance per cm² membrane surface should not be less than 66 millimho.

Transport number (t₊) of the sodium ion in the negative membrane 0.93 and in the positive membrane 0.05 when placed in 0.3N NaCl solution at room temperature (20–25° C.).

Bursting strength determined by the Mullen test should not be less than 25 lb./sq. in.

Considerable quantities of membranes, however, have been made at

the CSIR having properties of the following range (the units are the same as indicated above) :

Free diffusion of NaCl	0.2 (upper limit)
Conductance	50-250
Transport number (t_+) :	
for negative membranes	0.97 (lower limit)
for positive membranes	0.03 (upper limit)

These membranes are of value when water of high salt content is to be desalted, such as sea water, or highly brack water as met with in the " farm unit " development work. In such cases where high concentration differences are met with, membranes with the last mentioned properties prove to be highly selective and capable of desalting efficiently.

Positive, or anion-selective, membranes have generally proved the least stable. Fortunately, it is more important to have stable negative membranes. When considering the transfer of sodium chloride and using a perfect negative membrane the coulomb efficiency in the electro dialysis process will not drop below 60% even if the positive membrane becomes completely inactive since the ratio of the transport numbers of Na^+ to Cl in free solution is 4 : 6.

MEMBRANE TESTING AND CHARACTERISATION

A large part of the work at the CSIR has dealt with the development of reliable routine methods for characterising membranes and relating plant performance to such characteristics.

Membranes that are available from other producers are also characterised and the more promising ones tested on laboratory units for lifetime, selective ion-transfer, effects on " critical polarisation velocity ", coulomb efficiency, etc., under a range of standard current densities, salt concentrations, and electrolyte compositions.

Some of these apparently excellent membranes have been faulted for operation on large-scale plant for reasons such as unequal swelling in the wet state, dimensional instability, mechanical weakness, extreme susceptibility to breakdown if scale is formed on the surface, non-uniformity of electrochemical properties, development of pinholes, etc.

MEMBRANE BEHAVIOUR IN THE F.S.G. PLANT

The stability of the commercially produced CSIR-type parchment base membranes on the F.S.G. plant has generally been better than those prepared in the laboratory and used on the pilot plant.

Thus, as seen from Fig. 10, the average coulomb efficiencies on the plant, for a given set of membranes remain almost constant throughout the 200 days continuous operation, while the pilot plant membranes, although showing better average initial properties, give continuously falling coulomb efficiencies as their use is prolonged.

The maximum coulomb efficiencies reported for the commercially produced membranes on the F.S.G. plant throughout the 200-day period were constant at 82%.

The electrochemical properties of the used membranes were redetermined after an operational lifetime of nine months. Only a slight change showed up in the case of the negative membranes, while in the case of the positive membranes a marked deterioration had taken place (see Table IX).

Table IX.—Table of properties of F.S.G. plant membranes

Mean values		Conductance	Transport no. (t+)
Sample	Dialysis (free salt diffusion)		
New negative membrane .	1.3	66	0.93
Used negative membrane .	2.5	52	0.92
New positive membrane .	1.3	66	0.03
Used positive membrane .	4.6	13	0.33

MEMBRANE COSTS

One of the major means of reducing costs of electro-dialytic water desalting will probably be through the development of cheaper membranes. The O.S.W. considers the 1959 average price for membranes, if produced on a large scale, to be about one dollar per sq. ft.²¹ Most membranes are at present quoted somewhat in excess of this. The parchment-based membranes used on the F.S.G. plant have an F.O.B. price equivalent to approximately \$0.2 per sq. ft. (\$2.80 = £1 sterling). Much of this cost is absorbed in labour costs of batch production. With continuous—or semi-continuous—production, costs could be expected to decrease and prices to be lowered. When considering the effect of membrane price on desalting costs the practical operating life of the membrane must be taken into account. This life can be affected by factors such as scaling, "poisoning", and "wear and tear", which can vary with design of plant. At present there are insufficient data to assess accurately the performance of all the commercially available membranes under typical field conditions and in the various designs of apparatus.

Acknowledgements

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References

1. Demineralization by Electrodialysis, by the NCRL/CSIR Water Desalting Team, edited by J. R. Wilson. Butterworth's Scientific Publications, London, 1960.
2. VOLCKMAN, O. B. Treatment of Brack Water Supplied for Farm Stock. Paper to be presented at the CCTA/CSA Specialist Conference on Water Treatment, Pretoria, Sept. 1960.
3. NACHOD, F. C., and SCHUBERT, J. Ion Exchange Technology. Academic Press Inc., N.Y., 1956.
4. COOKE, B. A., and MANDERSLOOT, W. G. B. The Electrodialysis Process. *Trans. Inst. Chem. Engs.*, London, **37**, 14-25 (1959).
5. U.S. Dept. of the Interior—Office of Saline Water—Saline Water Conversion Report for 1959, p. 69.
6. RAPSON, W. S. Purification of Mine Water. *Optima*, **5** (No. 2) (June 1955).
7. VOLCKMAN, O. B. The Practical Application of Electrodialysis to the Desalting of Brackish Water. *Brit. Chem. Eng.*, **2**, 146-8 (March 1957).
8. MOYERS, W. H. Desalting of Mine Water on a Large Scale. *Optima*, **7** (No. 3) (Sept. 1957), and *Brit. Chem. Eng.* (Feb. 1958).
9. MOYERS, W. H., and VOLCKMAN, O. B. Demineralisation of Saline Water. *Trans. S. A. Inst. Civil Eng.*, **7**, 309-324 (Oct. 1957); *idem, ibid.*, **8**, 17-22 (April 1958).
10. VOLCKMAN, O. B., and MOYERS, W. H. Ion-selective Membrane Research and Electrodialysis Engineering Development in the Union of South Africa. National Academy of Sciences—National Research Council, *Publ. No. 568*, 283-315, Washington, D.C. (1958).
11. COOKE, B. A. Scaling Problems in Electrodialysis using Permselective Membranes. *Chem. and Ind.*, **19**, 555-6 (1958).
12. WILSON, J. R. Factors in the Design of Electrodialysis Equipment. *Trans. Inst. Chem. Eng.*, **37** (No. 4), 198-205 (1959).
13. General Technical Department, T.N.O. Report No. T.A. 270 (The Hague, Netherlands).
14. T.N.O. (Netherlands) Brit. Pat. 750,220; *idem, ibid.*, 736,888; *idem, ibid.*, 682,703; *idem, ibid.*, 750, 238.
15. CSIR (WILSON, J. R.). South African Patent 556/59.
16. COOKE, B. A. Papers to be published in *Electrochem. Acta*.
17. MOYERS, W. H. Operation of the 2½ million gallon per day Desalting Plant at the Free State Geduld Mine, Orange Free State. Paper to be presented at the CCTA/CSA Specialist Conference on Water Treatment, Pretoria, Sept. 1960.
18. Private Communication. CSIR Contract Report F31 (Feb. 1960). Demineralisation of Brackish Mine Water by Electrodialysis—the 100,000 Imperial gallons per hour Free State Geduld Electrodialysis Plant—a Report on the Current Position Authorised by the Steering Committee for Water Demineralisation by Electrodialysis. Compiled by J. R. Wilson.
19. CSIR (COOKE, B. A., HEIDE, H. S., and SCHWEIGART, H.). South African Patent 2343/55.
20. CSIR (COOKE, B. A., MORGEN, T. D., and SCHWEIGART, H.). South African Patent 2530/56.
21. U.S. Dept. of the Interior Saline Water Conversion Report for 1959, p. 67.

TREATMENT OF BRACK WATER SUPPLIES FOR FARM STOCK

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INTRODUCTION

Early in 1956 the South African Council for Scientific and Industrial Research started investigating the possibility of developing a simple electro-dialytic water desalting apparatus suitable for use on farms where drinking water supplies for cattle, sheep and other animals is obtained from brack water boreholes. Many factors were involved in the decision to undertake research and development work in such a technically and economically unpromising field.

Extensive cattle, sheep and karakul (Persian lamb) farming is carried on in semi-desert areas of the Union of South Africa such as the north-western districts of the Cape Province, and in areas in South West Africa adjacent to the Union, while the potential in Bechuanaland is also considerable. In these areas the grazing is generally good but underground water sources are frequently too brack for animals to drink. These areas are subject to periodic droughts, 1959-60 having seen a particularly bad one in a series of three successive drought years. (In the summer of 1959-60 the water position was so bad that the Army was continuously employed for several months carting fresh water in water tankers to farms where the grazing was still adequate, but the relatively fresh water boreholes had dried up. In many of these areas deeper highly brack unusable boreholes were believed to be still capable of yielding adequate supplies. The cost to the country, and to the farmer, of the Army water transport operation was very considerable.)

In view of the long-term need for increased food production it was considered that appreciable areas could be opened up if the existing brack waters could be made potable for animals, and provided that sufficient water for domestic use could be made available. Many cases already exist, in fact, where only a small part of a farm can be used, because the greater part has water above 3,000 ppm TDS. Waters containing up to about 3,000 ppm TDS are not uncommonly used for domestic consumption in these areas.

In opening up such areas the demand for animal drinking water would not exceed about $2\frac{1}{2}$ gallons per day per morgen (1 morgen = 2.1 acres = 0.8 hectares) and would often be less, so there would not be a severe load

on the underground water resources. Care would have to be taken, nevertheless, to ensure that, with adequate animal drinking water supplies, over-grazing is not allowed to take place.

The problem called for the co-operation of a number of organisations. A co-ordinating committee was set up between the CSIR and the Department of Agricultural Technical Services. The project is divided into three parts thus :

- (i) **A survey of existing brack water boreholes ($> 1,000$ ppm TDS) and the general types of brack waters encountered, with information as to their use.**

The Division of Chemical Services and the regional extension officers of the Department of Agricultural Technical Services are responsible for this survey, with the co-operation of other Government departments.

It soon became apparent that existing information was very incomplete and that considerable differences of opinion existed amongst farmers as to what waters were suitable for animals. Cases were reported of sheep drinking a highly brack water, while a similar water in another area was rejected.

Any programme involving the development of water desalting apparatus for animal drinking water requires a detailed knowledge of the economics involved, the quality of water required and the local conditions.

At present it is difficult to assess the economics as each farmer seems to view the situation differently. Probably the simplest starting point is to estimate the amount of water required by an animal up to the time it is sold. The average market price of the animal, the minimum reasonable profit and the expenses (other than for drinking water) involved up to the time that the animal is sold, can give a rough idea of what costs can be allowed for drinking water. This is an over-simplification of the problem, but does provide a starting point.

One point to be borne in mind when considering the electro-dialytic water desalting of brack waters for animals is that in many cases the degree of desalting required to make a brack water potable for animals will be only a few thousand ppm, in a region where the water is still brack and the electrical conductivity of the water is high. Thus, a 10,000 ppm TDS water might only have to be desalted to say, 6,000 ppm TDS for sheep or, say, 4,000 ppm TDS for cattle, whereas for human consumption the level would have to be reduced to between 500 and 1,000 ppm TDS, i.e., to a region where power consumption becomes appreciable owing to the reduced electrical conductivity of the water.

The second part of the project, which arises from the first, is

(ii) The determination of maximum tolerable salinities for drinking water for animals.

Apart from some work done in Australia and the Argentine on sheep and cattle, which may not apply directly to conditions in South Africa, most of the information is empirical and unsatisfactory.

The Veterinary Research Laboratory, Onderstepoort, of the Department of Agricultural Technical Services, has for some time been interested in the problem. As it is necessary to know what salinity levels are practical before the need for farm water desalting units can be properly assessed, it was decided that the proper approach was for the Department of Agricultural Technical Services, under the direction of its Veterinary Research Laboratory, to obtain further information on the effect of brack waters on stock health. To obtain this information a long-term research programme is required, during the first two years of which, at least, no definite conclusions will be reached.

The investigation requires prolonged stock watering tests under actual farming conditions, as climate, vegetation, type of water, type of animal and distance to which it has to go to seek water all have to be taken into account.

The third part of the project is the responsibility of the CSIR and involves

(iii) The design and testing of a very simple and cheap electro-dialytic water desalting unit that would meet the needs of stage (ii).

Experience of the operation of the unit under actual farming conditions, but initially under technical supervision, would show how practical such a unit might be.

For the stock watering tests a typical " arid area " farm was required where adequate grazing and a supply of brack water of at least 12,000 ppm TDS was available. The farm had to be reasonably accessible and alternative sources of relatively " sweet " water were considered necessary in case of a prolonged breakdown on the desalting installation.

For a properly controlled experiment at least sixty cattle and 150 sheep are required. It was planned to divide the grazing area into three identical camps set so that the watering point is at the common point or apex of all three camps. The animals in the three camps would be watered with brack water of approximately 12,000, 8,000 and 4,000 ppm TDS water, and their condition, fertility, etc. would be compared over several seasons and sets of progeny.

To find a suitable site was extremely difficult. Eventually a farm, " Vaalkoppies ", in the Gordonia district of the Cape Province, bordering

on the Kalahari Desert, was chosen. The water from a borehole on this site contains approximately 25,000 ppm total dissolved solids (approaching sea water concentration) so that the desalting unit has had to be designed for a far greater degree of desalting than would generally be necessary.

Several prototypes of a simple desalting unit have been developed at the CSIR and have undergone limited field tests.

It is hoped to have a unit, and stand-by unit, operating on the final site by about August 1960. After undergoing a two-month reliability test the stock watering investigation will then be started.

Not until this programme is well advanced and reliable data have been obtained, will it be known if electro dialysis will prove a practical and economic means of meeting the needs of farms in highly brack areas.

Limited applications for simple desalting units for other purposes may be found and the experience obtained in this project will then be of wider use.

Economic considerations preclude the use of this method of desalting water for providing irrigation water except under very special circumstances where cost is not the primary factor.

FACTORS INFLUENCING THE DESIGN OF ELECTRODIALYTIC WATER DESALTING UNITS FOR PRODUCING STOCK DRINKING WATER

(i) Water quality

Table I lists the analyses of a number of typical types of brack waters found in the farming areas of South Africa and South West Africa. They are nearly all characterised by a high bicarbonate and sulphate content with appreciable quantities of calcium or magnesium, or both.

For animal drinking purposes it is known that high amounts of sulphates in combination with magnesium are harmful, and that under certain conditions high calcium levels are undesirable. It may therefore be necessary sometimes to desalt a water, not to a certain level of total dissolved solids, but to a certain level of a particular ion. This may require desalting to a greater degree than at first would seem necessary. Fig. 1 shows a typical example of the change in composition of a water as desalting proceeds during electro dialysis. This information was obtained from the desalting of water from the Department of Agricultural Technical Services stock water experimental site at "Vaalkoppies". The preferential removal of ions during the desalting process can thus be important.

One of the most important results of the Department of Agricultural Technical Services stock watering investigation will be to obtain more definite information on the safe "ionic" levels for stock health. As a generalisation, water with a maximum TDS of 8,000 ppm and 5,000 ppm should be tolerable to sheep and cattle respectively, although its prolonged use may not lead to their continued good condition.

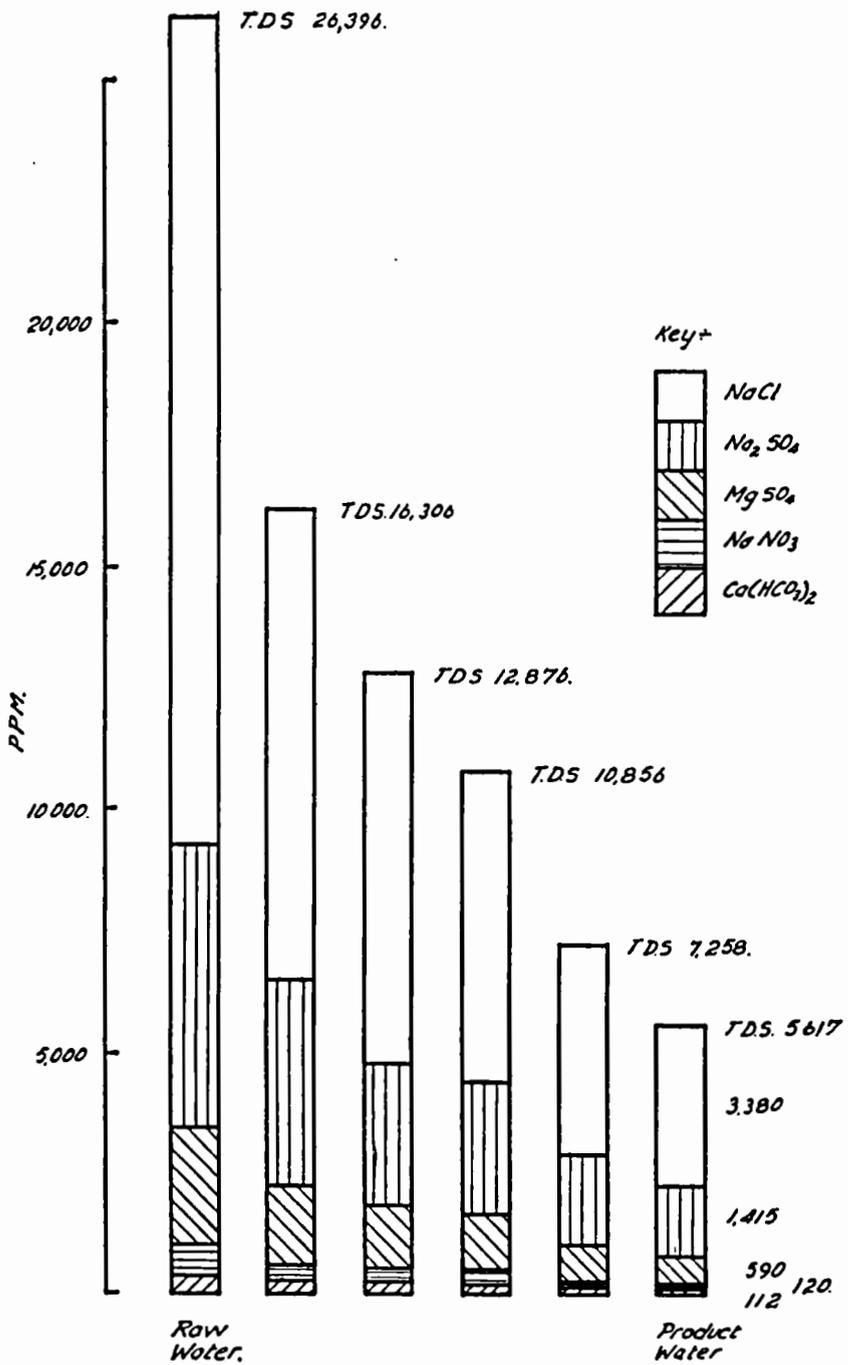


FIG. 1.

(ii) Flexibility

A wide range of water types, dissolved solids concentration and degrees of desalting require, for utmost economy of production, a single design which will permit both a range of outputs and degree of desalting to meet particular needs. Normally, batch operation would meet the need of variable desalting ranges, but to some extent it lacks the desired simplicity, since recycle pumps are needed, and either the operation must be supervised when the end point is reached, or automatic controls must be fitted to shut down the unit when the desired desalting has been achieved. Within certain limits, depending on the design of the unit, capacity can be varied by altering the number of compartments.

(iii) Simplicity and cheapness

By far the most difficult problem is that of simplicity of design, operation and maintenance.

At the present stage of development, the electro dialysis process still requires some technical control or supervision. With a very few exceptions, farmers, especially in the remote arid areas under consideration, have not the necessary background for operating this type of process ; moreover, most of the farming operations are left to Natives to carry out.

Table I.—Major constituents of typical brack waters of the Union of South Africa and South West Africa

(Constituents are reported in the form of their ions rather than in the conventional manner as this is found to be more convenient in desalting work which is concerned essentially with the transfer of ions.)

	1	2	3	4	5	6	7
pH	7·4	7·0	7·3	8·4	8·0	—	7·5
Total dissolved solids—							
TDS—ppm	4,647	4,751	6,865	9,389	12,000	15,506	24,970
Sodium (Na ⁺)	1,032	253	1,234	2,355	4,018	4,897	8,209
Potassium (K ⁺) ppm	20	—	—	—	—	—	—
Calcium (Ca ⁺⁺) ppm	152	282	731	561	180	491	220
Magnesium (Mg ⁺⁺) ppm	385	696	316	468	109	225	438
Chloride (Cl ⁻) ppm	2,106	2,333	3,000	2,002	4,189	6,195	9,656
Sulphate (SO ₄ ⁻²) ppm	459	174	1,321	3,386	3,458	3,722	5,331
Carbonate (CO ₃ ⁻²) ppm	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Bicarbonate (HCO ₃ ⁻) ppm	476	769	140	329	165	—	860
Nitrate (NO ₃ ⁻) ppm	—	< 5	115	—	Nil	—	705
Iron (Fe) ppm	—	Nil	—	—	—	0·7	Nil
Silica (SiO ₂) ppm	—	52	—	—	—	9	—
Fluorine (F) ppm	—	< 1	0·3	5	2·8	—	1·6
Carbonate hardness (as CaCO ₃) ppm	—	—	115	270	135	—	705
Non-carbonate hardness (as CaCO ₃) ppm	—	—	3,010	3,055	765	—	1,645

Of importance in practical electro dialysis of natural water are :

- (a) Clarification of the raw water.
- (b) Control of scale formation.

- (c) Control of flow rates of the diluting, concentrating and electrode rinse streams.
- (d) Source of direct electric current and control of current density to effect the required desalting.
- (e) Replacement of ion-selective membranes and electrodes and general maintenance.
- (f) Disposal of concentrated effluent.
- (g) pH adjustment of desalted water.
- (h) Prevention of algal growth.

(a) Preclarification of the raw water

This is not generally necessary with many borehole waters. The CSIR "farm unit" has been designed so that only coarse filtration, or natural settling of heavy particles, is required. The compartments have a modified "tortuous path" profile (Fig. 2) and are in the horizontal position. The sizes of the flow channels and the liquid velocities selected are such that the unit is more or less self-cleaning. Runs totalling several hundred hours have taken place with unfiltered and turbid raw water, during which the compartments have remained clean.

(b) Control of scale formation

Precipitation of "hardness" salts is usually effected by adjusting the pH of the feed water with sulphuric acid, hydrochloric acid or acid salts such as sodium bisulphate, etc., while the precipitation of salts due to concentration effects in the concentrating compartments is prevented by limiting the degree of concentration.

The handling of concentrated acids by inexperienced personnel is to be avoided, especially in areas far from medical aid. At present this aspect has not altogether been satisfactorily solved. Dilute acids mean costly transport costs and large containers for storage. The answer may be to use soluble solid acids and to control the amount dissolved—this method has been used overseas with partial success. At present the CSIR unit uses sulphuric acid. Flow meters, control valves or proportioning pumps are dispensed with by using a pneumatically actuated system, by passing a small direct current through the brack water flowing through a gas-tight chamber and using the gases evolved in the electrolysis of this water to displace the acid. The amount of acid delivered is a function of the current density used in the electrolyser. For a given water the required pH is obtained at a given current density which is indicated on a simple ammeter calibrated in suitable units.

(c) Control of flow rates to the diluting, concentrating and electrode rinse streams

For utmost simplicity all the streams of the CSIR unit are fed from a single constant-head supply, and to eliminate pumps a once-through

system is used. The constant head will generally be a head tank above the borehole, fed by the borehole pump, which would be required in any case. In the Department of Agricultural Technical Services' test installation the borehole pump feeds to a large reservoir on top of a sand dune, from which the desalting unit is fed by gravity. If wind-driven borehole pumps are used, a storage reservoir becomes necessary. Unless steps are taken to prevent growth of algae this is not recommended. Direct power-driven pumping to a head tank of a few hours' capacity is preferred.

Although for research purposes flow meters are used in the feed lines, the pressure drop through the unit remains practically constant, enabling fixed orifices to be used, so doing away with manual or automatic flow control.

(d) Source of direct electric current and control of current density to effect the required desalting

A source of direct current is necessary to carry out the electro dialysis. In practically all the areas under consideration the D.C. will have to be generated on site. This requires small paraffin- or diesel-engined D.C. generators—alternatively, A.C. generators combined with rectifiers can be considered where this arrangement is favoured. Where an A.C. mains supply is available the position is simpler as a small A.C./D.C. rectifier only is needed. The CSIR units have been based on the use of small D.C. generators that are readily available and widely used or house lighting sets, etc. For this reason 120 volts maximum is allowed for. Kilowatt demand depends on the capacity and desalting range of the unit. About 3–6 kW should meet most potential requirements.

For any particular water supply the operating conditions will be fixed so that the generator will be operated at constant power output. A slow rise in resistance, and the applied voltage required, takes place as the membranes age. Membranes of the type at present used exhibit an almost constant coulomb efficiency after the first few weeks' operation. During these first weeks the desalting would be a little greater than specified, but this would cause no inconvenience.

A simple conductivity control to shut down the generators if the output of salinity becomes too great would be a refinement.

(e) Replacement of ion-selective membranes and electrodes, and general maintenance

The membranes are the heart of the process, and it is at this point that failures in the plant are most likely to occur.

It seems that in a number of potential applications brack water desalting will only be a seasonal operation—when surface supplies dry up. All

membranes exhibit changes in dimensions between the wet and dry state, therefore there is considerable danger of membrane damage if a unit is allowed to dry out after use. It is usually adequate to let water drip through an electrodialysis unit during extended shut-down periods ; this is sufficient to keep the membranes damp. It cannot be guaranteed that this will be done under farming conditions, especially as it would require the borehole pump to be started up from time to time to replenish the head tank. The better approach seems to be to use cheap membranes that can be thrown away at the end of a season. A new, prefabricated stack of membranes could then be fitted before restarting. The same principle would apply for operation throughout the year, when a useful life of about one year could be expected.

Graphite electrodes are used in the CSIR unit for cheapness. Graphite is rather brittle, and replacement on site might well be beyond the capabilities of the farmer or local service agent ; similarly, with the replacement of membrane stacks. The potential areas of use of these desalting units are difficult of access and far from towns, sometimes 150 miles or more over very bad tracks. It was decided that maintenance must be kept to the minimum as the units would otherwise be a completely uneconomic proposition and servicing difficulties would be insuperable. For this reason no pumps or automatic controls or instruments (except of the simplest kind such as ammeters) are used. To overcome the difficulty of membrane and electrode replacement the whole unit has been designed so that scrap graphite can be used for the electrodes, while the body of the apparatus is made from a special impervious, flexible concrete which can easily be cast, so that no machining or engineering skill is required. The design of the components is such that where servicing charges would be too great it might not be uneconomic to order a complete new sealed unit with membranes, and either send back the old unit for reconditioning, obtaining a credit for it, or throw it away. The units would be received by the farmer so that the only work required would be to connect the water pipes to the nipples provided, and to connect the generator leads to the terminals.

Any firm or agency involved in the distribution of the units could assemble and test the membrane stacks at a central point and send them and the graphite electrodes and terminal blocks to a local distribution point where they could be assembled in the locally made concrete bodies or end plates.

The electrodialysis unit is simple in construction (see Fig. 3). It consists essentially of two concrete end plates containing the electrodes, electrode terminals and inlet and outlet connections, and the membrane stack proper, which comprises alternate anion- and cation-selective membranes separated by gaskets which also provide the spacing for the membranes and form the flow channels over their surfaces.

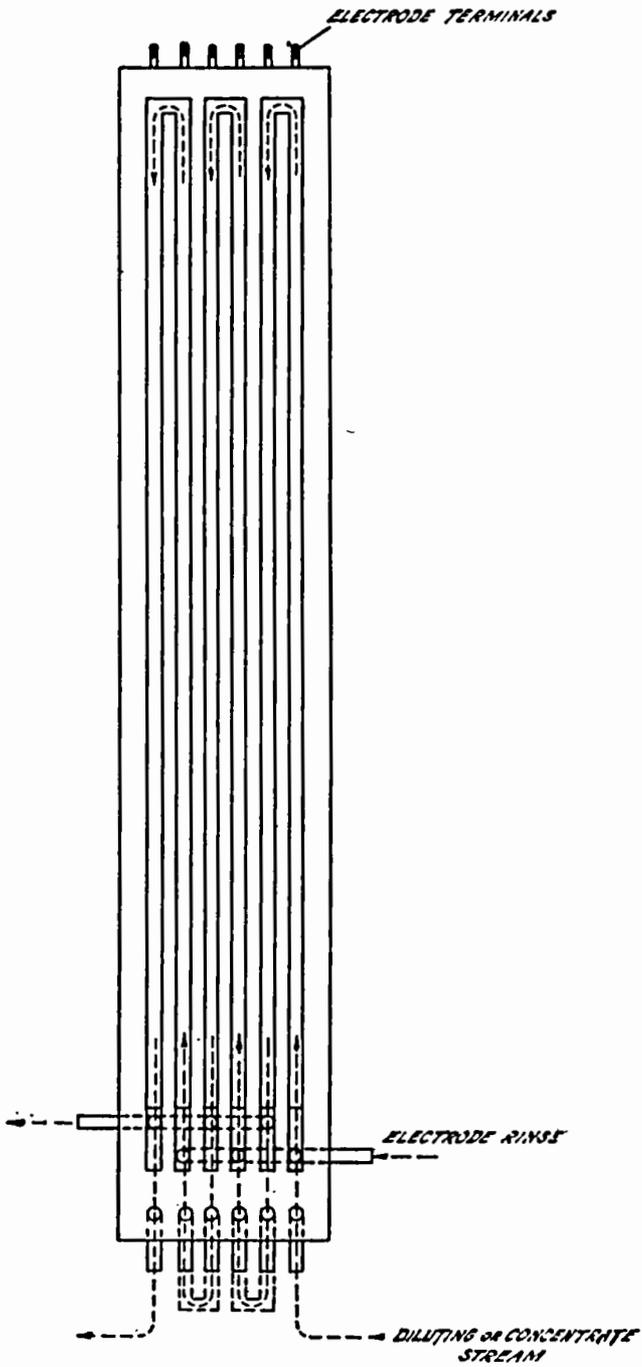


FIG. 2.

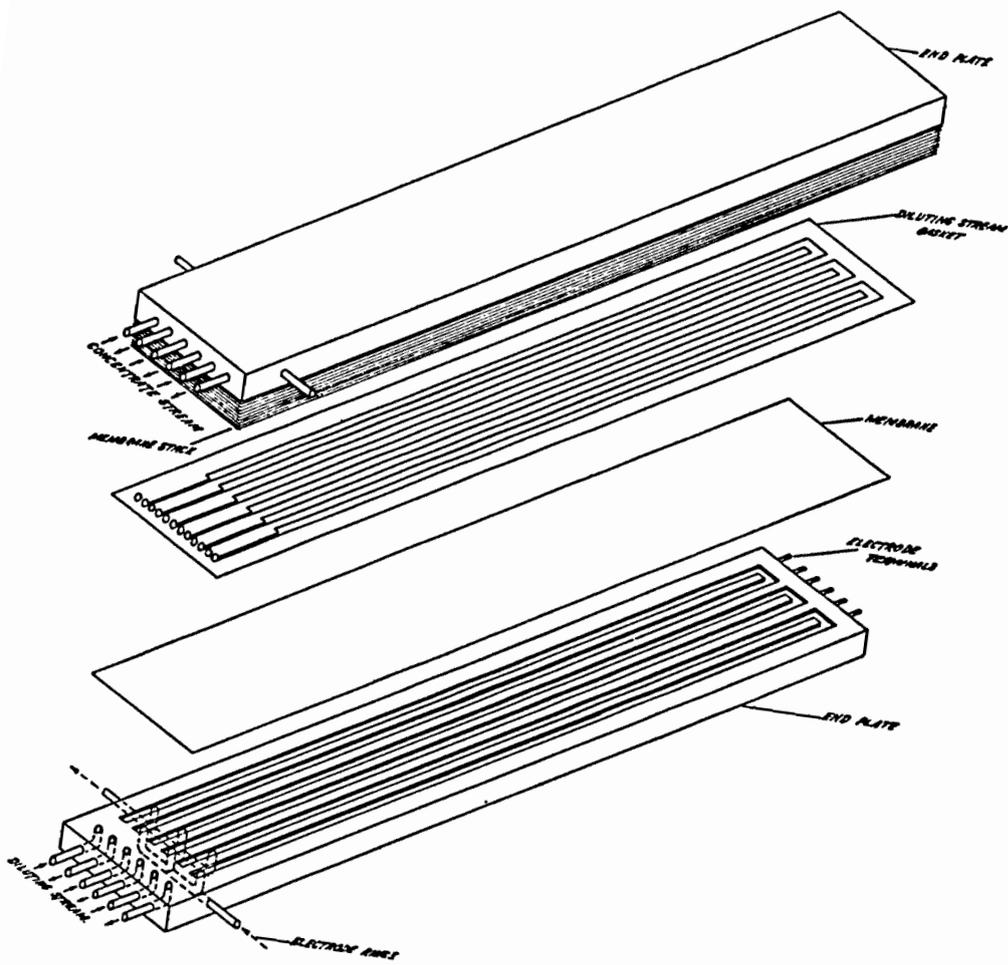


FIG. 3.

(f) Disposal of concentrated effluent

In the farming areas visited this does not pose a problem in view of the small amount of effluent to be handled. In most cases small evaporation pans would be constructed.

(g) Prevention of algal growth

In large plants chlorination of the water is used to ensure sterility. So far the CSIR unit has been used in the field without chlorination. Further experience is required, but it seems that no special precautions are necessary provided the feed tank and lines are kept clean and the water shielded from direct sunlight.

It must be emphasised that the above points represent the basic approach to the problem. The economics have yet to be determined. The actual demand may well be too small for such units to be an attractive commercial proposition, but special cases may permit relatively high prices being paid. Probably the most uncertain feature at present is the guaranteed availability of membranes at a suitably low price and the prevention of scaling.

Desalting costs

It will be obvious that where electricity has to be generated at site the process will not be cheap. As a rough guide the energy requirements can be taken at about 0.001 kWh per gram of salt removed for typical waters and desalting ranges considered. At a bulk diesel price of 2s. 3d. per gallon the cost of desalting 1,000 gallons of water by 1,000 ppm TDS would be about 1s. for fuel costs alone. Even so, some farmers have stated that this could form the basis of a reasonably economic water desalting scheme, especially where the desalting range need be of the order of only a few thousand ppm.

PROTOTYPE DESALTING UNIT

The essential features are shown in Figs. 2 and 3 which represent diagrammatically the type of unit being used for the Department of Agricultural Technical Services stock watering tests.

The unit is exceptional in that it had to be designed for a very high degree of desalting, from 25,000 ppm TDS to 4,000-5,000 ppm TDS. The desalting range is thus rather larger than is likely to be required normally. The designed output is 60-70 gph.

The analysis of the borehole water at the site is given in Table I, column 7.

The intention is to desalt the water to 4,000-5,000 ppm TDS and blend in raw water for the two of the three camps to bring the TDS up to 8,000 ppm and 10,000-12,000 ppm TDS respectively.

The design also permits of taking out waters at three different points in the unit. To maintain non-polarising conditions as the flow is thus

reduced in the following sections special gaskets can be fitted to enable the flow to be kept constant by reducing the channel width.

Provision is also made for separate electrodes so that the practicability of applying different current densities to the separate sections can be examined. The multi-point take-off system also enables the basic unit to be operated as three individual units, each fed separately (except for the electrode rinses) where a lower amount of desalting is required. In this case, the capacity of the unit is correspondingly increased. It might also, by this arrangement, be possible to use one section of the unit to provide a small amount of domestic water and the other sections stock drinking water.

Tables II and III show the principal design data of the unit.

Table II.—Principal dimensions of prototype "farm unit" desalting apparatus

	cm.	in.
Concrete end plates and electrode holders		
Length	217	85½
Width	37.5	14½
Thickness	7.6	3
Electrodes (Acheson AGX electrographite)		
Length	200	78½
Width	2.5	1
Thickness	3.2	1¼
Number per plate		6
Gaskets (Klingerit steam jointing)		
Length	217	85½
Width	37.5	14½
Thickness	0.08	0.032
Width of baffles	2.5	1
Width of flow channels	2.5	1
Length of channels	200	78½
Total path length	1,200	472
Membranes (CSIR parchment base)		
Length	217	85½
Width	37.5	14½
Total surface	8,140 cm ²	1,262 in ²
Active surface	3,000 cm ²	465 in ²
% Active surface		37
Liquid connections (all streams)		
	¾ in. i.d.; 1 in. o.d. polythene	
Approximate weight of sixty cell pair apparatus, 600 lb.		

Table III.—Designed operating conditions for prototype "farm unit" desalting apparatus

Maximum designed input concentration	30,000 ppm TDS
Minimum designed output concentration	4,000 " "
Maximum designed desalting range	26,000 " "
Maximum daily (24 hr.) output at maximum desalting range	1,620 gals. (67.5 gph)
Number of cell pairs	60
Number of anionic membranes	60
Number of cationic membranes	60
Maximum current density	30 mA/cm ²
Maximum applied current	90 amps.
Maximum terminal voltage	105
Maximum power	9.5 kW.
Approximate energy consumption per 1,000 gals. of 4,000 ppm final water	140 kWh.
Ratio of output of concentrated stream to diluted stream	1.1
Throughput per compartment	1.1 gph

Operating experience with the prototype unit

Some 500 hours operating experience have been obtained on this and earlier designs of the prototype. Of this time, about 200 hours represent desalting experiments on a borehole water at the Langvlei factory of the Cape Lime Company Limited, Worcester, Cape Province. Analyses of this water are shown in Table IV.

As will be seen, this water is of high hardness. Preliminary treatment with lime could have been used, but as lime dosing and settling would possibly not be suitable for farm applications, acid dosing with hydrochloric acid was used. The acid consumption was high, a maximum of half a gallon 30% HCl per 1,000 gallons of raw water. This high acid consumption represents a fundamental obstacle when desalting high bicarbonate containing waters. Other means of removing hardness are available and are also being considered.

Table IV.—Borehole water at Langvlei, C.P.

pH	7.4*
TDS—ppm	4,647
Na ⁺	1,032
K ⁺	20
Ca ⁺⁺	152
Mg ⁺⁺	346
Cl [']	2,106
SO ₄ ^{''}	459
CO ₃ ^{''}	Nil
HCO ₃ [']	476
Fe	1.1

* pH as analysed. pH of freshly issuing water from borehole was 6.6.

Table V.—Desalting tests on Langvlei water

<i>Acidulated borehole water</i>	<i>Product water</i>	
	(1)	(2)
pH	5.5	5.2
TDS	1,120	386
Na ⁺	240	74
K ⁺	4	1.4
Ca ⁺⁺	36	9
Mg ⁺⁺	94	32
Fe	2.4	< 0.1
Cl [']	532	164
SO ₄ ^{''}	143	58
CO ₃ ^{''}	46	24
HCO ₃ [']	Nil	Nil
All in ppm		
High Fe content from technical HCl used for pH adjustment		
No. of cell pairs	40	40
Product rate—gph	46	50
Overall voltage	33	82
Current—amps.	12.8	18.5
Current density—mA/cm ²	4.3	6.2
TDS removed—ppm	4,158	4,898
Coulomb efficiency—% (based on Cl ['] and SO ₄ ^{''} only)	71	59
Overall energy consumption kWh/1,000 gals. product	18.4	61.0
kWh./1,000 gals. product per 1,000 ppm TDS removed	4.4	12.5

The first field tests were carried out on the high hardness Langvlei water during November 1958 to February 1959 (for water analysis see Table IV). The tests were aimed primarily at testing the unit over an extended period using *untreated* water to determine the suitability of various descaling methods. A further series of tests was carried out with an improved desalting unit during February and March 1960, using in one case hydrochloric and in another case sulphuric acid for pH adjustment of the raw water.

The Langvlei tests were set up as the opportunity arose to erect a test installation there, although it was not the type of water for which the prototype was specifically designed. Nevertheless, it represented a typical medium brack, high hardness water and valuable experience was obtained.

Table V gives values for tests where the water was reduced in one case from about 5,300 ppm TDS to 1,100 ppm TDS, and in the other case to 386 ppm TDS.

The overall energy consumption for a number of tests on this small forty-compartment unit averaged 4.5 kWh. per 1,000 gallons of product per 1,000 ppm TDS removed, for product concentrations of from 1,000 to 1,200 ppm TDS.

Data for tests on synthetic brack waters, using a seventeen cell pair stack only, are given in Table VI. The unit was operated at designed flow rates, as given in Table III (1.1 gph per compartment) and the current density adjusted to give the required desalting.

Table VI.—Data on prototype desalting tests on synthetic brack waters using 17 cell pairs

	(1)	(2)	(3)	(4)
Raw water—TDS (ppm) *	19,500	15,174	3,880	3,880
Product—TDS (ppm)	4,515	2,288	1,042	463
TDS removed (ppm)	14,985	12,886	2,838	3,417
Coulomb efficiency %	87	87	92	84
Energy consumption kWh./1,000 gals.	62	54	5.3	17
kWh./1,000 gals./1,000 ppm TDS removed.	4.1	4.2	1.9	5.0

* Type of water corresponding approximately to borehole water at Department of Agricultural Technical Services test site—Table I, column 7.

Table VII.—Desalting tests in low concentration range (17 cell pair unit)

Raw water (synthetic)	ppm
NaCl	1,200
HCO ₃	230
SO ₄	60
TDS	1,490 approx.
Product	
TDS	230 approx.
Desalting	
TDS	1,260 approx.
Energy consumption	
kWh./1,000 gal. product	8-10
kWh./1,000 gal. product/1,000 ppm TDS removed	6-8 approx.

Note :

Raw water of approximately 1,490 ppm used for electrode rinses.

Table VIII.—Properties of membrane used in prototype tests

	Dialysis (m-eq. cm ⁻² sec. ⁻¹ 10 ⁻⁶)	Conductance (m. mho cm ⁻²)	Transport number
Anion selective :			
Unused	0·58	16	0·073
Used*	1·68	26	0·130
Cation selective :			
Unused	0·16	22	0·957
Used*	0·21	35	0·952

* After seven months in the wet state and 500 operating hours.

A short test was carried out on the prototype to see what energy consumption would be needed if a typical low brack water had to be desalted for irrigation purposes (Table VII). The raw water was used for the diluting, concentrating and electrode rinsing streams, resulting in high electrical resistance. In practice, the concentrating stream outlet could be used for the electrode rinses and the energy consumption thus be reduced. It should be pointed out that the prototype was not designed for this application. Flow rates were, as usual, 1·1 gph per compartment.

Membrane properties slowly deteriorated over a total electrolysing period of some 500 hours with a wide range of operating conditions. The membranes were in the wet state in the unit for a little over seven months.

Coulomb efficiencies dropped in this period from an average of 88% to an average of 78%.

As was to be expected, the electrochemical properties of the positive, or anion-selective, membranes deteriorated the most (Table VIII).

Acknowledgements

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RECHERCHES ET PERFECTIONNEMENT CONCERNANT L'ELECTRODIALYSE — RESULTATS OBTENUS EN AFRIQUE DU NORD

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A. INTRODUCTION

L'Afrique du Nord est une région défavorisée des points de vue hydrologique et hydrogéologique. Les problèmes d'eau s'y posent depuis toujours avec une acuité particulière.

La recherche, la mobilisation et la régulation des ressources en eau demandent des travaux de longue haleine, d'une réalisation difficile et d'une ampleur disproportionnée quelquefois si on la compare au volume des eaux réellement mises à la disposition des usagers.

Néanmoins la continuité de l'effort accompli depuis des dizaines d'années par la France en Afrique du Nord permet de faire face aux besoins toujours croissants et permet d'envisager avec un optimisme raisonnable les possibilités d'amélioration futures.

Les eaux ainsi mobilisées sont par contre d'une qualité médiocre et parallèlement aux problème de la **quantité** il existe un problème de la **qualité insuffisante** des eaux. Ce dernier problème fort important même dans une économie à dominante agricole devient, s'il n'est pas résolu, un obstacle majeur au développement industriel que la France cherche à promouvoir dans ces régions.

Une des caractéristiques les plus constantes des défauts des eaux de l'Afrique du Nord est leur minéralisation élevée. Cette permanence est telle que les normes de qualité admises dans les pays de civilisation européenne et qui ont été reprises par l'Organisation Mondiale de la Santé (OMS) ne sont, dans la pratique, prises en considération qu'à leur limite supérieure. En d'autres mots une teneur ionique qui serait une limite supérieure de tolérance devient en Afrique du Nord l'idéal à atteindre si la technique du traitement et le prix de revient le permettent.

Il est intéressant de noter que la tolérance aux eaux salées des populations nord-africaines (y compris celles de souche européenne) qui est proverbiale, provient d'une part d'un état d'esprit de résignation devant un mal auquel on ne pouvait jusqu'à présent apporter de remède, et

d'autre part d'un mode de vie adapté à une consommation réduite d'eau. A partir du moment où de l'eau faiblement minéralisée est mise en abondance et à peu de frais à sa disposition le nord-africain répugne très rapidement à consommer de l'eau salée. Enfin à partir du moment où il doit adopter une vie rythmée par les exigences de la civilisation industrielle même l'autochtone le plus accoutumé ressent le besoin d'une eau de qualité.

L'exemple le plus frappant peut être trouvé parmi les ouvriers des chantiers de forage du Sahara. Le nomade qui subsistait avec un ou deux litres d'eau salée par jour en ne se déplaçant derrière ses troupeaux qu'aux heures de moindre chaleur, doit par pure exigence physiologique, consommer dix à douze litres d'eau par jour, quand il s'embauche sur un chantier. Comme l'européen d'origine il ne peut supporter sans inconvénient l'ingestion des 40 à 50 grammes de sels divers par jour que lui apporte alors son eau de boisson non déminéralisée. Il faut alors fournir à l'autochtone saharien comme au spécialiste venu d'Europe de l'eau à faible salure.

Il existe donc en Afrique du Nord un besoin généralisé d'appareils de déminéralisation.

Alors que dans le domaine de la distillation solaire et des échangeurs d'ions des études de recherche et d'application technologique ont été directement poursuivies en Afrique du Nord (Algérie et Maroc en coopération avec la Tunisie) il a semblé préférable à la haute administration de participer dans un premier temps aux travaux de recherche et de mise au point qui ont été proposées à l'époque par un groupe de travail de l'OECE pour l'avancement de nos connaissances en électrodialyse.

L'origine des connaissances de base et du know-how technologique de l'électrodialyse en Afrique du Nord se trouve donc dans les travaux menés à La Haye par l'Institut TNO, sous la Direction coopérative d'un certain nombre de pays intéressés.

A la fin d'une période d'études en coopération de trois ans on disposait en Afrique du Nord de la licence de brevets originaux du TNO (dépôtés avant la période de coopération), de brevets pris pendant la période de coopération et d'une licence d'un brevet sud-africain déposé par le SACSIR. On disposait de plus des connaissances théoriques et pratiques acquises au cours de travaux en laboratoire et dans l'exploitation d'un prototype industriel (dénommé WD 10-4) d'une capacité d'extraction de l'ordre de 500 kg de sels par jour, et qui avait été mis à l'épreuve pendant un an environ en déminéralisant de l'eau de mer en Hollande.

B. TRAVAUX DE RECHERCHES EFFECTUES EN AFRIQUE DU NORD

Deux voies différentes mais complémentaires ont été suivies.

Il s'agissait d'une part, de mettre le plus rapidement possible à la disposition de l'économie des pays nord-africains, des appareils susceptibles

de répondre aux besoins locaux. Une société à objet industriel a été créée (Société SODEMI). Les droits et obligations résultant des travaux en coopération lui furent transmis, et elle reçut pour mission de réaliser dans les délais les plus brefs, des appareils industriels.

Il s'agissait, d'autre part, de compléter les études générales, faites en coopération, par l'étude propre des problèmes posés par les eaux de l'Afrique du Nord. Il fallait également poursuivre les études de perfectionnement sans lesquelles la technique de l'électrodialyse se serait sclérosée. Il était indispensable que la société SODEMI participe à cette activité de recherche et de perfectionnement. Compte tenu de l'intérêt général de ces études, des organismes de recherche relevant du Conseil supérieur de la Recherche scientifique appliquée en Algérie furent également saisis de la question.

Les études faites localement en Afrique du Nord ne portent pas sur la conception et la fabrication des membranes elles-mêmes, qui relèvent du domaine des services de recherche de la grande industrie chimique. Par contre, l'essai systématique de membranes d'origines diverses et l'examen de leur comportement au contact des eaux d'Afrique du Nord a été inclus dans l'activité des organismes susnommés.

C. CONSTRUCTION D'APPAREILS INDUSTRIELS

C. 1. La minéralisation des eaux rencontrées en Afrique du Nord se tient, dans la plus grande généralité des cas, entre 600 mg/l (600 ppm) et 17.000 mg/l (17.000 ppm). Cependant la plus grande fréquence des problèmes de déminéralisation se pose pour des eaux dont la teneur en ordre de grandeur est voisine de :

2.000 mg/l (2.000 ppm)
5.000 mg/l (5.000 ppm)
8.000 mg/l (8.000 ppm)

Les besoins quotidiens en eau s'échelonnent ainsi :

besoins familiaux (poste fixe)	15 à 100 l/jour
petit groupe technique ou militaire, petit hôtel (poste fixe)	100 à 1.000 l/jour
chantier (poste mobile)	2,5 à 5 m ³ /jour
groupe technique ou militaire important, hôtel (poste fixe)	2,5 à 5 m ³ /jour
agglomération (poste fixe)	100 à plusieurs milliers m ³ /jour

Traduits en puissance d'extraction de sel par jour les chiffres précédents conduisent à considérer la gamme d'appareils ci-après :

	<i>kg sels par jour</i>
appareils fixes	1
	5
	10
	25
	50
	500 et plus
appareils mobiles	25
	50

Il est apparu également que les appareils " fixes " devaient être construits de telle façon que les risques de détérioration en cours de transport soient réduits et que les travaux d'assemblage sur place soient ou supprimés ou réduits au strict minimum.

En d'autres termes les appareils " fixes " devaient présenter des caractéristiques propres aux appareils " mobiles " mais sans que soient recherchés jusqu'à leur extrême logique la robustesse et le monolithisme de l'appareillage.

C. 2. Appareil dérivé du WD 10-4

L'appareil dessiné et expérimenté en Hollande au cours des études en coopération comprenait 8 paquets partiels de 100 membranes d'une dimension de 100×40 cm environ.

Sa capacité de dessalement était de l'ordre de 500 kg/jour. L'appareil expérimental ne pouvait supporter des pressions trop élevées (moins de 1 kg/cm^2) et n'était pas conçu pour supporter des différences de pression entre les étages de déminéralisation au sein du même empilage de paquets partiels.

L'appareil étant bien connu et ses performances exactement mesurées, il était logique de dériver un appareil industriel directement du WD 10-4. Il correspondait par ailleurs au plus gros poste fixe nécessaire (500 kg de sels par jour).

L'appareil construit par SODEMI sous la désignation de 1410-I constitue cet appareil dérivé.

On avait le choix entre deux voies :

- copier très exactement le WD 10-4,
 - le modifier tout en conservant les caractéristiques de base.
- C'est cette deuxième voie qui a été adoptée.

Les améliorations principales ont porté sur :

- le dessin et la réalisation des cadres de paquets partiels,
- le nombre de paquets partiels pouvant être mis en œuvre dans une cellule presse (10 paquets au lieu de 8, soit 1.000 membranes sélectives au lieu de 800),
- la pression de service qui a été portée de 1 kg/cm^2 en tête de la cellule à 3 kg/cm^2 ,
- la possibilité d'utiliser la cellule avec plusieurs étages en série sans nécessité de rompre la pression entre les étages successifs,
- le mode de réalisation des électrodes et de leur support,
- la disposition générale des paquets partiels et des tuyauteries d'alimentation et d'exhaure qui permet d'extraire aisément un paquet partiel de la cellule par le haut au moyen d'un palan monorail.

Ces améliorations peuvent de prime abord apparaître bien simples. En fait comme cela se produit souvent dans la technologie de réalisation, les solutions simples demandent des études approfondies.

L'augmentation de la pression de service a en particulier conduit à une mise au point délicate de la structure du plastique armé moulé à chaud et sous pression constituant les cadres des paquets partiels. Elle a conduit à étudier avec soin les problèmes d'étanchéité, en particulier entre les paquets partiels. L'utilisation de doubles joints toriques incrustés dans des logements moulés a permis de tourner la difficulté.

Cette augmentation de la pression de service a provoqué l'éclatement des paquets partiels, les joints situés entre les membranes étant chassés par la pression nettement supérieure à celle qui avait été expérimentée en Hollande. Il a fallu analyser avec soin le phénomène et déterminer avec exactitude le rapport entre les pressions de serrage de la cellule, la surface des joints, leur nature et la fraction de la surface des membranes à inclure entre les joints. Un dispositif d'appui spécial a de plus favorisé la mise au point définitive.

Enfin la mise en série, sans rupture de pression intermédiaire des différents étages d'une même cellule conduit à la création d'une pression différentielle importante appliquée sur la surface séparant un étage du suivant et ceci en raison de la perte de charge non négligeable créée par l'écoulement des liquides de déminéralisation et de concentration dans les cellules élémentaires.

Cette difficulté également a été aisément surmontée. Dans certains cas cette possibilité de mise en série sans précaution particulière permet de faire l'économie d'un nombre considérable de pompes de recirculation (deux ou même trois par étage).

Trois cellules DE 1410-I ont été construites à Alger dont deux pour les besoins sahariens et une pour l'alimentation en eau d'une petite agglomération algérienne. La puissance d'extraction de chaque cellule est de l'ordre de 600 à 700 kg de sels par jour.

Ces cellules pourraient bien entendu être utilisées dans des dispositifs à "cuvée" (et non à passage direct), être montées avec un nombre plus réduit de paquets partiels, ou encore être assemblées en parallèle ou en série pour réaliser des usines de traitement de très gros débit.

C. 3. Appareils de faible puissance DE 124-2 et DE 224-2

L'enquête sur les besoins en appareils de déminéralisation mentionnée plus haut au C. 1. a montré que la cellule DE 14 10-I dérivée du WD 10-4 était beaucoup trop puissante pour constituer une solution convenable à toute une série de problèmes.

On a été conduit à dessiner une cellule nettement moins importante. La dimension choisie pour la membrane a été de :

$$15 \times 41 \text{ cm.}$$

La cellule est composée de 5 paquets partiels de 100 membranes ce qui donne pour des densités de courant raisonnables une puissance d'extraction par cellule de l'ordre de :

25 à 30 kg de sels par jour.

L'utilisation de deux cellules en parallèle permet de faire face à des besoins de l'ordre de :

50 à 60 kg de sels par jour.

Ceci couvre donc l'ensemble des besoins tels qu'ils étaient apparus à l'issue de notre enquête.

Bien qu'il ne soit pas impossible d'utiliser la cellule dans un dispositif "à passage direct", la décision a été prise de ne réaliser la plupart des appareils de faible puissance que sous la forme de traitement par "cuvée" (batch).

Le dispositif par "cuvée" est beaucoup plus simple, plus rustique d'exploitation, et il s'adapte aisément au traitement d'eaux de minéralisations différentes par simple variation de la durée du cycle de déminéralisation, les autres caractéristiques restant constantes. Ceci constitue un énorme avantage pour les exploitants d'un appareil mobile; cela permet également de standardiser les fabrications des petits appareils fixes sans tenir compte des variations sensibles de la minéralisation des eaux d'un utilisateur à l'autre.

La réalisation des paquets partiels a été directement inspirée de celle de l'appareil DE 1410-I; le principe de l'assemblage est identique. Les cadres de paquets partiels ont été fabriqués en CPV et non en polyester stratifié. Le serrage de la cellule est obtenu par des tiges filetées avec écrous.

Toutes les membranes sont utilisées en parallèle dans la cellule et il n'y a pas d'alimentation séparée par paquet partiel.

C. 4. Appareils mobiles

Ils se présentent sous une forme compacte formant bloc aisément transportable, monté sur skid. Cette formule d'une grande robustesse mécanique permet à l'usager de déplacer les appareils sans précautions spéciales. Le chargement et le déchargement sont grandement facilités et peuvent être effectués soit par grue, soit plus simplement à l'aide d'un treuil.

Les appareils fonctionnent par "cuvées" successives. Ils comportent pour cette raison deux réservoirs de 2,5 m³ chacun disposés à la partie supérieure du bâti-skid.

Un jeu de vannes permet de faire circuler en circuit fermé à l'aide d'un groupe électro-pompe le contenu de chaque réservoir dans les compartiments de déminéralisation de la cellule. Le temps de déminéralisation de la cuvée dépend de la salinité initiale des eaux brutes et de la minéralisation finale choisie. Pour un appareil à une cellule de cinq paquets partiels

il faut 12 heures pour ramener à 500 mg 2,5 m³ d'une eau titrant 5 g/litre au départ.

Lorsqu'un des réservoirs est déminéralisé, on peut poursuivre l'opération avec le deuxième réservoir. Le premier constitue alors une réserve d'eau potable dont l'utilisateur peut choisir à sa convenance le moment de dépotage.

Un réservoir situé à la partie inférieure constitue le réceptacle des sels extraits par l'intermédiaire du circuit de concentration muni, lui également, d'un groupe électro-pompe.

Un circuit séparé de rinçage des électrodes comprend lui aussi un groupe électro-pompe et un petit réservoir. Ce circuit est un circuit fermé sans perte d'eau ni dégagement de chlore. On reviendra sur cette question plus bas.

Le circuit de concentration peut être utilisé ou en cycle fermé ou en circuit ouvert. Dans ce dernier cas un appoint permanent d'eau brute doit être assuré pour compenser la perte d'eau créée par la purge continue.

Un autre élément essentiel est constitué par le groupe transformateur redresseur disposé dans une armoire étanche qui comporte également tous les organes de commande électrique.

Plusieurs questions de principe ont dû être tranchées au moment de la conception de l'appareillage.

a) Groupe électrogène

Fallait-il ou non inclure un groupe électrogène dans l'équipement standard du poste de déminéralisation mobile ?

Notre réponse a été non. En effet, un poste d'électrodialyse mobile ne peut servir à équiper qu'un chantier relativement peu important muni certainement d'instruments ou d'appareils consommateurs d'énergie électrique (sans parler des besoins d'éclairage). Or la puissance absorbée par les appareils d'électrodialyse de chantier est faible (1,5 à 3 kVA), et cette puissance sauf des cas très exceptionnels peut être directement obtenue de la source d'énergie électrique du chantier.

Pour répondre aux cas exceptionnels, il est toujours possible de prévoir la fourniture, en appareil annexe séparé, d'un groupe électrogène lui-même monté sur chassis-skid.

b) Automatisation

Fallait-il ou non prévoir un fonctionnement automatique ?

Notre réponse a été non, sauf dans des cas très particuliers. En effet, l'introduction de l'automatisation ne présente un intérêt certain que dans le cas où il permet une économie d'investissement ou de frais de main-d'œuvre.

Dans le cas de l'électrodialyse, l'automatisation n'apporte aucune économie possible sur les frais d'investissement, au contraire.

Pour les frais de main-d'œuvre, l'économie ne peut apparaître que dans

le cas où le fonctionnement sans automatisme demande soit des manipulations fréquentes soit une surveillance permanente, Ce n'est pas le cas des appareils fonctionnant en "cuvée" quand la durée de déminéralisation d'une cuinée s'inclut harmonieusement dans la journée de travail des agents chargés de l'exploitation de l'appareil. Pour une durée de 12 heures, il suffit, deux fois par jour, de venir manipuler les vannes de transfert du circuit de déminéralisation d'un réservoir sur l'autre ainsi que les vannes de remplissage d'eau brute et de dépotage d'eau déminéralisée. L'ensemble des manipulations ne dépasse pas en durée 1 heure environ.

Entre temps l'appareil fonctionne sans surveillance, un dispositif d'alarme sonore venant avertir le préposé à l'exploitation en cas de défaillance de l'appareillage.

Si la durée de la déminéralisation d'une "cuvée" est très courte, par exemple 20 minutes, comme c'est le cas pour des appareils que nous avons pu visiter, il est certain qu'un dispositif automatique d'intervention, de vidange et de remplissage est alors indispensable pour éviter l'immobilisation 24 h sur 24 d'un agent d'exploitation (c'est à dire trois agents dont un de nuit). Mais il nous semble évident que l'augmentation du volume des réservoirs de cuinée représente une dépense inférieure à celle qui correspond à la mise en place d'un automatisme complet.

Par ailleurs, surtout dans les régions sahariennes et dans les conditions de vie d'un chantier, le fonctionnement de l'automatisme est relativement aléatoire et on est conduit, comme le montre l'expérience, à prévoir un surveillant du bon fonctionnement de l'automatisme lorsque cette solution est adoptée.

c) Prétraitement

Fallait-il ou non systématiquement prévoir un prétraitement complet de l'eau soumise à l'électrodialyse ?

Notre réponse a été non. La nature des prétraitements à appliquer est très variable puisqu'elle est fonction des défauts (autres que la minéralisation) que l'on peut constater dans l'eau soumise à l'électrodialyse.

D'autre part un équipement "moyen" de prétraitement (coagulation, décantation, filtration, stérilisation) représente un encombrement du même ordre de grandeur que l'appareillage d'électrodialyse. Il nous a semblé préférable de prévoir un équipement sur skid dans un bâti séparé.

A titre de précaution il est cependant monté d'une façon systématique un filtre à grande vitesse sur la canalisation de remplissage des réservoirs. Ce filtre qui ne peut assurer une clarification suffisante si l'eau d'alimentation est tant soit peu chargée, a pour rôle d'empêcher par son colmatage l'accès d'une eau insuffisamment clarifiée au sein de l'appareil.

d) Appareillage enregistreur de mesures

Dans un appareil fonctionnant par "cuvée" il importe à l'usager de connaître le moment où il peut utiliser l'eau déminéralisée. Dans la plupart

des cas la qualité de l'eau, en un point donné d'exploitation de l'appareil, est, à peu de choses près, constante. Donc le moment du dépôtage sera obtenu au bout d'un temps fixe de fonctionnement de l'appareil. Il n'est pas essentiellement utile à l'usager de suivre la déminéralisation. Il lui est par contre utile de savoir, en fin de "cuvée", si la qualité recherchée a bien été obtenue.

Il nous a semblé plus conforme aux besoins réels de l'usager (qui n'est pas un savant ou un expérimentateur) de munir l'appareil d'instruments de mesure sur **échantillons**. Chaque appareil est doté d'un résistivitémètre et d'un pH mètre.

Un avantage de cette solution réside dans la fragilité moindre d'appareils séparés que l'on peut par ailleurs transporter dans des caissons protecteurs spécialement aménagés. Leur révision et leur entretien périodiques peuvent être aussi mieux assurés que ceux d'appareils montés à demeure.

Enfin l'ensemble de l'appareillage d'electrodialyse est sous tension, ce qui peut produire des causes d'erreurs dans les indications données par des appareils de mesure au contact direct du châssis et surtout faisant leur mesure au sein même du circuit d'eau contrôlé.

Nous croyons d'autre part que la surveillance de la vérification du bon état d'appareils de mesure est effectuée avec plus de soins et plus d'attention sur des appareils séparés au moment même où l'usager prélève son échantillon et effectue sa mesure que sur des appareils fixes à indication continue.

En particulier, dans le cas de la mesure de la résistivité, il faut vérifier avec soin l'état des électrodes de la sonde de résistivité (absence de bulles d'air) et mesurer avec soin la température de l'eau soumise au contrôle pour tenir compte du facteur correction de température.

C. 5. Appareils fixes

Lorsque les difficultés d'acheminement jusqu'au lieu d'emploi et d'exécution de travaux sur place sont considérables il est préférable de fournir un appareil mobile de chantier. C'est le cas de certains points du Sahara ou du Sud marocain.

Cependant bien qu'il faille toujours tenir le plus grand compte des difficultés et des aléas des transports dans les régions nord-africaines, l'appareil de chantier constitue dans la plupart des cas un ensemble trop robuste et trop lourd pour convenir systématiquement à la résolution des problèmes d'alimentation des petits groupes humains sédentaires.

Deux types d'appareils ont été réalisés.

1) L'un dérive directement des appareils DE 124-2 et DE 224-2 sur skid. Il comporte une ou deux cellules de cinq paquets partiels travaillant en "cuvée" avec les pompes de recirculation et le redresseur montés dans un châssis skid léger facilitant le transport de l'ensemble.

Cet appareillage est branché soit sur des réservoirs d'eau à déminéraliser ou à concentrer existant sur place soit sur des réservoirs fournis séparément et qui sont alors disposés à côté du châssis skid susmentionné.

En cas de besoin l'ensemble est muni d'un dispositif de commande hydraulique automatique asservi à un programme horaire, d'une part, et au niveau dans le réservoir d'eau déminéralisée d'autre part.

2) L'autre a été construit autour d'un seul paquet partiel. C'est également un appareil fonctionnant en "cuvée". Il est muni de cuves d'un volume variable suivant le point à desservir.

Un troisième type d'appareil est à l'étude. Un prototype en a été réalisé. C'est un appareil domestique à "passage direct". Il est muni d'un paquet partiel spécial à 150 membranes réalisant plusieurs étages en série au sein du même paquet. Cet appareil fonctionne avec une pression de 1 K/cm² environ et peut directement alimenter une prise d'eau déminéralisée dans une cuisine par exemple. Il peut être directement branché sur le réseau urbain d'alimentation en eau.

L'appareil fonctionne d'une façon satisfaisante. Quelques détails méritent encore des mises au point. Ils se situent dans les pompes de recirculation et le dispositif d'injection d'acide. Les débits de circulation et d'acide sont faibles, et il est difficile de trouver du matériel standard de qualité dans d'aussi faibles puissances.

D. RECHERCHES ET PERFECTIONNEMENTS

D. 1. Les eaux de l'Afrique du Nord

Les eaux de l'Afrique du Nord sont chlorurées sodiques, séléniteuses et magnésiennes. Leur alcalinité est sensible et varie peu avec la minéralisation totale. Quelques analyses typiques sont données ci-dessous :

Teneurs en mg/litre

	Ca	Mg	Na	Cl	SO ₄	CO ₃	R.S.
Alger	112	22	58	85	140	142	565
Hassi Messaoud	320	50	150	420	580	90	1.700
Tolga	381	96	103	144	1.154	99	2.160
Biskra	166	85	450	642	617	117	2.270
El Oued	653	69	214	270	1.671	60	3.053
Tarfaya (Maroc)	118	107	1.012	1.616	476	60	3.500
Messouda	536	207	595	964	1.900	111	4.325
Touggourt	552	186	721	1.242	1.709	71	4.504
Sud Tunisien	536	277	670	2.112	887	196	4.678
Kenadza	555	349	1.021	2.011	694	143	5.676
Tanezrouf	611	395	1.336	1.535	3.582	109	7.811
Sud Tunisien	980	210	1.430	3.255	1.550	132	7.815
eau de mer	500	1.400	11.400	20.070	2.700	175	35.245

Les eaux sont très dures. Leur teneur en gypse est élevée (certaines eaux sont mêmes très voisines de l'état de saturation en sulfate de calcium).

On devait attendre a priori que le comportement de ces eaux dans les appareils d'électrodialyse soit différent de celui de l'eau de mer où la prédominance en chlorure de sodium est très marquée. Il fallait donc acquérir le plus rapidement possible une expérience directe du dessalement par électrodialyse des eaux d'Afrique du Nord.

Pour cela un appareil du type DE 124-2 a été spécialement affecté à l'expérimentation. Sa mise en service date de la fin de l'année 1958.

D. 2. Effet sélectif ionique

Les teneurs ioniques respectives étant réparties d'une façon plus homogène que dans le cas de l'eau de mer il a été examiné si une déminéralisation sélective préférentielle sensible apparaissait pour certains des ions en présence.

Les essais ont été effectués avec des membranes hétérogènes d'un type dérivé des membranes "Amberplex". Il est apparu qu'une différence sensible existait dans les vitesses d'élimination des ions de différente nature mais que, dans le domaine des eaux potables, cette différence ne présentait ni inconvénient ni avantage particuliers. Les teneurs relatives des différents ions en fin de cycle de déminéralisation sont dans des proportions différentes des proportions initiales existant dans l'eau brute. Mais la variation de ces proportions relatives, tout en restant parfaitement décelable à l'analyse, reste faible.

Dans le tableau ci-dessous sont donnés, à titre d'exemple, des résultats obtenus au cours d'un des essais.

Teneurs ioniques en % de la teneur initiale de chaque ion

Temps	Ions						
	Ca	Mg	Na	K	Cl	SO ₄	CO ₃
0 . . .	100	100	100	100	100	100	100
2 H . . .	71	84,5	72	67	73	72	90
4 H . . .	56	51	53	41	50	57	70
6 H . . .	39	30	28	23	29	35	51
8 H . . .	22	22	18	14	17	19	36
10 H . . .	13	14	9,5	7,9	9,5	15	25

Teneur ionique en % de la teneur totale en ions de la solution (cations et anions pris séparément)

0 H . . .	22,25	22,25	53,50	2,0	67,00	25,00	8,00
10 H . . .	25,50	27,75	45,50	1,25	52,00	31,00	17,00

Il apparaît que les ions monovalents sont extraits plus rapidement que les bivalents. Tout en se déminéralisant l'eau voit, en proportions relatives, s'accroître les teneurs en calcium et magnésium et en sulfate et surtout en carbonate.

Cependant cette évolution ne produit pas une modification profonde du faciès chimique de l'eau ; l'eau déminéralisée reste de même nature que l'eau initiale.

Les différents essais effectués ont montré que le problème était complexe. La sélectivité dépendait :

- de la nature des membranes,
- de la densité de courant appliquée,
- du degré de déminéralisation total,
- de la répartition ionique initiale.

On ne peut pour l'instant formuler de loi générale même approximative.

Il nous apparaît cependant important de continuer à étudier cette sélectivité préférentielle qui peut déboucher sur des applications intéressantes dans les domaines des eaux potables et des traitements industriels, mais également dans le domaine agricole. Cette déminéralisation sélective, si on pouvait s'en rendre maître, ouvrirait la voie aux modifications de composition ionique des eaux d'irrigation, ce qui devrait permettre de limiter l'importance et la complexité des traitements appliqués à ces eaux et en réduire le prix de revient à des limites raisonnables.

D. 3. Incrustation des membranes

Les précipitations de sels au sein de la cellule constituent dans l'état de choses actuel la difficulté majeure rencontrée dans l'exploitation des appareils d'électrodialyse en Afrique du Nord.

Ces incrustations proviennent soit de la mise en saturation de certains sels au cours du processus de déminéralisation, soit de l'effet d'une élévation de pH au voisinage immédiat des membranes, élévation de pH qui produit une précipitation de carbonate de calcium et de magnésie hydratée.

Le résultat de l'apparition d'incrustations et de précipitations est désastreux. L'intervalle entre les membranes se bouche, le débit de l'eau admis diminue, la vitesse de passage tombe au-dessous de la vitesse critique de dépolarisation. La polarisation apparaît ; d'une part la consommation d'énergie s'accroît, d'autre part le rendement de la déminéralisation diminue et la qualité de l'effluent se détériore.

La polarisation a pour effet d'accroître le pourcentage relatif de transfert des ions hydroxyle ce qui élève davantage encore le pH et un effet de boue de neige apparaît. Dans certains cas la rapidité de l'évolution est considérable et en quelques heures tout se trouve bloqué.

L'obstruction de l'espace intermembranes conduit à une augmentation de la perte de charge, le débit pompe diminue, la pression s'accroît et les différences de pression entre les espaces intermembranes partiellement obstrués et intacts peut atteindre des valeurs telles que des déchirures de membranes se produisent.

Enfin les incrustations cheminent lentement au sein même des membranes et le gonflement dû à la cristallisation dans les espaces lacunaires des membranes produisent la destruction de la structure de ces dernières et leur rupture.

Le gonflement d'une membrane produit une obstruction partielle du compartiment voisin. La diminution de débit, passant dans ce compartiment qui en résulte, produit une polarisation qui engendre à son tour dans le compartiment suivant la formation accélérée d'incrustations et ainsi de suite.

Dans ces conditions, même lorsque la formation d'incrustations par précipitation chimique ou par sursaturation n'est pas généralisée dans l'ensemble de l'appareil mais se trouve localisée dans un seul espace intermembrane élémentaire, le gonflement de cette cellule élémentaire peut conduire à l'envahissement progressif de l'ensemble du paquet partiel et à la mise hors service.

De ce qui précède, il résulte que l'apparition de cristallisation peut survenir, même si les conditions générales d'exploitation paraissent convenables. Il suffit en effet qu'une seule des cellules élémentaires présente un défaut (épaisseur non conforme, mauvaise alimentation, défaut du séparateur qui répartit mal le débit ou n'assure pas une turbulence suffisante) pour qu'une polarisation locale naisse dans cette cellule élémentaire. Cette polarisation provoque la formation de cristaux de carbonate de calcium et de flocons de magnésie. La boule de neige est amorcée et peu à peu, si ce premier dépôt n'est pas éliminé, les incrustations gagnent l'ensemble du paquet partiel.

D. 4. Moyens de lutte contre les incrustations

D. 4. 1. Adoucissement préalable

Les incrustations sont dues aux ions alcalino-terreux : Ca et Mg.

L'élimination totale de ces ions permettrait d'éviter les précipitations. L'adoucissement total est donc souhaitable. Un adoucissement partiel peut faire tomber le sulfate de calcium au-dessous de son taux de saturation. Il évitera la formation d'incrustations de sursaturation. L'adoucissement partiel diminuera l'intensité des précipitations dues à l'augmentation de pH.

Un adoucissement total ou partiel n'est pas toujours compatible avec les exigences techniques et économiques d'une exploitation donnée.

Cependant dans de nombreux cas, lorsque les eaux sont très dures et très minéralisées on peut concevoir une double distribution d'eau, l'une simplement adoucie pour les besoins généraux, l'autre déminéralisée pour les besoins en eau potable et pour assurer l'alimentation d'appareils délicats. Dans un tel cas on peut parfaitement concevoir que l'eau brute envoyée vers l'appareil d'électrodialyse soit puisée dans le réseau d'eau adoucie.

Enfin on peut se demander si l'effluent concentré provenant d'un appareil d'électrodialyse alimenté en eau adoucie peut servir de liquide de régénération pour des résines échangeuses d'ions assurant l'adoucissement préalable des eaux envoyées vers l'appareil d'électrodialyse.

Le calcul et les essais effectués montrent que cela est en effet possible. Avec notre appareil expérimental fonctionnant à Touggourt, il a été démontré que l'utilisation des eaux concentrées comme liquide de régénération conduisait à une économie de 50 à 70% sur la quantité de sel marin NaCl qu'il aurait été nécessaire d'employer pour adoucir les eaux.

Voici à titre d'exemple les conditions expérimentales d'un essai :

eau brute : dureté 230° hydrotimétriques français

eau adoucie : dureté 40° " " "

rapport eau concentrée/eau déminéralisée dans l'appareil d'électrodialyse : 1/7

consommation de sel d'appoint par m³ d'eau adoucie 3,2 kg

consommation de sel qu'il faudrait utiliser dans un adoucissement sans emploi de l'effluent concentré : 13 kg

économie réalisée sur la consommation de sel : 75%.

Le procédé est donc intéressant et viable.

La difficulté qui se pose est celle des dépôts de sulfate de calcium dans la résine échangeuse d'ion au moment de la régénération.

L'effluent du liquide de régénération est fortement chargé en ions Ca et Mg qui précipitent au contact des ions SO₄.

Des modes opératoires particuliers sont possibles pour éviter cet inconvénient.

D. 4. 2. Augmentation du débit d'eau concentrée

Une manière simple d'éviter ou de ralentir les précipitations dues à la sursaturation consiste à augmenter sensiblement le débit d'eau concentrée de façon à maintenir le taux de gypse au voisinage et au-dessous de la saturation.

Ce mode opératoire a été très volontiers accepté par les usagers alors que nous pensions au départ qu'ils rechercheraient systématiquement la plus grande économie d'eau.

Ce moyen, quand il est applicable, est certainement le plus économique puisqu'il ne se traduit que par un envoi d'eau à l'égoût. Cette eau peut d'ailleurs être utilisée pour des besoins d'irrigation, soit directement soit par renvoi dans un réseau d'irrigation où elle se dilue.

D. 4. 3. Acidification de l'eau concentrée

Le maintien du pH de l'eau concentrée au-dessous du pH de dissolution des carbonates et de précipitation de la magnésie supprime ou ralentit la formation d'incrustations.

Le procédé est très efficace. Son efficacité est d'autant meilleure que l'abaissement du pH est plus marqué.

Son inconvénient majeur réside dans la dépense d'acide qu'il implique, dans la sujétion d'approvisionnement en quantités appréciables d'un liquide dangereux.

Enfin si l'abaissement du pH des eaux à concentrer est très marqué, il se produit un transfert d'ions H des compartiments de concentration dans les compartiments de déminéralisation (en raison en particulier du défaut de sélectivité des membranes qui ne sont pas sélectives à 100%).

Le passage de ces ions H dans l'eau déminéralisée produit une destruction des ions bicarbonates dont la diminution de taux ne doit pas alors être attribuée au processus de déminéralisation. L'effet tampon des ions bicarbonates disparaissant, cette introduction d'ions H, même en quantités faibles, conduit à un abaissement non négligeable du pH de l'eau déminéralisée, ce qui provoque une réaction de la part de l'utilisateur.

L'acidification des eaux à concentrer connaît donc des limites d'emploi.

D. 4. 4. Inversion de la polarisation

Ce procédé signalé par les chercheurs du SACSIR a été expérimenté en Afrique du Nord.

Son effet sur le tartre carbonaté ou magnésien est peu sensible ou tout au moins suffisamment lent pour qu'il ne puisse pas être considéré comme un moyen de lutte à utiliser seul.

Son effet sur le tartre gypseux est par contre beaucoup plus net. L'inversion de polarité est un fort bon procédé de remise en état sans démontage de membranes incrustées de dépôts sulfatés. Comme ces dépôts ne se produisent jamais isolément on peut dire que l'inversion de polarité est un procédé certainement utile mais dont le champ d'application est limitée. Il n'est pas apparu en Afrique du Nord que l'inversion de polarité pouvait à elle seule fournir l'arme d'efficacité totale dans la lutte contre les incrustations.

D. 4. 5. Procédé de désincrustation combiné

1) Les incrustations se produisant essentiellement dans les compartiments de concentration, un des moyens étudiés en Afrique du Nord par la SODEMI consiste à augmenter sensiblement l'acidification des eaux à concentrer à la fin d'une période de fonctionnement donnée de façon à désagréger en partie le tartre carbonaté et magnésien qui a pu commencer à se former, puis à intervertir par un jeu de vannes convenablement disposées (qui peuvent être remplacées par une vanne à voies multiples), les circuits de déminéralisation et de concentration. Après cette interversion, l'appareil décharge à l'égout pendant un temps limité, le débit de l'eau déminéralisée (sortant du circuit qui avant interversion était le

circuit de concentration). Puis en laissant les choses en état, l'appareil est maintenu en fonctionnement normal jusqu'à la fin d'une nouvelle période, l'effluent déminéralisé étant envoyé vers le réservoir de stockage.

Dans cette méthode, en dehors de la courte période d'envoi à l'égoût de l'effluent déminéralisé, le détartrage s'accomplit automatiquement en fonctionnement normal, les compartiments de concentration se désincrustent pendant qu'ils servent de compartiments de déminéralisation.

Cette méthode donne d'excellents résultats à condition que le rythme des périodes soit judicieusement adapté aux conditions locales (composition ionique, densité de courant, vitesse de passage, etc.).

Son inconvénient réside dans le fait que si les incrustations pour une raison quelconque ont atteint une importance sensible, le courant d'eau ne balaye plus les compartiments intéressés et la désincrustation ne se produit pas. Cette méthode est une méthode de prévention s'appliquant à une incrustation naissante.

2) C'est pourquoi on a mis récemment au point à la SODEMI, une méthode très efficace qui détruit simultanément les deux sortes de dépôts. Les détails de cette nouvelle méthode ne peuvent être divulgués pour l'instant. On peut dire cependant que le traitement de désincrustation est appliqué périodiquement avec une fréquence déterminée par l'expérience, l'appareil étant mis provisoirement hors service, exactement comme on met un filtre encrassé hors de service pendant un court laps de temps, pour le laver et le remettre en état.

Cette nouvelle méthode a de plus l'avantage de permettre de réduire sensiblement la consommation d'acide à injecter dans les eaux à concentrer. Avec certaines eaux, on a pu même complètement supprimer l'injection d'acide en cours du fonctionnement normal tout en maintenant dans un parfait état de propreté les membranes en service.

La méthode a été longuement expérimentée et elle est maintenant adoptée pour les appareils livrés aux usagers.

D. 5. Rinçage des électrodes

Dans les dispositifs classiques tels qu'ils sont connus à l'heure actuelle les électrodes sont rincées en circuit ouvert avec une injection permanente d'acide dans le liquide de rinçage cathodique.

La consommation d'acide est sensible et la perte d'eau non négligeable.

Une méthode particulière de rinçage en circuit fermé a été mise au point par la SODEMI. Ses détails ne peuvent pour l'instant être divulgués. Elle supprime pratiquement toute consommation d'eau, et réduit la consommation d'acide de 80% (la consommation d'acide pour le rinçage est de l'ordre de 20% de celle des procédés classiques).

La méthode, mise au point en 1958, a maintenant de très longs mois d'application continue sur les appareils en service et peut être considérée comme tout à fait satisfaisante.

D. 6. Equilibrage automatique des pressions

Le maintien de l'équilibre de pression entre les trois circuits : déminéralisation, concentration, rinçage des électrodes est fort important si l'on veut éviter des mises hors service prématurées des membranes.

En particulier lors de la mise en service ou lors de l'arrêt des pompes de recirculation ou d'alimentation, des ondes de pression ou de dépression relativement brutales peuvent parcourir les différents circuits hydrauliques.

Il a été mis au point un dispositif purement hydraulique de compensation automatique des pressions dérivé du principe des obturateurs à disques à commande asservie aux différences de pression régnant entre les circuits.

Une disposition judicieuse des appareils et des asservissements permet de décharger les circuits en excès de pression et ceci sans inertie et d'une façon automatique.

Les coups de bélier se trouvent ainsi amortis et l'effet d'une augmentation de pression due à un entartrage par exemple compensé.

Un appareil automatique de 450 m³/jour a été équipé de ces régulateurs.

E. CONCLUSION

L'électrodialyse présente un très gros intérêt en Afrique du Nord, aussi bien dans les régions côtières que sahariennes. Elle constitue l'instrument parfaitement adapté aux problèmes posés par la mobilisation de ressources d'eau saumâtres dont la salure est relativement peu élevée.

Des appareils industriels de différents types sont construits en Afrique du Nord même (à Alger), aussi bien pour répondre à des besoins de chantiers qu'à des besoins de petits groupes humains.

Pour montrer l'importance des services que ces appareils peuvent rendre, on peut citer l'exemple d'un chantier de forage perdu dans les sables dunaires, d'un accès extrêmement difficile et dont la totalité de l'approvisionnement en eau a été assuré sans défaillance, depuis cinq mois par un appareil d'électrodialyse traitant l'eau d'une nappe saumâtre locale. La société exploitant le forage considère avoir en ce court laps de temps complètement amorti le prix d'achat et les frais d'exploitation par l'économie faite sur les frais d'acheminement d'eau en camion citerne par une piste de sable de 150 km.

Mais si cet exemple frappant constitue un motif d'encouragement en ce qui concerne l'efficacité de l'électrodialyse et la sûreté de marche des appareils, l'intérêt qui est porté à l'électrodialyse en Afrique du Nord est plus large.

L'électrodialyse doit être l'instrument qui permettra la mise à disposition des populations et de l'économie de quantités accrues d'eau de qualité. Elle sera donc un facteur de développement important de ces régions semi-arides et arides qui occupent une vaste fraction des territoires nord-africains.

Enfin l'électrodialyse est un nouvel instrument de Génie Chimique mis à la disposition de l'homme. Elle trouve une application immédiate dans le domaine des eaux saumâtres. Il nous paraît évident que son domaine d'application s'étendra aux problèmes industriels de concentration et de séparation ionique et de purification des liquides aqueux minéraux et organiques.

THE RATE OF SULPHATE REMOVAL IN SODIUM CHLORIDE CONTAINING FEED WATERS USING A SIMPLIFIED TYPE OF ELECTRODIALYTIC WATER DEMINERALISATION APPARATUS

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ABSTRACT

The removal of sulphate in the presence of chloride, bicarbonate, calcium and magnesium ions has been investigated, synthetic saline waters made up from Pretoria mains water having been used in these tests.

The feed waters were not subjected to any pretreatment, such as liming or other pH adjustment.

It was found that within the flow velocity range of these tests, and with the apparatus and membranes used, there occurs a preferential removal of chloride ions over sulphate ions, the equivalent fraction of the sulphate ion in the desalted stream increasing from the outset of desalting, reaching a peak value with progressive desalting, and from then on decreasing rapidly to about its initial value below a total dissolved solids concentration of 25 m-eq. per litre. Variations in current density had no apparent effect on the rate of sulphate removal relative to that for the other ions. Variations in flow velocity did, however, appear to have a certain influence.

Calcium and magnesium ions are removed at substantially equal rates. Their rate of removal relative to total ions present increases with decreasing concentration of the dialysate.

THE TWO-POINT-FOUR MILLION GALLON PER DAY DESALTING PLANT AT THE FREE STATE GEDULD MINE, ORANGE FREE STATE

W. H. MOYERS

SUMMARY

The paper gives the reasons why various mining companies decided to investigate the possibilities of desalting, by electro dialysis, the saline water pumped from underground by the Orange Free State gold mines and describes briefly the original laboratory and pilot plant experiments. These experiments were followed by the design and construction of the plant at the Free State Geduld Mine which is described in detail. The paper then deals with the difficulties experienced during the commissioning of the plant in bringing the production rate up to the present rate which is about two-thirds of the design rate, and describes various modifications that have had to be made to the plant.

Finally the reliability of the plant and the possibility of increasing production still further is discussed.

THE SALINE WATER PROBLEM OF THE ORANGE FREE STATE GOLDFIELDS

When shaft sinking commenced in the Orange Free State Goldfields unexpected large quantities of saline water were encountered. Apart from the additional hazard this caused to mining operations, the Mining Companies were faced with a disposal problem. The water contained up to 4,000 ppm of dissolved solids, of which over 90% is sodium chloride, and cannot be discharged on to adjoining farm lands. The most obvious method of disposal was by solar evaporation in dams and natural pans as the average rate of evaporation in the goldfields is about 4,000 gallons per acre per day. By 1952, however, the rate of pumping from underground was increasing so rapidly that other solutions were sought and the most promising appeared to be desalting of the water by electro dialysis which was then still in the laboratory stage.

EARLY EXPERIMENTS

In July 1953 discussions between the Anglo American Corporation of South Africa Limited and the South African Council for Scientific and Industrial Research resulted in the drawing up of a research programme and work commenced on the construction of a small electro dialysis press. Other mining houses became interested in the project and in April 1954 a formal contract was entered into between the CSIR on the one hand and the Anglo American Corporation on the other on behalf of themselves and Anglo Transvaal Consolidated Investment Company Limited, Rand Mines Limited, Johannesburg Consolidated Investment Company Limited, and Union Corporation Limited. Later New Consolidated Gold Fields Limited also joined the project.

The small press operated in the CSIR Laboratories from early 1954 till June 1955. At the same time development of parchment base membranes was carried out.

Table I.—Basic details of 24,000 gpd Pilot Plant

Pretreatment Plant

- (i) Lime dosing stage for primary pH adjustment to eliminate heavy metals
- (ii) 3,000 gallon conditioning and flocculation tank
- (iii) 1,800 gallon per hr. rapid gravity sand filter
- (iv) Acidification and chlorination stage
- (v) 10,000 gallon filtered pretreated raw water storage tank

Electrodialysis Units

Number of stages (of one unit each)	4
Number of packs per unit (in parallel)	4
Number of electrode pairs per unit of four packs	1
Number of membrane pairs per pack (i.e. fifty concentrating and fifty diluting compartments)	50
Total number of membranes	1,000
Overall area per membrane	276 sq. in.
Available active area per membrane	182 sq. in.
Electrode dimensions and area	(7½ × 15½ in.) 120 sq. in.
Percentage of membrane area active:	
Based on electrode area	44%
Based on available active area	66%
Electrodes: Anodes	(a) magnetite; (b) graphite
Cathodes	(a) nickel; (b) graphite
Membrane separation	Perforated corrugated P.V.C.
Gaskets	Klingerit steam jointing
Compartment thickness (membrane spacing) Stages 1, 2 and 3	¼ in. nominal
Stage 4	½ in. nominal
Diameter of dialysate conduit in pack	1 in.
Diameter of brine conduit in pack	½ in.

Designed and Actual Operating Conditions

	<i>Designed</i>	<i>Operational</i>		
		1/3/50	18/8/50	20/11/50
Feed inlet conc., ppm NaCl	3,800	3,738	3,706	3,770
Dialysate outlet conc., ppm NaCl	1,000	949	1,003	990
Brine outlet conc., ppm NaCl	14,000-16,000	10,520	14,200	14,300
Desalted water at 1,000 ppm NaCl—gph	800	683	815	754
Brine to waste at 14,000-16,000 ppm NaCl—gph	200	200	200	200
Brine to dialysate conc., ratio at inlet to stages	4 : 1	Approx. 4 : 1 to 3 : 1		
Electrode rinses:				
Anode gph—pH 6 to 7.5	44 gph/stage	33 gph/stage		
Cathode gph—pH 6 to 7.5	55 gph/stage	55 gph/stage		
Current density (at electrodes) mA/sq. cm.:				
Stage 1	12	12	11.5	11.0
Stage 2	10	10	10	11.25
Stage 3	10	10	10	9.8
Stage 4	8	6.25	7.5	8.75
Overall operating voltage at 25° C. new membranes:				
Stage 1	220	221	222	193
Stage 2	220	196	180	207
Stage 3	280	210	219	327
Stage 4	350	285	345	299
Coulomb efficiency (over life of membranes)	85-00%	92-00%		
Membrane life	6 months	Over nine months (over fifteen months achieved in some cases)		
Total kWh./1,000 gal. product:				
(Excluding pumping and rectification losses, etc.)		9.42	8.7	11.1
(Av. coulomb efficiency)		(77.9)	(75.8)	(70.1)

All quantities in Imperial gallons. Operating conditions taken at random. Variations reflect changes in cell design, membrane types, age, etc.

By August 1954 the experiments had confirmed the theoretical calculations and a preliminary estimate indicated that the mine water could be desalted on a large scale from 4,000 to 1,000 ppm at a cost of about 2s. 6d. per 1,000 gallons.

The mining houses then decided to proceed with the design and construction of a pilot plant. This was situated at the Western Holdings Mine in Welkom and was capable of treating 1,000 gallons per hour.

The basic data are given in the accompanying Table I. The first press was installed in September 1955 and the other three by the end of January 1956. The plant operated as an integral unit on a three shifts per day, seven days a week basis from February 1956 to May 1957.

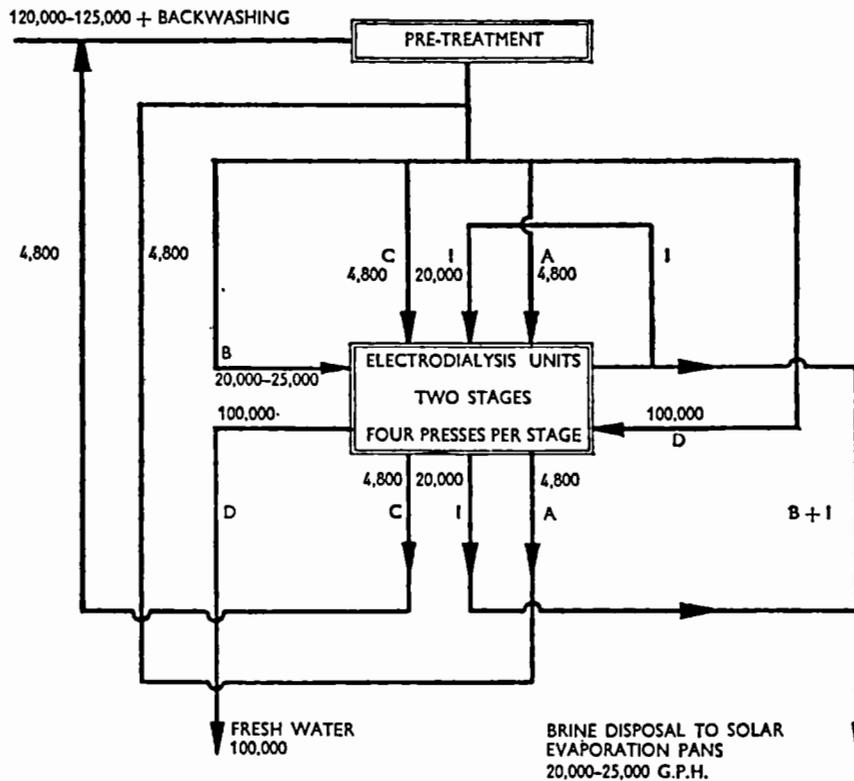
The pilot plant operated very successfully and estimates based on the results obtained by April 1956 indicated that a large-scale plant capable of producing 100,000 gallons per hour of desalted water was a practical proposition. Design was started therefore on a large-scale prototype press which would use membranes having an effective area of 1,060 sq. in. each. Construction started in January 1957 and was completed at the beginning of June 1957. Testing continued till the end of July 1957 using 200 compartments for hydraulic tests and fifty compartments for electrical tests, all of which proved satisfactory.

PRELIMINARY PLANNING OF FREE STATE GEDULD PLANT

Calculations for a plant to treat 3,000,000 gallons per day to give 2,400,000 gallons per day of desalted water and 600,000 gallons per day of concentrated brine were started in December 1956. It was decided to site the plant at the Free State Geduld Mine where the underground water was slightly less saline than at the other mines, and where water could also be drawn from Welkom Mine or Western Holdings Mine if necessary. A typical analysis of the water pumped from underground at Free State Geduld is given in the following Table II:

Table II.—Analysis of underground water from Free State Geduld Mine

	No. 1 shaft	No. 2 shaft
pH.	8.6	8.55
Conductivity (micromho)	5,000	4,600
Total solids, dried at 180° (ppm)	3,206	3,115
Dissolved solids, dried at 180° (ppm)	3,018	2,896
Suspended solids (ppm by difference)	188	219
Total alkalinity	44	54
Total hardness (ppm as CaCO ₃)	166	121
Calcium hardness	146	110
Magnesium hardness	20	11
Chlorides (ppm as Cl ⁻)	1,720	1,680
Chlorides (ppm as NaCl)	2,826	2,766
Sulphates (ppm as SO ₄ ²⁻)	71	38
Silica in filtered sample (ppm as SiO ₂)	27	28
Sodium (ppm as Na)	1,080	1,080
Potassium (ppm as K)	7	7
Iron in filtered sample (ppm as Fe)	0.1	0.2



D DIALYSATE
(DILUTING STREAM)

B BRINE
(CONCENTRATING STREAM)

Series Flow Through Stages

A ANODE RINSE
C CATHODE RINSE
I INTERMEDIATE PLATE RINSE

Parallel Flow Through Stages

QUANTITIES GIVEN IN IMPERIAL GALLONS PER HOUR.

D & B AND A & C ARE INTERCHANGEABLE IN PRESSES FOR REVERSED POLARITY.

FIG. 1.

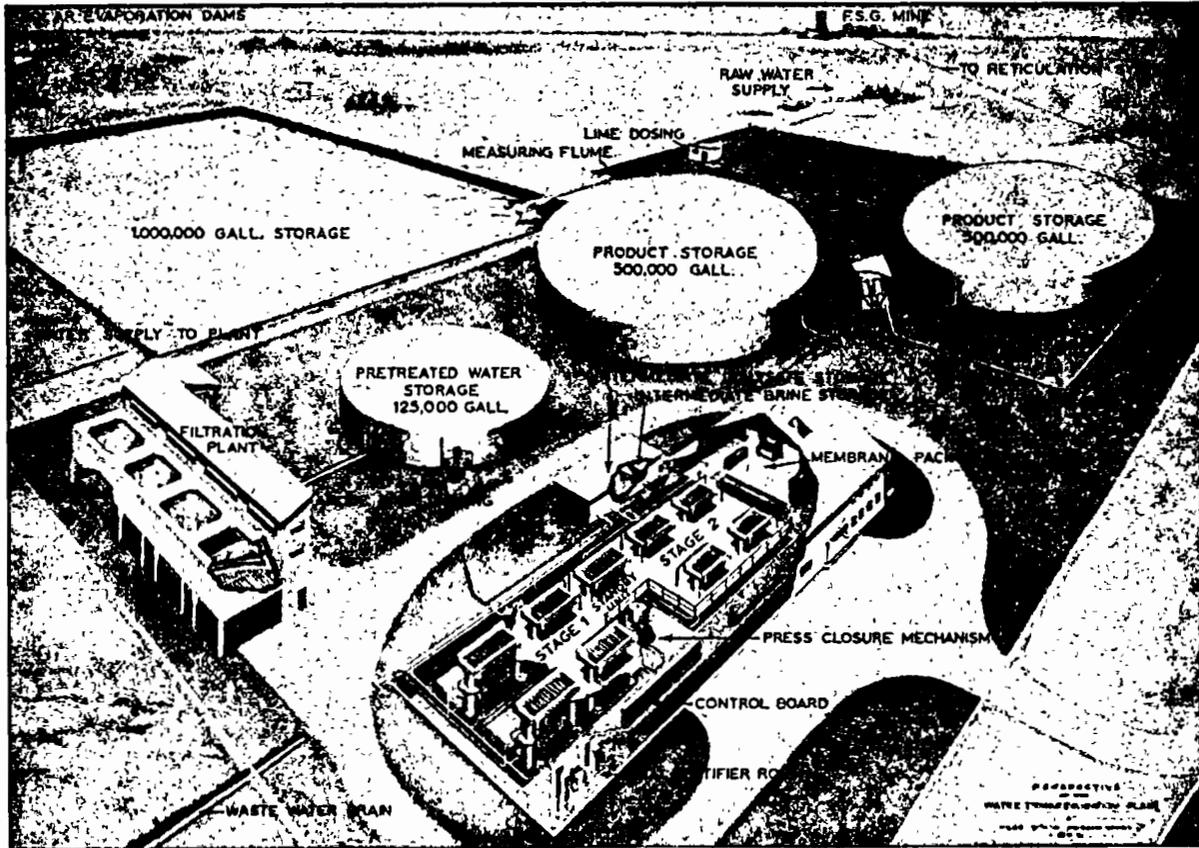


FIG. 2

As it was intended to use the purified water in the Welkom Uranium Plant as well as for general use on the Free State Geduld and Western Holdings Mines the water had to be desalted to not more than 500 ppm NaCl.

The most economical plant was shown to be a two-stage plant with four working presses in each stage. The basic data are given in the following Table III and the flow sheet in Fig. 1. The plant is financed by the eight mines in the Free State administered by the following mining houses :

- Anglo American Corporation of South Africa Limited ;
- New Consolidated Gold Fields Limited ;
- Rand Mines Limited ;
- Union Corporation Limited.

Table III.—Saline water conversion
Basic data for 100,000 gph Plant

Nominal desalting range.	. . . . .	3,000 to 500 ppm NaCl
Capacity . . . . .	. . . . .	100,000 gph desalted water
Brine . . . . .	. . . . .	20,000 gph (25,000 max.)
Number of stages . . . . .	. . . . .	2
Number of presses per stage . . . . .	. . . . .	4
Number of standby presses . . . . .	. . . . .	1 serving either stage
Number of packs per press . . . . .	. . . . .	10
Number of membranes per pack . . . . .	. . . . .	100 anionic, 100 cationic
Number of membranes per press . . . . .	. . . . .	1,000 anionic, 1,000 cationic
Size of membranes, overall . . . . .	. . . . .	7 ft. 0½ in. by 2 ft. 1½ in.
Total area of a membrane . . . . .	. . . . .	15.1 sq. ft.
Effective area of a membrane . . . . .	. . . . .	10.5 sq. ft.
Effective area—percentage . . . . .	. . . . .	69.6 %
Space between membranes . . . . .	. . . . .	½ in.
Materials :		
Membranes . . . . .	. . . . .	Parchment base
Gaskets . . . . .	. . . . .	½ in. Klingerit
Spacers . . . . .	. . . . .	Perforated corrugated P.V.C.
Electrode and intermediate plates . . . . .	. . . . .	Wood/" Perspex " / " Permalin "
Electrodes . . . . .	. . . . .	Graphite
Design Data *		
Current density Stage 1 . . . . .	. . . . .	15.8 mA/sq. cm.
Current density Stage 2 . . . . .	. . . . .	6.4 mA/sq. cm.
Maximum overall voltage per press :		
Stage 1 . . . . .	. . . . .	1,000
Stage 2 . . . . .	. . . . .	800
Maximum voltage to ground :		
Stage 1 . . . . .	. . . . .	500
Stage 2 . . . . .	. . . . .	400
Coulomb efficiency over effective membrane life of nine months . . . . .	. . . . .	87 to 60% ; (average estimated at 78%)

* Takes into account minimum winter water temperatures (15° C.) and old membranes with 60% coulomb efficiency.

General layout

Fig. 2 is an artist's impression of the general layout of the plant. Water pumped from underground flows to the plant in an open channel, past the chemical dosing plant into a 1,000,000 gallon storage and settling

dam. From here it is pumped to the filter plant which feeds into a 125,000 gallon reservoir by gravity. The water is then pumped through the electro-dialysis plant which discharges the purified water to two 500,000 gallon reservoirs from whence it is pumped to the user mines. Brine is discharged into an open drain leading to evaporation dams.

Pretreatment

The raw water flowing to the plant is metered in a venturi flume and has its pH measured on a recorder. Cathode rinse and lime are added at this point to raise the pH to 9.0 and also a flocculating agent. After settlement the water is pumped to a filtration plant consisting of four rapid gravity filters of a standard water-works design except that all pipes on the outlet side are bitumen-lined to prevent pick-up of iron. Great care is exercised in the operation of this plant to keep the suspended solids in the filtrate to below 0.1 ppm. On leaving the filters the water is chlorinated and flows to a 125,000 gallon storage tank. On leaving this tank anode rinse and sulphuric acid are added to reduce the pH to below 7.0.

Electrodialysis plant

The electro-dialysis plant, consisting of nine identical presses and the attendant pumps, transformers, rectifiers, control gear, pack assembly, laboratory and office, is housed in a single steel-framed building clad with asbestos. Wherever possible water pipes have been located in ducts in the floor which also act as drains, whereas cables and compressed air lines for the control gear are carried on the underside of the overhead walkways.

Dialysate circuit

From Fig. 3 it can be seen that there are two stages each consisting of four presses with a ninth press, press S, situated between the two stages and capable of being connected into either stage as a standby for when one of the other presses needs to be taken off stream.

Incoming water is pumped at the rate of 100,000 gph to the four presses of Stage 1 through a 10 in. main which feeds four separate 6 in. pipes, each leading to a press inlet manifold. Each of these 6 in. pipes is fitted with an orifice plate which actuates a Saunders valve by means of a differential flow controller so that flow is maintained constant. The outlet manifolds from the four presses are connected to a single 10 in. main leading to an intermediate sump. From the sump the dialysate is pumped by a similar arrangement of piping through the four Stage 2 presses and discharged into the treated water reservoirs.

Brine circuit

A further 20,000 gph of incoming water is pumped through a 6-in. diameter pipe which feeds four 3 in. pipes leading to the inlet manifolds of Stage 2 presses. Again the flow to each press is maintained constant by

means of an orifice plate, Saunders valve and flow controller. The four discharge manifolds are connected to a 6 in. pipe leading to an intermediate sump, from which the brine is pumped through the Stage 1 presses by a similar piping arrangement and discharged to waste.

Press manifolds

The press manifolds are illustrated in Fig. 3. The inlet manifolds are below the presses and each consists of two legs connected by valves to both the brine and dialysate pipes. The setting of the valves determines through which leg of the manifold dialysate will flow (the brine flowing through the other leg) and hence which compartments of the press are dialysate compartments. Each leg of the manifold is connected to the presses by means of rubber hoses so that both brine and dialysate are fed to both ends of each of the ten packs forming a press.

The outlet manifolds are situated above the presses and again consist of two legs, each of which is connected by rubber hosing to one end of each pack. By means of control valves, interlocked with the inlet manifold valves, the two legs discharge to the dialysate and brine discharge lines. Throttle valves are provided on the brine lines to regulate the pressure in the presses.

Anode and cathode rinse circuits

The anode and cathode rinse waters are drawn from the incoming water and pumped to all electrode compartments in parallel. Discharge is by gravity to the pretreatment plant with the circuits interconnected so that the two streams can be interchanged when polarity is reversed.

Intermediate brine

The final brine discharge pipe is tapped for the intermediate plate rinse water, which is pumped through all intermediate plates in parallel and then discharged to waste.

Electrical equipment

A separate transformer and set of six phase rectifiers is provided for each of the nine presses so that the voltage, and hence the current, to each press can be regulated to compensate for varying efficiencies of the membranes due to age. The connections to the presses are so arranged that positive current is fed to the end electrodes of a press and negative current to the central electrode, or vice versa, with the neutral point of the rectifiers connected to earth.

Presses

All nine presses are the same. The frames are made of reinforced concrete and each press consists of ten packs, one central electrode plate, and two end electrode plates, all suspended in a vertical position and sealed by the pressure of four jacks on end thrust plates.

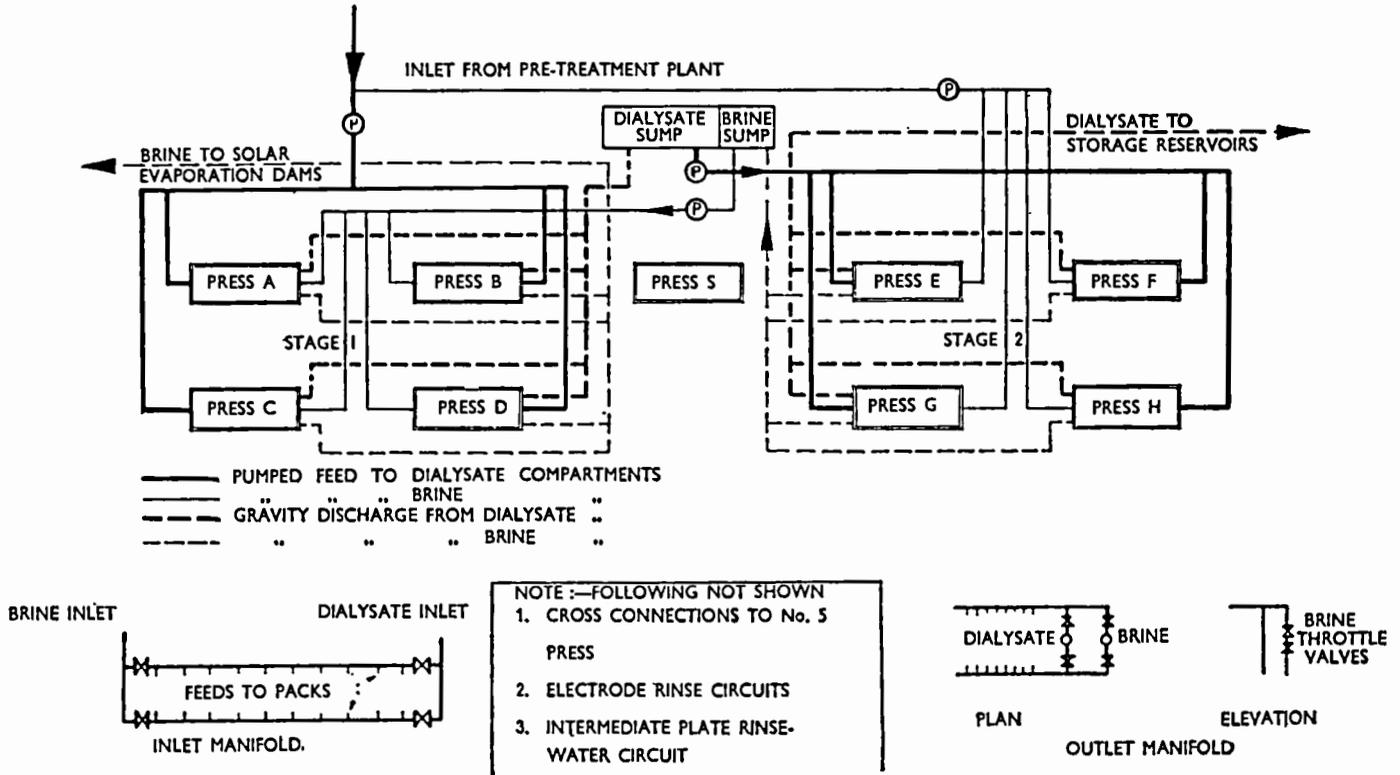


Fig. 3.

Each pack consists of two intermediate plates and contains 200 membranes so that there are 2,000 membranes in a press. The compartments between the membranes, through which the dialysate and brine flow, are formed by gaskets $\frac{3}{8}$ in. thick which have their centres cut out to form spaces $22\frac{3}{4}$ in. \times 66 in., which are filled with perforated, corrugated spacers. These spacers serve the dual purpose of supporting the membranes and imparting turbulence to the water flowing through the compartments.

The dialysate is fed into the bottom of one side of an intermediate plate and flows along a channel in the plate which is connected by ports to conduits formed in the length of the pack by concentric holes cut in the gaskets and membranes. Feed to alternate compartments is achieved by slots cut in the gaskets leading from the conduits to the central space. Discharge is by a similar system of slots, conduits and channels to the discharge point at the top of one side of the plate. A similar arrangement feeds the brine through the intermediate compartments. A third feed allows the flow of intermediate brine rinse through and over a grid system in the central portion of the intermediate plate to maintain electrical continuity through the intermediate plates.

The electrode plates each contain seven graphite electrodes which are rinsed by a constantly flowing stream of water fed to the plates by connections on the side.

Control room

All controls and gauges for pumps, valves and electrical gear are centralised in the control room, situated on the first floor of the building and overlooking the presses, so that the whole electro dialysis process can be controlled by one operator. Each press has its own panel with controls for switching it on and off stream and regulating the rate of flow of the brine and dialysate and the voltage. A master central panel has controls for switching the whole plant off and also a single pushbutton for reversing the polarity of all electrodes simultaneously and at the same time, by altering the valve settings, interchanging the flows of brine and dialysate through the packs and the discharges of the electrode rinses. This operation necessitates the shutting off of power for a few moments. Multipoint pH and conductivity recorders are used for checking the pH and salinity of the water at various points in the plant.

Pack assembly

A section of the building is set aside for the washing, cutting and storing of membranes and for their assembly in the packs.

MATERIALS OF CONSTRUCTION

Great difficulty was experienced in obtaining suitable materials for many of the components in the electro dialysis plant and many failures

have been experienced which have caused great delay in commissioning the plant. Table IV gives the materials used for the major items.

Table IV.—Materials used in the Electrodialysis Plant

<i>Item</i>	<i>Initial Installation</i>	<i>Present Installation</i>
Main feed pipe to plant	Rubber-lined steel	Unchanged
Pipe work in plant:		
(a) 8 in. dia. and over	Glass-fibre reinforced polyester	Unchanged
(b) 6 in. dia.	High density Polythene	Rubber-lined steel and Acronitrile butadiene
(c) 4 in. dia. and less	Acronitrile butadiene	Unchanged
(d) Pumps	Rubber-lined	Unchanged
(e) Valves	Rubber-lined	Unchanged
(f) Electrode plates	Beech wood impregnated with phenolformaldehyde* "Perspex" †	"Perspex"
(g) Intermediate plates	(i) Beech wood impregnated with phenolformaldehyde* (ii) "Perspex" †	(i) "Permal" * (ii) "Perspex" †
(h) Electrodes	Graphite	Unchanged
(i) Gaskets	$\frac{1}{2}$ in. Klingerit	Unchanged
(j) Spacers	P.V.C.	Unchanged
(k) Membranes	Parchment base (made under licence from CSIR by the Permutit Company)	Unchanged

* Sufficient for seven presses and spares.

† Sufficient for two presses only.

CONSTRUCTION

Construction of the entire plant other than the assembly of the presses was done by contractors. Work commenced in February 1958 and was completed in March 1959. The installations of the pipework and control gear proved to be slow work because of there being no previous similar plants and both designers and erectors had to feel their way. The only real difficulty experienced, however, was with the welding of the high density polythene piping.

Press assembly

Assembly of the first membrane pack commenced on 29 September 1958. No difficulty was experienced in handling the various components or in obtaining correct register of the holes in the membranes and gaskets to form good conduits for the brine and dialysate. The spacer material, however, was found to be too thick, with the result that the packs bulged in the middle, even when pressure was applied. When this difficulty was overcome, see later, pack assembly proceeded smoothly.

COMMISSIONING OF PLANT

The assembly of the first press in Stage 1 was completed for hydraulic tests to start on 20 November 1958. These tests proved satisfactory and a second press in Stage 2 was assembled during December. On 3 January

1959 power was switched on to these two presses, which operated as a unit. Testing and assembly of presses continued till the end of April 1959 by which time numerous defects in design and materials had been discovered, as could be expected in the first plant of this size. During May the plant was handed over to the mine management for operation with four presses in use. Since then many further defects have been encountered with the plant in continuous operation except for a test period in April-May 1960.

Major defects

The following are the major defects encountered in operating the plant :

1. Spacers

The thickness of the spacer material in an electro dialysis plant is critical in order that " flat " membrane packs may be obtained. Spacers thinner than the gaskets give " hollow " membrane packs, with the result that the membranes are not adequately supported and the flow distribution is upset. Thick spacers give " humped " packs which put undue strain on the grids of the intermediate plates and also lead to squashing of spacers in the end compartments which again upsets the flow distribution with resulting polarisation and burning of membranes. In specifying the spacers for the Free State Geduld plant undue allowance was made for compression of the spacers under pressure, tolerances of manufacture were too wide, and most of the spacers supplied were at or near the upper limit with the result that severely " humped " packs were obtained. This led to breakages of grids in the intermediate plates, squashing of end spacers and even damage to the electrodes and electrode plates.

The difficulty was overcome in part by squashing spacers under heat and pressure in an improvised press and also by scrapping large numbers and replacing them with ones manufactured to a revised and more stringent specification.

2. Intermediate plates

As originally designed these were fabricated from beech wood impregnated with phenolformaldehyde. The centre portion corresponding to the effective area of the membranes consisted of P.V.C. strips formed into an " egg-box " grid. Laboratory tests had shown that impregnated beech was a suitable material but great difficulty was experienced in obtaining suitable timber and eventually this had to be specially cured and imported from England. At first these plates appeared to be satisfactory, but in a very short time leaks developed, along the lines of the glued joints, both to the outside of the plates and between the channels for brine, dialysate and rinse waters. All attempts to seal the joints by pumping in glue under pressure proved unsuccessful. Due to the delay

in obtaining timber for plates, sufficient plates were ordered to be supplied in "Perspex" despite the extra cost. These proved to be completely watertight but mechanically weak and either broke if the pressure from the press jacks was not applied evenly or blew out sideways under pressure of the water. Cross members enclosing bolts were tried to overcome this difficulty with partial success. The "egg-box" grids were also not very satisfactory, as they proved too flexible and also tended to cut into the membranes of the end compartments.

An extensive search for other materials was instituted as the plates were failing so fast that the assembly of the presses could not be completed. Eventually three plates made from "Permalin" gave promise of satisfactory results. Deliveries of material were slow, due to other commitments by the manufacturers, and the fabricating firm had to develop the technique required to drill the long holes for the feed channels, with the result that it is not anticipated that plate troubles will be overcome before the end of August. The design of the plates has also been modified to eliminate the necessity for the egg-box grids by forming a grid in the "Permalin". Modified stronger "Perspex" plates were also ordered for two presses while awaiting deliveries of "Permalin", but these have again not proved strong enough.

The grids in the "Permalin" have proved to give insufficient support to the membranes with the result that tearing of the latter takes place in the end compartments. It is hoped to overcome this by facing the membrane side of the plate with perforated rigid P.V.C. sheets $\frac{1}{8}$ in. thick.

3. Electrode plates

These were originally also made of impregnated beech with two sets of Perspex. The same troubles were encountered as for the intermediate plates. Redesigned, stronger "Perspex" plates have proved successful, however, and are now used in all presses.

4. Hose connections to plates

These were made from P.V.C. and were held to the plates by brass studs. Tremendous leakage occurred until a suitable rubber gasket, that could be glued to the plates, was found. The brass studs corroded badly due to the external leakage and also internal leakage where the impregnation of the timber was inadequate. Eventually "Permalin" studs were substituted for the brass ones and leakage at connections has been virtually eliminated where "Permalin" and "Perspex" plates are in use.

5. Electrical connections

The design of the electrical connections to the electrodes called for graphite rods, connected to the electrodes by graphite nipples, to pass through the sides of the electrode plates and to be held in position by clamps

and sealing rings. These connections have proved too weak and the graphite rods are continually breaking. At present connections are made by soldering copper leads into the electrodes and leading them to the outside through polythene tubes screwed into the electrodes. These have also proved unsatisfactory and a new type of connection is being designed at present.

6. Piping

From the start trouble was experienced with the high density polythene piping because vibration from the pumps and the expansion and contraction of the long runs caused the welds to open up. Great efforts were made to improve welding techniques and to strengthen the joints but eventually all this type of piping has had to be replaced. Rubber-lined steel was used in the pump bay and, when it became available in larger sizes, acronitrile butadiene for the lines leading to the presses.

7. Membranes

These are manufactured by the Permutit Company under licence from the Council for Scientific and Industrial Research. Initially the suppliers had difficulty in the manufacture of the membranes on a commercial scale and the first consignments were not all up to specification. However, after visits by CSIR personnel to the works in England, later batches have all been up to specification and give a life of at least ten months in the plant.

8. Electrical Resistance

The electrical resistance of the presses has proved in practice to be much higher than was expected from the design calculations. This, combined with internal and external leakage, has kept the output of the plant down to about two-thirds of the design output. Tests have indicated that the resistance is due to polarisation. Initial experiments at the CSIR laboratory, using a press with a single pack the same size as the ones at Welkom but having only twenty-five compartments, indicated that, if the brine flow rate was increased to the same as that for the dialysate by recirculation of brine, then the resistance fell to that anticipated in the design. This was tried out at the plant by altering the feeds to one press but proved to be unsuccessful. Experiments are still in progress to discover a way of overcoming this problem.

OPERATION OF PLANT

As mentioned previously, the plant was handed over to the Free State Geduld Mine in May 1959 for operation as a production unit with four presses in use. Due to the various defects and the difficulties experienced in overcoming them, the build-up of output has been very slow and at

present is only about half the designed output. All desalted water so far produced has been sold to the Welkom Gold Mine Uranium plant. Table V gives the quantities sold per month and the number of presses in use.

Table V.—Sales of purified water and Presses in Use

Month	Water sold Millions of gallons	No. of presses	Remarks
1959 May	2·1	4	
June	5·0	4	
July	6·9	4	
August	14·7	4	
September	21·0	5	
October	22·6	6	Part of month only
November	23·5	6	
December	23·6	6	
1960 January	20·7	6	
February	26·5	6	
March	24·1	7	Plant closed five days due to power cuts
April	23·5	7	Production suspended after eighteen days for tests
May	17·6	8	On production for eighteen days only
June	31·1	8	

Pretreatment

It has been found most essential that great care be exercised in the operation of the pretreatment plant if scaling troubles are to be minimised in the dialysis plant. In the initial stages of operation the water was fed to the presses at a pH of 7 but this allowed a scale containing calcium carbonate to form on the membranes. Increased acid dosing to reduce the pH to 6·8 overcame this difficulty. At present the filtered water is delivered to the plant containing less than 0·05 ppm on the silica scale.

Electrodialysis plant

Normal routine operation of the plant is readily carried out by one operator who is able to keep a check on the performance of the plant by means of the numerous gauges and recorders in the control room. The polarity of the presses is reversed daily to prevent build-up of scales on the membranes. Despite this, and the extreme clarity of the water, however, a deposit of clay gradually accumulates in the compartments. A weekly system of "washing" has been introduced because the effect of the clay deposit is to increase the electrical resistance enormously. First the plant is flushed for 1–3 hours with very dilute H₂SO₄ (pH 2·8–3·0). This is followed by an air scour which consists of flushing with water for 1–2 hours and at the same time introducing air into the inlet manifolds.

Coulomb efficiencies of 60 to 85% are not as high as they should be due to polarising, tearing of membranes, interconduit and external leakage,

all of which have been mentioned before. A considerable amount of inter-compartmental leakage also takes place due to the membranes folding into the gasket feed slots. Steps are being taken to rectify this. It is not possible to say what proportion of dialysate passes into the brine and rinse streams and what proportion is lost in external leaks, but with six presses working, i.e. 75,000 gph passing through the plant, the difference between Stage 1 and Stage 2 has been as high as 17,000 gph. This is gradually being improved as the new improved plates and pipework and other modifications are introduced and it is confidently expected that when the polarising problem is overcome, possibly by the use of new or modified spacer material, the plant will operate nearer the original design capacity.

Table VI is extracted from the June 1960 monthly report on the plant and shows the running times and operating conditions of the eight presses in use that month.

Table VI
Schedule of running times for treatment month of June 1960

Date	A	B	C	D	E	F	G	H	S	
25.5.60 . . .		23	20	23	20	23	23	23	23	C press air washed. Trouble with S rectifier. Plant off production 1 hour
26		22	22	18	18	22	22	22	22	Air washed D and E—rest of the presses acid rinsed.
27		22	24	24	24	24	13	24	15	B off to replace electrode harness—G off line for repairs.
28		24	24	24	24	24	—	24	—	
29		24	24	24	24	24	—	24	—	
30		24	24	24	24	24	—	24	6	S on line—running four presses First Stage, three presses Second Stage.
31		24	24	24	24	24	—	24	24	
1.6.60		24	24	24	24	24	—	24	24	
2		24	24	24	24	24	—	24	24	
3		23	23	23	23	23	—	23	23	1 hour acid rinse.
4		22	22	22	22	22	—	22	22	2 hour acid rinse.
5		24	24	24	24	24	—	24	24	
6		24	20	24	24	24	—	24	24	C press air washed.
7		24	24	24	24	24	—	24	20	S press air washed.
8		24	24	24	24	24	—	24	24	
9		20	24	24	24	24	—	24	24	B press air washed.
10		20	24	24	24	24	—	24	24	
11		24	24	24	24	24	12	24	24	G press on line with canvas supports.
12		24	24	24	24	24	24	24	24	
13		24	24	24	24	24	22	24	22	G and S off—G changed cracked plate—S repaired studs.
14		24	24	24	24	24	24	24	24	
15		24	24	24	24	24	24	24	24	
16		24	21	21	24	16	24	21	24	C, D and F air washed. H off line to fit new trip relays.
17		24	24	24	22	24	22	21	22	E, S and H air washed. G press rams removed and manual jacks used.
18		24	8	24	25	10	23	24	24	C and F off line—canvas supports put in packs C press.
19		24	11	24	24	11	24	24	24	C and F off line—canvas supports put in packs C press.
20		24	24	24	24	24	24	24	24	
21		24	24	24	24	24	24	24	24	
22		24	24	24	24	24	24	20	16	A on line 4 hours heavy polarisation. S and H off to repair centre electrode plate "S".
23		24	24	24	24	24	24	12	12	S off line to replace centre electrode plate internal arcing. H to repair studs.
24		24	24	24	24	24	24	24	24	
Total		732	609	711	728	703	319	716	635	

Total possible : 744.

Table VI.—Continued

Free State Geduld Mines Limited.—Water Demineralisation Plant.—From 25 May to 24 June 1960

NaCl = ppm Sodium chloride
 TDS = Total dissolved solids ppm
 H = Hardness ppm CaCO₃

Turb. = Turbidity ppm (Patterson Turbidity Meter)
 N = Nalco feed ppm
 F/R = Forward or reverse and running time

Date	° C	F/R	N	Incoming water				Final dial				Final brine		Water sold in 1,000 gallons	
				Turb.	H	NaCl	TDS	H	NaCl	TDS	NaCl	TDS	Daily	To date	
25.5.60	19.1	R & F	1	0.70		2,591				778		5,065			
26	19.2	F & R	1	0.28		2,474				783		5,007			
27	20.0	R & F	1	0.23		2,621				763		5,419			
28	20.7	F & R	1	< 0.05		2,650				774		5,814			
29	21.5	R & F	1	—		2,661				753		5,895			
30	21.8	F & R	1	0.05		2,650				757		5,841			
31	20.1	R & F	1	0.29	141	2,580	2,806	38.8		757	892	5,248			
1.6.60	19.6	F & R	1	0.29		2,542				764		5,159			
2	19.8	R & F	1	0.40		2,666				755		5,154			
3	21.6	F & R	1	0.60		2,585				769		5,219			
4	22.4	R & F	1	0.40		2,569				764		5,273			
5	22.0	F & R	1	—		2,600				754		5,392			
6	21.2	R & F	1	0.27		2,640				767		5,294			
7	21.2	F & R	1	0.25		2,578				746		5,225			
8	20.2	R & F	1	0.43	140	2,513	2,818	37.7		755	872	5,139			
9	20.2	F & R	2	0.55		2,528				757		5,064			
10	19.6	R & F	2	0.43		2,561				768		5,068			
11	19.4	F & R	2	0.18		—				774		—			
12	20.1	R & F	2	—		2,551				797		5,209			
13	19.8	F & R	2	0.15		2,631				777		5,182			
14	18.1	R & F	2	0.08		2,578				759		5,220			
15	17.0	F & R	2	0.10		2,578				840	585 NaCl	5,021			
16	19.1	R & F	2	0.08	155	2,470	2,830	31.1		832	748	4,940			
17	19.4	F & R	2	0.23		2,492				801		5,477			
18	19.4	R & F	2	0.45		2,554				800		4,800			
19	19.8	F & R	2	—		2,567				806		5,424			
20	18.8	R & F	2	1.05		2,645				826		5,532			
21	18.7	F & R	2	0.60		2,572				819		5,187			
22	18.7	R & F	2	0.60		2,687				857		5,001			
23	19.4	F & R	2	0.34		2,575				825		5,389			
24	19.5	R	2	0.28	151	2,618	2,570 TDS 2,314 NaCl	34.0		832	964	5,214			
Mean	19.9			0.34		2,587				784		5,264			31,007.2

Plant meter out of order—
 water sold measured at
 Welkom uranium plant.

Table VI.—Continued

Free State Geduld Mines Limited.—Water Demineralisation Plant.—From 25 May to 24 June 1960
Treatment Month of June 1960

A = Volts B = Amps C = Dialysate efficiency D = Brine

Date	Press S				Press B				Press C				Press D				Press E				Press F				Press G				Press H			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
25.5.60	816	96			850	116			889	101			804	100			651	69			649	55			650	98			648	54		
26 . . .	808	95	66	15	850	116			884	110	76	30	826	117			650	68			648	55	81	22	649	98	68	35	645	55	70	29
27 . . .	700	94			852	116			888	119			834	131			651	72			654	68			650	98			623	52		
28 . . .	—	—			852	126			885	118			852	141			652	74			653	67							631	52		
29 . . .	—	—			806	125			814	123			844	147			640	70			653	63							611	50		
30 . . .	823	120			812	122			880	120			824	141			623	69			632	62							595	50		
31 . . .	818	114			832	115			884	107			836	129			644	65			650	52							601	50		
1.6.60	824	103			847	105			887	100			829	122			642	64			653	50							605	50		
2 . . .	820	105	64	23	849	113	64	55	885	99	65	51	846	123	71	51	620	62	63	35	653	52	76	48					608	49	74	45
3 . . .	828	106			852	117			887	100			849	131			631	69			651	55							620	53		
4 . . .	827	106			837	112			872	100			821	126			651	68			652	56							612	52		
5 . . .	820	101			852	108			888	99			888	129			643	69			659	59							613	52		
6 . . .	819	102			818	113			810	108			854	128			653	68			647	56							605	49		
7 . . .	827	113			806	107			815	113			857	122			646	66			652	52							626	51		
8 . . .	834	122			804	102			816	113			852	120			645	63			643	51							623	50		
9 . . .	831	117			801	104			817	107			850	117			641	64			635	51							634	49		
10 . . .	807	103			818	116			818	101			801	111			649	60	09	38	641	50	70	49					609	47	78	49
11 . . .	813	103			818	120			813	103			844	113			649	63			648	50			652	94			629	48		
12 . . .	805	100			800	123			810	107			848	118			635	63			659	51			605	97			626	49		
13 . . .	811	103			816	120			872	101			816	113			637	61			640	50			651	93			604	47		
14 . . .	815	104	57	32	814	116	66	49	891	100	65	57	832	110	65	48	646	59	67	41	642	49	78	57	650	91	73	40	601	44	77	48
15 . . .	830	98			813	112			891	101			842	106			646	60			647	48			651	92			611	44		
16 . . .	813	101			811	119			883	107			832	117			654	62			654	51			649	98			617	47		
17 . . .	815	103			799	124			880	114			832	132			646	64			649	62			650	104			625	52		
18 . . .	815	101			801	117			815	102			828	131			646	65			650	57			645	103			631	54		
19 . . .	799	100			831	119			875	99			848	136			634	71			650	66			656	101			604	53		
20 . . .	753	88			807	116			808	104			835	127			642	67			641	61			642	93			599	59		
21 . . .	699	69			800	106			873	101			854	122			637	67			649	62			654	89			608	53		
22 . . .	677	56	62	7	806	108	67	39	805	104	74	50	859	123	69	38	629	68	64	26	643	62	81	40	641	89	72	58	610	55	74	34
23 . . .	842	122			835	110			862	100			850	123			626	66			643	54			650	80			619	56		
24 . . .	838	118			820	105			854	95			851	119			586	61			652	52			651	82			629	53		

Table VI.—Continued
25 May to 24 June 1960.—Treatment Month of June 1960

Resistance Ohms per Electrode Pair at 25° C.

Power Consumption
kWh/1,000 gallons

Date	Resistance Ohms per Electrode Pair at 25° C.									Power Consumption kWh/1,000 gallons	
	A	B	C	D	E	F	G	H	S	Stage I	Stage II
25.5.60 . . .		12.9	15.1	14.2	16.6	20.8	11.7	21.2	15.0	5.6	2.5
26 . . .		12.9	14.2	12.5	16.9	20.8	12.3	20.7	15.0	5.6	2.7
27 . . .		13.2	13.4	11.5	16.3	20.2	12.3	21.6	15.1	5.0	1.4
28 . . .		12.4	13.7	11.0	16.1	20.9		23.2		5.1	1.9
29 . . .		12.0	13.5	10.7	17.0	22.9		23.7		5.0	1.8
30 . . .		12.5	13.7	10.9	16.9	22.8		23.3	12.8	5.4	1.0
31 . . .		13.0	14.0	11.7	17.9	22.5		21.7	12.9	5.6	1.6
1.6.60 . . .		14.4	15.8	12.1	17.9	23.3		21.6	14.3	6.3	1.6
2 . . .		13.5	16.0	12.3	17.9	22.5		22.2	14.0	5.6	1.6
3 . . .		13.6	16.2	12.1	17.0	22.1		21.8	14.6	6.4	1.9
4 . . .		14.2	16.5	12.3	18.1	22.1		22.3	14.8	6.0	1.8
5 . . .		14.8	16.9	12.9	17.5	21.0		22.2	15.3	6.1	1.8
6 . . .		13.4	15.5	12.3	17.7	21.4		22.8	14.8	5.7	1.8
7 . . .		13.9	14.6	13.0	18.1	23.2		22.7	13.4	5.9	1.7
8 . . .		14.3	14.3	12.8	18.5	22.6		22.5	12.4	6.2	1.7
9 . . .		13.0	15.2	13.1	18.1	22.5		23.4	12.8	6.2	1.9
10 . . .		12.3	15.8	13.8	19.3	22.9		23.1	13.3	6.4	1.6
11 . . .		12.1	15.4	13.3	18.3	23.0	12.3	23.3	14.0	5.6	2.6
12 . . .		11.8	15.0	13.0	18.2	23.3	12.4	23.1	13.7	5.6	2.4
13 . . .		12.2	15.5	13.0	18.7	22.9	12.5	23.0	14.1	5.1	2.3
14 . . .		12.1	15.4	13.0	18.9	22.6	12.3	23.5	13.5	6.0	2.3
15 . . .		12.3	15.0	13.5	18.3	22.8	12.0	23.5	14.4	5.5	2.4
16 . . .		12.0	14.6	12.5	18.6	22.6	11.7	23.1	14.2	5.9	2.6
17 . . .		11.5	13.7	11.2	17.9	18.6	11.1	21.3	14.1	5.5	1.9
18 . . .		12.2	15.6	11.2	17.7	20.2	11.1	20.7	14.3	5.2	2.5
19 . . .		12.5	15.8	11.2	16.0	17.6	11.6	18.3	13.5	6.8	3.3
20 . . .		12.2	14.6	11.5	16.8	18.4	12.1	19.4	15.0	5.4	2.7
21 . . .		13.2	15.1	12.2	16.6	18.3	12.8	20.7	17.7	5.3	2.5
22 . . .		13.0	14.4	12.2	16.2	18.1	12.6	19.4	21.1	4.8 + A	2.6
23 . . .		13.5	15.3	12.3	16.8	21.1	13.4	19.6	12.3	6.3	2.6
24 . . .		13.9	16.0	12.7	17.1	22.3	14.1	20.5	12.4	5.8	2.4
Mean . . .		13.0	15.0	12.3	17.5	21.5	12.2	21.8	14.3	5.7	2.4

Schedule of Availability for Treatment Month of June 1960

Date	Possible press hours	Actual press hours	
25.5.60 . . .	102	178	
26 . . .	102	168	
27 . . .	102	170	(1) Possible press hours = number of presses on line x hours of possible operation.
28 . . .	144	144	(2) Actual press hours = number of presses on line x hours of actual operation.
29 . . .	144	144	
30 . . .	150	150	(3) % Availability = actual press hours expressed as percentage of the possible press hours.
31 . . .	168	168	
1.6.60 . . .	168	168	
2 . . .	168	168	
3 . . .	168	161	% Availability = 97 of the total actual press hours.
4 . . .	168	154	
5 . . .	168	168	
6 . . .	168	164	
7 . . .	168	164	
8 . . .	168	168	8 Presses were on line for 58% of the time.
9 . . .	168	164	7 " " " " " 37% " " "
10 . . .	168	168	6 " " " " " 5% " " "
11 . . .	180	180	
12 . . .	192	192	
13 . . .	192	188	
14 . . .	192	192	
15 . . .	192	192	
16 . . .	192	175	
17 . . .	192	183	
18 . . .	162	160	
19 . . .	160	160	
20 . . .	192	192	
21 . . .	192	192	
22 . . .	192	180	
23 . . .	192	168	
24 . . .	192	192	
Total . . .	5,482	5,321	

LES PROBLEMES GENERAUX DE LA DEMINERALISATION DES EAUX PAR DISTILLATION — APERÇU RESUME DE LA QUESTION

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A. INTRODUCTION

Le dessalement par distillation comprend les procédés qui à partir de l'eau salée fournissent de l'eau pure au moyen de deux changements de phase successifs :

- 1) eau salée transformée en vapeur ;
- 2) vapeur transformée en eau pure.

La distillation doit comprendre les opérations ci-après :

- apport de calories ;
- transfert de ces calories à l'eau salée et évaporation ;
- transfert de la vapeur de l'évaporateur vers un condenseur ;
- condensation de la vapeur et extraction des calories de l'eau condensée ;
- évacuation des calories.

L'énergie consommée, les investissements nécessaires, les difficultés rencontrées dépendent étroitement du mode de réalisation pratique des opérations successives ci-dessus énumérées.

Un facteur important d'amélioration réside dans l'utilisation des calories évacuées comme calories apportées dans une nouvelle distillation. La possibilité de réutilisation comme la proportion des calories réutilisées dépendront également du mode de réalisation des opérations ci-dessus.

B. CONSIDERATIONS THEORIQUES

B. 1. Chaleur latente

A température constante lors du changement de phase liquide-vapeur ou vapeur-liquide, la pression reste constante, tandis que le volume du mélange vapeur + liquide augmente (vaporisation) ou diminue (condensation). L'isotherme, dans la représentation de Clapeyron, comprend trois parties dont un palier horizontal qui correspond au changement de phase.

Si on considère une isotherme à une température supérieure, on obtient, un palier plus élevé d'une longueur plus faible. Le volume spécifique de la vapeur saturante diminue quand la température augmente tandis que le volume spécifique du liquide augmente.

La longueur du palier est réduite à zéro, pour une certaine température dite **critique**, le point d'inflexion à tangente horizontale qui le remplace est dit le point **critique**.

Pour des températures supérieures on n'observe plus le phénomène de liquéfaction ; au-dessus de cette température il est possible de liquéfier le gaz quelle que soit la pression à laquelle on le soumet.

Le changement d'état liquide-vapeur exige la fourniture d'une certaine quantité de chaleur qui, lorsqu'il s'agit de l'unité de masse est appelée chaleur latente de vaporisation.

Le fait remarquable est que cette chaleur latente diminue lorsque la température augmente, et qu'elle est **nulle** au point critique. Dans le cas de l'eau cette chaleur latente a fait l'objet de nombreuses déterminations.

Si nous considérons maintenant, dans une transformation à pression constante, la quantité de chaleur fournie à un système pour le faire passer d'un état 1 à un état 2, nous pouvons démontrer qu'elle est égale à l'**enthalpie** :

$$H = U + p v \quad (U = \text{énergie interne})$$

L'enthalpie de l'eau est somme toute la quantité de calories à fournir à l'eau prise dans des conditions normales de température et de pression pour l'amener au point de vaporisation choisi. L'enthalpie de la vapeur saturante est celle de l'eau plus la chaleur latente. L'enthalpie a fait l'objet également de déterminations précises.

Dans le tableau ci-après figurent des valeurs de la chaleur latente et de l'enthalpie pour l'eau.

Chaleur latente et enthalpie

Température ° C	Pression kg/cm ²	Chaleur latente kg cal/kg	Enthalpie eau kg cal/kg	Enthalpie vapeur kg cal/kg
25	0,0323	583,2	25,02	608,2
50	0,1258	569,0	49,95	619,0
100	1,0332	539,9	100,04	638,9
150	4,854	504,6	150,9	655,5
200	15,857	463,5	203,5	667,0
300	87,61	335,1	321,0	656,1
350	168,63	271,8	364,2	636,0
375,15	225,65	0,0	501,5	501,5

B. 2. Elévation de la température d'ébullition en fonction de la concentration

La température d'ébullition des solutions salines est supérieure à celle de l'eau pure. Cette élévation de température d'ébullition provient de l'abaissement de la pression de vapeur d'équilibre au contact d'une solution salée.

L'élévation de la température d'ébullition est donnée par la formule de Clapeyron :

$$DT = \frac{RT^2}{L} \text{Log} \frac{p_0}{p}$$

L : chaleur latente à la température T (température absolue) ;

p : pression de vapeur saturante eau salée à T ;

p_0 : pression de vapeur saturante eau pure à T .

B. 3. Energie nécessaire

L'énergie nécessaire au changement de phase liquide-vapeur qui assure en fait le dessalement est au moins égale à l'enthalpie de la vapeur si aucune récupération de calories ne s'effectue même pour le préchauffage de l'eau soumise à évaporation.

Dans un tel cas, l'énergie nécessaire croît avec la température sauf lorsqu'on arrive au voisinage des conditions critiques.

Si les calories de condensation sont récupérées pour assurer le préchauffage de l'eau salée, le minimum d'énergie nécessaire est égal à la chaleur latente de vaporisation.

Dans de telles conditions l'énergie nécessaire décroît quand la température augmente et devient pratiquement nulle au voisinage du point critique (en faisant abstraction de l'énergie minimum de dessalement nécessaire et des pertes thermiques).

Nous constatons ainsi qu'au voisinage de 100° C l'énergie nécessaire pour la distillation de 1 m³ d'eau est de l'ordre de :

1.000 kWh/m³ sans aucune récupération

850 kWh/m³ avec préchauffage,

si on admet un rendement de l'ordre de 75% pour l'ensemble de l'installation (générateur thermique, échangeurs, etc.).

Ces valeurs extrêmement élevées sont celles des distillateurs élémentaires simple effet.

Il apparaît également qu'à moins de travailler dans les conditions très particulières et très difficiles du point critique les variations de la température de distillation ne sont pas susceptibles de provoquer un abaissement massif de la quantité d'énergie nécessaire.

Il faut donc essayer de recycler l'énergie de condensation de vapeur dans une nouvelle opération de distillation.

B. 4. Modes de récupération

B. 4. 1. Multiple effet

Considérons une distillation simple effet. Nous pouvons concevoir des conditions théoriques telles que l'eau salée et l'eau condensée résultante soient maintenues à des températures aussi voisines que cela est possible.

Cette différence minimum correspond à l'élévation de la température du point d'ébullition mentionnée en B. 2.

L'eau salée obtenue au départ à la température de T_1 fournira de l'eau condensée à la température :

$$T'_1 = T_1 - DT_1$$

L'eau condensée à la température T'_1 pourra, dans un échangeur de chaleur, évaporer à cette température de l'eau salée. La vapeur obtenue fournira à son tour de l'eau condensée à une température :

$$T''_1 = T'_1 - DT'_1$$

et ainsi de suite.

Dans un intervalle de température T_1 à T_2 on pourra ainsi insérer un certain nombre d'opérations de distillation en utilisant toujours la même quantité de chaleur introduite au niveau de température T_1 .

Ce nombre d'opérations théoriquement possibles peut être obtenu avec une approximation très suffisante par intégration de la relation citée en B. 2., en considérant DT , qui est petit, comme une différentielle vis-à-vis de T , et le deuxième membre comme constant.

Cette intégration nous conduit à la relation :

$$\frac{T_1 - T_2}{T_1 T_2} = n \frac{R}{L} \log \frac{p_0}{p}$$

A titre d'exemple avec de l'eau de mer et entre 100°C et 25°C on pourrait ainsi théoriquement effectuer 166 distillations successives sans introduction de calories.

Dans ce cas, l'énergie à fournir serait égale à la différence d'enthalpie de l'eau à 25°C et de la vapeur à 100°C soit :

$$614 \text{ kg cal/kg}$$

et ceci pour la production de 166 kg d'eau distillée à 25°C .

La consommation d'énergie serait alors de :

$$4,3 \text{ kWh/m}^3.$$

Il faut cependant remarquer que les étages successifs fonctionneront sous des pressions de plus en plus faibles (le dernier étage distillera sous $1/300^{\text{e}}$ d'atmosphère) et que les auxiliaires seront complexes et consommeront bien plus d'énergie que le processus lui-même.

Ce qu'il y a lieu de retenir c'est qu'il est théoriquement possible de réutiliser l'énergie de condensation en un nombre élevé de cycles successifs : que ce nombre de cycles est cependant limité, même en théorie.

B. 4. 2. Compression de vapeur

La vapeur fournie par l'eau salée à une température T se trouve à une pression p , inférieure à la pression saturante de vapeur de l'eau pure, la vapeur ne pourra donc se condenser sous forme d'eau pure qu'à une

température inférieure à T . L'eau salée ne peut servir de fluide de refroidissement pour la condensation de la vapeur produite.

Par contre, si nous élevons la pression de la vapeur dégagée par l'eau salée jusqu'à la valeur p_0 , pression de vapeur saturante en présence d'eau pure à la température T la vapeur produite par l'eau salée pourra se condenser dans un échangeur placé au sein de l'eau salée. Cette condensation fournira la quantité de chaleur nécessaire pour évaporer une nouvelle quantité de vapeur à partir de l'eau salée. Si nous supposons le tout réalisé dans des conditions thermodynamiques idéales et réversibles, le cycle se poursuivra indéfiniment sous réserve de fournir l'énergie nécessaire à la compression de la vapeur de p à p_0 .

Un calcul thermodynamique simple nous donne pour la quantité d'énergie nécessaire :

$$w = - RT \log \frac{p_0}{p}$$

Ce mode de distillation, lorsqu'il est effectué dans les conditions thermodynamiques idéales, permet de déterminer la valeur minimum d'énergie nécessaire pour obtenir le dessalement d'une eau donnée.

Pour l'eau de mer, prise à température ordinaire, le raisonnement conduit à la valeur :

$$0,80 \text{ kWh/m}^3.$$

Malgré les apparences différentes nous retrouvons dans la distillation par compression de vapeur les opérations indiquées en A.

L'apport de calories se fait sous forme d'énergie mécanique sur l'arbre du compresseur.

Le transfert à l'eau salée se fait par l'intermédiaire de la vapeur comprimée.

Le transfert de la vapeur vers le condenseur est obtenu par le mouvement créé par le compresseur.

La condensation et l'extraction des calories se font simultanément avec l'opération " transfert des calories à l'eau salée ".

L'évacuation des calories se fait sous forme de la détente indirecte que constitue la création du même poids de vapeur à la pression p à partir de la condensation de ce poids de la vapeur à la pression p_0 .

B. 5. Importance des coefficients de transmission de la chaleur

Il ne peut être question dans la pratique d'approcher les conditions de réversibilité de très près. Un des facteurs les plus importants dans la limitation des possibilités pratiques est constitué par la valeur des différents coefficients de transmission de la chaleur.

Des parois séparent les fluides (vapeur-liquide, liquide-liquide); sur les parois au contact de la vapeur se forment des films de liquides. D'autre

part la transmission de la chaleur entre liquide et vapeur dépend des conditions régnant aussi bien au sein des deux fluides qu'à l'interface.

Le flux de chaleur passant d'un fluide à l'autre est donné par la relation :

$$Q = k A DT.$$

k : coefficient de transmission global ;

A : surface de transfert des calories ;

DT : différence de température des deux fluides.

Si Q nous est imposé par la recherche d'un effet déterminé, par exemple évaporation ou condensation :

$$Q = LM \begin{cases} M \text{ masse à évaporer ou condenser} \\ L \text{ chaleur latente} \end{cases}$$

pour une valeur de k nous devons ou bien augmenter A jusqu'à une valeur compatible avec un DT très faible, ou bien augmenter DT pour l'adapter à une valeur raisonnable de A .

Dans le premier cas nous augmenterons sensiblement les investissements et par conséquent le prix de revient de l'eau produite par le jeu des amortissements financiers et des frais d'entretien.

Dans le deuxième cas nous nous écarterons davantage des conditions thermodynamiques, nous diminuerons le rendement de l'opération, le nombre d'étages possibles, les fuites thermiques s'accroîtront, etc. nous augmenterons par conséquent la quantité d'énergie consommée pour la distillation d'un volume d'eau donné.

Par contre, si nous arrivons à accroître les valeurs pratiques de k nous pourrions obtenir le même résultat avec des valeurs plus faibles de A et de DT , donc pour des investissements et une dépense d'énergie moindre.

De même dans le cas d'un compresseur de vapeur, ce dernier devra fournir de la vapeur comprimée non à la pression p_0 correspondant à la pression saturante de la vapeur à T , mais à une pression p'_0 correspondant à la pression saturante à $T + DT$. Le travail de compression en sera accru d'autant et la consommation d'énergie mécanique, compte tenu du rendement du compresseur, s'en ressentira sensiblement.

B. 6. Moyens permettant d'augmenter la valeur du coefficient de transmission de la chaleur

B. 6. 1. Lorsqu'il existe une paroi il faut évidemment rechercher des matériaux ayant la meilleure conductivité thermique.

B. 6. 2. Lorsqu'un fluide est directement au contact de la paroi il y a lieu de lui donner une vitesse élevée et le soumettre aux conditions hydrauliques de l'écoulement turbulent.

B. 6. 3. Lorsqu'un film liquide sépare la paroi de la vapeur, il y a intérêt à obtenir le film le plus mince possible, à le soumettre à un écoulement turbulent, à imprimer à la vapeur au contact du film une grande vitesse.

B. 6. 4. Il a été démontré que l'on a intérêt à supprimer la formation du film et à rechercher une condensation en gouttes.

B. 6. 5. Enfin, il faut éviter avec le plus grand soin la formation de pellicules à faible conductivité sur les parois (entartrage).

C. PROCÉDES PRATIQUES DE DISTILLATION

C. 1. Distillation simple effet

C'est l'alambic. Il peut être employé dans des circonstances particulières pour la production dans des conditions très rustiques de faibles quantités d'eau.

La consommation d'énergie déjà mentionnée plus haut est de l'ordre de :

750 à 1.000 kWh/m³ et plus.

La rusticité de l'appareil permet l'emploi de combustibles très divers :

- combustibles nobles : électricité, huile de parafine, alcool, etc. ;
- combustibles de circonstance ; racines de plantes désertiques, feuilles de palme séchées, bouses de zébu ou de chameaux séchées, etc.

Les distillateurs solaires du type " serre " sont des distillateurs simple effet. Ceci explique d'ailleurs leur faible production au m².

C. 2. Distillation à multiple effet

Le procédé est employé depuis longtemps aussi bien pour la production d'eau alimentaire de chaudière à haute pression que sur les navires de guerre.

Le nombre d'effets successifs utilisés dans la pratique va de trois à six, rarement plus.

Il a été démontré que dans des conditions moyennes pour le prix de l'énergie et des constructions d'appareils, le nombre d'étages conduisant à un prix minimum est de l'ordre de quinze. Le nombre d'étages qu'il serait rentable d'utiliser est d'autant plus élevé que la conception de l'évaporateur-condenseur conduit à un prix de construction plus faible.

La source de calories dans les distillateurs à effet multiple est constituée soit par de la vapeur, soit par des huiles lourdes.

Dans le premier cas on traduit l'efficacité du distillateur en poids d'eau distillée par kg de vapeur admise dans l'appareil, dans le deuxième cas on indique le poids fourni par kg de fuel oil consommé.

Dans les appareils en exploitation on obtient les valeurs ci-après :

	Poids d'eau obtenu	
	par kg de vapeur	par kg de fuel
Simple effet . . .	0,9	13 à 10 kg
Triple effet . . .	2,3	30 à 25 kg
Sextuple effet . . .	4,2	53 à 45 kg

Si on admet pour le fuel un pouvoir calorifique de 11.000 kg cal/kg, cela donne en équivalent énergétique :

- simple effet 980 à 1.280 kWh/m³ ;
- triple effet 425 à 510
- sextuple effet 240 à 280.

Le prix de revient du m³ distillé dépend essentiellement des conditions locales. Dans certaines régions le combustible, huiles de bunker sans valeur commerciale, n'a pas de prix ; dans d'autres cas les conditions d'installation sont particulièrement difficiles.

De toute façon le prix de revient reste élevé.

Dans les régions les moins favorisées où le fuel est plus cher, le prix de revient de l'eau distillée peut aisément dépasser 10 et même 20 NF au m³. Il s'agit bien entendu là de prix de revient " usine " qui ne peuvent être considérés comme des prix de " vente " aux consommateurs.

Les investissements nécessaires sont considérables.

Pour des distillateurs de moyenne puissance (100 à 200 m³/jour) ils sont de l'ordre de 4.000 NF par m³/jour pour les triple effet, et de l'ordre de 7.500 NF par m³/jour pour les sextuple effet.

La multiplication du nombre d'effets conduit à une surface énorme de parois où doivent se produire des échanges thermiques (évaporateurs-condenseurs, échangeurs de température, etc.). Le distillateur à multiple effet sera donc très étroitement tributaire des progrès effectués dans l'amélioration des échanges thermiques et dans la lutte contre les incrustations.

C. 3. Distillation à évaporation instantanée

La distillation à évaporation instantanée ne se différencie de la distillation classique que par la technologie de réalisation des appareils. Ces différences technologiques ont cependant une très grande importance pratique.

Dans ce type de distillateur la vapeur est produite par toute la masse de l'eau salée et non pas par la fraction au contact avec les surfaces d'échange assurant le transfert des calories de la source de chaleur vers l'eau.

L'eau est soumise au préalable à un préchauffage, sans évaporation, et se trouve ensuite introduite dans un ou une série d'évaporateurs où règne une pression inférieure à la pression de vapeur saturante en équilibre avec l'eau. Dans les étages successifs la pression est artificiellement portée à des valeurs de plus en plus faibles.

Les calories de condensation sont récupérées par un cheminement à contre courant de l'eau de réfrigération qui à la sortie de l'ultime condenseur reçoit les calories nécessaires d'un réchauffeur et sert d'eau alimentaire au distillateur.

Les principaux avantages des distillateurs à évaporation instantanée, sont les suivants :

- Ils se prêtent à la réalisation d'un très grand nombre d'étages successifs avec de très faibles différences de pression et de température entre les étages,
- Ils se prêtent à la réalisation d'ensembles compacts sans tuyauteries extérieures et d'un prix de revient sensiblement inférieur aux distillateurs multiple-effet classiques.

Les distillateurs à évaporation instantanée sont bien adaptés au fonctionnement, avec des étages multiples, dans un faible écart de température et avec une alimentation avec des eaux à des températures moyennes (inférieures à 100° C).

Il faut donc faire appel à ce type d'évaporateur lorsqu'on cherche à utiliser des chaleurs perdues : eaux de refroidissement de diesel, vapeurs perdues dans des fabrications diverses, eaux de refroidissement de réacteurs chimiques exothermiques, etc.

Un autre avantage des distillateurs à évaporation instantanée réside dans le fait que l'évaporation se faisant dans toute la masse de l'eau et non au contact de surface de chauffe, la tendance à l'entartrage est moins marquée. L'entartrage se produit, bien entendu, à l'extérieur des tuyauteries du réchauffeur, mais à température égale avec une intensité moindre que dans les évaporateurs classiques à tubes immergés puisqu'il n'y a pas d'évaporation dans le réchauffeur. L'entartrage se produit également à l'intérieur des tuyauteries de condensation. Mais l'entartrage **intérieur** se prête plus aisément aux opérations de détartrage que l'extérieur.

Enfin, les évaporateurs instantanés fonctionnant généralement à des températures inférieures à celles des évaporateurs multiple-effet conventionnels, la vitesse de formation du tartre est plus faible et surtout la nature du tartre est différente (carbonates) et moins isolante et moins difficile à enlever que le tartre complexe (carbonate, hydroxyde, sulfate) qui se forme normalement au-dessus de 120° C.

Du point de vue économique les évaporateurs instantanés sont moins onéreux en investissement sans pour cela être vraiment beaucoup moins chers que les distillateurs multiple-effet. Leur consommation en énergie au m³ produit est la même (à des nuances près) que celle des distillateurs conventionnels d'un nombre d'étages identique.

Les avantages principaux sont donc :

- l'encombrement plus faible,
- l'exploitation et l'entretien plus aisés,
- la possibilité d'utiliser des chaleurs perdues à des niveaux nettement plus dégradés.

C'est ce dernier avantage qui est le principal.

C. 4. Thermo-compression

Contrairement à la distillation à évaporation instantanée, la distillation à compression de vapeur fait appel à de l'énergie à un niveau plus élevé susceptible de fournir des effets mécaniques.

Dans les centrales électriques et sur les navires on a employé la vapeur haute ou moyenne pression pour produire l'effet de compression mécanique sur la vapeur extraite du bouilleur, l'appareil de compression utilisé étant un éjecteur. Cet ensemble constitue une réalisation avec un rendement médiocre du principe de la thermo-compression :

1 kg de vapeur produit 2,4 kg d'eau distillée,

ce qui donne une consommation réelle d'énergie de l'ordre de :

375 kWh/m³

c'est-à-dire celle qu'exigerait une distillation conventionnelle quadruple effet environ.

Les dimensions de l'appareillage sont très faibles, comparées à celles de l'évaporateur multiple-effet correspondant.

Son inconvénient principal est d'exiger de la vapeur à 12 kg/cm² ; il ne peut donc être considéré que comme un auxiliaire mis en place dans une usine où la vapeur à moyenne pression est couramment utilisée.

Une amélioration très sensible du rendement est obtenue en employant un compresseur mécanique de la vapeur. On obtient alors la forme actuelle des appareils de thermo-compression.

Suivant la taille de l'appareillage, la source d'énergie utilisée pour l'entraînement du compresseur, on obtient des rendements énergétiques sensiblement différents.

Avec de petits appareils domestiques faisant appel à l'électricité, et en supposant encore un fonctionnement continu, la consommation est de :

75 à 100 kWh/m³.

Pour des appareils fournissant quelques mètres cubes à l'heure on a intérêt à faire appel à des compresseurs entraînés par des diesels. Dans ce cas, et compte tenu des différents perfectionnements, la production d'eau traduite en rapport eau/fuel est de l'ordre de :

240 kg d'eau par kg de fuel

c'est-à-dire pour un équivalent énergétique de 11.000 kg cal/kg :

53 kWh/m³.

Si on se rapporte aux chiffres cités plus haut, concernant les distillateurs multiple-effet, on touche du doigt le considérable gain énergétique réalisé, même vis-à-vis de distillateurs avec un grand nombre d'effets.

Par ailleurs, le prix, l'encombrement, le poids des thermo-compresseurs, est à l'avantage de ces derniers, à capacité de production égale.

En ce qui concerne le matériel seulement et pour une capacité de l'ordre de 200 m³/jour, le thermo-compresseur coûte à peu près deux fois moins qu'un évaporateur instantané à cinq étages (prix du matériel départ usine).

Pour des capacités plus faibles, la différence est moins sensible mais reste toutefois à l'avantage de la thermo-compression.

L'appareillage est lui même encore plus compact que les évaporateurs instantanés, moins lourds et, ce qui est important, ne demande pratiquement pas d'eau de refroidissement, etc. L'installation d'un thermo-compresseur conduit à des sujétions bien moindres que celles liées à la mise en place des évaporateurs instantanés ou conventionnels.

Les hauts rendements du thermo-compresseur sont cependant liés au maintien de coefficients d'échanges thermiques élevés. La conduite de ces appareils demande du personnel d'une qualification plus élevée ; enfin, dans son ensemble, le matériel est moins rustique et les frais d'entretien sont plus élevés.

D'autre part, l'amortissement du matériel devra être assuré en un temps moindre que celui des évaporateurs.

Dans ces conditions, la charge financière due aux investissements ne sera pas très différente entre les deux systèmes et le choix sera gouverné surtout par des considérations d'adaptation aux conditions locales : nature et prix de l'énergie disponible.

C. 5. Machines thermiques à faible différence de température

Si on dispose de deux masses d'eau à température différente, on a la possibilité de faire fonctionner une machine à vapeur utilisant ces deux masses d'eau comme source chaude et source froide.

Il a été démontré par le calcul et par l'expérience qu'une machine pouvait être conçue et pouvait fonctionner même lorsque la différence de température entre les deux masses d'eau était faible, par exemple 3° C seulement.

Une telle machine (turbine à vapeur à très basse pression) peut entraîner un générateur d'énergie électrique d'une part et, d'autre part, fournir de l'eau distillée comme sous-produit, cette eau étant le résultat de la condensation de la vapeur détendue sortant de la turbine.

Cependant, pour être économiquement viable, une telle machine doit atteindre des dimensions gigantesques et sa conception reste encore du domaine des études et des projets.

Certains chercheurs ont proposé d'utiliser ce principe en se donnant comme tâche principale la production de l'eau, la production d'énergie se limitant alors à celle nécessaire aux auxiliaires (pompes, extracteurs d'air, etc.). Il est apparu que le problème sera résolu d'autant plus aisément que les différences de température seront plus élevées (tout en ne dépassant pas 15 à 20° C).

Le procédé semble être viable en principe. Il reste de nombreux problèmes technologiques à résoudre.

Le procédé sera, une fois mis au point, particulièrement bien adapté à la récupération des chaleurs perdues.

C. 6. Distillation au voisinage du point critique

La chaleur latente au voisinage du point critique étant nulle, il est possible de passer de l'état liquide à l'état gazeux au moyen de simples échangeurs de chaleur avec de très faibles écarts de température et théoriquement sans apport sensible d'énergie extérieure.

Von Platen a construit un appareil à très haute pression consistant essentiellement en un échangeur de température dans lequel l'eau est chauffée à une température légèrement supérieure à la température critique.

Le fluide ainsi réchauffé est conduit vers un séparateur où il se partage en deux fractions, l'une contenant le sel, l'autre entièrement purifiée.

La difficulté essentielle à laquelle se heurte la mise en pratique est celle de la nature des matériaux de construction. Aux températures employées, les chlorures se trouvent hydrolysés et l'acide chlorhydrique formé est extrêmement corrosif. Cet acide se retrouve par ailleurs dans l'eau déminéralisée en grande quantité.

Enfin l'ensemble du comportement des sels dissous dans l'eau est mal connu dans les conditions de température et de pression en cause et toute une série de difficultés échappent même à la prévision. En particulier, à côté des phénomènes de corrosion, se rencontrent des entartrages très rapides.

Les rendements énergétiques prévisibles sont cependant estimés à 500 ou même 1.000 kg d'eau produite par kg de fuel, soit encore :

26 à 13 kWh/m³.

D. IDEES NOUVELLES ET REALISATIONS RECENTES

D. 1. W. L. Badger et F. C. Standiford

Les idées de W. L. Badger correspondent à une tentative de pousser jusqu'à leur extrême logique les conceptions classiques.

W. L. Badger a d'abord sélectionné un type d'évaporateur à tubes verticaux dont le prix de revient de construction est le plus faible dans l'état actuel des choses. Ceci lui a permis d'envisager l'emploi d'un nombre élevé d'effets.

Il a d'autre part soumis à l'analyse les différentes combinaisons possibles des procédés classiques de distillation.

Il est arrivé à la conclusion que deux schémas correspondaient à la meilleure utilisation de l'énergie suivant que l'on pouvait ou non produire de l'énergie électrique commercialisable.

Dans le premier cas il propose la production d'énergie électrique et la

distillation dans un distillateur à douze effets, à partir de la vapeur détendue sortant de la turbine.

Dans le deuxième cas il propose de disposer, en tête du distillateur multiple-effet mentionné, un distillateur à thermo-compression dont le compresseur serait entraîné par la turbine fournissant la vapeur détendue. Dans ce cas le nombre d'effets serait réduit à dix.

Il considère que dans le premier cas la distillation de l'eau de mer conduirait à un prix de revient de :

$$0,35 \text{ NF/m}^3$$

si l'énergie électrique produite est vendue 0,026 NF/kWh.

L'eau distillée produite serait gratuite si le kWh est vendu 0,035 NF/m³.

Dans le deuxième cas il estime le prix de revient à :

$$0,44 \text{ NF/m}^3.$$

Ces estimations sont faites en supposant que le prix du fuel (° à 11.000 kg cal/kg) est de 0,065 NF/kg. Cette estimation porte sur une usine produisant :

$$63.000 \text{ m}^3/\text{jour}.$$

D. 2. K. C. D. Hickman

Les travaux de K. C. D. Hickman portent sur l'amélioration du coefficient d'échange de chaleur dans la thermo-compression, aussi bien pour la condensation que pour l'évaporation.

Son idée réside dans la recherche de films de condensation comme d'évaporation aussi minces que possibles et animés d'une certaine agitation. La réalisation de ces films est obtenue au moyen de la répartition de l'eau sur une surface tournante, l'épaisseur du film et sa vitesse de déplacement étant fonction du débit de l'eau et l'intensité de la force centrifuge elle-même liée à la forme et à la vitesse de rotation de la surface tournante.

Dès les premières réalisations on a pu constater une très sérieuse amélioration du pouvoir d'échange : au lieu de

2.500 kg cal/m²/d°C/h obtenus dans les compresseurs de vapeur classiques, M. Hickman obtient :

$$15.000 \text{ à } 20.000 \text{ kg cal/m}^2/\text{d}^\circ\text{C/h}.$$

Depuis quelques années, sous l'égide en particulier de l'Office of Saline Water des États-Unis, des essais systématiques ont été effectués avec un appareil disposant d'un rotor de 0,45 m environ, appareil susceptible de fournir 750 l/jour d'eau distillée à partir de l'eau de mer.

Les résultats sont extrêmement encourageants et on peut affirmer d'ores et déjà que le procédé Hickman constitue un progrès certain.

Les appareils de petits débits peuvent être considérés comme ayant atteint un stade commercialisable. Des études sont poursuivies pour la construction d'appareils de plus grande dimension.

Les petits appareils produisant 1 à 1,2 m³/jour avec des rotors d'un

diamètre réduit ne posent pas de problèmes technologiques difficiles ni pour leur construction, ni pour leur exploitation. D'une dimension semblable à celle d'un petit réfrigérateur leur prix ne devrait pas être très élevé. La consommation d'énergie est de l'ordre de 25 kWh/m³.

Les appareils plus importants sont plus difficiles à construire; le poids des pièces en rotation, leurs dimensions plus élevées (rotors de 2 m. de diamètre) la multiplication des étages en parallèle, conduisent à affronter des difficultés ignorées dans le cas des modèles plus petits.

Cependant l'inventeur pense pouvoir obtenir des conditions satisfaisantes d'exploitation et produire 100 m³/jour environ, au prix d'une dépense énergétique de l'ordre de

20 à 10 kWh/m³.

Une telle performance, que l'on peut raisonnablement espérer, montre bien tout l'intérêt pratique des idées de M. Hickman.

Une difficulté importante réside, comme dans tout procédé thermique, dans la formation d'incrustations sur les surfaces d'échange (ici sur le rotor). L'appareil se prêtant à un fonctionnement à température relativement basse (50 à 60° C) le tartre formé est relativement facile à enlever et sa vitesse de formation est plus réduite qu'à des températures plus élevées.

D. 3. Evaporateur à film mince de la General Electric

L'utilisation d'évaporateurs à film de liquide n'est pas nouvelle. En 1909 Kestner a introduit dans l'industrie l'évaporateur vertical à tubes qui pour un régime de température déterminé conduisait à la création spontanée d'un film du liquide à évaporer à la surface intérieure des tubes.

La méthode utilisée par Hickman n'est donc pas la seule utilisable.

La General Electric après une série d'études a proposé récemment un évaporateur vertical dans lequel l'eau est répartie mécaniquement à la surface intérieure d'un tube sous forme d'un film très mince. Les calories d'évaporation sont fournies par de la vapeur circulant à une grande vitesse à l'extérieur du tube.

Les coefficients d'échange thermique ainsi obtenus sont très élevés et le dispositif de répartition de l'eau sous forme de film procure en même temps un moyen permanent de nettoyage de la paroi qui balaye les germes cristallins formés et empêche toute apparition de tartre.

E. AMELIORATION DU COEFFICIENT DE TRANSMISSION DE CHALEUR

E. 1. Traitements Antitartre

E. 1. 1. L'élévation de température que subit l'eau dans tout procédé de distillation conduit à une décomposition des bicarbonates et à une hydrolyse des carbonates.

Dans un stade ultérieur il y a formation d'ions hydroxyles et élévation

du pH avec formation de tartre hydroxydé qui agit comme un ciment sur le tartre carbonaté préformé.

Enfin, si la température augmente ou si la concentration du liquide soumis à évaporation conduit à dépasser les taux de saturation des sulfates alcalino-terreux il se produit des tartres sulfatés durs.

E. 1. 2. Traitement acide

Un des moyens d'éviter la formation de carbonate et l'élévation du pH qui favorise la formation des hydroxydes, consiste à abaisser le pH de l'eau par une acidification directe ou par l'introduction de sels d'acides forts.

Les recherches effectuées par l'Amirauté Britannique entre autres, a montré que dans le cas de l'eau de mer le chlorure ferrique au taux de 80 g/m³ donnait d'excellents résultats, sous réserve d'un ajustement correct et d'un maintien précis de ce taux de traitement.

E. 1. 3. Stabilisation par contact et précipitation préalable

Si on offre aux cristaux disposés à se déposer une surface de dépôt auxiliaire considérablement plus grande que les surfaces des parois au travers desquelles doit s'effectuer le transfert de la chaleur, le tartre se déposera de préférence sur ces surfaces auxiliaires et préservera les parois.

La méthode peut comprendre un circuit extérieur : l'eau dont on cherche à éviter l'effet entartrant étant obligée à transiter par percolation au travers d'un lit en expansion de petits germes cristallins. Elle peut comprendre aussi le maintien en permanence dans l'eau, au sein même des évaporateurs, d'une suspension fine jouant le rôle de surface de dépôt auxiliaire.

La surface de dépôt auxiliaire peut être obtenue avec des matériaux divers : sables calcaires mélangés de magnésie, grains de silice très fins.

W. L. Badger et F. C. Standiford qui sont pleinement conscients de l'importance que présente pour leur projet de distillateur à multiple étages la possibilité d'éviter la formation d'incrustations, préconisent l'ensemencement du liquide soumis à l'évaporation avec de fins granulés de tartre lui-même. Ce système doit comporter, à l'extérieur du circuit de distillation, un dispositif de séparation permettant d'éliminer en continu les particules ayant dépassé une certaine dimension. Le procédé exige également une circulation à une vitesse suffisamment grande au sein des évaporateurs pour que les cristaux soient maintenus en suspension.

E. 1. 4. Modification de la structure du tartre — Emploi de produits complexants

Si la structure physique du tartre est convenablement modifiée on peut obtenir une diminution de son pouvoir d'adhésion suffisante pour que les cristaux formés soient entraînés par l'eau en circulation rapide.

D. Neville-Jones a signalé des travaux effectués au Royaume-Uni portant sur l'emploi, dans ce but, du sel de sodium de l'acide di-naphtyl butane di-sulfonique.

Afin d'éliminer des corps, tels que le cuivre, dont la présence favorise, même à l'état de traces, le début de formation de tartre adhérent on a cherché à employer des produits complexants tels que les sels (bien connus en d'autres domaines) de l'acide éthylène diamine tétraacétique.

Le Service de Recherches de l'Amirauté Britannique a mis au point un mélange antitartre combinant les effets ci-dessus énumérés.

E. 2. Circulation forcée de la saumure et temps de retention

E. 2. 1. Aux effets physico-chimiques énumérés aux différents alinéas du paragraphe **E. 1.** on peut ajouter des effets obtenus en agissant sur les conditions hydrauliques.

E. 2. 2. Différents chercheurs ont signalé l'intérêt que présente une sensible diminution du temps de séjour du liquide évaporé dans les évaporateurs.

La diminution de ce temps de séjour se répercute d'une part sur la **vitesse** de formation du tartre, et d'autre part sur la **structure** du tartre.

Cependant tous les chercheurs ne sont pas unanimes sur l'efficacité réelle de la méthode.

E. 2. 3. Une grande vitesse de passage de la saumure au contact de la paroi d'échange de chaleur augmente sensiblement le coefficient. Les recherches faites en différents pays et à différentes époques sont assez concordantes sur ce point. Cette grande vitesse de passage modifie de plus, dans un sens favorable, les conditions de formation du tartre.

Il est maintenant démontré que l'énergie de pompage dépensée pour assurer cette recirculation accélérée est largement compensée par les effets bénéfiques qui en résultent, et que la circulation forcée de la saumure doit faire de l'équipement normal d'un évaporateur.

E. 3. Condensation

La condensation en film conduit à des coefficients de transmission de chaleur qui ont fait l'objet depuis longtemps à la fois d'études théoriques et d'investigations expérimentales.

On a déterminé également un certain nombre de facteurs susceptibles d'améliorer ces coefficients.

Mais il a été constaté que dans le cas où la condensation de la vapeur se fait non sous forme de film continu mais sous forme de gouttes le coefficient augmente considérablement.

C'est pourquoi de nombreux chercheurs se sont appliqués à déterminer à la fois les conditions de formation de la condensation en gouttes, et la valeur numérique des progrès réalisés.

Il est intéressant de noter que l'utilisation de produits formant des

films et employés pour éviter la corrosion des condenseurs (films d'amines-grosses molécules) conduit à une condensation en gouttes.

Il est maintenant bien connu que la condensation en gouttes est le résultat de présence d'impuretés sur la paroi de condensation ou à la présence de films non mouillables.

La recherche de la condensation en gouttes s'est ainsi transformée en recherche sur les traitements de surface à appliquer aux parois.

Des produits comme : les silicones, des acides gras, des composés organiques divers, ont été essayés avec succès.

Ces produits doivent répondre à plusieurs exigences simultanées : ils doivent posséder des propriétés hydrophobe, avoir une affinité d'adhésion envers le métal constituant la paroi de condensation et avoir une durée de vie assez longue.

De plus, ces produits, et c'est là un point extrêmement important dans le cas particulier de la fabrication d'eau potable par distillation, ne doivent pas être toxiques ou plus simplement suspects du point de vue médical.

Des recherches ont porté également sur des modifications de forme de la surface (cannelures).

F. CONCLUSION

La préparation d'eau déminéralisée par distillation relève d'une technique éprouvée disposant de moyens industriels dont les possibilités, et les difficultés d'emploi, sont bien connues.

Le degré de perfection atteint par les appareils actuels est considérable. Cependant aussi bien les investissements élevés que la consommation énergétique spécifique limitent les applications à des cas particuliers de dessalement d'eaux fort minéralisées (eau de mer par exemple).

Un travail important de recherche dans des directions diverses permet de croire que des progrès substantiels pourront être obtenus dans un avenir assez proche. Cependant il paraît assez clairement que :

- ces progrès sont liés très étroitement aux progrès faits dans les méthodes de transmission de chaleur entre fluides,
- que l'amélioration espérée, tout en étant substantielle, se limitera vraisemblablement à une diminution du prix de revient jusqu'au $\frac{1}{3}$ ou au $\frac{1}{4}$ des prix actuels,
- que dans un avenir à moyen terme les techniques de distillation ne pourront être appliquées que pour la production d'eau potable (ou industrielle bien entendu) à partir d'eaux moyennement et fortement salées, c'est-à-dire au-dessus de 10 à 15 g/litre.

DISTILLATION SOLAIRE — RECHERCHES ET TRAVAUX RECENTS EFFECTUES EN AFRIQUE DU NORD

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A. INTRODUCTION

Dans des publications précédentes et au cours de différents congrès ou réunions de spécialistes, les travaux effectués ces dernières années en Afrique du Nord ont été longuement décrits en détail.

Les résultats les plus marquants ont été obtenus en Algérie qui est une des rares et sans doute la seule région du monde où la distillation solaire a franchi le domaine des études et des recherches pour entrer dans celui de la livraison commerciale d'appareils au public.

Plus de 250 appareils de distillation solaire acquis par des usagers sur leurs propres deniers (et non pas reçu sous forme de cadeaux ou achetés dans un esprit de subvention de recherche) sont utilisés en Afrique : Algérie, Maroc, Territoires Sahariens de l'O.C.R.S., Tchad, Sénégal. Un appareil a même été vendu dans l'île de Malte.

La surface totale de ces distillateurs est faible, elle ne dépasse pas 375 m². Leur production annuelle réunie se monte à environ 550 m³ par an. Ces chiffres nous paraissent fort éloquentes. Ils montrent bien la limite des services que la distillation solaire peut rendre dans l'état de choses actuel. Dans d'autres régions du monde, aux Etats-Unis en particulier, des tentatives fort intéressantes et fort instructives sont faites actuellement pour la construction de distillateurs solaires à grande échelle. Ces réalisations, dont l'intérêt scientifique et technologique sont considérables, ne modifient pas pour cela notre opinion mentionnée ci-dessus.

Nous reviendrons sur cet aspect de la question dans le courant de cet exposé.

Sans vouloir entrer dans le détail de la description de l'appareil étudié en Algérie, nous rappellerons ses caractéristiques principales :

- distillateur simple effet, utilisant l'effet de serre ;
- coque en amiante ciment ;
- couverture transparente et de condensation en verre à vitre ;
- forme du toit : double pente, angle d'inclinaison 10° ;
- surface insolée utile : 1,25 m² ;
- production moyenne : 1,9 à 2,5 m³ par appareil et par an, soit 1,5 à 2 m³/m²/an ;
- isolation : fond de la cuve avec de la laine de roche ;
- rendement du distillateur par rapport à l'énergie solaire reçue effectivement par m² horizontal : 61 à 49%.

Nous rappellerons, et ces détails ont leur importance, que l'appareil est très plat, le volume d'air séparant l'eau de la surface de condensation est pratiquement le plus petit possible, la distance de l'eau à la surface de condensation est en moyenne de l'ordre de 10 cm. L'épaisseur de la lame d'eau est de l'ordre de 2 cm.

B. ESSAIS DIVERS D'AMELIORATION CONCERNANT LA CONSTRUCTION ET LE PRIX DE REVIENT

B. 1. L'appareil prototype a reçu, bien entendu, une série d'améliorations relevant de la petite technologie dont l'énumération ne présente pas d'intérêt ici. Cependant, une de ces améliorations a produit un effet néfaste qui mérite plus d'attention.

Les appareils très plats, dont le fond de cuve était horizontal dans les prototypes, virent au cours d'une première amélioration, leur fond incliné de quelques % de façon à faciliter l'évacuation des boues cristallines au cours des nettoyages périodiques.

Cette inclinaison ramena le fond de la cuve en sa partie haute à 2,5 cm du bord de la goulotte de recueil d'eau distillée, et les usagers se plaignirent de la facilité avec laquelle, pour la moindre raison et à la moindre inattention, au cours des opérations de remplissage, l'eau salée de la cuve se déversait dans ces goulottes et venait se mélanger au distillat. Pour remédier à cet inconvénient, nous approfondîmes la cuve uniformément de 2 cm, la hauteur de l'eau dans la cuve ne se trouva pas modifiée; cependant, la distance de la surface évaporatoire à la surface vitrée de condensation, se trouva automatiquement augmentée de 2 cm (sur les 10 cm en moyenne).

Cette modification était apparemment sans grande importance et il fallait faire un effort réel d'attention pour distinguer un type d'appareil de l'autre. Cependant, la production d'eau distillée réagit à cette modification et réagit dans le mauvais sens.

Dans le tableau ci-après, figurent quelques résultats de production au cours d'une période d'essais comparatifs des deux types d'appareils.

Production quotidienne moyenne

Mois	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
10 cm	7,25	6,8	5,5	3,6	2,1	1,6	1,8	2,4	4,0	5,4	6,3	7,3	7,4
12 cm	—	—	—	3,0	1,8	1,4	1,6	2,2	3,75	5,3	6,0	6,75	7,0
% déficit . . .	—	—	—	16,7	14,0	12,5	11,0	8,3	6,2	1,8	4,8	7,5	5,1

Les trois premiers mois sont donnés pour faire ressortir la symétrie de la courbe de production par rapport aux solstices. Cette symétrie permet de limiter la durée de l'expérimentation à six mois (grossièrement de janvier à juin ou de juillet à décembre).

La production moyenne sur six mois (janvier à juin), c'est à dire la production quotidienne moyenne annuelle, est de :

- 4,533 litres par jour pour l'appareil de 10 cm,
- 4,266 litres par jour pour l'appareil de 12 cm.

Le déficit de production moyen est donc de : 5,89%, et ceci pour une augmentation de 2 cm sur la distance de la vitre de condensation à la surface opératoire, *toutes les autres conditions restant identiques.*

B. 2. Prototypes de M. Medinger

M. Medinger, Ingénieur, Chef de Section au Service des Etudes Scientifiques à la Direction de l'Hydraulique à Alger, a construit un appareil distillatoire du type verrière avec une cuvette à gradins, inclinée sur l'horizontale et une vitre de condensation placée au plus près des arêtes des gradins. La cuvette en gradins est d'ailleurs fabriquée en amiante ciment moulé.

Le distillateur à cuvette en gradins a une production supérieure aux distillateurs horizontaux pour une même surface d'appareil. Cette augmentation de production se fait sentir tout particulièrement en hiver où la production de l'appareil " gradins " est quelquefois plus du double des distillateurs horizontaux. En été par contre, les productions des deux types d'appareils sont sensiblement analogues.

L'expérimentation comparée a été faite à Alger (36° 46 N), où l'inclinaison du soleil en hiver est considérable. En hiver, un appareil incliné, à surface d'appareil égale, capte davantage d'énergie qu'un appareil horizontal. Il est certain que plus on se rapproche de l'équateur moins l'inclinaison de la cuvette présente de l'intérêt. Au contraire, un distillateur solaire à cuvette horizontale est d'autant moins avantageux que l'on se rapproche des pôles.

Le prototype de M. Medinger n'ayant pas été commercialisé (bien qu'un certain nombre d'unités soient en service et donnent satisfaction) on ne connaît pas le prix de revient exact de l'appareil (le prix de l'appareil de recherche ne présentant pas d'intérêt de ce point de vue). Le choix entre les deux types ne pourrait être déterminé que par des considérations de prix unitaires, comparés au débit fourni.

En fait, une augmentation sensible de la production des appareils horizontaux (100% en hiver et 30% en été) peut être obtenue en utilisant des réflecteurs plans en aluminium ou recouverts de matière plastique aluminée. La comparaison devrait donc être faite entre les appareils à cuvette inclinée à gradins, et les appareils horizontaux munis de réflecteurs.

B. 3. Appareils horizontaux bâtis

B. 3. 1. Si on s'en tient au principe du distillateur solaire à simple effet du type " serre ", une production importante d'eau demande l'équipement

d'une grande surface. Cette grande surface de captage et de distillation peut parfaitement être constituée par un assemblage de petits appareils construits en grande série. Les possibilités d'assemblage d'appareils du type commercialisé ont été étudiées en Afrique du Nord. Il a été démontré que l'assemblage est réalisable et ne présente pas de difficulté spéciale.

Les appareils doivent être rationnellement disposés. Un groupement compact offre l'inconvénient majeur de mettre hors d'atteinte les appareils intérieurs. Il est apparu, à l'étude, que le groupement des appareils en files est celui qui présente les plus grandes commodités d'exploitation. Suivant la place disponible et les conditions locales, ces files peuvent être réalisées par rangées simples ou doubles, les rangées elles-mêmes étant implantées en forme : d'échelle, d'étoile, de cercle, etc. Dans tous les cas, l'alimentation des appareils en eau brute et la collecte des eaux distillées sont communes. Dans un dispositif particulièrement économique, l'alimentation et la collecte se font par le même réseau de conduites, le remplètement des appareils étant effectué de nuit, en dehors des heures de production. La conduite de collecte est mise sous pression et alimente la cuve par débordement des goulottes latérales de recueil, le maintien du niveau correct d'eau dans la cuve étant obtenu par un trop plein.

Seul le problème de la vidange simultanée n'a pu être résolu d'une façon simple. En effet, la mise en place d'une vidange commune exige un calage en niveau très précis (à quelques millimètres près) de tous les appareils, puisque la vidange commune ferait communiquer hydrauliquement tous les appareils entre eux.

L'inconvénient principal du "pavage", réside dans le fait que, par son principe même, le prix de revient d'une surface de $N \text{ m}^2$ sera à peu de choses près N fois le prix d'un m^2 . On ne peut espérer un abaissement sensible du prix de revient unitaire si on équipe de grandes surfaces.

B. 3. 2. C'est pourquoi en Afrique du Nord nous avons examiné si la réalisation de grandes surfaces par la construction de grands appareils bâtis sur place, en utilisant la technique du bâtiment ou des travaux publics, pouvait conduire à un abaissement sérieux du prix de revient unitaire.

Dans une première étape on a établi le projet d'un distillateur solaire en béton armé, reproduisant à une plus grande échelle le distillateur en amiante ciment. Le module de la cellule unitaire a été déterminé par les dimensions maximales des vitres utilisables et par la dimension admissible pour la réalisation d'une dalle en béton armé, sans joints de dilatation (dans les conditions de travail particulières prévues). Cette cellule unitaire, dont la multiplication par juxtaposition devait permettre de couvrir toute surface désirée, avait pour dimension : $2,75 \times 12 \text{ m}$ environ, soit 35 m^2 en chiffres ronds.

L'ensemble se présentait comme une sorte de longue table en béton armé, supportée par des pieds en maçonnerie. Le dessous de la table recevait un isolement thermique en laine de verre.

Deux variantes avaient été étudiées à simple pente et à double pente.

L'étude du prix de revient montra que, même dans le cas d'un chantier très important, le prix de revient unitaire d'un tel appareil était supérieur à celui d'un assemblage de petits appareils préfabriqués.

Dans une deuxième étape, au lieu de dessiner un appareil, directement dérivé du petit appareil amiante ciment, on rechercha la voie à suivre pour réduire le prix de revient unitaire d'un distillateur du type " serre ".

Il est apparu qu'une économie sensible pouvait être obtenue en posant l'appareil à même le sol, l'isolement thermique moins parfait étant assuré par le béton de propreté, qui pouvait être choisi cellulaire. On pouvait également supprimer tout isolement thermique. Pour les parois latérales, on pouvait faire appel à des briques en ponce.

Sans isolement la production en eau distillée est nettement inférieure à celle d'un petit appareil. Une étude détaillée ayant montré que le prix de la surface unitaire d'un appareil bâti restait du même ordre que pour un petit appareil, il en résulta que l'intérêt économique de tels appareils bâtis était pratiquement nul.

A la suite de ces différentes études, il est apparu que la seule voie permettant d'abaisser très sensiblement le prix de revient devait être recherchée dans une technique de réalisation la plus fruste possible. Par exemple, en faisant pour l'instant abstraction de la couverture transparente et des accessoires de recueil d'eau distillée, il semble qu'un abaissement très sérieux du prix de revient unitaire pourrait être obtenu en faisant appel à la technique de construction des routes.

Le distillateur solaire pourrait alors être considéré comme un ruban plat, imperméable, bordé de murettes ou de diguettes en terre. Sur un fondement de matériau local tassé (gypse par exemple), serait étendu un revêtement imperméable industriel, l'imperméabilisation du fond pouvant être améliorée par des introductions périodiques dans l'eau soumise à l'évaporation de produits colmatants.

A condition d'envisager la construction de très grandes surfaces, le prix de revient unitaire pourrait théoriquement être divisé par 5 environ. La production probable étant sans doute la moitié de celle des petits appareils, le prix de revient de l'eau serait divisé par 2 environ. (Il resterait encore extrêmement élevé.)

L'étude technique a montré que la réalisation d'appareils à très grande surface est d'autant plus délicate à mener, et d'autant plus onéreuse, que les conditions sur le nivellement du radier sont plus sévères et les exigences concernant la constance de l'épaisseur de la lame plus grandes. Tout restant égal par ailleurs, il était pratiquement impossible d'envisager sur de grandes surfaces l'utilisation de lames d'eau très minces de l'ordre de 1 à 2 centimètres.

Enfin, la suppression de l'isolement conduisait à se demander si, pour diminuer l'importance des fuites thermiques vers le sol à travers le

radier, il ne fallait pas chercher à utiliser un régime de distillation à température plus basse, quitte à étaler la durée de la distillation au-delà de la période d'insolation. En d'autres termes, on pouvait se demander si la construction de distillateurs solaires du type " serre " de grandes dimensions n'exigeait pas l'augmentation de l'inertie thermique des appareils, inertie qui, de toute façon et quel que soit le mode de réalisation, devait être a priori supérieure à celle des appareils de petite dimension. Fallait-il donc réduire cette inertie thermique au minimum compatible avec les possibilités constructives ou, au contraire, fallait-il l'admettre et même l'accroître ?

Une expérimentation systématique fut mise sur pied pour répondre à la question. Nous y reviendrons plus loin.

B. 3. 3. Surfaces de condensation

Nous sommes arrivés, après de multiples essais, à la conviction que, dans l'état actuel des choses, le verre est le seul matériau utilisable pour les surfaces de condensation des appareils de structure conventionnelle utilisant l'effet de serre.

Les matières plastiques transparentes, dont l'étude permanente doit être poursuivie, fourniront sans aucun doute, à l'avenir, le matériau de couverture le meilleur marché.

A l'heure actuelle, les difficultés résultant de la non mouillabilité de la surface de condensation, du vieillissement de la matière plastique sous les effets conjugués du rayonnement solaire, de l'atmosphère humide interne, sèche externe, des agents atmosphériques, conduisent à les écarter provisoirement.

Le verre constituant la surface de condensation, les dimensions de cette surface, et par conséquent du distillateur lui-même, sont donc déterminées par le module de construction des plaques de verre, d'une part, et par leur limite de résistance, d'autre part.

Il résulte d'une enquête faite auprès de l'industrie du verre que les dimensions de sécurité du verre épais sont de l'ordre de : $1,26 \times 1,26$ m, de très loin inférieures au module de fabrication du verre ($3 \times 1,26$ m).

L'industrie du verre ne garantit d'ailleurs pas la résistance mécanique d'un verre de ces dimensions ($1,26 \times 1,26$) quand il est posé à plat : la dimension de sécurité est alors de $0,4 \times 1,0$, à condition encore d'encadrer le verre d'un châssis résistant.

Dans ces conditions, les surfaces de condensations devraient être réalisées comme un hall de gare, charpente autoportante à multiples " petits bois " déterminant des rectangles $1 \times 0,4$ m.

Une simple et rapide étude économique montre que, même si les difficultés de collecte étaient surmontées, la solution ne pourrait être économiquement viable.

Nous avons donc recherché dans quelle mesure il était possible de dépasser les normes de sécurité fixées par l'industrie du verre.

Les essais effectués ont montré que, avec des verres minces (simples ou demi-doubles), il était pratiquement impossible de ne pas s'en tenir aux supports périphériques de dimensions de l'ordre de $0,4 \times 1$ m.

Par contre, avec des verres épais, il est apparu que l'on pouvait en envisager l'emploi avec un support par quadrillage, tous les 1,25 m dans tous les sens.

On peut également **manipuler**, sans rupture, des plaques de verre épais de $2,3 \times 1,25$ m, et les poser à **plat** en les plaçant sur deux supports à leurs extrémités les plus éloignées, à condition de prévoir deux supports chandelles relais à mi-longueur.

Les dimensions en largeur des surfaces couvertes sont donc limitées à 2,3 m, pour des appareils à simple pente, et à 4,6 m, pour des appareils à double pente et arête support médiane.

Les essais effectués sur des appareils témoins ont montré que l'emploi du verre épais diminue la production de 85 %, tout restant égal par ailleurs.

Le verre épais armé ne présente pas une résistance supérieure au verre épais ordinaire. Il est simplement moins dangereux en cours de manipulation. S'il y a bris, on évite avec le verre armé l'éclatement de la plaque de verre en multiples morceaux. Par contre, le verre armé présente l'inconvénient majeur de se fendre à la longue, sans doute sous l'effet des variations de températures et de la différence des coefficients de dilatation du métal et du verre.

B. 4. En conclusion provisoire, nous sommes arrivés, en Afrique du Nord, à considérer que la construction d'un appareil de grandes dimensions, utilisant le dispositif conventionnel, conduisait à un prix de revient sensiblement équivalent à celui du pavage de même surface, par de petits appareils préfabriqués, ce prix étant même supérieur si on veut obtenir le même rendement thermique.

La réalisation d'un appareil plus rudimentaire pourrait sans aucun doute faire tomber le prix de revient au m^2 . Pour rester dans la logique de cette voie, il fallait admettre des épaisseurs de lame d'eau nettement supérieures aux deux centimètres du petit appareil.

Il fallait également admettre un fonctionnement suivant un régime de températures différent. L'inertie thermique d'un appareil de grande dimension à lame d'eau épaisse serait sensiblement plus élevée que celle d'un petit appareil à lame mince.

On soulevait là une série de problèmes auxquels il était bon de donner une réponse préalable au moins partielle, avant de se lancer dans la construction, somme toute fort onéreuse, d'un appareil de grandes dimensions.

C'est pourquoi nous avons organisé une expérimentation et fait quelques études dont les résultats sont mentionnés ci-dessous.

Avant de clore ces premières indications, il faut remarquer que le pavage d'une grande surface, par de petits appareils du type commercialisé en Afrique du Nord, revient approximativement à 250 NF au m^2 . Le prix

de revient qui a été indiqué pour le distillateur de 2.500 pieds carrés qui doit être construit à Port Orange aux Etats-Unis est de l'ordre de 5 dollars par pied carré, soit 54,5 dollars par mètre carré, c'est à dire environ 275 NF au mètre carré.

C. EXPERIMENTATION SUR L'INERTIE THERMIQUE ET L'INFLUENCE DE LA PROFONDEUR DE LA LAME D'EAU

C. 1. Dispositif expérimental

Nous avons établi à Touggourt (33° 7' N) six appareils identiques en tout, sauf en ce qui concerne la profondeur de la cuve. Ces appareils, d'une surface captante utile de 1,765 m², étaient recouverts d'un toit vitré à double pente (inclinaison 10°). Leurs parois extérieures étaient très soigneusement isolées thermiquement au moyen d'une double couche de laine de verre et de mousse de polyurethane.

La surface supérieure de la lame d'eau était dans tous les appareils à la même distance de la surface vitrée de condensation. La distance moyenne était de 7 cm.

Les différentes épaisseurs de lame d'eau choisies, étaient :

— 2 cm — 5 cm — 15 cm — 40 cm — 100 cm.

Les appareils étaient munis de sondes thermométriques disposées à différents endroits des lames d'eau. On mesurait le volume produit quotidien et, une fois par semaine, le débit horaire pendant les heures d'insolation.

Périodiquement on mesurait également les températures de la surface extérieure des vitres de condensation, à l'aide d'un pyromètre à contact.

La masse d'eau était colorée par un mélange de quebracho, noir animal et vert naphthol, de façon que l'absorption du rayonnement solaire se fasse uniformément pour tous les appareils, dans la couche d'eau supérieure.

C. 2. Epaisseur de lame et production quotidienne

Dans le tableau ci-après figurent les résultats moyens obtenus au cours d'une période d'expérimentation d'un an, après trois mois environ de mise en régime des appareils (période de mise en régime nécessaire aux appareils les plus profonds).

Production quotidienne moyenne en litres/jour

Mois	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI
<i>Appareils</i>												
2 cm .	10,2	10,4	8,0	5,0	2,7	2,0	2,4	3,1	5,3	8,0	9,1	9,8
5 cm .	10,1	9,2	7,3	4,5	2,4	1,8	2,0	2,8	4,2	7,5	8,2	10,0
15 cm .	8,7	8,5	6,4	3,9	2,0	1,5	1,8	2,3	3,2	6,0	7,4	8,5
40 cm .	8,2	7,8	5,9	3,7	1,9	1,2	1,6	2,0	3,5	5,4	6,5	7,8
100 cm .	7,4	6,0	5,6	3,6	1,8	1,4	1,5	1,7	2,9	5,4	5,9	7,0

Les productions quotidiennes moyennes annuelles, pour chacun des appareils, sont les suivantes :

Profondeur cm	Production l/jour	Rapport/z cm
2	6,33	100
5	5,83	92
15	5,02	80
40	4,62	73
100	4,18	66

La relation liant la production quotidienne moyenne annuelle à la profondeur en cm de la lame d'eau est la suivante :

$$Y \text{ l/j} = \frac{22,754}{x \text{ cm} + 7,872} + 4,025$$

La forme hyperbolique de l'équation est vérifiée pour les productions quotidiennes moyennes mensuelles. On peut donc dire que la relation liant la production d'un distillateur solaire du type "serre" à la profondeur de la lame d'eau x est de la forme :

$$Y = \frac{a}{x + b} + c$$

Les constantes a , b , c , dépendent de la forme de l'appareil et des conditions locales (latitude, intensité du rayonnement, époque de l'année, etc.).

On en déduit que la production d'un distillateur du type "serre" sera très sensiblement influencée par la hauteur de lame, dans les appareils à faible épaisseur de lame. Par contre, l'influence d'une variation d'épaisseur sera d'autant moins sensible, que la profondeur de lame sera grande.

Cela est fort affligeant car il aurait été très commode de pouvoir disposer d'une latitude de quelques centimètres dans la réalisation des appareils de grande surface à lame d'eau mince.

On en déduit également qu'à partir du moment où on ne peut trouver une solution satisfaisante pour maintenir la lame d'eau aux environs de 2 cm, on peut franchement faire faire un saut considérable à l'épaisseur de la lame d'eau. L'appareil aura certes une production sensiblement inférieure, mais la fixation de la cote d'eau au cm près, ne présente plus grande importance. On peut alors en particulier, admettre une sensible variation de l'épaisseur de la lame d'eau dans le même appareil (c'est-à-dire utiliser un radier incliné, favorisant l'écoulement de l'eau et le nettoyage).

On en déduit aussi qu'à partir d'une épaisseur de l'ordre de 100 cm la production deviendra sensiblement constante.

C. 3. Epaisseur de lame et production instantanée

L'augmentation de l'épaisseur de la lame d'eau accroît l'inertie thermique, ce qui a pour effet d'atténuer l'amplitude des variations de débit instantané en cours de journée.

Alors que, sur un appareil à lame mince, la variation de débit instantané suit de très près la variation de l'apport d'énergie solaire, un appareil à lame épaisse absorbe de l'énergie au moment du maximum d'insolation pour restituer lentement cette énergie pendant les périodes d'insolation plus faibles et même pendant la nuit ou une partie de celle-ci.

Par exemple, le débit instantané au cours d'une journée donne (en été) :

Débit instantané en l/h/m²

Appareils	2 cm	5 cm	15 cm	40 cm	100 cm
heure					
0	0,00	0,03	0,10	0,13	0,13
1	0,00	0,03	0,10	0,13	0,13
2	0,00	0,03	0,10	0,13	0,13
3	0,00	0,03	0,10	0,13	0,13
4	0,00	0,03	0,10	0,13	0,13
5	0,00	0,03	0,10	0,13	0,13
6	0,00	0,03	0,10	0,13	0,13
7	0,00	0,04	0,10	0,13	0,13
8	0,03	0,05	0,10	0,13	0,13
9	0,10	0,08	0,13	0,13	0,08
10	0,25	0,16	0,20	0,16	0,09
11	0,44	0,26	0,26	0,20	0,12
12	0,62	0,38	0,34	0,25	0,17
13	0,73	0,48	0,38	0,28	0,22
14	0,80	0,57	0,40	0,30	0,24
15	0,78	0,63	0,40	0,31	0,25
16	0,60	0,60	0,33	0,28	0,24
17	0,40	0,50	0,27	0,25	0,20
18	0,28	0,40	0,23	0,21	0,18
19	0,17	0,31	0,19	0,17	0,16
20	0,12	0,23	0,18	0,16	0,14
21	0,07	0,16	0,16	0,14	0,13
22	0,04	0,12	0,16	0,14	0,13
23	0,01	0,07	0,12	0,13	0,13

L'amplitude de variation de débit instantané en cours de journée est de l'ordre de :

Appareils	Amplitude en l/h/m ²
cm	l/h
2	0,80
5	0,60
15	0,39
40	0,18
100	0,12

Le débit maximum représente en pourcentage du débit minimum :

Appareils	Débit maximum	Débit minimum	%
cm			
2	0,80	0,00	infini
5	0,63	0,03	2.100
15	0,40	0,10	400
40	0,30	0,13	230
100	0,25	0,13	192

L'augmentation d'épaisseur répartit la production sur l'ensemble de la journée, mais le résultat global, comme on l'a vu précédemment, est moins bon.

C. 4. Epaisseur de lame et températures

Le dépouillement des très nombreuses mesures accumulées pendant l'expérimentation conduit aux conclusions ci-après :

- pendant les heures d'ensoleillement la température des couches supérieures dans le distillateur à lame de profondeur 100 cm, est plus élevée et s'accroît plus rapidement que la température des couches sous-jacentes ;
- chaque jour, chaque couche passe à un maximum et un minimum de température, d'autant plus accusés que la couche est plus proche de la surface ;
- le maximum de température est atteint d'autant plus tôt dans la journée que la couche est plus proche de la surface ;
- la situation est la même pour les minimums, les couches supérieures se refroidissent plus rapidement que les couches profondes ;
- dans les couches supérieures, il y a inversion du gradient de température après le coucher du soleil, les couches les plus proches de la surface sont plus froides que les couches immédiatement sous-jacentes ;
- cette inversion du gradient de température se fait quotidiennement dans la première couche de 5 cm, assez fréquemment dans la couche des 20 premiers centimètres, très exceptionnellement dans la couche des premiers 40 cm, et jamais en dessous.

Il en résulte qu'il y a formation de strates de couches d'eau isothermes au cours de la période d'ensoleillement, en d'autres termes, l'énergie rayonnante absorbée par l'eau colorée dans les couches supérieures fournit des calories dont une partie se propage verticalement vers le bas.

L'examen des courbes traduisant cette propagation montre une similitude frappante avec les courbes de propagation à travers un milieu isotrope d'une perturbation thermique superficielle. On peut donc affirmer

que, au cours de l'ensoleillement du distillateur, il se produit une fuite thermique par conduction vers les couches inférieures.

Au cours de la période de refroidissement, les couches situées tout près de la surface évaporatoire, fournissent l'énergie nécessaire à l'évaporation et deviennent plus froides que les couches d'eau situées dans les 20 premiers centimètres.

Ces dernières fournissent en retour les calories à la couche évaporatoire supérieure au moment de l'inversion du gradient de température. Mais cette récupération des calories emmagasinées n'intéresse généralement que ces 20 premiers centimètres, et très exceptionnellement les 40 premiers centimètres. Elle ne touche jamais les couches plus profondes.

On peut donc considérer que les calories emmagasinées dans les couches situées à une cote inférieure à 30 ou 40 cm sont définitivement perdues. Leur réutilisation demanderait un brassage mécanique du liquide dans toute sa masse.

Si on compare maintenant entre eux les appareils de différentes profondeurs, on constate, comme cela est prévisible, que la température maximum de la surface évaporatoire est d'autant plus faible que la lame d'eau est plus épaisse.

Voici quelques valeurs relevées en cours d'expérimentation et qui permettent de juger de l'importance des différences enregistrées suivant les saisons :

Appareils	Température maximum de l'eau en surface (degrés centigrades)		
	Eté	Automne Printemps	Hiver
cm	° C	° C	° C
2	85	67	53
5	76	57	39
15	62	48	23
40	56	43	21
100	53	40	20,5

L'amplitude des variations de températures en cours de journée est d'autant plus élevée que les variations de la température de l'ambiance extérieure sont plus fortes et que l'épaisseur de lame d'eau est plus faible.

Pratiquement, les appareils de 2 et 5 cm voient la température de l'eau tomber au cours de la nuit au voisinage de la température de l'ambiance extérieure, c'est-à-dire 25 à 30° en été, 8° à 3° l'hiver.

Les autres appareils conservent toute la nuit une température légèrement supérieure à celle de l'ambiance. En hiver en particulier, les appareils de 40 et 100 cm de profondeur conservent en surface une température voisine de 10 à 12° et, à cette époque, leur minimum est moins bas que celui des appareils à lame plus mince.

Il est intéressant de donner une vue sur les différences de températures existant entre l'ambiance, la surface vitrée de condensation et l'eau à la surface évaporatoire.

Voici quelques chiffres assez significatifs :

Saisons	Appareils	Températures		
		Ambiance	Eau	Vitre
Eté	cm	° C	°C	° C
	2		83	58
	5		72	53
	15	37	62	47
	40		51	45
	100		50	46
Automne Printemps	2		63	35
	5		52	32
	15	25	39	28
	40		36	28
	100		36	28
Hiver	2		52	26
	5		38	22
	15	17	23	20
	40		22	20
	100		22	19

Il apparaît très nettement que lorsque la température de l'eau tombe au voisinage de 50 à 40°, la température de la vitre de condensation devient très voisine de la température d'ambiance. Le rapport surface de condensation/surface d'évaporation est alors manifestement trop élevé. Le même pouvoir d'évacuation de calories pourrait être obtenu à partir d'une surface de condensation plus faible.

Quand la température de l'eau atteint 60°, la différence de température entre la surface de condensation et l'ambiance atteint 10° et croît ensuite très rapidement lorsque la température de l'eau continue à augmenter. La surface de condensation travaille alors fortement et il faudrait être prudent si on désirait diminuer le rapport surface de condensation/surface d'évaporation.

C. 5. Température de l'eau et débit

Nous avons cherché à déterminer s'il existait une relation entre le débit instantané et la température de l'eau dans la surface évaporatoire. Il est évident que ce débit instantané est également fonction d'autres paramètres, ne serait-ce que les conditions extérieures. Nous considérons cependant que les distillateurs solaires doivent être employés fréquemment dans les régions arides de latitude assez basse, où les conditions sont voisines de celles qui règnent au Sahara.

Nous avons dépouillé des observations faites en différents points du Sahara et à Alger même.

Nous avons déterminé ainsi que la courbe de production d'un distillateur plat du type " serre " était fonction de la température de l'eau suivant une loi hyperbolique.

Les deux courbes enveloppes des valeurs trouvées sont les suivantes :

$$Y = \frac{51,607}{117 - x^{\circ}} - 0,613$$

et :

$$Y = \frac{51,607}{112 - x^{\circ}} - 0,613$$

où — Y est le débit instantané exprimé en litres par heure et par m^2 de distillateur solaire (surface utile).

— x° est la température en degrés centigrades de l'eau dans la couche supérieure.

Les valeurs numériques sont propres au cas particulier. On peut cependant rappeler que la relation hyperbolique exprime une loi générale de débit pour les distillateurs du type " serre ".

Ces équations expriment bien la chute très rapide du débit lorsque la température s'abaisse. Au-dessous de 40 à 30° centigrades, la production devient quasiment négligeable.

C'est la raison pour laquelle la récupération de calories qui se fait au cours de la nuit dans les appareils à grande profondeur de lame d'eau, récupération qui s'effectue à un niveau de température voisin de 30 à 40° C, ne peut compenser le manque de débit de ces appareils en cours des heures d'ensoleillement.

D. REMARQUES SUR LES RESULTATS EXPERIMENTAUX

D. 1. La production d'eau par un distillateur solaire du type " serre " suppose :

- le transfert de molécules d'eau à travers l'interface eau/air humide ;
- le cheminement de ces molécules d'eau, soit par diffusion, soit par convection à travers l'espace séparant l'eau des vitres ;
- le transfert des molécules d'eau de l'air humide vers la couche d'eau condensée, à travers l'interface air humide/eau condensée.

Pour un apport ou une évacuation donnés de calories supposés a priori surabondant pour assurer du point de vue énergétique l'évaporation et la condensation, les vitesses instantanées d'évaporation et de condensation obéissent à une loi de la forme :

$$W = h_D A (c_0 - c)$$

où — W exprime la vitesse massique d'évaporation ou de condensation ;

- h_D est le coefficient de transfert de masse ;
- A la surface évaporatoire ou de condensation ;

- c_0 la concentration (masse par unité de volume) de vapeur à la surface du liquide ;
- c la concentration de vapeur dans l'air humide intermédiaire.

Le coefficient de transfert de masse a lui-même la forme :

$$h_D = \frac{D \cdot P}{y \cdot P_m}$$

- où — D est un coefficient appelé diffusivité ;
- P la pression totale de l'air humide ;
- P_m la pression moyenne logarithmique de l'air dans l'épaisseur d'air humide où se produit la diffusion ;
- y l'épaisseur d'air humide intéressée par la diffusion.

Le coefficient D de diffusivité dont les valeurs théoriques ne donnent pas toujours satisfaction, a été exprimé empiriquement par Maxwell. L'expression de Maxwell modifiée par Gilland permet de recouper de très près les résultats expérimentaux. Cette expression est la suivante :

$$D = \frac{0,0043 \cdot T^{1,5} \sqrt{\frac{I}{M_v} + \frac{I}{M_a}}}{P(V_v^{1/3} + V_a^{1/3})}$$

- où — M_v et M_a sont les poids moléculaires ;
- V_v et V_a les volumes moléculaires de l'eau et de l'air ;

$$V_v = 18,9 \quad - \quad V_a = 29,9.$$

Les vitesses instantanées de transfert obéissent donc à une loi de la forme :

$$W = A \cdot B \cdot \frac{P}{P_m} \cdot T^{1,5}(c_0 - c) \cdot \frac{I}{y}$$

ou encore en remplaçant les concentrations par les pressions partielles :

$$W = A \cdot B \cdot \frac{P}{P_m} \cdot T^{0,5}(p_0 - p) \cdot \frac{I}{y}$$

- où — A est la surface évaporatoire ou de condensation ;
- B un coefficient numérique ;
- P la pression totale de l'air humide ;
- P_m la pression moyenne logarithmique de l'air dans l'épaisseur d'air humide intéressée par la diffusion ;
- T la température absolue de l'air humide ;
- p_0 la pression partielle de la vapeur à la surface évaporatoire ou de condensation ;
- p la pression partielle de la vapeur dans l'air humide.

D. 2. En examinant la relation établie ci-dessus, nous voyons que pour augmenter la production instantanée d'eau distillée, c'est-à-dire pour

augmenter la fraction utilement employée de l'énergie solaire captée à chaque instant par une couche d'eau, il faut :

- augmenter A , c'est-à-dire la surface évaporatoire (ce qui veut dire, pour un volume d'eau donné, diminuer l'épaisseur de la lame d'eau) ;
- augmenter la fraction $\frac{P}{P_m}$, c'est à dire chercher à diminuer $P = P_m + p$, p étant constant pour une température donnée ;
- augmenter T ;
- diminuer γ , c'est-à-dire diminuer la couche d'air intéressée par la diffusion au contact des surfaces de condensation et d'évaporation, et diminuer la distance de la surface évaporatoire à la surface de condensation ;
- augmenter $p_0 - p$, c'est-à-dire réchauffer au maximum l'eau de la cuve et refroidir au minimum la surface de condensation.

D. 3. Si nous considérons un diagramme de l'air humide, nous constatons que la concentration c_0 croît très rapidement avec la température.

A 30° l'air humide saturé à la pression atmosphérique tient environ 30 mg/l de vapeur d'eau.

A 50° il en tient environ 90 mg/l.

A 70° „ „ „ „ 190 mg/l.

A 90° „ „ „ „ 400 mg/l.

D'autre part, à différence constante de température, la différence des teneurs en vapeur d'eau constitue le maximum susceptible d'être évaporé ou condensé. Or, cette différence croît très vite avec la température.

Comme, par ailleurs, l'expression de la vitesse de transfert de masse rapportée aux concentrations a la forme :

$$W = K \cdot T^{1,5} (c_0 - c)$$

on constate, non seulement que la valeur absolue d'eau susceptible d'être intéressée par le jeu évaporation-transfert-condensation augmente rapidement avec la température, mais encore que la vitesse à laquelle peut se dérouler cette suite d'opération s'accroît très vite.

Par conséquent il est conforme à ces diverses considérations de constater par l'expérience un très sensible accroissement du débit instantané, parallèlement à une augmentation de la température de l'eau soumise à évaporation.

D. 4. Les relations précédentes permettent également de prévoir que le rapprochement de la surface de condensation au plus près de la surface évaporation doit augmenter la production. En effet, la diminution de l'espace intermédiaire agit sur la violence des courants de convection qui pour une même énergie motrice intéressent un volume d'air humide bien moindre. Le brassage de l'air au voisinage des surfaces d'évaporation et de

condensation diminue l'épaisseur de la couche d'air humide "y" dans laquelle le transfert de vapeur ne se fait que par diffusion.

De plus, au sein des courants de convection eux-mêmes, la diffusion continue à faire son effet et s'ajoute aux transferts de vapeur dus aux mouvements des filets d'air humide. Cette diffusion doit s'effectuer à travers tout l'espace séparant l'eau de la vitre, et l'aplatissement de l'appareil donne donc une importance plus grande à ce transfert complémentaire, par diffusion, et ceci inversement proportionnellement à la distance "eau-vitre".

E. CONCLUSION

E. 1. Le distillateur solaire simple effet du type " serre " à la suite de l'expérimentation effectuée en Afrique du Nord paraît ne plus pouvoir être sérieusement amélioré dans son principe.

Les appareils de petites dimensions, à lame d'eau mince, au toit transparent plat, à deux pentes, construits avec une faible distance eau-vitre, bien isolés, fonctionnant suivant un rythme calqué sur celui du soleil, ont un rendement voisin du maximum que l'on peut espérer obtenir.

Toute amélioration de construction devra, d'une part, respecter les principes énoncés ci-dessus et, d'autre part, être appréciée en fonction de l'abaissement du prix de revient du volume unitaire d'eau produit.

E. 2. La construction d'un appareil de grande dimension, calqué sur le précédent, doit conduire à des résultats décevants.

A moins d'une idée particulièrement judicieuse et qui reste encore à concevoir et à énoncer, le projecteur d'un appareil de grande dimension sera peu ou prou obligé de dessiner un appareil moins satisfaisant dans son principe :

- distance " eau-vitre " plus grande,
- lame plus épaisse,
- régime de température plus bas, etc.

La production de cet appareil de grandes dimensions sera donc a priori moins bonne.

Par ailleurs, un tel appareil semble devoir être d'un prix de revient sensiblement équivalent ou même supérieur à celui d'un assemblage d'un nombre considérable de petits appareils construits en grande série.

Enfin, comme on est raisonnablement conduit à admettre pour les grands appareils un régime de température assez bas si on ne veut pas tomber dans des absurdités de construction, il est assez vraisemblable que la surface vitrée sera toujours surabondante en ce qui concerne ses fonctions de condenseur, et il est peu rationnel de couvrir toute la lame d'eau d'une surface de condensation assez compliquée à établir et onéreuse, alors qu'une partie seulement en est réellement utile.

E. 3. La conclusion qui résulte de tout cela est assez évidente. Le

distillateur solaire du type " serre " répond bien à certains besoins individuels ou de petit groupes humains. Il doit être alors réalisé sous forme de petits appareils utilisés isolément ou en assemblage d'un nombre restreint d'entre eux.

La production de quantités importantes d'eau, par énergie solaire, doit être recherchée par des procédés qui restent encore à découvrir ou à mettre au point.

Deux voies sont tracées.

L'une consiste à augmenter très sensiblement le niveau de température de l'énergie captée et de l'utiliser ensuite, dans des conditions favorables, au sein d'appareils à effet multiple.

L'autre consiste à réaliser le captage, par des moyens peu onéreux, de quantités très importantes de l'énergie solaire à un niveau assez bas de température et à transporter ensuite ces " basses calories " vers un dispositif adéquat de distillation à basse température.

Dans les deux cas, il faut séparer le captage de l'énergie du stade ultérieur de son utilisation.

La première voie est celle qui se prête le mieux à la construction d'appareils calqués sur les distillateurs thermiques classiques. Dans l'état actuel des choses, l'augmentation de production ne compense en rien la complication, la fragilité et le prix de l'appareillage. Cette voie mérite cependant de continuer à être explorée.

La deuxième voie est plus ardue. Le captage de l'énergie solaire à un bas niveau de température est aisé, son utilisation future l'est beaucoup moins. C'est cependant le procédé qui tôt ou tard conduira vers une production importante à un prix de revient acceptable.

Les essais de Georges Claude, les études d'appareils fonctionnant avec de faibles différences de températures, préfigurent une série de solutions possibles. D'autres doivent exister.

**II. SURFACE WATER SUPPLIES AND SOME HYDRO-
BIOLOGICAL ASPECTS — UTILISATION DES EAUX DE
SURFACE, QUELQUES ASPECTS DE L'HYDROBIOLOGIE**

FACTORS WHICH AFFECT THE CHEMISTRY, BACTERIOLOGY AND BIOLOGY OF SURFACE WATER SUPPLIES

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SUMMARY

The paper deals with the factors which govern the chemical and bacteriological quality of raw water supplies. The geology of the catchment area determines the nature and concentration of the dissolved salts in the water. Industrial and sewage effluents gaining access to a river can change the water profoundly. The development of residential areas, and industrial and agricultural activities in the catchment all have their effect. Tables of data gathered from a number of South African rivers illustrate these points. The significance of biological self-purification in removing pollutants from water supplies and facilitating purification is also discussed.

INTRODUCTION

Water is our most indispensable natural resource. It is agreed that clean pure wholesome water for our domestic, industrial and recreational activities must be regarded as a heritage which should be zealously preserved.

The industrialist, the domestic user, the agriculturist, the fisherman and the nature lover react most aggressively to interference with the particular quality of their water supplies. Yet seldom do they appreciate the impact of their activities on the quality of the water which flows in rivers and which are impounded in dams which serve as sources of water supply.

The ideal water catchment area on which there is no human habitation, no industrial and agricultural activity and where the only livestock is sheep and cattle is today almost non-existent. The costs of achieving and maintaining such conditions in the face of present day industrial development, expansion of cities, towns and recreational areas, and the intensification of agriculture would be beyond the reach of any local or water supply authority. Fortunately, however, modern water purification systems provide multiple safety barriers and it is possible to strike a balance between control in the catchment area and control in the purification works; to achieve this, however, a comprehensive analysis of factors which affect water quality and costs of purification is an absolute necessity.

The pipeline that leads away from the house, the business premises and the factory, and its effect on the chemistry, biology and bacteriology of water supplies is well known; no matter, however, how stringent effluent control may be, there are interferences with water quality which

must be accepted. Thus, the problem of preserving quality of water supplies becomes more complicated by factors which arise from :

- (i) the cultivation of land with the concomitant large-scale use of fertilisers, insecticides and fungicides ;
- (ii) the introduction of new materials, e.g. synthetic detergents which make the daily life of the housewife easier ;
- (iii) the deposition of filth, dirt and smog, and radioactive material ;
- (iv) residues of animal population ;
- (v) the establishment of rubbish dumps ;
- (vi) pollution from densely populated areas where the standard of sanitation is primitive ;
- (vii) use of radioactive materials ;
- (viii) specific types of salt-bearing geological formations.

The extent to which all these factors affect the chemistry, biology and bacteriology of water supplies is of paramount importance from the point of view of purification and distribution of water, particularly in South Africa where water resources have to be exploited judiciously as well as to the utmost.

It should be borne in mind that water conservation does not lie in the number of dams that are built, but in the number of times the water is used. The greatest enemy to water supplies is the destruction of the quality of water ; all the aforementioned factors tend to depreciate the purity and quality of water and eventually could lead to the destruction of the usefulness of our water supplies. Furthermore, it costs money to purify water and to distribute it not only in a potable condition, but also properly stabilised in order to prevent corrosion and encrustation, and of high chemical quality compatible with the specific requirements of a diversity of industrial uses. It is, therefore, necessary that the engineer who designs water purification plants, reticulation systems and water conservation dams should be fully informed of all factors which affect the chemistry, biology and bacteriology of the sources of water supply and of the extent to which these factors could be economically controlled.

The only way to prevent the ever present tendency to depreciate the quality of water is to build up, through research on water resources, a reservoir of basic information by which it is possible to measure progressively the effects of changing industrial, agricultural and domestic activities on their quality and quantity. By following this line of approach, it is possible to develop in advance and in accordance with the principle of economics, new methods of water purification, new chemical engineering techniques in manufacturing processes to recover waste materials from water circuits, new processes in the purification and stabilisation of sewage effluents and more effective sanitary services in densely populated areas ; furthermore,

such an approach would also provide the scientific and technical data required for the prevention and control of pollution by legislation.

CHEMISTRY

Geological factors

Rain-water can collect a diversity of chemical compounds while passing through the air and flowing over the surface of the earth before it ultimately reaches rivers and streams. Waters arising from underground sources may find their way into rivers. These may carry in solution inorganic constituents in varying degrees of concentration depending on the geological composition of the formations through which they percolate. The geological structure of the river bed itself may have an influence on the chemical composition of the water.

The main chemical contributions from both surface and underground geological formations to the composition of water are essentially inorganic salts such as the carbonates, bicarbonates, chlorides, sulphates, nitrates, silicates and fluorides of sodium, magnesium, calcium and potassium. Trace elements such as boron, barium, strontium phosphates, etc. may also be present.

The extent to which the geological formations can affect water quality is clearly illustrated in the case of the Swartkops River near Uitenhage (Diagram 1). The data are recorded in Table I.

Table I shows that the river contains soft water of good quality down to station 3 and probably a mile or so lower down. There is no real difference between stations 1 and 3; this stretch of the river flows over the quartzite of the Table Mountain Sandstone.

Just below station 4 the river begins to flow over the Uitenhage marine beds; the Elands River has also entered these beds at about this point, station 16. From here mineralisation is rapid up to station 13 after which there is little change until the estuary is reached.

Although the case of the Swartkops River may tend to overemphasise the influence of geological formation on the chemical composition of raw water supplies, the important point to take note of is that the design of water purification plant and the location of dam sites require comprehensive evaluation of these factors with respect to the chemical composition of the water which would be stored and purified eventually.

Industrial and Sewage Effluents

It is common knowledge that almost any use of water tends to impair its quality; furthermore, it is economically impossible to purify sewage and industrial effluents to such an extent that their return to a water course would not cause some change in the chemical quality of the water. It is true that pollution control measures could limit the degree of such changes

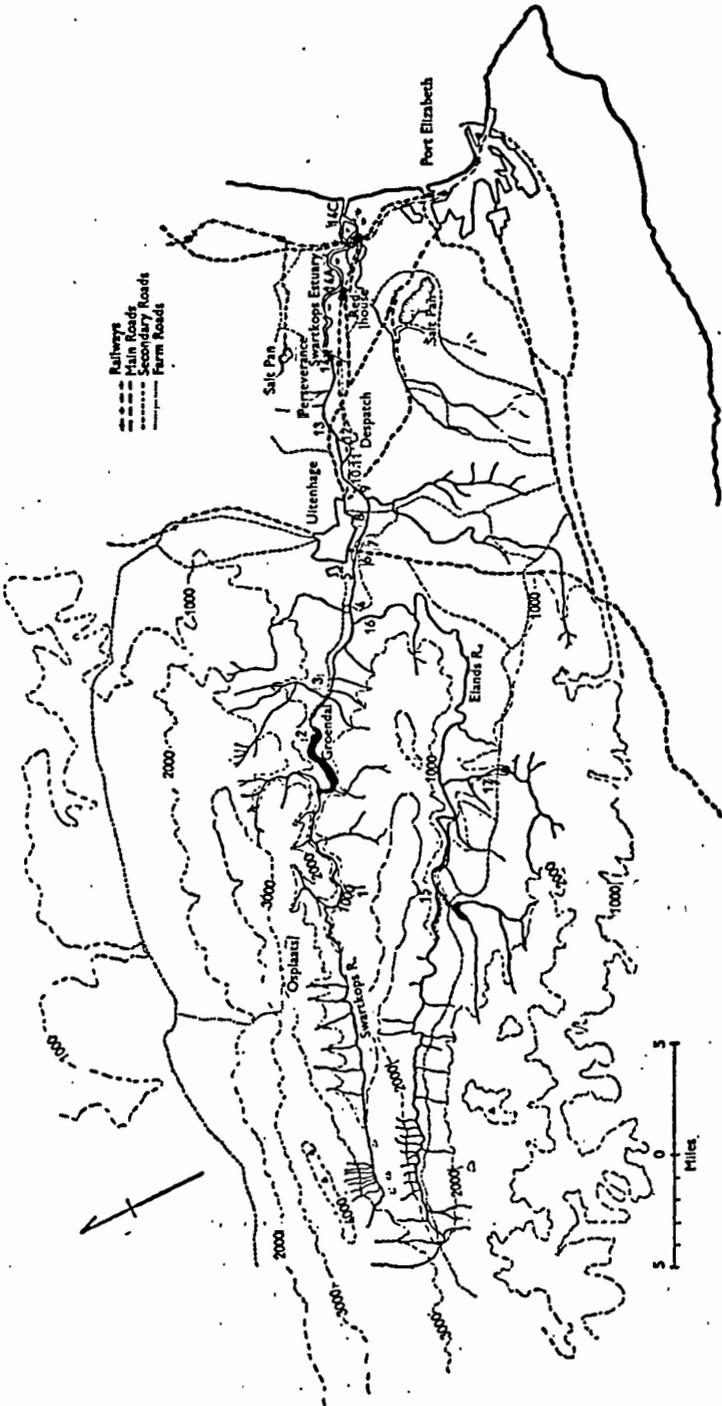


DIAGRAM I.

Table I.—Swartkops and Elands Rivers. Mineral analysis of water
Results in parts per million

Test	Monitoring stations									
	Stn. 1 10 miles above Groendal Dam	Stn. 3 Rooikrantz Causeway	Stn. 4 Below confluence with Elands River	Stn. 6 Niven's Bridge	Stn. 8 Causeway just above Uitenhage	Stn. 12 Despatch	Stn. 13 National road bridge 3 miles below Uitenhage	Stn. 14 Perseverance Causeway just above tidal reach of estuary	Stn. 15 Elands River at Golden Grove	Stn. 16 Elands River just above confluence with Swartkops River
Date	9/9	6/9	11/9	8/9	8/9	8/9	10/9	10/9	9/9	11/9
Conductivity (micromhos)	180	175	900	1,230	1,550	2,000	2,100	2,100	320	2,400
pH	7.2	6.8	7.1	8.1	8.1	—	8.5	7.8	6.1	—
Total dissolved solids	110	108	550	780	964	1,280	1,374	1,370	192	1,540
Total alkalinity	4.6	10	37	150	178	176	190	166	4	76
Total hardness	24	25	137	167	200	282	322	315	43	332
Calcium hardness	6	6	36	55	60	97	105	110	11	77
Magnesium hardness	18	19	101	112	140	185	217	205	32	255
Sodium ppm Na	28	28	150	190	250	330	350	350	50	420
Sodium percentage	70.9	70.1	70.0	63.6	66.1	66.7	66.6	67.6	70.9	73.0
Potassium, ppm K	0.9	1.0	2.5	53.5	62	47	47	40	1.4	3.5
Chloride, ppm Cl	52	50	235	300	368	528	560	576	95	640
Sulphate, ppm SO ₄	6.5	8	79	92	108	152	164	166	13.5	304

but ultimately there is no escape from accepting some measure of change as the price for progress and a higher standard of living.

There are no means by which it would be possible to keep most surface water supplies in the condition in which they would be if there were no industries and no cities and towns. Sewage and industrial effluent disposal cannot be isolated from water supply. The catchment area of the Vaal Dam is a typical case. In this area one finds a very wide variety of industrial establishments such as coal and gold mining, textile industries, milk processing factories and torbanite mining; furthermore, there are a number of large towns which are expanding rapidly. Effluents arising from these activities must find their way ultimately into the Vaal Dam. It is quite certain that in course of time changes will occur in the chemical quality of the water and with them modifications in purification plant design.

Sewage and industrial effluents can contribute both inorganic and organic materials to a water course. Whereas the former are of significance because of their effect on the hardness, mineral salt content, corrosive and encrusting properties of the purified water, the latter tend to increase costs of purification and to impair the taste and odour of the water in distribution systems. The extent to which a water supply can be affected by effluents carrying inorganic salts in solution is illustrated strikingly in the case of the Vaal River after its confluence with the Klip River (Diagram 2) which carries both industrial and sewage effluents from the Witwatersrand area between Germiston and Krugersdorp. The data are recorded in Table II.

For a true interpretation of the data recorded in Table II, the relative flows in the two rivers should be taken into consideration. For example, during the dry season of 1952 the average discharge from the Vaal Dam as measured at Engelbrecht's Drift (996 cusecs) was twenty-nine times that of the Klip River but the total mineral load carried by the former (average = 274 tons per 24 hours), was only 4.5 times that of the latter (63 tons per 24 hours).

Apart from causing a general increase in the mineral salt concentration of surface waters, industrial and sewage effluents may contain substances which are not removed in the purification process; synthetic detergents, phosphates and nitrates are some of the most significant from the point of view of storage of raw water and subsequent treatment in the purification plant.

Topographical Factors

It is frequently not appreciated to what extent the chemical composition of surface water is influenced by factors such as the construction of roads, the establishment of residential and recreational areas, production of smog, sanitation in built-up areas, refuse dumping, accumulation of industrial waste materials, the cultivation of land and control of pests. The problem

becomes even more complicated than in the case of sewage and industrial effluents, which can at least be controlled effectively by water pollution legislation and enforcement; beyond "clean housekeeping" there is so little which can be done economically.

Residential and Industrial Areas

Surface run-off during rain storms can contribute both mineral and organic pollution to streams and where these drain into storage dams, the

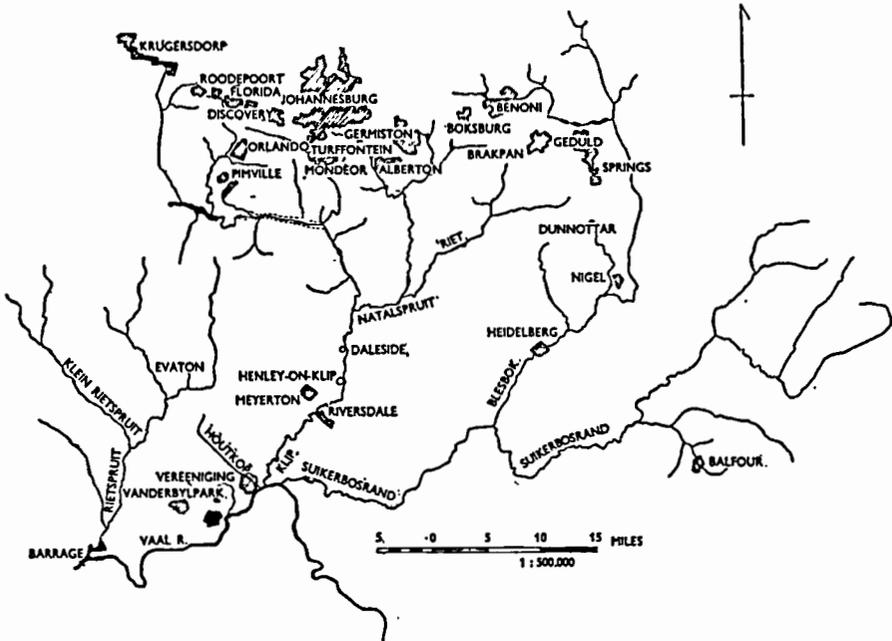


DIAGRAM 2.

effect on the chemical quality of the water supply can be quite marked, as illustrated by the following examples :

(i) The Klip River–Natal Spruit system and the Blesbok Spruit–Suikerboschrand River system drain an extensive area of Witwatersrand, and all run-off flows into the Vaal River at Vereeniging (Diagram 2). The excess mineral load carried by the run-off water during periods of rainfall and its effect on the chemical composition of the Vaal River water are detailed in Table III.

By comparing the data recorded in Table II and III, it will be observed that during the months of heavy rainfall, increases occur in total dissolved solids and total hardness; surface run-off water therefore leaches a considerable amount of accumulated mineral salts from the soil in the catchment areas of these river systems.

Table II.—Total dissolved solids concentration of the Vaal River and the Klip River for each month of the year

Sampling station : No. 1—Vaal River—Engelbrecht's Drift
 No. 2—Vaal River—Barrage
 No. 3—Klip River—at Vereeniging
 (Results in parts per million)

Month	Station 1			Station 2			Station 3		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
January . . .	100	95	100	559	133	205	875	675	200
February . . .	100	75	90	595	86	379	900	450	740
March . . .	75	60	70	225	83	93	800	725	790
April . . .	75	60	70	313	83	97	950	850	890
May . . .	105	105	105	160	100	130	850	675	735
June . . .	105	95	102	310	179	205	820	775	790
July . . .	115	100	105	300	133	153	1,150	775	920
August . . .	115	95	100	149	93	137	900	875	890
September . . .	100	95	100	113	90	105	700	525	600
October . . .	105	100	103	179	86	97	450	375	410
November . . .	100	80	95	380	105	179	225	400	950
December . . .	125	100	105	775	224	275	1,100	875	970

Table III.—Excess Mineral Load carried in run-off water and effect on the Vaal River water

Constituent	October		November		December		January	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
* Excess mineral load reaching the Vaal River [lb./24 h.] . .	1.6×10^4	(Av.)	3.75×10^4	3.2×10^4	7.6×10^4	1.25×10^4	2.5×10^4	1.0×10^4
Total dissolved solids of resultant Vaal River water (ppm)	170	86	380	105	775	224	550	133
Total hardness of resultant Vaal River water (ppm) . . .	115	55	235	60	470	135	345	85

Constituent	February		March		April		May	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
* Excess mineral load reaching the Vaal River [lb./24 h.] . .	3.5×10^4	1.6×10^4	4×10^4	1.3×10^4	2.8×10^4	7×10^4	5×10^4	1.8×10^4
Total dissolved solids of resultant Vaal River water (ppm)	595	86	225	83	313	83	160	100
Total hardness of resultant Vaal River water (ppm) . . .	370	58	140	55	185	55	05	60

* Mineral salts other than natural contributions.

(ii) The organic and mineral loads carried by run-off water itself to streams have not been studied in great detail as yet. The British Water Pollution Research Laboratory examined the quality of rainfall run-off water from a housing estate; according to the results of these tests the total weight of polluting matter discharged with

32,200,000 gallons of surface water would be equivalent, on the basis of B.O.D., to 12,500,000 gallons of sewage.

(iii) In Table IV are given the results of a few tests on run-off water from different types of areas in South Africa. The composition of this water is equivalent to diluted domestic sewage.

(iv) There are a variety of waste disposal dumps which can contribute both inorganic and organic material to surface water and thus cause changes in the chemical composition.

Table IV.—Composition of run-off water from various areas
(Results in parts per million)

Test	Type of area			
	Industrial and Bantu township	Farm lands and Bantu townships	Predominantly white residential area	Predominantly white residential area and industrial
O.A. value (4 hours)	30	15	5.0	10
Ammonia (as N)	30	6.4	1.0	12
Nitric nitrogen (as N)	1.5	1.2	0.5	0.5
Sodium chloride	700	660	800	2,400

In Table V are recorded some analytical data on the composition of seepage from two types of dumps during a three months period of heavy rainfall on the Witwatersrand.

In the above connection, it should be noted that refuse dump drainage can also percolate into underground water supplies particularly where surface strata are permeable.

From a detailed analysis of records of stream flow, mineral loads and rainfall figures, it is estimated that in an area with a rainfall of 30 in. per annum mineral salt contributions from slag, ash and domestic refuse dumps can range from 2,000 to 3,000 tons per square mile of dump area. In the case of coal and gold mine dumps, the load could be appreciably higher.

Agricultural Activities

Grazing of stock, cultivation of the soil, the use of fertilisers, irrigation and crop spraying are all factors which make specific contributions to the chemical quality of raw water supplies.

Soil erosion is chiefly responsible for the heavy silt loads carried by run-off water. Apart from serious silting up of dams the colloidal clay and organic material have a deleterious effect on the beneficial biochemical reactions which should take place during storage of raw water.

The extensive irrigation of land and the use of fertilisers can be

Table V.—Composition of seepage water from waste dumps
(Results in parts per million)

Test	Date	Slag dump drainage	Refuse dump drainage
Oxygen absorbed in 4 hours (as O)	1.12.54	6	54
	7.12.54	2	23
	4. 1.55	16	9
	11. 1.55	4	45
	3. 2.55	8	89
	24. 2.55	8	70
Ammoniacal nitrogen (as N) .	1.12.54	1.3	2.9
	7.12.54	0.7	31.5
	4. 1.55	1.9	16.9
	11. 1.55	0.4	12.6
	3. 2.55	0.3	10.1
	24. 2.55	0.2	37.6
Nitrous nitrogen (as N) .	1.12.54	0.24	0.01
	7.12.54	0.15	Nil
	4. 1.55	0.38	0.48
	11. 1.55	0.25	0.72
	3. 2.55	0.20	0.03
	24. 2.55	0.10	Nil
Nitric nitrogen (as N) . .	1.12.54	0.1	—
	7.12.54	0.1	0.1
	4. 1.55	3.5	—
	11. 1.55	0.1	0.2
	3. 2.55	0.2	0.4
	24. 2.55	0.2	0.1
Sulphates (as SO ₄) . .	1.12.54	673	366
	7.12.54	383	220
	4. 1.55	388	1,040
	11. 1.55	328	840
	3. 2.55	201	2,588
	24. 2.55	332	202
Total alkalinity (as CaCO ₃) .	4. 1.55	250	697
	11. 1.55	74	653
	3. 2.55	104	1,087
	24. 2.55	92	1,624
Dissolved solids (at 180° C.) .	1.12.54	1,180	2,530
	7.12.54	1,890	2,470
	4. 1.55	1,340	3,210
	11. 1.55	870	3,870
	3. 2.55	570	5,170
	24. 2.55	800	3,570

responsible for large contributions of nitrogen and phosphorus to water supplies which receive drainage from such areas. In Table VI are recorded the results of a survey carried out in the United States; no figures detailing conditions in South Africa are as yet available.

Rivers generally show a progressive increase in dissolved mineral concentration between headwaters and the mouth. Diversion of water for irrigation use followed by a return of drainage to the river increases

Table VI.—Contributions of fertilising elements in drainage from agricultural lands

Drainage area tributary to	Pounds contributed per year per square mile			
	Inorganic nitrogen	Organic nitrogen	Inorganic phosphorus	Organic phosphorus
Lake Monona . . .	2,800	1,035	35	—
Lake Waubesa . . .	3,130	1,180	62	186
Lake Kegonsa . . .	4,100	1,150	62	200

Table VII.—Comparison of chemical composition of Vaal River water and drainage from the Vaalhartz Irrigation Scheme
(Results in parts per million)

Constituent	Vaal River at Vaalhartz Weir	Hartz River at Barkley West Kuruman Road crossing
Total dissolved solids . . .	95	330
Total alkalinity (as CaCO ₃) . . .	45	125
Total hardness (as CaCO ₃) . . .	55	169
Magnesium hardness (as CaCO ₃) . . .	31	83
Calcium hardness (as CaCO ₃) . . .	24	86
Sodium (as Na) . . .	10.3	48
Potassium (as K) . . .	6.3	3.8
Chloride (as Cl) . . .	12	66
Sulphate (as SO ₄) . . .	3.0	50

Table VIII.—Smog deposition per year over four South African cities in tons per square mile per year

City	Combustible material	Water soluble material	Insoluble material	Total
Durban	47	141	155	343
East London	47	127	145	319
Johannesburg: Central	52	75	220	347
Suburbs	23	56	200	279
Bantu townships	42	65	200	307
Pretoria	28	56	120	204
Average	40	87	173	300

this tendency materially. As a result of evaporation and transpiration there is an appreciable increase in mineral salt concentration which is carried in the smaller volume of return flow; furthermore, leaching of arid soils, which usually contain a higher concentration of soluble material than soils in high rainfall areas, can cause a considerable increase in the mineral salt concentration of the receiving stream. The entire flow of the Hartz River, estimated at 50,000,000 gallons per day, consists of drainage from the

Vaalhartz Irrigation Scheme ; the Hartz River drains into the Vaal River some 80 miles below the irrigation intake. The extent to which the Vaal River water becomes mineralised during the process of irrigation is illustrated by the data recorded in Table VII. The analyses were carried out on snap samples.

The application of insecticides and fungicides over large areas, particularly by spraying from aircraft, can have far-reaching effects on water supplies. The presence of D.D.T. in water supplies to the extent of 2 ppm, for example, has been reported by overseas workers. Substances such as D.D.T., parathion and synthetic detergents do not decompose readily during biological oxidation ; the latter substances are usually the major ingredients of agricultural sprays. These substances are adsorbed on the leaves of plants and on the surface of the soil ; during rainstorms they are carried away to rivers and streams and accumulate in the mud layers of dams from where they can be released and decomposed slowly by biological processes. Apart from long-term and accumulative effects of agricultural sprays, direct damage to water supplies can result ; in the case of Harrismith, for example, the entire water purification process was put out of action within a matter of a few days after spraying a forest in the catchment area of the town's water supply ; the concentration of spray was reported to be only 3 gallons per acre, but this figure is questionable.

Smog and Radioactive Rains

No specific data on the effect of deposition from smog on water supplies are available. In Table VIII are recorded the order of deposition arising from smog in four South African cities ; a rainfall of 30 inches per annum over a city area would on a basis of its total run-off cause an increase in the total dissolved solids concentration of the water to the extent of 41 mgm per litre of which 50% could be organic material. This contribution is always masked by dilution with run-off water from rural and other sparsely populated areas ; the presence, however, of micro-concentrations of organic and certain inorganic substances in raw water supplies has become quite significant, particularly with respect to their role in the process of self-purification, and in the production of tastes and odours ; their effect on human health has not been assessed as yet.

The effects of radioactive fall-out on water supplies have received prominent publication. As a particular instance the data recorded by R. L. Morris for the Iowa River at Iowa City, U.S.A., could be quoted. During the period July to October 1957, seven periods of above-normal radioactivity in precipitations were recorded ; six of these incidents were evidenced by marked rises in the activity levels of the river water, and in the case of two peaks the radioactive level of the tap-water increased well above the accepted limit for beta-gamma activity.

The International Commission for Radiation Protection (ICRP)

prescribes a maximum permissible concentration for drinking water of 1×10^{-8} $\mu\text{C}/\text{ml}$. The dangers to man do not, however, arise solely from drinking radioactive contaminated water. The intake of radioactive isotopes by means of vegetal and animal food, originating in water, is a much more dangerous source because of the considerable concentration of radio-isotopes in these substances.

A concentration factor of 1.5×10^6 has been reported for the yolk of eggs of wild ducks and geese : for their flesh the factor is 2,000–2,200 and for their liver 2,500–2,800.

Algae, snails and tadpoles had accumulated Cs^{137} to over 100 times the concentration in the water after only two hours contact and for the same isotope the concentration range in the flesh of waterfowl was 5,000–6,000 times.

In the case of black crappies and bluegills (types of fish), the concentration factor for radiostrontium in the skeletal system amounted to 20,000 to 30,000 that of the water in which they lived.

Carp grown in water containing Cs^{137} at the prescribed ICRP level of 1.5×10^{-3} $\mu\text{C}/\text{ml}$, may concentrate the isotope by a factor of 3,000. Thus only 20 gm. of this flesh might contain the equivalent of the long-term maximum permissible body burden of 90 μC for man.

Krumholz carried out extensive investigations on accumulation of radio-isotopes in fish of White Oak Lake in Tennessee. He reported that during the summer of 1952, the average total body burden of radioactivity carried by a black crappie 7 inches long was well over a microcurie and that, on the average, a 6 inch bluegill carried only slightly less.

The importance of these statistics is reflected in the fact that a background radioactivity of 5.7×10^{-9} $\mu\text{C}/\text{ml}$ has already been recorded in South Africa ; this is all the more significant if we take into consideration that South Africa is not as yet exploiting nuclear energy.

BACTERIOLOGY

From the public health point of view the most important aspect of the bacteriological quality of raw water is the possible transmission of water-borne diseases such as typhoid, dysentery, gastro-enteritis, infectious hepatitis, cholera and virus diseases.

Sewage and sewage effluents from the various stages of purification can contribute faecal organisms to raw water supplies. From the results recorded in Table IX it will be observed that high contributions can be expected from sewage in all stages of purification including sand filter effluent, whereas maturation pond effluent can be of exceptionally high bacteriological quality.

The important point to realise is that contamination of raw water supplies with faecal organisms from domestic sewage can be limited

Table IX.—Most probable number faecal *E. Coli* per ml in effluent from the various stages of purification of sewage

Stage of purification	Faecal <i>E. Coli</i> m.p.n. per ml
Settled sewage	368,700
Biological filter effluent	24,700
Humus tank effluent	4,900
Sand filter effluent	2,260
Maturation pond effluent	1

effectively by controlled purification to limits which are compatible with international bacteriological standards for raw water supplies. In this connection it should be emphasised, however, that the effectiveness of sewage treatment processes in removing or destroying enteric viruses is not yet known. Up to 1948 the only viruses known to be present in human faeces were those producing poliomyelitis and infectious hepatitis; since then the presence of more than seventy viruses has been demonstrated. For this reason maturation pond treatment for purified sewage effluents is highly essential where the receiving water serves a source of raw water supply for domestic purposes.

Bacterial contamination of water supplies by factors such as the concentration of population in cities and towns, inadequate sanitation in rural areas, establishment of refuse disposal sites, industrial activity and agriculture can assume quite alarming proportions. The establishment of cities and towns without adequate sanitation can be responsible for heavy bacterial contamination of water supplies with entero-intestinal viruses. During storms run-off waters from these areas are heavily contaminated with faecal organisms. During the dry seasons when the river flow is low, surface waters arising in densely populated areas can become even more highly contaminated, particularly if sanitation is of a low standard. All these points are illustrated by the results recorded in Tables X and XI.

**Table X.—Ncabanga Spruit, East London
Run-off water contaminated with drainage from a Bantu township**

(Most probable number faecal *E. Coli* per ml. sample)

Date	Faecal <i>E. Coli</i> m.p.n. per ml.	Comments
15/1/58	240	Cleansed by thunderstorm
16/1/58	180,000	No further rain
17/1/58	43,000	Light shower
20/1/58	54,000	Before rain
22/1/58	330	After rain
11/4/58	17,000	After 12 hours light rain
12/4/58	160,000	No further rain
14/4/58	180,000	No further rain

**Table XI.—Flow in Umgeni River, Natal, and bacteriological composition
(Athlone Bridge)**

Date	Flow in cusecs	Faecal <i>E. Coli</i> m.p.n. per ml.
20. 2.57	1,370	110
27. 2.57	993	700
6. 3.57	939	1,400
3. 4.57	877	450
1. 5.57	209	90,000
15. 5.57	338	160,000
12. 6.57	234	180,000*
26. 6.57	156	25,000
3. 7.57	201	17,000
31. 7.57	125	60,000
18. 9.57	1,292	200
2.10.57	1,945	3,500
13.11.57	1,008	2,500
11.12.57	950	910

BIOLOGY AND SELF-PURIFICATION

Surface waters carried by rivers and stored in dams constitute by far the most important source of public water supply. These waters, as is evident from information detailed above, are recipients of polluting material contributed by the domestic, industrial and agricultural enterprises of the human population as well as contributions of mineral salts from geological formations. From the point of view of purification and supplying a safe and pure water, the access to raw water supplies of organic substances, of faecal bacteria and viruses, of mineral salts which are toxic to animal and plant life or which can cause secondary pollution by stimulating biological growths such as algal blooms in dams, could have material effects on the design of purification plant and on operation costs. Furthermore, mineral contamination increases the costs of conditioning the purified water for prevention of corrosion and encrustation.

This polluting material plays a significant role in determining the various types of biological life encountered in running and standing bodies of water. Thus polluted waters which reach streams and dams are subject to various processes of decomposition by microscopic organisms and bacteria which develop in the water and a considerable degree of purification results; this power inherent in water to purify itself is a natural process or combination of natural agencies which decompose foreign substances, destroy bacteria and viruses including those which are responsible for water-borne diseases.

The reactions of self-purification operate in the water and bottom zones of both running and standing water though in different degrees of magnitude; in the latter instance the process is frequently described as maturation and the self-purification reactions play a predominant role in the mud zone. These reactions are physical, chemical and biological in

nature, and are closely interrelated and mutually dependent in their function to restore the water and the bed of the river or lake to the natural condition of purity. Through the process of self-purification considerable loads of waste carried in the storm water from cities, towns, industries and agricultural activities could effectively be removed from raw water supplies, thus relieving water purification plants of very heavy burdens ; the process of maturation in raw water storage dams fulfils a very important function in any water supply system in that it represents a definite and important unit in the water purification system. The savings in treatment costs which could be effected by planned maturation in dams is generally disregarded mainly because of the fact that the chemistry, biology and bacteriology of the water sources of a catchment have not been properly surveyed and defined in specific terms.

The process of self-purification is no longer the vague terminology understood only by the chemist and the biologist ; from the civil and chemical engineering point of view it has become a major link in the control of pollution and in the provision of safe and pure water to the community. The economic justification of evaluating a dam site, of constructing the dam and of installing a water purification plant would be incomplete and unsound if the calculations are not based on :

(i) accurate information with respect to the chemistry, biology and bacteriology of the water which would be collected in storage eventually.

(ii) The function of the conservation dam as a natural unit in the purification cycle. Incorrect design of a dam and inadequate capacity to provide for the pollution load (apart from the volume of water) of the catchment area, result in high running costs of the purification plant. In this connection it should be noted that the amount of capital outlay in a water purification plant is not the only important criterion ; thus running costs have to be borne for the entire life of a purification plant ; it may well be that the preparation of the catchment area and the provision of extra capacity and refinements to a conservation dam to permit additional maturation could find economic justification in the reduction of running costs of the purification system.

The degree to which self-purification can reduce the concentration of organisms of faecal origin are illustrated by the data recorded in Table XII.

There are many factors which can interfere with the process of self-purification or rather direct the process along a specific course which causes a deterioration in the quality of a raw water supply. Thus, for example, algal blooms can have serious effects on the taste and odour of the water after purification, on the costs of chemical treatment, on sand filtration and on sterilisation. Furthermore, certain types of algal blooms have

been reported to be responsible for toxic effects such as gastro-intestinal disorders, skin lesions, liver poisoning and, in the case of animals, illness and death; algal toxins which are effective on mammals, birds and fish may survive chemical flocculation, filtration, chlorination and adsorption on activated carbon.

The access of improperly purified industrial and sewage effluents is regarded as the most important factor which may interfere with the normal course of self-purification. Access of an unduly high proportion of sewage effluent, even in a well nitrified and purified condition, to the receiving body of water may also affect self-purification. For this reason, as well as for the purpose of destroying organisms of faecal origin, sewage effluents should be subjected to maturation prior to discharge to a water course or conservation dam.

Table XII.—Reduction in number of bacteria by the process of maturation (m.p.n. per ml)

Stage	Faecal <i>E. Coli</i>
Biological filter effluent	40,000
Maturation pond No. 1 Circuit A	600
Maturation pond No. 2	8
Humus tank effluent	10,000
Maturation pond No. 1 Circuit B	240
Maturation pond No. 2	6

In the above instances the retention period was only 5–6 days. The high degree of bacterial contamination of run-off waters from urban areas and Bantu reserves make maturation an absolute necessity.

Eutrication is essentially due to accretions of nitrates and phosphates from sewage and sewage effluents. The removal of nitrates and phosphates from sewage effluents is still an unsolved problem. In South Africa, with its warm and sunny climate, this is a pressing problem. It is well exemplified by trends in Swiss lakes which have recently been described.

The accumulation of silt, organic debris and foreign materials from densely populated and agricultural areas can also cause outbreaks of excessive biological growths; the practical control of this type of interference is much more complicated than in the case of industrial and sewage effluents; the magnitude of this interference should always be carefully evaluated since it constitutes the basis for economic justification of providing pre-storage facilities, special facilities for reservoir management and control of catchment area.

Raw water supplies which are subject to excessive biological growths, particularly algal blooms, require the provision of special equipment for treatment, and costs of chemicals are high; pre-storage, double filtration and micro-straining are some of the additional stages which have to be provided; special refinements to the flocculation and sterilisation systems are essential to combat taste and odour nuisances.

References

- American Water Works Association. *Water quality and treatment*. New York, 2nd Edition, 1951, p. 297.
- BLACK, A. P. The Chemistry of Water Treatment. *Wat. & Sewage Wks.*, 95, 1948, p. 369.
- BRAUS, H., MIDDLETON, F. M., and WALTON, G. Organic chemical compounds in raw and filtered surface waters. *Analyt. Chem.*, 23, No. 8, August 1951, pp. 1160-1164.
- CUNNINGHAM, MORRISON B. Effect of irrigation run-off on surface water supplies. *J. Amer. Wat. Wks. Ass.*, 45, No. 11, November 1953, pp. 1159-1178.
- DAVIS, J. J. Dispersion of radioactive materials by streams. *J. Amer. Wat. Wks. Ass.*, 50, No. 11, November 1958, pp. 1505-1515.
- DAVIS, J. J., PERKINS, R. W., PALMER, R. F., HANSON, W. C., and CLINE, J. F. Radioactive Materials in Aquatic and Terrestrial Organisms Exposed to Reactor Effluent Water. Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva 1958, Vol. 18.
- DUNSTER, J., H. HOWELLS, H., and TEMPLETON, W. L. *District surveys following the Windscale incident, October 1957*. Second United Nations Conference on the peaceful uses of atomic energy, 1958. A/Conf. 15/P/316/U.K., pp. 296-308.
- ERIKSSON, E. Air-borne salts and the chemical composition of river waters. *Tellus*, 7, 1955, pp. 243-250.
- GABRILEVSKAJA, L. N. Investigations on the hygienic basis of the maximum permissible concentration of Dichlo-diphenyl-trichlorethane (D.D.T.) in the water of reservoirs. *Hyg. and Sanit.*, Moscow, 1953. Also: Zentralblatt für Bakteriologie, I, 155, 1955, p. 498. Water Pollution Abstracts, No. 2359, October 1955.
- GORHAM, E. Atmospheric Pollution by hydrochloric acid. *Quart. J. R. met. Soc.*, 84, No. 361, July 1958, pp. 274-276.
- GORHAM, E. On the acidity and salinity of rain. *Geochim. et cosmoch. Acta.*, 7, London, 1955, pp. 231-9.
- HAYWARD, H. E. The salinity factor in the re-use of waste waters. *Future of arid lands*, pp. 279-290. Publ. by the American Association for the Advancement of Science, Washington, D.C., 1955.
- HENDERSON, C., ROBECK, G. C., and PALANGE, R. C. Effects of low-level radioactivity in the Columbia River. *Publ. Hlth. Rep., Wash.*, 71, No. 1, January 1956.
- HOWELLS, D. H., and SAWYER, C. N. Effect of synthetic detergents on chemical coagulation of water. *Wat. & Sewage Wks.*, 103, No. 2, February, 1956, p. 103.
- HUTCHINSON, G. E. *A treatise on limnology*, I. Publ. Chapman & Hall, London, 1957.
- IVES, J. K. *An investigation of engineering problems of algal removal*. University College, London, November 1952 to October 1954.
- IVES, J. K. Algae in water supplies. *Wat. & Wat. Engng.*, 61, Nos. 737-742, 1957, pp. 293, 339, 387, 432, 481 and 542.
- JAAG, O. Die neuere Entwicklung und der heutige Zustand der schweizer Seen. *Verh. d. int. Verein für theoretische und angew. Limnologie*, 10, 1949, pp. 102-209.
- JAAG, O. Der derzeitige Zustand, der schweizerischen Gewässer, E.A.W.A.G., 1951.
- JAAG, O. Gewässerschutz in der Schweiz. *Das Gas- und Wasserfach.*, 93, No. 6, 1952, pp. 1-8.
- JAAG, O. La crise des lacs et rivières de l'Europe centrale. *Bull. mens. du C.B.E.D.E.*, No. 37, Aug.-Sept. 1953, pp. 157-160.
- JAAG, O. La crise des lacs et rivières de l'Europe centrale. *Bull. français de pisciculture*, No. 177, 1955, pp. 129-140.
- KRUMHOLZ, LOUIS A. Observations on the fish population of a lake contaminated by radioactive wastes. *American Museum of Natural History Bull.* 110, 1956, pp. 277-367.
- MIDDLETON, F. M., ROSEN, A. A., and RUCHHOFT, C. C. Experiences in studying organic taste and odor substances in water, using carbon filter sampling methods. *Proc. Amer. Wat. Wks. Ass.*, 44th Annual Convention, Illinois Section, March, 17, 18 and 19, 1954, Chicago, Illinois.
- MIDDLETON, F. M., GRANT, W., and ROSEN, A. A. Drinking water taste and odour. Correlation with organic chemical content. *Indust. Engng. Chem. (Industr.)*, 48, No. 2, February 1956, p. 268.
- MIDDLETON, F. M., and ROSEN, A. A. *Organic contaminants affecting water quality*. Dept. of Health, Education and Welfare, U.S.A. Public Health Service—Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, February 1956.
- Ministry of Housing and Local Government. *The control of radioactive wastes*. Her Majesty's Stationery Office, Cmnd. 884, November 1959.
- MORRIS, R. L. Radioactive rains and surface water supplies. *Wat. & Sewage Wks.*, 15 September 1959, pp. R-133-R-135.

- PENDLETON, R. C., and HANSON, W. C. Absorption of Cesium¹³⁷ by components of an aquatic community, Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, Vol. 18.
- Robert A. Taft Sanitary Engineering Center. *Technical Report W. 59-3*.
- ROSEN, A. A., and MIDDLETON, F. M. Identification of petroleum refinery wastes in surface waters. *Analyt. Chem.*, 27, No. 5, May 1955, p. 790.
- Sanitary Engineering Research Laboratory. *Report on the investigation of leaching of a sanitary landfill*. California State Water Pollution Control Board, Publication No. 10, Sacramento, California, 1954.
- SAWYER, C. N. Fertilisation of lakes by agricultural and urban drainage. *J. New Engl. Wat. Wks. Ass.*, 61, No. 2, 1947.
- SETTER, L. R., and GOLDIN, A. S. Radioactive fall-out in surface waters. *Industr. Engng. Chem. (Industr.)*, 48, No. 2, February 1956, pp. 251-5.
- SETTER, L. R., and RUSSELL, H. H. Radioactive contamination of the environment in the Cincinnati area. *J. Amer. Wat. Wks. Ass.*, 51, No. 4, April 1959, pp. 449-462.
- SILVEY, J. K. G. Relation of irrigation run-off to tastes and odours. *J. Amer. Wat. Wks. Ass.*, 45, No. 11, November 1953, pp. 1179-1186.
- TAYLOR, C. B. Bacteriology of water. *Nature*, T/192, G., 25 October 1947.
- TAYLOR, E. W. The reservoirs of the Metropolitan Water Board and the influence upon the character of the stored water. *Proc. Internat. Ass. of Theoretical and Appl. Limnology*, 12, 1955, pp. 48-56.
- WHIPPLE, G. C. Revised by Fair, G. M., and Whipple, G. C. *The microscopy of drinking water*. New York and London, 4th Edition, November 1948.
- WILKINSON, R. The quality of rainfall run-off water from a housing estate. Paper presented by the Sessional Meeting of the Institution of Public Health Engineers, London, 17 November 1955. *J. Inst. Publ. Hlth. Engrs.*, April 1956, pp. 70-78.
- WINTER, P. A. D. Die entero-viruskrankheiten in openbare gezondheidspraktijk. *Publ. Hlth. Johannesburg*, 21, No. 12, December 1958, p. 37.
- World Health Organisation. *International standards for drinking water*. Geneva, 1958.
- Various Authors. Der Bodensee. Eine Denkschrift. Published by the *Südwestdeutschen Wasserwirtschaftsverband*, Freiburg/Karlsruhe, December 1953.

THE ROLE OF RIVER FAUNA IN THE ASSESSMENT OF POLLUTION

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It is now well established that a study of the biota can help in the detection and control of the pollution of natural waters ; the purpose of this paper is to discuss the part played by faunal studies where river and stream pollution is being investigated. In cases where clear-cut and complete chemical results are available faunal results are not so necessary, but such instances are rare except where a known effluent enters a stream of known volume and rate of flow. Faunal data can be valuable in the following circumstances :

(a) In cases of toxic pollution such as by heavy metals and agricultural poisons

- (i) where toxic matter is not suspected,
- (ii) where toxic matter is not detectable by normal chemical tests,
- (iii) where toxic matter is added intermittently.

The effect in these cases would be the disappearance of the whole fauna or the more sensitive species, or stunting or other adverse effects on the animals present.

(b) In cases of pollution with soluble mineral matter, non-toxic in normal concentrations, such as the salts of alkali metals, alkalis and mineral acids. In most cases the fauna shows little reaction unless the osmotic pressure is greatly raised ; however, large changes in pH can have profound effects. This type of pollution is usually easy to detect chemically but the fauna can prove useful when it is intermittent.

(c) In cases of pollution with insoluble inert matter such as clays, powdered ore, etc. These are usually easy to detect without studying the fauna except when the pollution is intermittent.

(d) In cases of organic pollution, i.e. pollution with soluble or insoluble matter which is readily attacked and oxidised by micro-organisms with a resultant biochemical oxygen demand. A study of the fauna is useful for :

- (i) detecting mild pollution, especially in cases when the organic matter is low in nitrogen,
- (ii) tracing pollution to its source,
- (iii) studies on self-purification, namely, to see if the stream can cope with the organic load or to see if the self-purification is proceeding normally,

- (iv) for the study of long-term effects, for instance to see if counter measures are proving successful or if there is progressive deterioration in river systems. Long-term eutrophication of streams is very difficult to detect chemically but is very important to water users.

Organic pollution is usually very easy to detect from the faunal associations and acts in the following ways :

- (1) By adding organic nutrients—this results primarily in abnormal growths of bacteria, protozoa and other micro-organisms with the appearance of larger organisms feeding on such growths or directly on the organic matter.
- (2) By adding soluble inorganic compounds of nitrogen and phosphorus which are usually breakdown products of organic matter, these result in algal growths and associations of fauna which feeds on them.
- (3) By causing oxygen depletion ; de-oxygenation results when the biochemical oxygen demand overtakes the re-oxygenation rate. The depletion may be periodic but, in any case, only low-oxygen resistant forms can survive.
- (4) By producing pH changes. Heavy photosynthetic activity can produce wide pH fluctuations in the pools of slow-flowing streams. At a point in the Swartkops River, Uitenhage, the pH was raised during the day from *c.* 7·6 to 9·5.
- (5) By reducing the clarity of the water. Many animals cannot tolerate suspended matter of various types.
- (6) By fouling the substratum ; this is linked with point 1 and can occur with very little organic pollution. Some organisms are very sensitive and may disappear, others are more tolerant and might even benefit specially when the fouling material is organic (e.g. *Tubificidae*).
- (7) By affecting the current speed or the water flow over and through various habitats. This is linked with point 6. The water flow can be stopped altogether through certain microhabitats.

BACKGROUND KNOWLEDGE

Before any effective use can be made of a knowledge of faunal changes during pollution, considerable background knowledge of the normal faunal associations is necessary. This involves detailed studies on rivers and streams in all their reaches from the mountains to the sea ; the fauna of all the main habitats has to be taken into account, stony bottoms, sandy and muddy bottoms, aquatic and marginal vegetation, and all of these in fast and slow-flowing sections, runs and pools.

In South Africa, as in most regions of sub-continental size, the effects

of geography must be taken into account. Here the fauna appears to consist of four main elements :

- (i) A temperate climate element—found in the high veld and cooler coastal regions, with mountain, foothill and plain species.
 - (ii) A tropical to sub-tropical element, continuous with the fauna of East and Central African lowlands—found mainly in the low Veld of the Transvaal and Natal coastal districts.
 - (iii) A Western Cape element—limited mainly to the acid streams in that region which run off Table Mountain sandstone formations.
 - (iv) A ubiquitous element—found in all parts of the country where habitats are suitable.
- (i), (ii) and (iv) are probably all part of one fauna.

Once the geographical conditions are established, the river or stream zone and the habitat defined, it should be possible to predict the faunal association. Stream survey work has already made this possible in some parts of South Africa, at least as far as some of the animal groups are concerned.

Unfortunately in South Africa there is another overriding problem which can upset the picture. Faulty farming methods, usually overgrazing, have resulted in extensive soil erosion which is accentuated by the irregular rainfall pattern ; this results in abnormal amounts of sand and clayey silt in many rivers, which are swept along or carried in suspension during floods and deposited at other times. Both the suspensions and deposits can have very detrimental effects on the fauna though some species are more resistant than others.

In all studies it is important to sort the fauna to species though this is not always possible, especially in the case of such groups as chironomid larvae and Tubificidae. In these cases sorting must be to the smallest possible category. Only in this way can the percentage composition of the association be calculated. Where possible, numbers per unit area or relative numbers should also be obtained. A mere list of fauna is of little or no value as the absence of information on relative abundance makes it impossible to distinguish significant species from those which might be strays from other habitats.

EXAMPLES OF FAUNAL INVESTIGATIONS

The following are a few examples of the use of faunal studies in the investigation of pollution.

Mineral Pollution

As explained by Harrison, 1958*a*, gold and coal mines in the Transvaal produce considerable acid sulphate pollution. Where this acid is neutralised by passing over dolomite or other formations containing alkaline substances,

the fauna of the streams is practically normal and appears to be unaffected by total dissolved solids values of 1,450 mg/lit., mostly sulphates. However, when the pH is constantly below 6 characteristic associations appear. These are still more characteristic at pH values below 5 and a fauna was found in stream with a pH which was constantly of the order of 2.9 to 3.1.

The presence of the characteristic fauna indicated that the pH was constantly acid. When the pH fluctuates from these very acid values into the alkaline range neither the acid nor the normal association can become established, the stream may be practically devoid of all fauna or contain a few resistant forms. Oliff, 1960b, reports such a condition in the coal mining district of Natal.

In these cases faunal results indicate conditions which could only be established chemically by continuous readings over a long period.

Organic Pollution

Mild Organic Pollution

A survey of the Great Berg River in the Paarl-Wellington region, Western Cape Province, though incomplete, showed how faunal studies can indicate mild, though important, pollution even when snap chemical tests showed practically nothing. See map (Fig. 1).

Fish kills had been reported during spring, summer and autumn, i.e. during the dry season, as this is a winter rainfall area. It was suspected that organic pollution was entering from food factories, wineries and a sewage works.

Station 1 (Fig. 1) was above the sources of pollution, station 2 was below the entry of effluent from factories and street run-off from Paarl; it was placed at the sewage works but no effluent was seen to run into the river. Station 3 was just below Wellington which did not seem to contribute appreciably to the pollution, station 4 was about twelve miles below Wellington.

As will be seen from Table I, snap chemical samples revealed practically nothing except for a dissolved oxygen value of zero at Wellington in March 1952. The sample was taken in a large pool crowded with fish when the river was extremely low, and certainly did not reflect general conditions. Figs. 1 and 2 show that the fauna reacted strongly to the very mild pollution. A more detailed description is given by Harrison, 1958b.

It is interesting to note that the faunas of the two habitats studied, stony stickles and trailing marginal vegetation, did not react in the same way to the pollution, and at certain times, when the one was normal the other was abnormal. In summer when the flow was very slow and the added nutrients resulted in the growth of micro-plankton in the larger pools, the fauna of the marginal vegetation showed very little qualitative change, even at station 3 where fish kills were recorded. On the other hand the

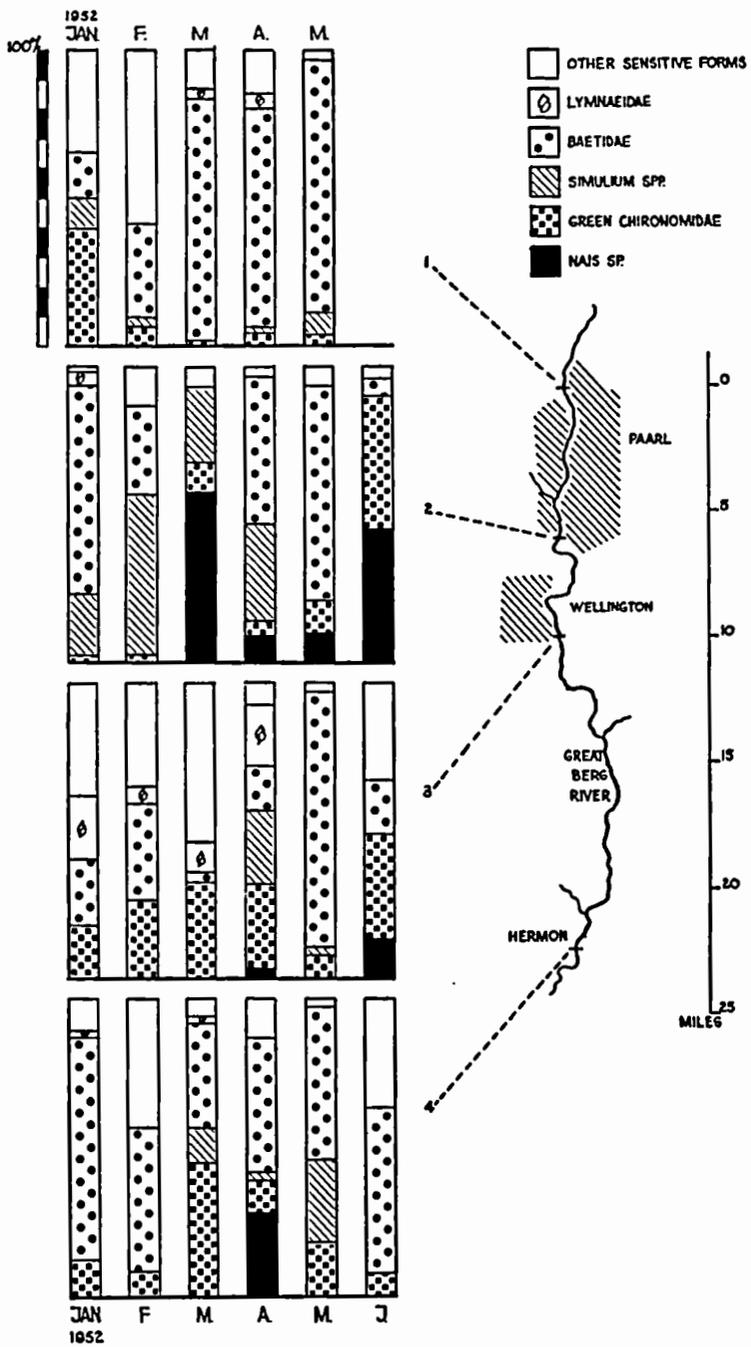


FIG. 1.—Great Berg River—Fauna of Marginal Vegetation.

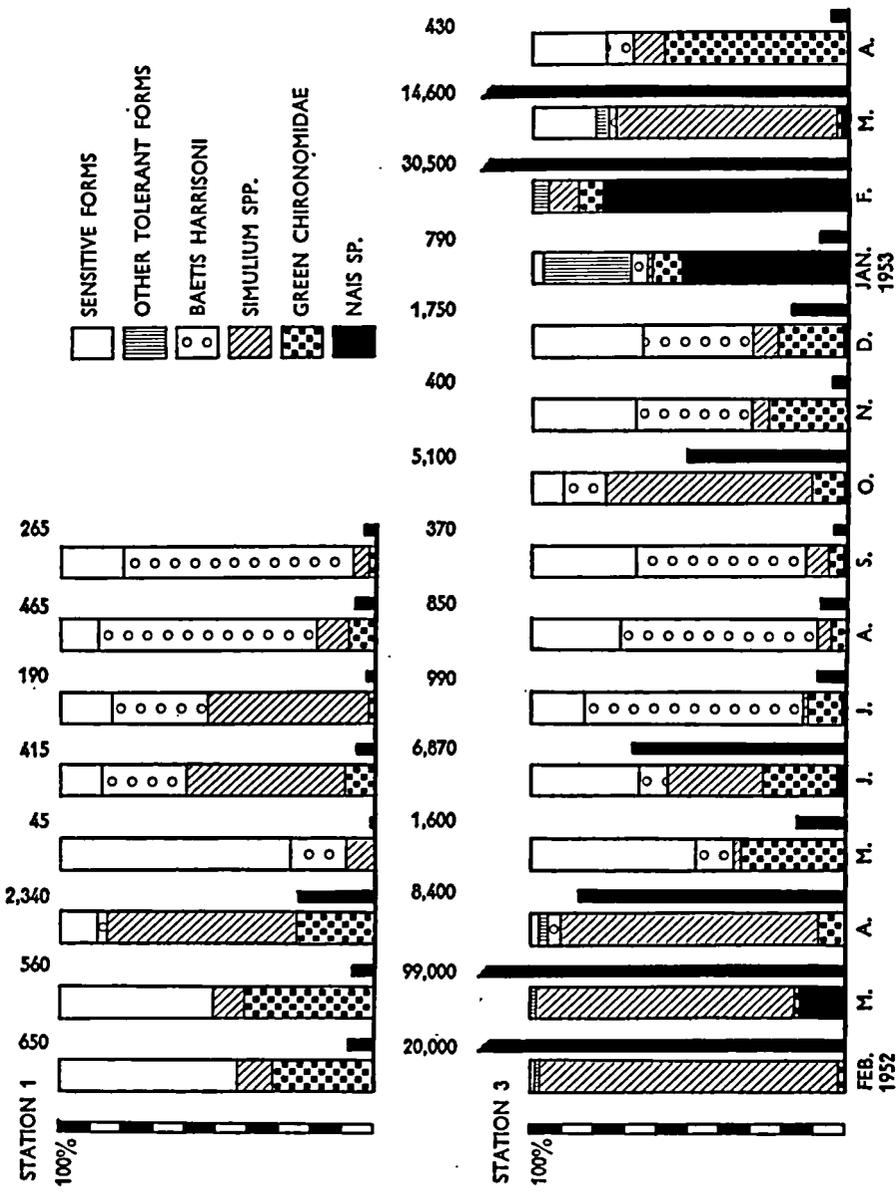


FIG. 2. Great Berg River—Fauna of Stony Runs. (% and Nos./sq.m.).

fauna of the stony stickles reacted strongly, both quantitatively and qualitatively. It is possible that the fauna of the marginal vegetation also increased in density but no measurements were made; however, rough observations indicated little difference from other times.

Fauna of Marginal Vegetation (Fig. 1)

During January and February 1952, when the river was very low, the fauna was very much the same at all stations except for a drop in the percentage of sensitive forms at station 2 and a rise in the proportion (and density) of snails at station 3. With some freshening of flow in March the fauna was upset at station 2 as the small worm, *Nais* sp., became prominent, but recovery was rapid (station 3). *Nais* was not a constituent of the normal fauna. In April the presence of *Nais* showed pollution at all three lower stations. The source of the rather temporary pollution at station 4 was not traced. Pollution effects were more noticeable during June and were probably largely due to street run-off although there were also reports of a sewer leak. The fauna at station 2 consisted mainly of *Nais* sp. and green chironomid larvae (mainly Orthoclaadiinae), the latter are normal constituents of the fauna but benefit from mild organic pollution if oxygen level remains normal. Recovery was partial at station 3 and complete at station 4.

Fauna of Stony Stickles (Fig. 2)

The fauna at station 1 was normal and that at station 3 indicated the pollution. Data from station 2 was incomplete and there were no stony stickles at station 4.

The summer pollution was clearly shown during both years. During February and March 1952, enormous numbers of *Simulium* spp. (mainly *S. adersi* Pom.) appeared, probably encouraged by abnormal growths of nannoplankton; conditions were worse in March when some *Nais* appeared. At this time some fish died at station 3. The winter pollution, June 1952, is also shown by an increase of those normal constituents of the fauna which benefit from mild pollution, and the appearance of *Nais* sp. Similar conditions appeared in October. Summer pollution appeared again in December 1952 to March 1953. The effects were not the same as during the previous year, except in March, as the river flow was lower. It will be noted that in January the composition of the fauna was upset without a significant change in the faunal density, the increase came in February.

Both Fig. 1 and Fig. 2 show that, using the faunal results from these two habitats, it was easy to detect the mild pollution and, if more stations had been worked, it would have been possible to trace it to its source.

Serious Pollution in the Krom Stream, Stellenbosch

In this case pollution from wine distilleries was suspected, during the pressing and distilling season from February to May. Table II and Fig. 3

Table I.—Water Analyses from Great Berg River

	Station	1952 January	March	April	May	June	November	1953 January	February	March
Flow, acre-feet . . .	3	898	2,134	2,840	27,295	11,779	11,953	458	64	586
Ammonia nitrogen ppm N . . .	{ 1 2 3 4	0·000 0·196 0·086 0·006	0·038 0·236 0·056 0·072	0·006 0·070 0·142 0·003	0·018 0·066 0·082 0·056	0·060 0·086 0·133 0·083	0·034 — 0·050 —	0·028 — 0·060 —	0·008 — 0·064 —	0·022 — 0·068 —
Albuminoid nitrogen ppm N . . .	{ 1 2 3 4	0·054 0·112 0·094 0·060	0·070 0·220 0·302 0·130	0·044 0·080 0·094 0·067	0·066 0·096 0·145 0·074	0·086 0·108 0·159 0·080	0·080 — 0·116 —	0·084 — 0·146 —	0·094 — 0·318 —	0·034 — 0·180 —
Nitrate nitrogen ppm N . . .	{ 1 2 3 4	0·15 0·44 0·49 0·08	0·19 0·11 0·26 0·13	0·10 0·12 0·17 0·10	0·10 — 0·11 0·13	0·05 0·05 0·12 0·13	0·06 — 0·18 —	0·07 — 0·03 —	0·09 — 0·13 —	0·09 — 0·12 —
Oxygen, % saturation . .	{ 1 2 3 4	93 88 79 89	100 89 0 86	92 84 84 91	92 88 86 86	97 82 79 87	89 — 88 —	100 — 86 —	95 — 68 —	94 — 72 —
B.O.D., ppm.	{ 1 2 3 4	0·20 0·30 1·80 1·57	1·50 2·60 — 1·40	0·50 2·50 0·80 1·20	0·40 1·00 3·00 0·80	0·70 0·50 0·50 0·80	1·10 — 1·30 —	1·60 — 2·80 —	1·20 — 5·75 —	0·80 — 2·00 —

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No pollution was detectable in the samples for the months not shown.

Table II.—Water Analyses from Krom, Stations 2 and 3

	Station	1952 August	September	October	November	December	1953 January	February	March	April
pH	2	7.4	7.2	7.5	7.4	6.8	6.8	6.7	6.6	6.8
	3	7.1	7.3	7.4	7.4	7.1	7.0	6.5	4.8	6.8
Total alkalinity as CaCO ₃ , ppm	2	36.0	37.0	42.0	39.0	47.0	29.0	17.0	34.0	35.0
	3	36.0	33.0	34.0	38.0	29.0	59.0	27.0	nil	37.0
Total acidity, ppm	3								100	
Ammonia nitrogen as ppm N	2	0.060	0.306	0.082	0.050	0.278	0.030	0.042	0.310	0.110
	3	0.076	0.000	0.110	0.022	0.026	0.024	0.020	0.800	0.074
Albuminoid nitrogen ppm N	2	0.179	0.418	0.190	0.142	0.248	0.096	0.186	0.430	0.188
	3	0.179	0.500	0.190	0.127	0.108	0.104	0.116	1.420	0.248
Nitrate nitrogen as ppm N	2	0.27	0.23	0.25	0.32	0.63	0.24	0.08	0.70	0.83
	3	0.19	0.18	0.25	0.85	0.39	0.26	0.08	0.17	0.86
Dissolved oxygen ppm	2	9.4	8.2	8.7	8.0	7.3	7.7	5.3	5.2	9.0
	3	8.6	8.4	8.6	7.7	8.4	6.9	4.6	2.0	7.6
Dissolved oxygen % saturation	2	88	78	88	88	80	87	60	56	88
	3	81	80	87	85	94	77	53	22	74
Biochemical oxygen demand, ppm	2	0.80	5.60	0.80	1.70	3.10	1.80	5.30	5.20	4.20
	3	6.25	5.40	3.70	1.60	3.10	5.30	3.80	2.00	7.60

No pollution was ever detectable chemically at Station 1.

give the relevant results, more details are given in Harrison, 1958b. Station 1 was about one mile above the town of Stellenbosch; as no pollution was detected the chemical results are not given in Table II. Station 2 was opposite the town which lies only on one bank of the stream; it was situated below the entry of a storm water drain and a drain bringing in returned irrigation water which had come through the town in open furrows. Station 3 was about half a mile below station 2, it was below the entry of an open furrow carrying returned irrigation water through the town, and also immediately below the distilleries.

Table II shows that pollution was detected chemically by slight rises in nitrate nitrogen in November, December and April, a slight rise in free and saline ammonia nitrogen in March, low dissolved oxygen figures from January to April at station 3 and high biochemical oxygen demand figures in August, September and January to April. Distillery effluent lowered the pH at station 3 to 4.8 in March and a test for tartaric/citric acid was positive. From the dissolved oxygen figures it would appear that conditions were at their worst at station 3 in March. However, as the stream flowed rapidly over stones, aeration was usually very efficient.

The fauna at station 1 can be considered as normal (Fig. 2) and it will be seen that there was a "pollution fauna" at the two lower stations during the whole period, although chemical figures did not always indicate pollution. This pollution appeared to originate from the storm water drains and the irrigation furrows and must have been intermittent. The fauna was much more seriously disturbed than in the Great Berg River as Tubificidae and aquatic "earth worms" appeared.

When distillery effluent began to enter in February, conditions became bad at station 3 and during March and April could be classified as "polysaprobic" as all the normal fauna was replaced by Tubificidae, other Oligochaeta and other pollution indicators such as the "sewage fly", *Psychoda alternata*. Polysaprobic conditions, or heavy organic pollution, were not obvious from the chemical results as the organic matter discharged was low in nitrogen and because of the efficient natural aeration in the stream. However, in the Eerste River into which the stream flowed, conditions sometimes deteriorated badly, fish kills occurred and farmers complained of the poor quality of the water.

A similar type of pollution is reported by Oliff, 1960a, in the Little Bushmans River, Natal. Effluents were from a hardboard factory and a powdered milk factory. Again the fauna was considerably upset though chemical results indicated little as the effluents were very low in nitrogen.

Organic Pollution of Eutrophic Streams

As already pointed out, one of the main uses of faunal studies is the detection of relatively mild or intermittent organic pollution. As the organic pollution adds nutritive matter, it naturally has its greatest effect on very

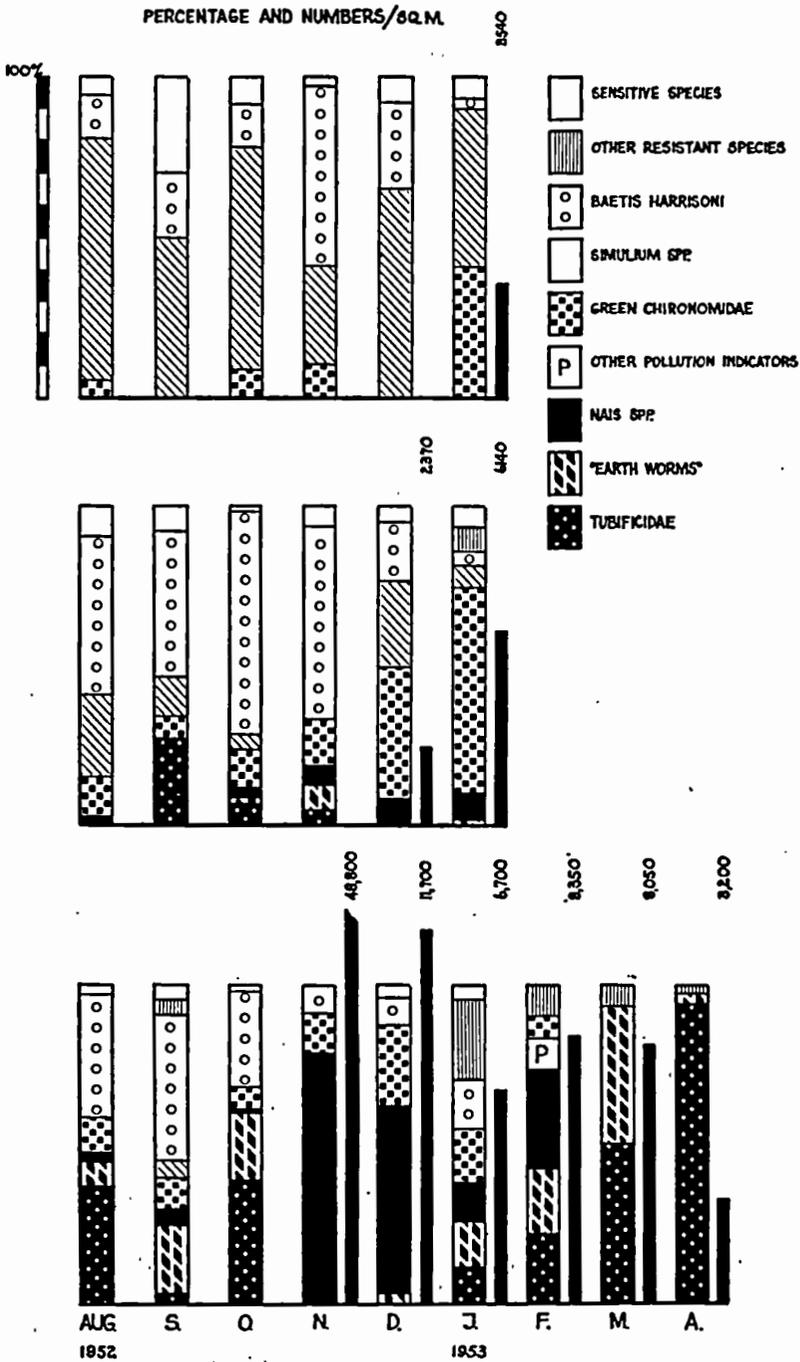


FIG. 3.—Krom Stream, Stellenbosch—Fauna of Stony Runs.

clean (oligotrophic) streams; here the faunal association is specialised for conditions where algae and other types of basic food material are relatively sparse, the water is clear, surfaces are clean and the dissolved oxygen is constantly not far from 100% saturation. Streams in mountain regions are examples of this type where even the slightest addition of organic matter will bring about profound changes.

When streams run through rich agricultural regions the presence of appreciable amount of nutrients, even of dissolved nitrates, is the normal order of things. These streams may be said to be, or to be becoming, eutrophic. In these cases the faunal associations are those which would indicate mild organic pollution in oligotrophic streams. The entry of an organic effluent, unless it is very strong, becomes harder to detect.

This was the case in the Swartkops River near Uitenhage. This small stream was studied in September 1958, and the fauna of the stony runs in the stretch near Uitenhage is given in Table III. Station 1 was just above the town and above all sources of serious pollution, here the stream was eutrophic; no chemical samples were taken in September but in February 1959, nitrate nitrogen content was 0.1 ppm, the biochemical oxygen demand lay between 3 and 4 ppm and photosynthetic activity produced a dissolved oxygen range of 80 to 120% saturation. Station 2 was below the entry of an effluent from a wool washery, nitrates were 0.2 ppm and the oxygen ranged from 50 to 122% saturation. Station 3 was about 1 mile below this but before the entry of further effluents, chemical figures were similar to those at station 1. Station 4 was near 3 but just below the entry of the effluent of humus tank effluent from the Uitenhage sewage works, nitrates were 13 to 15 ppm, ammonia nitrogen 5 to 13 ppm and oxygen nil to 30% saturation. Station 5 was about 1 mile below this, nitrates were about 7 ppm, ammonia 2 ppm and oxygen 20% to 100% saturation. Station 6 was about 1 mile further down and chemical conditions were much the same as at station 1. No further effluents entered below station 4. All chemical figures are for February 1959, the September figures would have been much the same.

Table III shows that the fauna at station 1 was already an eutrophic one, note the presence of *Nais* sp. and the absence of mayflies. The wool washery effluent was not detectable chemically but, nevertheless, changes were noticeable at station 2; note the absence of planarians and *Simulium* larvae, and the reduction in the proportion (and number) of snails.

There was recovery at station 3. The sewage works effluent entering at station 4 was well oxidised and did not contain enough organic matter to produce growths of "sewage fungus" or Tubificidae in the stony runs. However, faunal changes were observable; note the disappearance of planarians, *Simulium* larvae and snails, and the appearance of *Dero* sp. (Naididae) and *Paracyclops poppei*, the latter probably entered with the sewage effluent. The data from stations 5 and 6 show the course of the

Table III.—Fauna of Stones in Sticks, Swartkops River

	Station					
	1	2 (below effluent outfall)	3	4 (below sewage outfall)	5	6
	%	%	%	%	%	%
<i>Hydra spp.</i>	0·9		9·8			
<i>Planarians</i>	0·9		5·3			2·4
<i>Nematoda</i>	13·8	14·4	6·1	6·8	4·4	1·2
<i>Prostoma sp.</i>	2·8		5·3	0·3		0·5
<i>Nais</i>	0·5			20·4	0·3	
<i>Nais sp.</i>	30·3	68·6	28·1	21·5	62·2	71·3
<i>Dero sp.</i>				11·4	2·8	
<i>Cyclops spp.</i>	7·8	0·5		24·7	7·5	1·5
<i>Paracyclops poppei</i>	0·6			7·3	1·2	
<i>Cypridopsis</i>	2·5			0·9	1·6	4·4
<i>Simulium larvae</i>	0·8		0·4			2·6
Chironomidae						
<i>Cricotopus scottae</i>				3·2	7·2	0·7
<i>Cricotopus spp.</i>	mostly				0·1	mostly
<i>Chironomus sp.</i>					2·2	
<i>Other Chironomidae</i>	28·1	14·1	29·8	1·9	9·4	9·2
Snails						
<i>Burnupia stenochorias</i>	7·6	1·7	11·0		0·1	5·0
<i>Total Snails</i>	7·8	1·8	11·4		0·1	5·1
Total numbers in sample	5,164	6,560	1,960	2,944	7,584	16,640

recovery which went with the virtual disappearance of the extra load of nitrates and ammonia from the water. A diatom study (Cholnoky, 1960), gave a clearer picture, especially of the effects of the nitrogen compounds entering with the sewage effluents.

LONG-TERM STUDIES

Possibly more important than the use of faunal (and algal) data for the assessment of specific instances of pollution is their use for a long-term watch on the deterioration or improvement of streams and rivers. Stream surveys all over the country have shown which faunal associations and species are typical of streams unaffected or little affected by human agencies. In these the water is very clean and presents little or no difficulty as a water supply, either direct or impounded. However, in other streams and rivers the fauna indicates a deterioration from these satisfactory conditions. The changes are often very difficult to measure chemically and are usually the result of the combination of adverse factors such as silting, the entry of small amounts of nutrient matter from farm lands, pollution from cattle, incidental faecal pollution and street run-off. This results, in extreme cases, in a fauna such as seen at station 1 of the Swartkops River, Table III, where a large part of what would be the normal fauna has been practically eliminated. In less extreme cases only the more sensitive species disappear.

Observations have shown already that many species which are now considered "mountain" or "upper river" species can live at lower level but have been driven out by the eutrophication process. Water from eutrophic streams is liable to be difficult to handle in water purification plants and on impoundment because of taste, odour and filtration problems.

An example of what can happen was seen during a recent survey of a few streams in the mountains of the Eastern Transvaal. It was found that in many of these streams "mountain" species had virtually disappeared. This was because most parts of the region are accessible for cultivation, grazing, forestry and mining; the fauna showed that deterioration of water quality had begun already even at the mountain source.

References

- CHOLNOKY, B. J., 1960. Beiträge zur Kenntnis der Ökologie der Diatomeen in dem Swartkops Bache nãhe Port Elizabeth (Südost-Kaapland). *Hydrobiologia*, in press.
- HARRISON, A. D., 1958a. The Effects of Sulphuric Acid Pollution on the Biology of Streams in the Transvaal, South Africa. *Verh. internat. Ver. Limnol.*, 13, pp. 603-610.
- HARRISON, A. D., 1958b. Hydrobiological Studies on the Great Berg River, Western Cape Province. Part 4 : The Effects of Organic Pollution on the Fauna of parts of the Great Berg River System and of the Krom Stream, Stellenbosch. *Trans R. Soc. S. Afr.*, 35 (3), pp. 299-329.
- OLIFF, W. D., 1960a. Hydrobiological Studies on the Tugela River System. Part II. Organic Pollution in the Bushmans River. *Hydrobiologia*, in press.
- OLIFF, W. D., 1960b. Hydrobiological Studies on the Tugela River System. Part III. The Buffalo River. *Hydrobiologia*, in preparation.

THE TECHNIQUES AND OBJECTIVES OF STREAM SURVEYS

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ABSTRACT

The study of river systems, especially in relation to water pollution, has been widely accepted as a means whereby the effects of effluent discharges of one sort or another may be evaluated either on the chemistry and physics or biology of river systems. In recent years, however, this type of study has fallen into disfavour, especially in the United Kingdom and Europe, as it was felt that purely descriptive studies would not be useful in the accurate assessment of the effects of effluent discharges into river systems.

Experience in South Africa has shown, however, that these surveys, provided they are carried out exhaustively, do play a most important role in the assessment of pollution effects. In this paper the author points out the many omissions, especially with regard to technique and objectives, that have been made in the past which were largely responsible for the criticisms levelled at the data from river surveys. In addition, careful note is taken of sampling techniques, especially of the fauna of particular habitats found in rivers and used in the determination of faunistic changes due to the pollution of South African rivers.

THE RELATIONSHIP BETWEEN ALGAE AND THE CHEMISTRY OF NATURAL WATERS

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As far back as 200 years ago, i.e. at a time when algological research was in its infancy, it was discovered that certain kinds of algae lived in salt water, and others in fresh water.

Mention of this fact in contemporary literature was, however, confined to particulars about distribution and locality, and it was only later recognised that a third group of algae preferred the mixed waters round the coasts.

During the twenties of the present century, after an impetus had already been given to hydrobiology, detailed research and systematisation were found necessary in order to clarify the earlier very obscure ecological definitions, and at the same time to lay the foundations for a more scientific approach to the problem of salt-content in relation to locality.

Kolbe's investigations in 1927 in the Spereberg salt district and his later synopsis of generalisations based on these investigations (Kolbe, 1932), gave rise to the so-called "halobitic system". In this system the algae were arranged in groups designated polyhalobitic, mesohalobitic and oligohalobitic according to their having found their optimum environment in a high (sea water) or medium (brackish water) salt concentration, or in salt-free waters. The hypothetical explanation of the cause of this phenomenon was put down to the chemical influence of the chloride ion. The Cl-ion was thus the yardstick of ecological character of the species and the locality, and this was punctiliously stated in all papers dealing with the subject.

Until recently, the salt-content factor was regarded as the main cause of differences in the distribution of algal species (to mention only one example cf. Patrick, 1948), though it should have been apparent that in biotopes with an identical salt content, the algae were not uniformly distributed, but on the contrary, an almost unlimited variation of different associations could be found.

This discrepancy, which made the reconciliation of certain aspects of the halobitic system impossible, created one of the biggest arguments against acceptance of the system, and this in turn led to a more exhaustive study of the organisms that lived in brackish water. This in turn produced a starting point for the elucidation of new difficulties. Kolbe's observations showed that the algal associations or communities in the Spereberg district were similar to those found in coastal waters, such as in estuaries or in

* Translated by H. Welsh.

river mouths, in spite of the fact that at Sperenberg it was not a question of diluted sea water but rather of an almost pure NaCl solution. At the same time it became known that the algal associations of the shallow soda lakes of Hungary corresponded with those of Sperenberg and of the sea coasts, although here there were only carbonates and no chlorides at all (Cholnoky, 1929). In this way, the value of the Cl-ion as a means of determining the distribution of the algae was found wanting. Instead, it was necessary to seek an explanation by substituting the physical property of the various waters, namely, differences in osmotic pressure, which would be independent of the chemical composition of the salts.

Under the then existing conditions, no exact investigation could be made of the chemical composition and concentration of the salts. However, a gratifying opportunity to continue these enquiries occurred when it was decided to investigate the Jakkals, a brook in the Western Cape (Cholnoky, 1955a). Here it was possible to determine exactly what had only been suspected in Hungary, namely, that these brackish waters, in which the algal associations were so similar to those of estuaries, did not, as far as their salt content was concerned, occupy an intermediate position between sea water and fresh water, but on the contrary, their degree of concentration was several times that of sea water. In samples taken from the Jakkals during the summer a 2-mol. concentration of sodium carbonate was found; nevertheless, the algae which were found in it corresponded completely with those which are to be found in sea water that has been diluted to a brackish water.

It followed from this and many other similar observations that it was not the salt content of brackish water, nor even the static value of the osmotic pressure, that was responsible for the growth of characteristic species, but the dynamic fluctuations of osmotic pressure.

Where the osmotic pressure remains relatively high and constant, there one will find sea water associations, corresponding to Kolbe's polyhalobes. But if there is no osmotic pressure to speak of in those waters, or only a slightly measurable one, then one will expect to find fresh water algal associations, or the so-called oligohalobes. If the osmotic pressure is subject to fluctuations, then conditions become favourable for a brackish water association, or, as Kolbe would say, one suitable for mesohalobes.

This effect of the dissolved salts is a mere physical one, dependent on the osmotic pressure, and has been proved by cyto-physiological experiments in which the inhabitants of brackish water showed an unusually high degree of permeability to the salts mentioned already (Cholnoky, 1928 *et seq.*). But this conclusion does not mean that henceforth the chemical composition of the salt molecules can be completely disregarded. It only implies that this composition does not play a decisive role in the determination of the distribution of the algae, but only a subordinate one.

Although certain species which do not thrive in sea or brackish water

will always be found in carbonate solutions (Hustedt, 1959a and 1959b), investigations in this direction have only been of a floristic nature, as the dynamic osmotic pressure fluctuations in those waters remain unknown. In these circumstances, at the present time one cannot speak with certainty of species that are characteristically carbonate-loving or chloride-loving.

From this point of view, the investigation of South African brackish waters would be very significant, not only because of the part played by the salts already mentioned (as well as sulphides and fluorides), but because the significance of the ecological role of selective permeability could be established (Hofler, 1931). The practical value of such investigations as far as they concern the evaluation of water quality need hardly be emphasised.

During the short history of biology, a similar big change in the interpretation of the significance of the Ca-ion has taken place. It now appears more and more clear that calcium compounds as such play an insignificant part, especially as those that generally occur in nature are not at all or only slightly soluble in water. On the other hand, a bicarbonate is formed from the calcium contained in rocks such as limestone and dolomite, in the presence of the CO₂ dissolved in the water. This bicarbonate is easily soluble and constitutes a buffering system. This system is so well known and understood that it is superfluous to describe it more fully here, but mention should be made of the fact that it is widely upset by the assimilation of CO₂ which leads to fluctuations in the pH. Now the pH is of very great importance to submerged plants (of which the algae are the principal representatives), for their absorption of the dissolved nutrients, important for their life processes, depends on the one hand on the pH value of the environment, and on the other on the isoelectric points of the protoplasm of the species in question. The value of the isoelectric points varies with the species, and so the pH of the environment is vitally instrumental in determining the composition of the algal community.

It was only in the second quarter of the present century that the part played by calcium was discovered (cf. for example, Iverson, 1929; Nygaard, 1938), and systems evolved in which the algae were arranged according to the pH (cf. Hustedt, 1937-9; Jørgensen, 1948, etc.). Hustedt recognised five categories, which he calls alkalibiontic, alkaliphile, indifferent, acidophile, and acidobiontic, and in which "indifferent" is taken to mean those organisms which find their optimum around pH7. They are thus actually not at all "indifferent" as they are sensitive to an acid as well as a basic environment.

A careful study of European and American natural waters, especially that of the lakes, had shown already, even before these systems were evolved, that the pH values were not constant and fixed, nor could they be (cf. Ruttner, 1952: 57 *et seq.*; or Sernow, 1958: 278 *et seq.*). However, the system was categorised with hypothetically rigid boundaries expressed by

the terms "alkalibiontic", "alkaliphile", etc., although these could not be reconciled even from the very beginning with conditions as they actually occurred in nature (cf. for example, Hustedt's ecological characterisation of the species in Hustedt, 1937-9).

It was significant that the pH conditions of those waters with a high calcium content, namely those that were well buffered, were radically different from those that were poorly buffered. This is due to the fact that the possibility of fluctuations is much greater in poorly-buffered water than in well-buffered. The neglect of the alkalinity therefore led to erroneous conclusions and contradictions—which can often be seen even in present-day limnological literature.

The significance of the buffering, especially as regards its effect on the range of possible pH fluctuations, became apparent during the investigation of some poorly (gaseously) buffered water from the neighbourhood of Rustenburg. In this case, the water, which flows over quartzite, is unable to take up any calcium (cf. Cholnoky, 1957). Another investigation concerned a well-buffered swamp, namely the Olifantsvlei (cf. Cholnoky, 1958; Harrison, Keller and Dimovic, 1960). The extensive differences in the algal associations of these two waters (which have similar pH values), is due mainly to the fact that in the first case the pH is unstable, and in the second it is constant.

Although Knudson's work on the English Lake District (cf. Knudson, 1954) clearly showed the strong influence of differences of alkalinity where the pH remained steady, little importance had previously been attached to the influence of alkalinity.

Every carefully undertaken investigation has shown that the pH—as well as the salt content of brackish water—influences the distribution of the algae by means of its dynamic fluctuations. One should bear in mind that it is the magnitude of the deviation from the mean pH, i.e. the range, which determines the algal associations. Failure to grasp this point, which might be called the "dynamic conception", is the reason why some phenomena connected with the distribution of the algae are associated with very hypothetical and anthropomorphised assumptions which in reality can have no bearing on the problem. Thus, it is frequently asserted that organisms living in weakly-buffered, acid waters are "mountain forms" or "boreal-alpine forms", in spite of the fact that algae living submerged in water are obviously unaffected by "height above sea level". It is also obvious that the terms "boreal" and "alpine" biotopes are ecologically so distinct that the two cannot be coupled together at all. It is thus not surprising that organisms were found in Africa, right into tropical regions (cf. Hustedt, 1949), which had previously been described as "boreal-alpine". In reality, what they required is a constantly low pH value as an essential condition for thriving (cf. Cholnoky, 1955).

On the other hand, we find the most strongly buffered, alkaline waters

in the vicinity of the coast (especially in Europe). We thus find here those algae that habitually live under alkaline conditions, especially if they happen to be unresponsive to a slight increase of osmotic pressure, namely, "brackish water forms". In South Africa, however, a number of such species are found in alkaline but absolutely fresh water. They can thus be recognised as inhabitants of constantly alkaline waters.

The previously described effects of the dissolved salts and of calcium are thus seen to be of a physical nature, as on the one hand they influence the osmotic pressure and on the other the pH. But those molecules which serve or could serve as plant nutrients, and which are capable of being not only absorbed into the cell but of being modified according to its requirements, act in a more purely chemical manner.

As a result of the classical investigations of von Liebig, Pfeffer and Sachs, the nutritional processes and the nutrients of higher plants became known, and to this very day it is generally assumed that the nutritional requirements of the algae are identical with those of the higher plants. Although little was known about the origin and cycle of the nutrients, it was assumed that those molecules which were of the greatest importance to the higher plants, were also of the greatest importance to the algae.

The inadequate consideration given to the problem of the nutrition of the algae in the older literature omitted a study of the unequal distribution of nutrients, and did not even consider the possibility that it was not the absolute quantities that counted so much as the molecular form in which they were available.

As far as one of the most important of plant nutrients is concerned, namely, carbon dioxide, this attitude can be justified as the substance is available in unlimited quantities from the air and the respiration of animals and plants, as well as from the buffer system already described. Deficiency phenomena occur only seldom, such as in small bodies of standing water with a profuse submerged vegetation, but such deficiencies only affect the algal life indirectly. In such waters, $\text{Ca}(\text{OH})_2$ is formed from the calcium bicarbonate, thanks to the high consumption of CO_2 . In this way, enormously high pH values are developed, and it is these which actually exert their influence. A particularly high degree of CO_2 saturation appears to have no effect, so long as the necessary quantities of O_2 are available.

The other nutrients, in particular the nitrogenous compounds (of whose role and significance we have lately come to know more), react in a manner different from that of CO_2 .

The nitrogenous compounds which are the nutrients of plants and especially of algae, occur in relatively low concentrations in nature, and higher concentrations of these compounds can usually be ascribed to human, i.e. unnatural agencies. For a long time, the manner in which differences in concentration of nitrogenous compounds acted as a factor affecting the distribution of the algae remained unrecognised, and until

the researches of Einar Nauniann it was generally held that nitrogen, even when it occurred as a constituent of polluted water, played no decisive role.

Kolkwitz and Marsson, and later Kolkwitz (1950), followed one year later by Liebmann (1951), who took over their ideas *in toto* without making any significant improvements, completely ignored the nutritional factor of polluted waters, and instead they set up an hypothesis by which they sought to explain the differences in the distribution of living organisms in such waters. According to this hypothesis, waste products were regarded by the authors as homogeneous, almost as single chemical compounds which in natural waters first underwent reduction and then oxidation, so that self-purification ultimately occurred. Bacteria were tacitly held entirely responsible for these processes. Apart from the bacteria which were alleged to be important, lists of algae and animals were drawn up which were said to be characteristic of the various phases of the purification process. Those which occurred in the reduction zone were called polysaprobies, those in the oxidation zone were mesosaprobies, while those which were able to survive after the oxidation were called oligosaprobies.

This hypothesis does not make it clear why the particular animals and plants are characteristic of the various zones, and upon investigation the actual basis of the division can easily be shown to depend on something other than what the authors have taken into account, namely, reduction and oxidation, so that their categorisation becomes invalid.

First of all, it must be established that the substances which cause the pollution are not homogeneous, and all that they have in common is that they contain many organic nitrogenous compounds, which in turn provide an unusually rich nutrient. Naumann (1932) was the first to recognise the importance of what he called "nutrient content", and this generally meant nitrogen content. On the basis of this knowledge, he divided his natural waters into eutrophic, mesotrophic and oligotrophic regions, and quite rightly pointed out the arbitrary and hypothetical nature of the Kolkwitz system. Naumann's divisions were based on research into Swedish lakes, and they carried with them the correct interpretation of such concepts as "pollution" and "self-purification", for they sprang from the postulate that organisms that thrive optimally in various types of water, also derived physiological advantages from their environment.

Naumann's early death prevented him from developing his realistic conception, and probably for reasons of convenience the Kolkwitz-Marsson hypothesis achieved an unexpected impetus and popularity. This was in spite of the fact that it could never really be reconciled with the findings of research into natural waters, nor could it find any practical application, for example, in the improvement of purification plants.

Research into the South African waters (which are small enough to show the result of pollution quite clearly), together with experiments

carried out at the Pretoria Sewage Works, revealed the untenability of the saprobic system and the correctness of Naumann's conceptions.

The result of high nitrogen content in the Pretoria Bon Accord storage dam (Cholnoky, 1953) was unmistakable. The whole of this dam showed algal associations indicative of a high nitrogen content. But amongst these associations were scattered some that indicated anaerobic conditions (such as one would expect during reduction), thus proving that the associations had no connection with the **degree of pollution** as required by the Kolkwitz system.

In the heavily polluted Jukskei River (Cholnoky, 1958*b*), Olifantsvlei (Cholnoky, 1958*a*), or in the varyingly polluted Swartkops River near Port Elizabeth, as well as in some parts of the Tugela River in Natal, and the Berg River and environs in the Cape, algal associations occurred in the nitrogenous sections which would be labelled "mesoaprobic" by Kolkwitz, but which clearly indicated the connection between nitrogen content and the "meso-" and "polysaprobic" character of the associations. At the Pretoria Sewage Works it was further possible to show experimentally the connection between gradual changes of nitrogen content and algal associations, so that these could actually be predicted.

It became clear from the investigations just described that the "nutrient content", i.e. amount of nitrogenous compounds, was responsible for the types of associations characterised by pollution. But it could not be assumed, as even Wuhrmann (1957) had assumed, that the algae in nitrogen-rich waters consumed only so much of the available compounds as they required for the production of their protoplasm.

The nitrogen exchanges of organisms taking part in the self-purification of natural waters remains, however, unknown, in spite of recent papers (for example, Fogg, 1953) and the comprehensive investigations of Algeus (1946, 1948*a*, 1948*b*, 1948*c*, 1949*a*, 1949*b*, 1950*a*, 1950*b*, 1950*c*, 1951*a*, 1951*b* and 1951*c*).

In collaboration with the author, Saubert (1957) undertook some promising experiments which showed that the algae that were adapted to living in nitrogen-rich waters consume the organic nitrogen compounds, in other words, probably use them partly as sources of energy and so contrive or help to contrive at the self-purification.

This publication unfortunately failed to deal with all the important concomitant effects of the proved deamination, and further investigation of these phenomena will require more experiments. Even so, there can be no doubt that they suffice to refute the Kolkwitz hypothesis, and to prove the correctness of Naumann's conceptions.

In this connection it needs to be emphasised repeatedly that the splitting of the molecules of nitrogenous compounds can only be detected in the case of algae which, according to Kolkwitz's classification, come under the heading of poly- and mesosaprobic. Therefore, only a limited

number of nitrogen heterotrophes can be expected, although these may be regarded with certainty as indicators of ordinary pollution (sewage, stock farming, etc.).

The significance of, and the role played by, phosphorus, which is another important plant nutrient, is only slightly understood. According to Ohle (1953, 1955*a*, 1955*b*, etc.), this element is one of the main causes of the eutrophying of waters and its presence and quantities should help in determining pollution.

As far as the author is aware, however, no reliable ecological studies or laboratory experiments are available in support of this view. It follows that all speculations in this connection should be temporarily regarded as hypotheses only.

Oligotrophic conditions, which are caused by a shortage of nutrients, may also be regarded as a more or less chemical effect. At the present time, little is known about the ecological mode of action of such a shortage or about the metabolic relationships of algae living under such conditions. But it is certain that closer study of such problems might produce very important results. This is borne out by Sioli's researches (1954, 1955, 1957, for example) in which he investigated the chemical conditions of a large oligotrophic area in Brazil with surprising results.

Problems concerning oligotrophy are of particular interest to us in South Africa, as there exist large oligotrophic areas, for instance, those situated on the old sandstone deposits of the higher plateau. Research into the metabolism of algae living in these waters would be of very great theoretical and practical importance, because they somehow have to obtain the nitrogen for the production of their protoplasm.

When investigating the problem of nutrients, it would be a mistake not to take into consideration the question of fluctuations in the oxygen concentration as well. The importance of this gas in the respiration of algae and animals is, however, not confined to the realisation of the hypothetical oxidation previously mentioned which occurs, for example, during the process of self-purification, and which is generally mentioned in the so-called "applied literature", because self-purification is primarily not a pure oxidation process at all. The direct result of O₂-tension is practically unknown, but its ecological importance has recently been investigated in South Africa. It was found here that the speed of movement and turbulence of the water were capable of producing a richness of oxygen in those waters where, owing to the prevailing oligotrophy, the plant life was unable to bring about an O₂ saturation (cf. Chohnoky, 1953, where the problem of breaking waves is discussed; 1958*a*, where the effect of assimilation is considered; and 1958*b* and two works on Natal and the Berg River which are now in press, where the ecological effects of water velocity and depth of water are discussed).

On the strength of those results, it can be stated already that the algal

associations are affected more by the fluctuations in oxygen content than by the mechanical effect of water movement (cf. Cholnoky, 1949). It follows that the greatest care must be taken when using such terms as "rheophile", "aerophile", etc.

Ecological investigations have disclosed a great diversity of algal associations, so that it is probable that other substances, apart from those already mentioned, somehow influence the algae and would help to explain the existing ever-changing picture.

The consequences of the factors which have already been discussed are themselves so little understood—in some cases not at all—that an elucidation of the part played by other and possibly subordinate substances and compounds may be difficult to arrive at. Furthermore, we have mainly only laboratory experiments to go on, and the results of these have scarcely been applied to the ecology of the plants. Most of these experiments are difficult to assess from the ecological point of view, as they concern substances which, though available in the laboratory, may be either entirely absent (alkaloids) or permanently available (silica) in nature, and so may have little real effect (cf. Algeus, 1946, vitamins; Cholnoky, 1930, alkaloids (cocaine); Jørgensen, 1952, 1953, silica; Hofler, 1958, aluminium salts).

As far as ecology is concerned, it would be more important to ascertain the effects of harmful substances, such as phenols, detergents and industrial wastes, as up to the present no such experiments have been made.

Another desirable line of approach would be to investigate the effect of trace elements, as one is inclined to accept the view that when all other factors are equal, different algal associations will occur when the waters flow over different kinds of rocks.

In conclusion, it should be pointed out that the changes in one or other of the factors which have been discussed here need not necessarily bring about the death of one or other of the algal species so long as the changes remain within the limits occurring in nature. On the contrary, these changes will inhibit the multiplication of some of the species originally present, and encourage that of others, so that primarily the association, i.e. the percentage composition, and not the flora as such, will be changed.

I am moved to make this observation at the conclusion of this discussion because it seems to me quite clear that the appearance of individual examples of a species has little ecological significance.

The inevitable inference of this assertion is, however, that the conclusions drawn from mere lists of flora (as is all too often the case) have produced few worth-while results. On the contrary, they have led to mistakes and faulty conclusions.

References

- ALGEUS, S. (1946). Untersuchungen über die Ernährungsphysiologie der Chlorophyceen mit besonderer Berücksichtigung von Indolylessigsäure, Ascorbinsäure und Aneurin. *Botaniska Notiser*, 1946, 124.

- ALGEUS, S. (1948a). Glycocoll as a source of nitrogen for *Scendesmus obliquus*. *Physiologia Plantarum*, 65.
- (1948b). The utilisation of glycocoll by *Chlorella vulgaris*. *Physiologia Plantarum*, 1, 236.
- (1948c). The deamination of glycocoll by green algae. *Physiologia Plantarum*, 1, 382.
- (1949a). Deamination of glycocoll by *Scendesmus obliquus* in intermittent light. *Physiologia Plantarum*, 2, 145.
- (1949b). Alanine as a source of nitrogen for green algae. *Physiologia Plantarum*, 2, 266.
- (1950a). Nitrogen heterotrophy of a green alga. *Proc. of the Seventh Internat. Bot. Congr.*, Stockholm.
- (1950b). The utilisation of aspartic acid, succinamide and asparagine by *Scendesmus obliquus*. *Physiologia Plantarum*, 3, 255.
- (1950c). Further studies on the utilisation of aspartic acid, succinamide and asparagine by green algae. *Physiologia Plantarum*, 3, 370.
- (1951a). Effect of pyridoxine on growth of *Scendesmus obliquus*. *Physiologia Plantarum*, 4, 449.
- (1951b). Note on the utilisation of glutamine by *Scendesmus obliquus*. *Physiologia Plantarum*, 4, 459.
- (1951c). Effect of -alanine and pantothenic acid on growth of *Scendesmus obliquus*. *Physiologia Plantarum*, 4, 495.
- CHOLNOKY, B. J. (1928). Über die Wirkung von hyper- und hypotonischen Lösungen auf einige Diatomeen. *Internationale Revue d. ges. Hydrobiol. u. Hydrogr.*, 19, 452.
- (1929). Adnotationes criticae ad floram Bacilliarum Hungariae IV. Floristisch-okologische Untersuchungen in den südlichen Teilen der ungarischen Tiefebene (Alfold). *Magyar Botanikai Lapok* 1929, 100.
- (1930). Die Dauerorgane von *Cladophora glomerata*. *Zeitschr. f. wiss. Bot.*, 22, 545.
- (1949). Über den Diatomeenbewuchs eines Mühlrades. *Österr. Bot. Zeitschr.*, 96, 221.
- (1953). Studien zur Ökologie der Diatomeen eines eutrophen subtropischen Gewässers. *Berichte d. Deutsch. Bot. Ges.*, 66, 346.
- (1955a). Diatomeen aus salzhaltigen Binnengewässern der westlichen Kaap-Provinz in Südafrika. *Berichte d. Deutsch. Bot. Ges.*, 68, 11.
- (1955b). Hydrobiologische Untersuchungen in Transvaal. I. Vergleichung der herbstlichen Algengemeinschaften in Raytonvlei und Leeufontein. *Hydrobiologia*, 7, 137.
- (1957). Über die Diatomeenflora einiger Gewässer in den Magalies-Bergen nahe Rustenburg (Transvaal). *Botaniska Notiser*, 110, 325.
- (1958a). Beitrag zu den Diatomeenassoziationen des Sumpfes Olifantsvlei südwestlich Johannesburg. *Berichte d. Deutsch. Bot. Ges.*, 71, 177.
- (1958b). Hydrobiologische Untersuchungen in Transvaal. II. Selbstreinigung im Jukskei-Crocodile Flusssystem. *Hydrobiologia*, 11, 205.
- (1960). Beitrag zur Kenntnis der Ökologie der Diatomeen in dem Swartkops Bache nahe Port Elizabeth (Südöst-Kaapland). *Hydrobiologia*, in press.
- FOGG, G. E. (1953). The metabolism of algae. Methuen's Monographs on Biological Subjects, I.1. Catalogue No. 4122/U. London.
- HARRISON, A. D., KELLER, P., and DIMOVIĆ, D. (1960). Ecological studies on Olifantsvlei, near Johannesburg. *Hydrobiologia*, XV (1-2), 89-134.
- HOFER, K. (1931). Die Permeabilitätsproblem und seine anatomischen Grundlagen. *Berichte d. Deutsch. Bot. Ges.*, 49, 79.
- (1958). Aluminiumsalzwirkung auf Spyrogyren und Zygmenen. *Protoplasma*, 49, 248.
- HUSTEDT, F. (1937-9). Systematische und ökologische Untersuchungen über die Diatomeenflora von Java, Bali und Sumatra. *Arch. f. Hydrob.*, Suppl. 15 u. 16.
- (1949). Süßwasserdiatomeen. Exploration du Parc National Albert. Mission H. Damas (1935-6). Institut des Parcs Nationaux du Congo Belge. Fasc. 8, Bruxelles.
- (1959a). Die Diatomeenflora des Neusiedler Sees im österreichischen Burgenland. *Österr. Bot. Zeitschrift*, 106, 390.
- (1959b). Die Diatomeenflora des Salzlackengebietes im österreichischen Burgenland. Sitzungsberichte der österr. Akademie d. Wiss.; ath.-Natw. Kl., Abt. 1, Bd. 168, 387.
- IVERSEN, J. (1929). Studien über die pH-Verhältnisse dänischer Gewässer und ihren Einfluss auf die Hydrophytenvegetation. *Botaniska Tidskrift*, 40.
- JØRGENSEN, E. G. (1952). Effect of different silicon concentrations on the growth of Diatoms. *Physiologia Plantarum*, 5, 161.
- (1953). Silicate assimilation by Diatoms. *Physiologia Plantarum*, 6, 301.
- KNUDSON, B. M. (1954). The ecology of the Diatom genus *Tabellaria* in the English Lake District. *The Journal of Ecology*, 42, 345.

- KOLBE, R. W. (1927). Zur Ökologie, Morphologie und Systematik der Brackwasserdiatomeen. Die Kieselalgen des Sperenberger Salzgebiets. *Pflanzenforschung, Heft 7*, Jena.
- (1932). Grundlinien einer allgemeinen Ökologie der Diatomeen. *Ergebnisse der Biologie*, 8, Berlin.
- KOLKOWITZ, R. (1950). Ökologie der Saprobien. Über die Beziehungen der Wasserorganismen zur Umwelt. Schriftenreihe des Vereins für Wasser-, Boden- und Luftthygiene. Nr. 4.
- LIEBMANN, H. (1951). *Handbuch der Frischwasser- und Abwasserbiologie*, 1, München.
- NYGAARD, G. (1938). Hydrobiologische Studien über dänische Teiche und Seen. I Teil. Chemisch-physikalische Untersuchungen und Planktonwagungen. *Archiv. f. Hydrob.*, 32.
- OHLE, W. (1953). Phosphor als Initialfaktor der Gewässereutrophierung. *Vom Wasser*, 20, 11.
- (1955a). Beitrag zur Produktionsbiologie der Gewässer. *Archiv. f. Hydrob.*, Suppl. 22, 456.
- (1955b). Die Ursachen der rasanten Seeneutrophierung. *Verh. d. Internat. Ver. f. theor. u. angew. Limnologie*, 12, 373.
- PATRICK, R. (1948). Factors affecting the distribution of Diatoms. *The Botanical Review*, 14, 473.
- RUTTNER, F. (1952). *Grundriss der Limnologie*, 2. Auflage, Berlin.
- SERNOW, S. A. (1958). *Allgemeine Hydrobiologie*, Berlin.
- SIOLI, H. (1954). Beitrag zur regionalen Limnologie des Amazonasgebietes. II. Der Rio Arapiuns. *Arch. f. Hydrob.*, 49, 448.
- (1955). Beitrag zur regionalen Limnologie des Amazonasgebietes. III. Über einige Gewässer des oberen Rio-Negro Gebietes. *Arch. f. Hydrob.*, 50, 1.
- (1957). Beitrag zur regionalen Limnologie des Amazonasgebietes. IV. Limnologische Untersuchungen in der Region der Eisenbahnlinie Belem-Braganca ("Zona Bragantina") im Staate Para, Brasilien. *Archiv. f. Hydrob.*, 53, 161.
- WUHRMANN, K. (1947). Die dritte Reinigungsstufe. Wege und bisherige Erfolge in der Eliminierung eutrophisierender Stoffe. *Schweizerische Zeitschr. f. Hydrobiologie*, 19, 409.

**III. CONTROL AND PREVENTION OF POLLUTION —
METHODES DE PREVENTION ET DE LUTTE**

THE ADMINISTRATION AND ENFORCEMENT OF THE LAWS RELATING TO THE USE OF WATER FOR INDUSTRIAL PURPOSES AND TO THE PREVENTION OF WATER POLLUTION IN THE UNION OF SOUTH AFRICA

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SUMMARY

Legislation relating to the control of pollution in the Union prior to 1956 is reviewed and its shortcomings are examined. The factors which gave rise to those provisions of the Water Act, No. 54 of 1956, which are concerned with the use of water for industrial purposes and the prevention of water pollution are considered, and the basic principles underlying the legislation discussed. The machinery which has been set up to administer and implement the legislation passed in 1956 is described, and an account given of its operation. The difficulties encountered in the practical application of control measures are discussed, and ways and means of surmounting these considered.

INTRODUCTION

In most highly-industrialised countries in the world today the limitations of the available supplies of naturally fresh water, in the face of the rising demands of agriculture, industry and urban development, are giving cause for increasing concern. Apart from the quantitative limitations on the availability of surface and underground water supplies imposed primarily by climatic factors, the quality of naturally-occurring waters is being adversely affected to an increasing extent owing to pollution by industrial effluents and wastes, and by other deleterious matter which finds its way into natural drainage channels and water courses. In many of the older countries the solution of the problems thus created is often a matter of considerable difficulty, since the remedial measures necessary must be applied with due regard to their effects on an established economy.

The Union of South Africa, in relation to its area, is not over-abundantly endowed with water resources, and the mean surface run-off, inclusive of the contributions by the British High Commission Territories of Basutoland and Swaziland, has been provisionally assessed at approximately 40 million acre-feet per annum. The run-off is furthermore characterised by a pronounced seasonal distribution, since flows derived from melting snows are of no great account, and approximately 87% of the area receives the vast bulk of its rainfall during the summer period October to March. Since World War II industrial development in the Union has proceeded at a phenomenal pace, and the demands by industry for water, and the dangers inherent in industrial use if uncontrolled, served to focus attention on the need to ensure that the country's available

water supplies are used as efficiently as possible in the national interest. Unlike the position in many of the older countries, industrialisation in the Union had fortunately not at that stage reached the point where the institution of control over the use of water for industrial purposes would pose any insuperable economic problems, but this particular field of state control is largely unexplored, and the enabling legislation, after promulgation, inevitably gave rise to certain difficulties in its implementation. This paper is essentially a review of the legislation introduced in the Union to control the use of public water for industrial purposes and prevent the pollution of public and private water supplies, and of the administrative procedures adopted to implement the relevant legislative provisions.

DEVELOPMENTS PRIOR TO 1956

After the Union of South Africa was formed in 1910, it became necessary to provide the country with a unified body of water law. As a result the Irrigation and Conservation of Waters Act, No. 8 of 1912, was enacted and served to regulate the use of the flow of public streams. The administration of the Act was entrusted to the Irrigation Department functioning under a Ministry of Irrigation. Industrial development in the Union was in its infancy at that stage, and the legislation understandably concerned itself almost exclusively with the use of water for agricultural purposes. The Act made it an offence to render water unsuitable for irrigation and industrial use, but took no regard of the effects of the pollution of water on the public health of the community, and thus did not concern itself with the pollution of domestic water supplies. The Parliamentary Regulations, promulgated in terms of the said Irrigation and Conservation of Waters Act, required that all effluent returned to a public stream should be pure, but the penal section of the Act was so vaguely framed that it was extremely difficult, if not impossible, to enforce the regulation. The Public Health Act, 1919, also contains certain provisions for preventing the pollution of streams in order to safeguard the health of the community, but in this case also the legal position in regard to the interpretation of these provisions leaves something to be desired.

In the predominantly agrarian economy which, apart from gold-mining, obtained in the Union prior to 1939, the need for strong action to control pollution and ensure economy in the use of water was not so readily apparent, and the efficacy of the earlier legislation, despite its deficiencies, was never seriously challenged. During and after the war years, however, it became increasingly evident that a measure of competition for water supplies was developing between industrial, urban and agricultural interests, and that the existing legislation relating to the use of water, in spite of a succession of patchwork amendments at intervals, was quite inadequate to cope with the changed economic and social circumstances which had arisen in the country since 1912. The Govern-

ment therefore decided to appoint a special Commission to examine the basis of the Union's Water Law, with a view to making recommendations for the revision of the existing legislation. As a result a " Commission of Enquiry concerning the Water Laws of the Union " was constituted in April 1950, under the chairmanship of the Honourable Mr. Justice C. G. Hall, and submitted its report and recommendations in August 1951, after evidence had been taken from interested bodies and persons throughout the country. The main recommendations of the Hall Commission in the field of the control of the industrial use of water and the prevention of pollution, were concerned with promoting economy in the utilisation of water resources, and encouraging the re-use of purified effluents.

After the recommendations contained in the Report of the Commission of Enquiry had been considered, it was decided to repeal the Irrigation and Conservation of Waters Act, No. 8 of 1912, in its entirety, and to replace it with completely new legislation. The necessary Draft Bill was tabled for the first time during the 1954 Session of Parliament by the then Minister of Lands and Irrigation and was referred to a Select Committee on which both Government and Opposition parties were represented. The Select Committee deliberated for nearly two years on the proposed legislation and gave particularly thorough attention to those clauses of the Draft Bill which dealt with the industrial use of water, the purification and disposal of effluents, and the prevention of pollution. A considerable body of expert evidence on these aspects was presented to the Select Committee during the course of its deliberations, and in 1956 the revised Bill, incorporating a number of amendments recommended by the Select Committee, was passed by Parliament virtually as an unopposed measure, and became law on 13 July 1956 under the short title of the Water Act, No. 54 of 1956.

THE WATER ACT, NO. 54 OF 1956

The Water Act, No. 54 of 1956, is administered by the Minister of Water Affairs. The provisions of the Act which are concerned with the issues under discussion in this paper, are set out in full in Annexure No. 1. The implications and purpose of the various individual sections are summarised in the notes which follow.

Section 11

This provision in essence renders it obligatory for any user, who wishes to abstract water directly from a public stream for industrial purposes, to obtain the permission of the Water Court. At the hearing of the application it is competent for any other person, who considers that his rights or interests will be adversely affected by the grant of the permission sought, to lay his objections before the Court. Where the contemplated scale of water usage exceeds certain minima laid down in

section 12 of the Act, a permit from the Minister of Water Affairs must be obtained before application to the Water Court is made. No Water Court authority is required where industries are to be established within the area of a local authority or similar body which has the right to supply water within its area of jurisdiction.

Section 12

This section vests in the Government, through the Minister of Water Affairs, the right to control the siting of new industrial undertakings which will use quantities of public water in excess of 60,000 gallons on any one day, or an average of 50,000 gallons per day during any month. Would-be industrialists who fall in this category are required to obtain a permit from the Minister. The considerations which should influence the Minister in reaching a decision are specified, and it is expressly laid down that the Minister of Economic Affairs shall be consulted. It will be noted that no control is exercised over the siting of new industries whose water requirements fall below the limits set. It is thus theoretically possible for a number of smaller undertakings, whose aggregate requirements exceed the prescribed minimum, to establish themselves along a particular public stream, provided the permission of the Water Court can be obtained. In practice, however, the Minister would still be in a position to exercise a large measure of control, since the majority of isolated industries, which are responsible for their own effluent purification and disposal arrangements, would require to seek exemption from the provisions of sections 21 (1) and 21 (2), to which reference is made in the following paragraph. Although one of the principal objects of section 12 is to provide the Government with the necessary powers to influence the location of heavy industry, it is obvious that the degree of control that can be exercised in this way is necessarily limited. Although a permit application in terms of section 12 can be refused, there is no certainty that the industry concerned will then establish itself at an approved site elsewhere in the country. In practice therefore, it is only in exceptional cases that the Government will choose to exercise its prerogative.

Section 21

The provisions of the various sub-sections which comprise this section contain in effect the key to the whole policy regarding the purification and re-use of industrial effluents and the prevention of the pollution of public streams in the Union, and a thorough understanding of the implications of these sub-sections is essential in order to obtain an adequate picture of the system of control envisaged.

Sub-section 21 (1) empowers the Minister, after consultation with the South African Bureau of Standards, to prescribe quality standards to which industrial effluents shall be purified, compliance with such standards being

then obligatory in the case of new industries unless an exemption permit in terms of the provisions of sub-section 21 (5) is obtained. It is a requirement of the sub-section that the standards thus prescribed by the Minister shall specify an effluent of a quality which is not less satisfactory than that which would have resulted had the recommendations of the South African Bureau of Standards been adopted.

Sub-section 21 (2) seeks to promote the re-use of water by requiring that industrial effluents, after purification in accordance with sub-section 21 (1), shall be returned to the public stream from which the water was abstracted. The Water Court is furthermore authorised in terms of this sub-section to allow such purified effluent to be returned to the bed of some other public stream, in cases where the water is used outside the catchment of the river from which it was originally taken. Exemption from the obligation to return the purified effluent to a public stream may be granted in terms of sub-section 21 (5).

Sub-sections 21 (3) and 21 (4) are self-explanatory and require little comment. The former relieves industries of the obligation to purify and dispose of their effluents in terms of sub-sections 21 (1) and 21 (2), in cases where unpurified effluents are accepted by a local authority or similar body which has assumed responsibility for their treatment, while the latter is designed to curb the wasteful use of water.

Exemption from the provisions of sub-sections 21 (1) and 21 (2) may, as has already been indicated, be granted by the Minister in terms of his powers under sub-section 21 (5). The circumstances under which such exemptions may be permitted are circumscribed in the sub-section. Any conditions imposed by the Minister in the exemption permit are required to be not less effective in preventing pollution than any conditions recommended by the South African Bureau of Standards. Caution in the granting of exemptions is very necessary, since the Minister's position in this regard is not unassailable. In terms of sub-section 21 (5) (b) any interested person, other than an applicant for an exemption permit, may, after due notification to the Minister, apply to the Water Court for the cancellation or modification of any exemption permit issued in terms of sub-section 21 (5) (a), and the possibility of such an application succeeding must, in the interests of sound administration, be eliminated as far as possible. Exemption permits are however essentially of a temporary character, and may be cancelled or amended by the Minister at any time.

The import of sub-sections 21 (6), 21 (7) and 21 (8) is clear and requires no explanation. It is interesting to note that a sewage treatment works is specifically classed as an industry for the purposes of the Water Act.

Section 22

This section is intended to facilitate the re-use of water by local authorities which are responsible for the operation of sewage purification

works which treat only domestic sewage. The scope of application of this section is obviously limited, and generally speaking the objectives sought can equally well be obtained in terms of an exemption under subsection 21 (5) (a).

Section 23

The necessary machinery is provided in this section for the institution of Court proceedings where pollution of public or private water, including underground water, is caused, and the section also serves to indicate what constitutes pollution for the purposes of a successful prosecution. The Minister is also empowered to use public funds for combating pollution caused by abandoned mining and industrial enterprises, and to recover the whole or any portion of the expenditure thus incurred from the persons concerned in such undertakings. This provision enables appropriate action to be taken, where drainage from worked-out coal mines or abandoned mine dumps is responsible for pollution.

Section 24

It was realised while the provisions of the Draft Water Bill were under consideration that the promulgation of prescribed standards for effluents in terms of section 21 (1) would, in many cases, place a heavy if not intolerable burden on industries which were already in existence when the Water Act became law, since fundamental changes in factory layouts and processes would be necessary to enable such industries to comply with effluent quality requirements. In order to assist such industries it was decided to allow, on application, a certain period of grace, during which the requirements of section 21 would not apply. Provision for this relief is contained in section 24.

Section 26

This section is essentially an enabling provision, which empowers the Minister to make the regulations necessary for the proper exercise of his controlling functions in relation to the use of water for industrial purposes, the purification and disposal of effluents, and the prevention of pollution.

Section 30 (2)

This provision forms part of the general body of legislation which is concerned with the control and use of subterranean water and of water found underground. Subterranean water control areas, in which the abstraction and use of underground water is subject to a permit issued by the Minister of Water Affairs, may be proclaimed where circumstances render this advisable. In such areas the Minister is given wide powers over water usage, which are aimed, *inter alia*, at preventing the pollution of underground water supplies.

Section 170

This is the penal section of the Water Act which lays it down that any person who is convicted of an offence under the pollution provisions of the Act shall be liable, in the case of a first conviction, to a fine not exceeding £500 or to imprisonment for a period not exceeding six months, or to both such fine and such imprisonment, and, in the case of a second or subsequent conviction, to a fine of not less than £250 or to imprisonment for a period of not less than six months or to both such fine and such imprisonment.

It is further provided that any person who has been convicted of any such offence, and who after such conviction persists in the course of conduct which constituted the offence, shall be guilty of a continuing offence and liable on conviction to a fine not exceeding £40 in respect of every day that he so persists or has so persisted.

ADMINISTRATIVE MACHINERY AND PROCEDURES

Responsibility for the administration of those provisions of the Water Act, No. 54 of 1956, which are concerned with the industrial use of water, the purification and disposal of effluents, and the prevention of pollution, is vested in the Department of Water Affairs—a department of state of the Central Government of the Union of South Africa. The South African Bureau of Standards has certain statutory responsibilities relating to the provisions of section 21 of the Act, and close liaison with the Bureau is therefore maintained in matters affecting the effluent quality requirements normally associated with industrial use.

Since it is one of the basic objects of the industrial usage provisions of the Water Act to ensure that water after it has passed through industrial plants is returned to the public stream for re-use, it follows that the quality standards laid down for such effluents must be relatively high, particularly in areas where the natural stream flow decreases very considerably during the winter months, and effluent discharges can therefore form a not inconsiderable proportion of the water available. In such circumstances no reliance can be placed on dilution as a factor in the achievement of a final water of satisfactory quality, and it can therefore be expected that a large number of industries will not be able to purify their effluents economically to the standard prescribed. In such cases recourse must be had to an exemption permit issued in terms of section 21 (5).

The disposal of effluents by industry creates no problems in cases where a local authority, which undertakes responsibility for the purification of sewage and trade wastes, is prepared to accept the particular effluent into its drainage system for treatment at a central works. Each such works is, as already mentioned, an industry for the purposes of the Water Act, and the onus is on the local authority concerned to ensure that the final effluent produced conforms to prescribed quality standards, or to obtain

an exemption from such standards in terms of section 21 (5). When applications from industrialists who wish to establish themselves within an area controlled by a local authority are considered, the Department is normally satisfied if a written undertaking is obtained from such local authority stating that it is prepared to accept and treat the effluent in question. The bye-laws of such local authorities may of course embody certain saving clauses which make it essential for certain types of effluent to be pre-treated at the factory before discharge into the municipal drainage system.

The effluent disposal problems which can be expected to require special consideration in terms of the Water Act arise (a) where water is abstracted directly from a public stream by an individual industry which must itself assume responsibility for the purification and disposal of the effluent produced, and (b) where industries are to be established within the areas of local authorities which are not prepared to allow the effluent to be discharged into the sewers. The number of cases in the latter category will generally be small, since the industrialist will normally negotiate with the local authority before deciding upon a site for his project.

Since the promulgation of the Water Act in July 1956 considerable attention has been given to the procedure to be followed in dealing with applications for permits in terms of section 12—which requires that the authority of the Minister of Water Affairs must be obtained where a new industry is to be established which will use on an average more than 50,000 gallons per day, or more than 60,000 gallons on any single day—and for exemptions from the requirements of the effluent sections 21 (1) and 21 (2), in terms of section 21 (5). Applicants are required to submit detailed information in regard to those aspects of the particular industrial process which are concerned with the water cycle and the production of effluents, as well as of the methods of purification proposed. Information guides have been compiled to assist applicants in framing their submissions, so as to obviate delays caused by lack of sufficient data. The procedure adopted after the receipt of the application in its proper form can be summarised as follows :

- (i) A copy of the application is forwarded to the Secretary for Commerce and Industries, with the request that the views of the Minister of Economic Affairs be obtained as to whether there is any objection to the establishment of the proposed industry at the site contemplated. The necessity for this consultative action is imposed by section 12 (4) of the Water Act.
- (ii) After the approval of the Minister of Economic Affairs has been received, an investigation is instituted by the Department to establish whether, from the standpoint of the available water resources and the likely effects of the proposed industry on other users, there is any obvious objection to the application.

- (iii) Copies of the application are forwarded to the South African Bureau of Standards, with the request that the Bureau's recommendations in terms of section 21 (5), in regard to the degree of relaxation which should be allowed from the requirements of section 21 (1), be furnished in due course.

If the Bureau at that stage has sufficient data at its disposal to enable it to deal with the matter without further ado, it submits its recommendations for a relaxed effluent specification to the Department, which then circulates these for comment to interested authorities such as the departments of Health and of Agriculture, and the Provincial Administration concerned. After the views of these bodies have been ascertained, the Department of Water Affairs reconsiders the whole matter and submits a recommendation to the Minister of Water Affairs for his consideration. The applicant is thereafter advised of the Minister's decision in regard to the application.

- (iv) If the Bureau of Standards is not in a position to furnish its recommendations immediately, it is usually necessary to arrange a meeting—generally at the site of the proposed industry so that an inspection *in loco* can be made—in order to consider and discuss the application, and obtain views regarding the conditions which should be incorporated in the exemption permit, should it be decided to make a favourable recommendation to the Minister of Water Affairs. Such a meeting is constituted under the chairmanship of the representative of the Department of Water Affairs, the government department responsible for the administration of the Water Act. All or some of the following bodies, depending on the nature and scope of the particular application, may be invited to be represented at the meeting :

- (a) The applicant for the permit.
- (b) The local authority in the area likely to be affected. This may be a Municipality, Irrigation Board or Water Board, etc.
- (c) The Provincial Administration which controls the area likely to be affected.
- (d) Department of Agricultural Technical Services.
- (e) Department of Health.
- (f) Department of Commerce and Industries.
- (g) Department of Lands.
- (h) Division of Marine Fisheries.
- (i) National Institute for Water Research of the South African Council for Scientific and Industrial Research.
- (j) South African Bureau of Standards.
- (k) Department of Water Affairs.

After the meeting the Bureau of Standards submits its recommendations to the Department, after which the procedure outlined in subparagraph (iii) above is followed as before.

The practice of holding meetings of enquiry to assist in determining the relaxed standards for effluents which should apply in particular cases, has been an outstanding success, and has led to satisfactory compromises in regard to conflicting interests and the better appreciation of differing points of view. In this connection it should be emphasised that experience thus far has shown that industry is fully prepared to do its share, within the economic limits of its undertakings, towards ensuring that effluents comply with any reasonable requirements, and the administration of the relevant provisions of the Water Act is, in practice, based on the active and voluntary co-operation of industry. The meetings of enquiry have the advantage that the relaxed standards, when set, are largely an agreed measure, and the possibility of a successful appeal to the Water Court, in terms of section 21 (5) (b), is thus considerably reduced.

In particular cases, where difficult effluents such as those emanating from paper-pulp mills, oil-from-coal plants, steelworks and similar industries are concerned, it is sometimes impossible to agree upon a relaxed standard which will not cause a measure of deterioration in the quality of the water into which such effluents are discharged. Industries falling in this category often play a major role in the economy of the country, and it may thus be necessary, at least temporarily, to condone a certain measure of pollution in the national interest. Permits issued in terms of section 21 (5) in such cases may provide that the effluent may be discharged in a semi-purified or unpurified state to a public stream, but this permission is usually granted subject to the condition that the industry concerned agrees to undertake a programme of research, designed to improve the quality of its effluent, under the guidance of an advisory *ad hoc* committee. This committee consists essentially of technical specialists, representing the industry concerned, and other bodies such as the South African Bureau of Standards, the National Institute for Water Research, the Provincial Administration and the departments of Health and Water Affairs, and is constituted under the chairmanship of the representative of the Department of Water Affairs. The committee is entirely consultative in character and its operation does not absolve the industry concerned from its responsibility of complying with the requirements of the Water Act. The committee meets at reasonable intervals to discuss progress reports and suggest alternative lines of research and enquiry, and its functions will generally extend over a period of several years. The system has worked well so far and has yielded gratifying results. The advantages of settling differences of opinion by discussion as opposed to correspondence have been amply demonstrated, and a most amicable relationship between the various bodies represented on such committees has prevailed. Although it is still too

early to pass final judgment, the indications are that the *ad hoc* committee system, where research into the purification of recalcitrant effluents is required, has much to commend it.

No specialist organisation has as yet been set up in the Department of Water Affairs to combat the pollution of water by means of inspection services responsible for the regular sampling of effluents and public streams, although exemption permits to particular industrial undertakings, issued in terms of section 21 (5) of the Water Act, usually contain a condition which provides for such sampling facilities. The position is being carefully watched, but it is considered that the operation of the pollution control provisions of the Act should be studied over a reasonably long period, so that any obvious weaknesses in control can be eliminated, before a decision is taken in regard to the form of enforcement machinery which should be adopted. In this regard it should however be made clear that section 23 of the Water Act is designed to allow any interested person to take legal action if he considers that pollution of water is being caused by another, and it was never envisaged that the department, as such, should be responsible for all prosecutions in connection with pollution offences, unless government work or land is affected, or unless it is deemed advisable to take such action in the national interest. The aggrieved person should take the necessary action, but is often reluctant to do so on account of the legal expenses involved and the uncertainties which in the past have attended prosecutions for pollution offences. In the cases of pollution of public streams which have so far been referred to the department, it has been found possible to deal with the problems by administrative action without recourse to the Courts. The offending industry or municipality has proved quite willing to co-operate, and has taken speedy action to remedy the position, after its obligations in terms of the Water Act have been brought to its attention. Pollution control in the Union at the present stage is largely a matter of co-operative effort, which depends for its success on mutual understanding and appreciation of each other's duties and responsibilities. It may well be found necessary later to adopt more positive enforcement measures, but these will need to be decided on with care, and with due regard to the psychological reactions among water users which their employment may tend to engender.

DIFFICULTIES ENCOUNTERED IN THE ADMINISTRATION OF THE POLLUTION PROVISIONS OF THE WATER ACT

The major problem which has arisen in connection with the administration of the pollution control provisions of the Act centres round section 21 (1), which requires that the Minister of Water Affairs, after consultation with the South African Bureau of Standards, shall prescribe standards for industrial effluents which shall not be less effective in

preventing pollution than the standards recommended by the said Bureau. When this section of the Act was drafted it was generally thought that it would be possible to lay down varying standards for different areas of the country, but responsible legal opinion has since declined to support this view, and it has been ruled that, in the light of the phraseology employed in section 21 (1), the effluent standard to be prescribed by the Minister shall be uniform and of Union-wide application. This interpretation has created a great deal of difficulty, and has led to an impasse as a result of which it has not yet been found possible to promulgate effluent standards in terms of section 21 (1). The Union is a country approximately 470,000 square miles in extent, and its area is subject to considerable variations as regards topography, rainfall, geological formation and soil types. The quality of the natural run-off of its rivers is determined by the foregoing factors, as well as by urban and industrial development in particular catchments and the system of land use practised. There is consequently a wide difference in quality between the run-off which emanates, for example, from the Karroo area of the central plateau, where the shales, mudstones and sandstones of the Beaufort Series predominate, and the flows derived from the mountain areas of the south-western Cape and the Drakensberg escarpment in the east. It can be appreciated, therefore, that a standard based on the natural quality of the former run-off might well be considered to open the door to pollution in the case of rivers having their sources in the latter areas. Conversely, the adoption of a standard based on the mountain water quality of the Eastern Escarpment would mean that industries in the Karroo areas would very likely be required to remove by purification part of the dissolved mineral load of the natural river flow, in order to enable them to produce an effluent complying with the prescribed standard. It is true that the position in the latter case could be met by exemptions under section 21 (5), but exemptions would then become the rule rather than the exception, and such a development would be contrary to the purpose which the Legislature had in view when the Water Act was passed. It was generally envisaged at that time that the effluent standard to be set under section 21 (1) would be a practical one, which could be achieved by a reasonable proportion of industrial undertakings which were prepared to adopt modern purification techniques in the treatment of their effluents. Entrepreneurs would then have a reasonable knowledge of their pollution control commitments, before embarking on enterprises which might involve them in effluent difficulties later.

In the situation with which it was confronted as a result of the foregoing circumstances the South African Bureau of Standards felt constrained to recommend an extremely high standard for effluent quality in terms of section 21 (1), which would in effect have meant that for practical purposes every present and future industry in the Union would be required to

obtain an exemption under section 21 (5) in respect of the quality of its effluent, unless it was in a position to be served by a local authority. In view of the unsatisfactory state of affairs which would thus have been created, it was decided to postpone the publication of standards in terms of section 21 (1) pending suitable amendments to the Water Act, which would allow of the prescription of effluent standards on a regional basis. The necessary amending legislation has not yet been passed, but it is hoped that it will be placed on the Statute Book during the 1961 Session of Parliament. The adoption of regional standards will provide the requisite degree of flexibility to enable high but reasonably practicable standards for effluents to be laid down, with due regard to the natural quality of the water available in each area. It is confidently expected that after these standards have been promulgated, the need for exemptions in terms of section 21 (5) will be reduced considerably and thus lessen the load of administrative work at present entailed in promoting pollution control. Although a small number of other minor deficiencies have come to light in the application of the pollution control provisions of the Water Act, these are not of any technical significance, and relate mainly to detailed administrative procedure. Due account of these will be taken when the proposed amendment to the Act is drafted.

CONCLUSION

The industrial usage and pollution control provisions of the Water Act, No. 54 of 1956, represent in many respects revolutionary legislation in the field of water utilisation, and the Union must be considered fortunate in having been able to introduce these measures at a stage in its industrial growth when the quality of the waters in the vast majority of its rivers and streams is still largely unimpaired by effluents, and when the effects of control are not likely to have any crippling economic repercussions on established enterprises. It is still too early to pass judgement on the efficacy of the control measures and the procedures adopted for their implementation, and it would similarly be premature to assume that the steps thus far taken will prove effective in finding a solution to the problems connected with pollution and the re-use of water with which the Union is faced. Much still remains to be done, but the initial hurdles have been negotiated and realisation of the need to ensure that water resources are used to maximum advantage is growing rapidly in the public consciousness. The results achieved so far are encouraging, and it must be hoped that, with the continued co-operation of industry and other water users, and the active assistance of authorities and other bodies concerned with the use of the country's water supplies, a steady improvement in the position will be maintained.

EXTRACTS FROM THE WATER ACT, NO. 54 OF 1956, OF THOSE PROVISIONS WHICH RELATE TO THE USE OF WATER FOR INDUSTRIAL PURPOSES, THE PURIFICATION, DISPOSAL AND RE-USE OF EFFLUENTS, AND THE PREVENTION OF POLLUTION

Section 11

Use of public water by certain persons subject to permission of Water Court

(1) (a) Save as is provided in sub-section (3) of section fifty-six and section sixty-seven, no person shall use public water for industrial purposes except with the permission of a water court and, where the quantity used exceeds sixty thousand gallons on any one day or fifty thousand gallons on an average per day during any month, under permit from the Minister: Provided that the permission of the water court shall not be required in the case of a local authority or any other body constituted under any law which has the right to control and supply either private or public water within its duly constituted area of jurisdiction, or in the case of any person to whom such water is supplied by such a local authority or other body: Provided further that, subject to the provisions of section nine, a person who is entitled or has acquired a right to use public water for agricultural purposes may, under permit from the Minister, and subject to such conditions as he may deem fit to impose, use water for the development of power not exceeding fifteen horse power, without the permission of the water court.

(b) Neither the permission of a water court nor a permit from the Minister shall be required in respect of the use by any person in connection with any undertaking of a quantity of public water not exceeding during any month the average quantity per month of such water lawfully used by him in connection with that undertaking during the last period of six months within the period of twelve months immediately preceding the commencement of this Act during which water was so used by him, nor shall the permission of a water court be required for the use by any person in connection with any undertaking of a quantity of public water which he has been authorised to use by order granted by a water court prior to the commencement of this Act under any law hereby repealed.

(2) A water court may on the application of a person (including the Government, the South African Railways and Harbours Administration and any provincial administration)

(a) who is entitled in terms of this Act to use public water for agricultural purposes or who has acquired a right to the use of such water, authorise the applicant to use the share of such water to which he is so

entitled or to the use of which he has acquired such a right, or any part of such share, for agricultural, industrial or urban purposes or such other purposes as the water court may determine, either on riparian land or elsewhere ;

(b) who is not entitled to use public water—

(i) if the water court is of opinion that the grant of such permission will be in the public interest, permit the applicant to abstract from a public stream or to impound and store within or outside the channel of a public stream and to abstract, for use at any place for agricultural, urban or industrial purposes or such other purposes as the water court may determine, whether on land riparian to such stream or elsewhere, a stated quantity of public water, whether surplus water or normal flow of such stream ;

(ii) if the water court is satisfied that during any period all the water of a public stream, whether normal flow or surplus water, is not or will not be used on land riparian to every stream in or into which such water naturally flows, permit the applicant to abstract from such stream or to impound and store outside the channel of such stream and to abstract during the said period so much of the water as in the opinion of the water court is not or will not be so used, for agricultural, industrial or urban purposes, either on riparian land within the catchment area of such stream or elsewhere.

(3) A water court shall not consider an application for permission to use a quantity of water exceeding 60,000 gallons on any one day or 50,000 gallons on an average per day during any month for industrial purposes, unless the application is accompanied by a permit issued by the Minister under sub-section (5) of section twelve.

(4) Before granting any permission under sub-paragraph (i) of paragraph (b) of sub-section (2), the water court shall determine in what manner and to what extent the rights of the persons or of any one or more of the persons entitled to the use of water from the stream in question shall be abated for the purpose of making available the water in respect of which such permission is to be granted :

Provided that—

(a) such abatement shall as far as practicable be made in the first instance in respect of the rights of persons who have not exercised such rights ;

(b) any rights to the water of the public stream in question vested in any person by virtue of any statute not specifically repealed or amended by this Act shall not be subject to any abatement ;

(c) the rights of a riparian owner to the use of the normal flow of such stream for domestic purposes and for the watering of his stock shall

not be so abated or otherwise prejudicially affected without his written consent.

(5) Any permission under sub-paragraph (ii) of paragraph (b) of sub-section (2) may be granted permanently or for such period as the water court may determine.

(6) The water court may—

(a) in respect of a permission granted under paragraph (a) or sub-paragraph (ii) of paragraph (b) of sub-section (2), impose such conditions as in its opinion will prevent lower riparian owners from being prejudicially affected; and

(b) in respect of a permission granted under sub-paragraph (i) of paragraph (b) of that sub-section, order the payment of compensation (the amount and manner of payment whereof shall be determined by the water court) to any person whose rights have been abated,

and may impose such other conditions in respect of any permission granted under the said sub-section as it may deem desirable.

SECTION 12

Permit for industrial use of water to be obtained from Minister in certain cases

(1) Any person who desires to establish an industrial undertaking in respect of which any quantity of water is required to be used for industrial purposes shall, before initiating or establishing such undertaking—

(a) advise the director of the nature and the method of purification of the waste water, effluent or waste, if any, which will be occasioned by the operation of such undertaking; and

(b) if he desires to use for industrial purposes a quantity of public water exceeding 60,000 gallons on any one day or 50,000 gallons on an average per day during any month (whether or not any portion of such water is, in the case of water abstracted from a public stream, subsequently returned to that stream), apply to the Minister for a permit authorising such use.

(2) Any person who has during the period of six months referred to in paragraph (b) of sub-section (1) of section eleven used in connection with any undertaking a quantity of public water exceeding on an average 50,000 gallons per day, shall within six months after the commencement of this Act lodge with the director a statement showing the quantity of such water so used during that period and particulars of the undertaking in connection with which that water was so used.

(3) An application under sub-section (1) shall be in such form and shall contain such particulars as may be prescribed by regulation.

(4) Upon receipt of such application the Minister shall after consultation with the Minister of Economic Affairs, and after such investigation as he may deem fit, consider the application with due regard to—

(a) the quantity of water which is, in his opinion, ordinarily available for use at the proposed source of supply ;

(b) whether or not the granting of a permit under this section would be likely to result in such a diminution of the supply as to endanger the reasonable supply of water from the same source to persons in the area of jurisdiction of the local authority, body or person concerned with the supply of such water, or (as the case may be) to persons entitled to use water from that source ; and

(c) whether it would not be desirable in the public interest or with a view to the decentralisation of industrial undertakings or the nature of the waste water, effluent or waste which will be occasioned by the operation of the undertaking in question or the method to be applied in the purification of such waste water, effluent or waste, that such undertaking be established at a place other than the place stated in the application.

(5) The Minister may thereupon grant a permit in terms of the application or with such modifications as he may deem fit, or refuse to grant a permit.

Local authority entitled to take water within its area for urban use

(6) Nothing in this section contained shall be construed as exempting any person from applying to a water court for permission to use public water for industrial purposes.

SECTION 21

Purification and disposal of industrial water and effluents

(1) (a) The purification of any waste water or any effluent or waste produced by or resulting from the use of water for industrial purposes shall form an integral part of the process of such use and, subject to the provisions of sub-section (5), any person using water for industrial purposes shall purify such water, effluent or waste so as to conform to such requirements as the Minister may from time to time after consultation with the South African Bureau of Standards, prescribe by notice in the *Gazette* either generally or in relation to water used for or in connection with any one or more specified industrial purposes.

(b) Any requirements prescribed under paragraph (a) shall be such as to ensure that the waste water, effluent or waste to which such requirements relate will, after purification in accordance with those requirements, be at least as free of impurities as would have been the case if the purification thereof had been effected in accordance with the recommendation of the said Bureau.

(2) Public water which has been used for industrial purposes and any effluent produced by or resulting from such use, other than water or effluent referred to in sub-section (3), shall, subject to the provisions of section eleven, after purification in accordance with sub-section (1), be returned by the user at the nearest convenient point to the bed of the public stream from which the said water was abstracted: Provided that where water has been so used at any place outside the natural watershed of the catchment area of a public stream from which it was abstracted and in the opinion of the water court it is for physical or economic reasons impracticable to return such water or any such effluent to the said stream, such water or effluent may be returned by the user to the bed of some other public stream at a point determined by the water court.

(3) The provisions of sub-sections (1) and (2) shall not apply in respect of a person supplied with water by the Minister or by any local authority or other person or lawfully constituted body having a right to control and supply public or private water, including underground water, within its area of jurisdiction, if the Minister or, as the case may be, such local authority, person or body or any other local authority has undertaken the duty of disposing of such water or any effluent or waste produced by or resulting from the use thereof after such water has been used by the said person and has been discharged into any channel, drain or sewer under the control of the Minister or the local authority, person or body concerned.

(4) Water used for industrial purposes and returned in accordance with sub-section (2), shall not be diminished in quantity save in so far as such diminution is caused by such use.

(5) (a) Any person or user referred to in sub-section (1) or (2) may apply to the Minister for a permit exempting him from compliance with the provisions of either of those sub-sections, and the Minister may, after such investigation as he may consider necessary, if he is satisfied that compliance with the said provisions is impracticable in the particular circumstances, grant a permit subject to such conditions as he may deem fit to impose, exempting such person or user from compliance therewith to such extent as the Minister may determine, or authorising such person or user to discharge any waste water, effluent or waste referred to in sub-section (1) in an unpurified state or in such state of semi-purification as the Minister may determine, into any public stream at a point to be fixed by the Minister: Provided that, in the case of an application for exemption from compliance with the provisions of sub-section (1), the Minister shall in considering such application have due regard to the regulations made under paragraph (d) of sub-section (1) of section ten of the Sea-shore Act, 1935 (Act No. 21 of 1935), and shall not issue such a permit unless he is satisfied that—

(i) the conditions to be imposed in connection with any such permit will be at least as effective for the purpose of preventing the

pollution of public or other water, including sea water, as any conditions or requirements which may have been recommended by the South African Bureau of Standards ; and

(ii) any point so fixed by him is in such proximity to the sea that it is unlikely that any other person will be prejudicially affected and that the dilution of such waste water, effluent or waste by sea water or other water contained in the said stream will be such that neither aquatic nor marine fauna or flora in the public stream or the sea will be detrimentally affected.

(b) Any interested person, other than an applicant for a permit under paragraph (a), may after written notification to the Minister apply to a water court for the cancellation or modification of any permit issued under that paragraph, and the water court may make such order on the application as it may consider equitable.

(c) The Minister may at any time by notice in writing to the holder of any permit issued in terms of paragraph (a), withdraw that permit or amend it in such manner as he may deem fit.

(6) (a) The Minister may in prescribing any requirements under sub-section (1) or imposing any conditions under sub-section (5), also specify the steps to be taken by any person carrying on any mining or other industrial operations, in order to prevent the pollution of public or private water, including underground water, by seepage or drainage from any area on which those operations are carried on both while such operations are in progress and after the abandonment thereof.

(b) Any such person who fails to take the steps so specified within a period determined by the Minister and made known by notice in the *Gazette* or by notice in writing addressed to such person, shall be guilty of an offence.

(7) For the purposes of this section, a local authority which uses water for the purification or disposal of sewage or any effluent or waste referred to in sub-section (3), shall be deemed to use such water for industrial purposes.

(8) Any person who contravenes or fails to comply with the provisions of this section shall be guilty of an offence.

SECTION 22

Disposal of effluent by local authorities

(1) Notwithstanding the provisions of the Public Health Act, 1919 (Act No. 36 of 1919), or any other law, but subject to the provisions of sub-section (2), a local authority having jurisdiction over the disposal of sewage may, after purifying the effluent derived from the treatment of such sewage in accordance with standards prescribed under sub-section (1) of section twenty-one, and with the permission of the Minister, use such effluent for any purpose approved by the Minister or dispose of such

effluent for use by any person or discharge such effluent into a public stream.

(2) The Minister may in writing, and on such conditions as he may deem fit, exempt from compliance with the provisions of section twenty-one, any local authority which does not dispose of water used for any industrial purpose other than the purification or disposal of sewage.

(3) Any local authority which contravenes or fails to comply with any condition subject to which any exemption has been granted to it under sub-section (2) shall be guilty of an offence.

SECTION 23

Prevention of pollution of water

(1) Any person who wilfully or negligently, and, where any provision of section twenty-one or twenty-two applies, contrary to that provision, does any act whereby any public or private water, including underground water, is polluted in such a way as to render it less fit for the purposes for which it is ordinarily used by other persons (including the Government, the South African Railways and Harbours Administration and any provincial administration) entitled to the use thereof, or for the propagation of fish or other aquatic life, or for recreational or other legitimate purposes, shall be guilty of an offence.

(2) (a) The Minister may out of the moneys appropriated by Parliament for the purpose, take any steps which he may consider necessary to prevent the pollution, as a result of seepage or drainage from any area on which mining or other industrial operations have been carried on, of public or private water, including underground water, after such operations have been abandoned, and may in his discretion recover the cost or any part of the cost incurred in taking such steps from any person who carried on or is entitled to carry on such operations.

(b) The Minister or a person acting under his authority may at any time enter upon any land for the purpose of taking any steps referred to in paragraph (a), and may take with him on to such land any men, animals, vehicles, equipment, appliances, instruments, stores or materials, and may erect such camps and construct such works as may be necessary for that purpose.

(c) No compensation shall be payable to any person for any loss which may be sustained by him in consequence of any action taken under this sub-section, except by order of a competent court.

SECTION 24

Commencement of Section 21 in relation to certain persons

The Minister may from time to time grant exemption from the operation of any provision of section twenty-one to any persons: Provided that

no such exemption shall be granted in respect of any period ending on a date more than three years after the commencement of this Act or such later date, not more than five years after the said commencement, as may with the consent, by resolution, of both Houses of Parliament, be determined by the Governor-General by proclamation in the *Gazette*.

SECTION 26

Regulations as to permits and control of pollution of water

The Minister may make regulations relating to—

(a) the form of application for permits under section twelve and the particulars to be furnished in connection with any such application or under paragraph (a) of sub-section (1) of section twelve ;

(b) the form of any application under sub-section (5) of section twenty-one, and the particulars to be furnished in connection with any such application ;

(c) the prevention of wastage or pollution of public or private water, including underground water, and the powers and duties of persons appointed to exercise control in respect thereof ;

(d) generally, any other matter which he considers it necessary or expedient to prescribe in order that the objects of sections twenty-one to twenty-four inclusive may be achieved.

SECTION 30

(2) The Minister may in relation to any subterranean water control area, make such regulations as he may deem necessary for exercising control over the drilling of boreholes for the purpose of locating water for use for any purpose, the sinking of wells and the abstraction, protection against pollution, and preservation of subterranean water contained in such area, including regulations limiting the number of boreholes or wells which may be sunk in any such area or the quantity of water which may be abstracted by means of any borehole or well, whether sunk before or after the commencement of this Act, or prohibiting the sinking of such boreholes or wells except with the consent of the Minister or a person acting under his authority and subject to such conditions as he may specify.

SECTION 170

(2) Any person who is convicted of an offence under section twenty-one, twenty-two or twenty-three shall be liable, in the case of a first conviction, to a fine not exceeding £500 or to imprisonment for a period not exceeding six months or to both such fine and such imprisonment, and, in the case of a second or subsequent conviction, to a fine of not less than

£250 or to imprisonment for a period of not less than six months or to both such fine and such imprisonment.

(4) Any person who has been convicted of any offence under this Act, and who after such conviction persists in the course of conduct which constituted the said offence, shall be guilty of a continuing offence and liable on conviction, in the case of an offence referred to in sub-section (2), to a fine not exceeding £40, and, in the case of any other offence, to a fine not exceeding £10 in respect of every day that he so persists or has so persisted.

IMPORTANT CONSIDERATIONS IN THE SPECIFICATION OF STANDARDS FOR EFFLUENTS DISCHARGED TO WATER COURSES

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ABSTRACT

The pollution of water courses including the sea is a universal problem. It is created by factors of nature seriously aggravated by the activities of man.

The most satisfactory basis for the scientific assessment and solution of the effluent problem lies in the specification of realistic standards to guide all interested parties in their efforts to achieve the national aim of the prevention of pollution of water courses.

The first important step is to see the effluent problem in its true perspective and to persuade the major contributors to the problem to accept voluntary responsibility towards its solution. A balanced appreciation of the problem and acceptance of responsibility is the first requirement in the formulation of quality criteria for effluents.

The geography and geology of South Africa, its peculiar industrial development and limited water resources are guiding factors in an equitable approach to the specification of standards, Environmental factors in defined regions are the second most important in the drafting of regional standards.

Specific problems arise from difficult effluents in relation to local conditions, and relevant considerations seen in the light of the broad implications of effluent control become important in specifying standards in individual cases.

THE INDUSTRIAL EFFLUENT POLICY OF THE LOCAL AUTHORITY WITH REFERENCE TO THE CONTROL OF POLLUTION

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ABSTRACT

The prosperity of a country depends on the prosperity of its industries. Industrial development is essential, but it brings a host of problems, not the least of which is the industrial effluent one. Industries are of great and ever-expanding variety, with concomitant increasing industrial effluent problems.

Industries are encouraged by local authorities who should accept the industrial effluents from them. Certain limitations are necessary. Many industrial effluents have unconventional effects on conventional methods of sewage purification.

Union Government Water Act, 1956, lays down that "the purification of an industrial waste shall form an integral part of the industrial process". Such purification is usually carried out at a local authority's sewage works, when the industrialist should pay for the load contributed to the sewers and sewage works. Where necessary, the waste must be pre-treated at the industry to a reasonable standard as required by the local authority, prior to discharge to the sewer.

How much should the local authority recover from the industrialist?
Pollution prevention necessitates industrial effluent control:

National policy—Institute of Sewage Purification memoranda—South African 1948, British 1952 and 1957.

Local authorities' duties—existing industries, industries planned for the future, town planning, special sewers.

Economic utilisation of sewage purification works will bring a country closer to the goal of water conservation.

**IV. TREATMENT OF SEWERAGE AND EFFLUENTS —
TRAITEMENT ET EVACUATION DES EAUX D'EGOUTS ET
DES EAUX VANNES**

TREATMENT AND DISPOSAL OF INDUSTRIAL WASTE WATERS IN GREAT BRITAIN

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There is an effective interchange of information between most of the industrial countries of the world on methods of treatment of liquid wastes, and the methods adopted in any particular country are likely to depend on such factors as the volume of surface water available for dilution, the distribution of population and industry, and the rate at which both population and industrialisation are increasing. These and similar factors are likely to have influenced the legislation of a country controlling pollution of surface waters, which in turn will have a marked effect on the means of purification adopted. Certainly this is true in Great Britain where, particularly during the last thirty or so years, changes in the law, made necessary by the increasing use of the limited surface waters of the country for domestic and industrial supply, have had an unmistakable influence on the course of development of methods of treating and disposing of industrial wastes.

DISPOSAL FACILITIES

Large-scale treatment of domestic sewage in Great Britain developed at a time when the only effective process of purification was irrigation on land. Except for its occasional use, mainly in rural areas, this method has for the most part now been abandoned. From what can now be gathered from contemporary accounts, its success seems to have varied very greatly in different places, a major factor no doubt being the nature of the soil, which varies from very porous gravel in some limited areas, to almost impervious clay in others. Irrigation, however, must clearly have been unsuitable for general use, particularly in the neighbourhood of towns where it became increasingly difficult to obtain sufficient land for the purpose. In some countries success is reported in disposing of individual industrial wastes by this means and the possibility of adopting it is often taken into account when considering possible means of disposal of industrial wastes, particularly of course in rural areas. There are one or two successful examples of this where effluents containing organic matter—for example from the canning of fruit and vegetables—are distributed by spraying over a large area of land, sometimes grassland and sometimes arable. Occasionally also attempts are made to discharge effluents to underground soakaways, but there seem to be very few examples of this being done successfully; a difficulty is the

very large number of wells in some districts from which water is taken for domestic supply, particularly for small communities. It is obvious that under British conditions these methods of disposal are very limited in their application and that substantially all the industrial effluents produced will have to be disposed of by discharge to rivers, to estuaries, or to the sea.

Since, however, almost all inland towns have a sewage-treatment works it is possible for a large proportion of the industrial waste to be discharged to a sewer rather than direct to a stream. In the early days of sewage treatment different local authorities took different views on the advisability of accepting industrial discharges. Some authorities, well before the beginning of the present century, were prepared to accept all wastes produced in their area and in these cases this has naturally become the accepted method of disposal. In other districts the manufacturer had much more difficulty in arranging to discharge in this way. Gradually, however, it has come to be accepted by almost everybody concerned with the prevention of pollution that, with proper safeguards, treatment of industrial wastes in admixture with sewage is generally more effective, and less costly, than treatment in a multitude of individual plants and, as will be seen, this view is now endorsed by legislation governing the relations between a manufacturer and his local authority.

It is of course very important that where this system is adopted industrial effluents should not be discharged if they contain substances which would damage or block sewers, or would be dangerous to men working in them, or would interfere seriously with the operation of sewage treatment works, or would cause a substantial deterioration in the quality of the sewage effluent. Thus it may be necessary for the manufacturer to pre-treat his waste to avoid damage of this kind and pre-treatment is now common for some types of waste liquor.

There remain many factories which cannot discharge to municipal sewers, either because they are outside the sewered area or sometimes because the volume of industrial effluent to be disposed of is very large in comparison with the volume of the sewage of the district. In some areas the numbers of these cases are being reduced by the formation of joint sewerage boards. When this occurs the scheme adopted depends on local conditions, but generally it results in the abandonment of most of the small sewage works of the district, the sewage being taken through trunk mains to a large new treatment plant. It is then often possible to accept trade wastes which, because of their large volume or difficult composition, could not have been treated effectively in the small plant of the constituent authority.

A local authority, in imposing conditions on the reception of industrial wastes, will have to take into account the effect of the liquor on the quality of the effluent which it will have to discharge, and its policy is likely to depend on whether the effluent is to be discharged to the sea or to an estuary,

or to a stream. If discharge is to an inland stream the quality of the sewage effluent which will be held to be acceptable is likely to depend on the dilution available and on the purposes for which the river water is used, and particularly on whether it is a source of domestic water supply. The same will apply with greater force to the manufacturer who has himself to treat his waste water for direct discharge without having the advantage of the purification which it would receive at a sewage works.

In Great Britain the rivers are generally small, at least by continental or American standards, but even so the dilution available varies widely from one district to another. Although it is unusual for a river-bed to dry out completely in the summer, as occurs in some countries, there is usually a very large difference between winter flow and summer flow; for example the flow of the River Thames as it enters its estuary, may be more than 5,000 million gallons a day or less than 100 million gallons. In some districts where low rainfall coincides with dense population, the dilution available for sewage and industrial effluents is very small; near the head waters of rivers in these areas there is often less dilution water than effluent. Some of the rivers in this condition are used as sources of domestic water supply. In these circumstances effluents to be discharged have to receive an unusually thorough purification and the investigation of suitable methods of treatment has, particularly during recent years, formed an important part of British research on waste disposal.

There are in Great Britain no statutory standards of quality of rivers though the possibility of adopting quantitative standards is often discussed. From a technical point of view it would seem to be difficult to formulate standards sufficiently simple to be practicable yet sufficiently inclusive to specify the quality of the water, particularly if one had to take into account the varying purposes which the river might serve. A very interesting discussion of this subject was given recently by Key¹ in a paper to the River Boards' Association. He concluded that even if quantitative tests were applied it would still be necessary in assessing quality to take into account factors which could not be measured quantitatively, and that in any case assessment by chemical tests of the water would have to be supplemented by biological examination. Taking into account, however, both quantitative and qualitative methods of assessment he classified the rivers of England and Wales into four classes, using data provided by River Boards. The less polluted portions of rivers—that is, rivers which were unpolluted or were recovering from pollution—were defined as those which were known to have received no significant polluting discharges; or which though receiving some pollution, had a B.O.D. of less than 3 ppm and were well oxygenated and had not received significant discharges of toxic materials or suspended matter which could affect the condition of the river-bed; or were generally indistinguishable from those in the same area known to be quite unpolluted. Grossly polluted rivers were defined

as having a B.O.D. of 12 ppm or more under average conditions, or as being incapable of supporting fish life; or which were completely deoxygenated at any time except in exceptional drought; or which were the source of offensive smells; or which were offensive in appearance, omitting those streams in this class offensive only because of the presence of detergent foam. There are two intermediate classifications based on generally similar methods of assessment. Using these criteria it was concluded that of some 20,000 miles of rivers on which data were available, a length equivalent to 73 per cent of the total would be classed as unpolluted or recovering from pollution, 6 per cent of the total length was grossly polluted, and 21 per cent was of intermediate quality.

LEGAL CONSIDERATIONS

Questions concerning the discharge of trade effluents to sewers are a matter for negotiation between the manufacturer concerned and the local authority, or sometimes the joint sewerage board, in whose area his works are situated. Relations between the two parties are regulated by the Public Health (Drainage of Trade Premises) Act, 1937, which applies to England and Wales except for the area of the London County Council; there is, however, no corresponding Act for Scotland. It is generally agreed that the operation of this Act has been very beneficial in reducing pollution of rivers, though some of its provisions have led to discussion and some criticism. Briefly, the effect of the Act is to give a manufacturer the right to discharge to the public sewers, subject to certain conditions. One of these is that the Local Authority may make a charge for receiving and treating his waste, and it may also impose conditions on the volume and on the nature or composition of the liquid which will be accepted; this last provision is of course operated in such a way as to prevent damage or danger in sewers or substantial interference with the purification of the sewage, and it is this which has led to the practice of pre-treating particularly difficult wastes. Disputes between a manufacturer and the Local Authority are determined on appeal by the Minister of Housing and Local Government, whose staff of Inspectors takes into account both the technical and financial aspects of the case.

The general composition of many types of waste water, and their effects on sewage treatment, are known from past experience. In some cases it may not be possible from existing knowledge to forecast what the effect of a discharge will be—perhaps because the liquor is of a type not previously encountered or because the proportion of a known type of effluent to be discharged is unusually high. It may then be necessary to carry out experimental work in which the waste, or a liquor made up to resemble it, is treated in admixture with sewage, sometimes in small experimental plants or occasionally in larger pilot plant. This is one of the types of

investigation sometimes made by the Water Pollution Research Laboratory, which has been built on a site where considerable quantities of purely domestic sewage can be pumped from the sewer of a Local Authority for use in work of this kind. .

The Act of 1937 contained an element of compromise in that the consent of the Local Authority to the discharge of an industrial waste to a sewer was not necessary if liquid of the same nature and composition had been lawfully discharged during the year which preceded the coming into force of the Act; nor could the Local Authority subsequently make a charge for its reception. This provision has caused difficulty in some areas, particularly where effluents were accepted many years ago before their effects on sewage treatment were properly appreciated. A Government Committee, which has been reviewing legislation on pollution prevention has recently recommended ² that, except where a contract is in force, Local Authorities should now be empowered to charge for the reception and treatment of these liquors which under the Act had acquired "prescriptive" rights. Another recommendation of this Committee is that waste waters from farm premises should rank as trade effluents. In Great Britain the discharge of waste waters—which are peculiarly difficult to treat—from farm premises, and particularly from the washing down of concrete floors on which animals are kept, has given rise to increasing difficulty during recent years; in some villages or small towns the character and volume of the sewage are influenced more by farm animals than by the human population.

Although many of the difficulties encountered at sewage works are the result of the presence of industrial wastes, one of the biggest troubles in the past few years has been caused by synthetic detergents, discharged almost entirely from households, and this the Act of 1937 can do nothing to remedy. Quite other methods have been adopted in an attempt to alleviate the difficulty.³

Almost all the sewage effluent discharged to streams is from the works of Local Authorities—a comparatively small volume is from works belonging to Government Departments, nationalised or private industry, or from isolated houses with their own small treatment plant—usually a septic tank and percolating filter. Thus Local Authorities are mainly responsible for any damage caused by the discharge of sewage effluents, and manufacturers for that brought about by those industrial effluents which they discharge direct to streams. There are two quite different methods by which an action can be brought to abate a pollution, the one by a riparian owner and the other by a River Board.

Under the common law of the country a riparian owner may bring an action if his interests are affected by a pollution, and if successful may be awarded compensation for damage and may obtain an injunction to have the source of pollution stopped. For many years little use seems to have

been made of these rights, but more recently there has been a series of actions at common law, many of which have been successful. This method of pollution prevention is, however, of necessity sporadic and so differs from the general and continuous supervision of streams and other surface waters which is exercised as part of their statutory duties by River Boards. It would be generally agreed that the formation of these Boards in 1948⁴ has been a major factor in checking the increase in pollution which might have been caused by the growth of sewered population and of industry, and in bringing about a gradual but quite significant improvement in the condition of rivers which were already polluted when the Boards were formed.

One of the reasons for the success which River Boards have achieved is that they employ technical staffs and many have laboratories and facilities for surveying the rivers in their areas. There is thus emerging a clear picture of the present state of British streams and of the volume and character of the effluents discharged to them; bearing in mind the improvement in conditions which River Boards have been able to bring about since their formation they have had remarkably little recourse to the law, most of the changes they have effected having been brought about by negotiation and persuasion. Where legal action is necessary Boards rely for the most part on two measures, the Salmon and Freshwater Fisheries Act, 1923, or the more comprehensive Rivers (Prevention of Pollution) Act, 1951. The former applies only to waters containing fish and is concerned with the effects of discharges on fisheries. The latter is concerned with the nature of liquids discharged to streams whether or not fish inhabit them.

Operation of the Act of 1951 has drawn attention to the difficulties involved in formulating any comprehensive system of standards of quality for a wide variety of industrial and sewage effluents. One provision of the Act empowers River Boards to make bye-laws (which require confirmation by Government) specifying standards of quality allowable for discharges to a river or part of a river. No such standards have come into force but those that have been suggested and discussed are of two general kinds. In the first the standard would specify some of the general properties of an effluent—for example its pH value and the maximum oxygen absorbing capacity acceptable—and in addition would set out the maximum allowable concentration of certain constituents, as for example toxic metals and radicals. In the second, each requirement of the standard would relate to the effect which the effluent would have on some property of the river; thus instead of a list of toxic substances the concentration of which was to be controlled, the maximum allowable toxicity of the whole effluent would be specified, this being determined by direct experiment with fish. It seems to be generally agreed that of these two types of standard the second is the more practicable, at least in a district having a wide variety of industry, where neither the identity nor the concentration of many constituents of effluents would be known or could easily be determined. Even so, however,

in such a district the formulation of standards, however simply defined, has been found to be very difficult and so far has not been adopted. Should such a method of control be undertaken, regard would have to be paid not only to the composition of effluents, but to their volume and the dilution available, since what is important is ultimately the concentration of undesirable substances in the river itself. Though it is sometimes possible to reduce the volume of an industrial effluent—and in some industries much progress has been made in doing this—the volume of some effluents, and certainly of sewage effluents, cannot normally be changed, and the only room for improvement is therefore in composition. Probably, however, a more important consideration is that some industrial effluents are much more difficult to purify than are others and, if it is agreed that in a long-established industrial area the removal of pollution must be a long-term process, the best approach is to require such improvements as are reasonably practicable in the present state of knowledge. Indeed, if the Act of 1951 is read as a whole this was clearly in the minds of those who framed it.

The Act of 1951, however, contained another provision which has suggested an alternative approach to the problem. It was declared necessary to obtain the consent of a River Board (subject to appeal to the Minister of Housing and Local Government) before bringing into operation any new discharge after the passing of the Act. In giving its consent the Board could impose conditions on the nature and composition, temperature, and volume of the discharge. Thus its consents referred to individual effluents and a Board could take into account any circumstances it considered relevant, including the means at present available for treating particular types of waste. Very little difficulty seems to have arisen in applying this provision throughout the country and a Committee set up by the Government has recently recommended that essentially the same procedure should be available to River Boards for all effluents in their areas, including those which were in existence in 1951. If this suggestion were adopted in future legislation it would obviously increase the flexibility of control of pollution by River Boards.

In England and Wales (the position is rather different in Scotland) River Boards do not have general powers of preventing pollution of estuaries unless, after an enquiry, a particular estuary has been brought within their area of authority. A few estuaries have in fact been brought under their jurisdiction since 1951. Generally, however, the condition of British estuaries, which often pass through centres of population and industry, is much worse than the general condition of freshwater rivers. Some are at present a barrier to the passage of migratory fish and a few have at times reached so anaerobic a condition that a public nuisance has developed. This state of affairs is giving rise to a good deal of discussion and there is at present before Parliament a Bill ⁵ which for most of the estuaries of England and Wales would give River Boards the same type of control

over new discharges as that they at present exercise in inland districts. It is not proposed, however, to extend their powers to the sea coast, though here again there has been some public disquiet recently on the polluted state of some coastal waters. Though a recent enquiry⁶ has shown that there is no evidence of the transmission of disease by bathing from polluted beaches, there is a widespread desire to reduce pollution of the sea, at least at coastal resorts. Most sewage from such places is discharged crude, or with very little treatment, though there are a few complete treatment works on the coast and one is at present being built.

METHODS OF TREATMENT

The methods of treatment of industrial wastes in use in Great Britain may perhaps be considered under four heads: (a) measures taken at a factory to reduce the volume, or to improve the quality of the liquor to be discharged; (b) treatment in admixture with sewage at the works of a Local Authority; (c) pre-treatment at a factory before discharge to a sewer; and (d) complete treatment before direct discharge to a stream.

The extent to which it is possible to reduce the problem of disposing of an industrial waste by measures taken within the factory itself varies very much from one industry to another, but the importance of adopting measures of this sort, where they can be applied, is very generally recognised, particularly in those industries such as paper-making, where the total weight of polluting matter to be disposed of is initially very great. It is common to find that within a given industry the attention which is paid to modification of manufacturing processes to reduce the difficulty of disposal varies very much from one plant to another, being influenced no doubt by the ease and cost with which the effluent finally produced can be disposed of. For example, it has been known for many years that in the milk industry the quantity of waste milk and other products entering the waste waters can be reduced to a comparatively small amount if sufficiently strict precautions to avoid leakage and spillage are taken. Many dairies, being in rural districts, have to treat their own waste waters (usually by alternating double filtration) and at some of these the strength of the liquor to be treated has been very much reduced by an organised campaign of waste prevention. Similarly in the paper industry it is generally recognised that the most profitable first line of attack on the effluent problem is by adopting, wherever possible, systems of recirculation of effluents within the mill and by removing solid matter, including fibre, wherever possible before the various liquors are mixed and are taken to a treatment plant for final disposal. Where conditions for disposal are particularly difficult—or where the supply of fresh water is limited—these measures have been taken to an advanced stage and now form an integral part of the paper-making process.⁷ Indeed economy in water where the supply is limited often is found to lead to an alleviation of the effluent disposal problem. In the electro-plating

industry, for example, there are plants at which little precaution is taken to reduce the weight of metals or cyanides in the effluent to be treated; at some works the quantity has been reduced significantly by adopting a counter-current system of washing and using the strongest solutions for making up the plating bath; at a few works, where the supply of water is limited, these measures are combined with a system of treatment and of recirculation and use of the washing water. There are probably few industries in which economies in waste water treatment could not be made by modifications in the manufacturing processes. Recently for example there has been a good deal of interest in the improvement of treatment of waste waters from slaughterhouses and meat processing plants from which, unless strict precautions are taken, large quantities of organic matter are discharged; surveys made within the industry have shown that, at least in some cases, it is possible to prevent a worth-while proportion of this material from leaving the premises.

In some industries the cost and difficulty of treating the waste waters would be so great that systems of recirculation or of recovery of solid materials before treatment have become accepted practice. This is so for example in the beet sugar industry where both transport water and process water are re-used, and in some sections of the steel industry where ferrous sulphate is recovered from spent pickle solution, the liquor being returned to the pickling bath. This last process has been in use for many years in different countries and much research has been undertaken in attempts to find an economic outlet for the recovered ferrous sulphate—a problem which does not yet seem to have been fully solved. In the somewhat similar process of pickling copper, however, it is easy and profitable to recover metallic copper by electrolysis, the regenerated acid being re-used. In one large industrial process in Great Britain—the preparation of coal for the market—discharge of effluents has been almost entirely eliminated by a major reorganisation of the various processes of washing and grading.

There are only a few sewage works in Great Britain at which plant of special design has been built as a result of the presence of industrial wastes in the sewage. Some of these are in the north of England in areas in which wool scouring is a major industry. By far the largest is at Bradford where the crude sewage is acidified to crack soaps, grease being expressed from the primary sludge after heating, and worked up into a number of saleable products. Generally, the chief effect of trade wastes in a sewage will be to cause a less conspicuous modification in the treatment plant; for example the volume of sludge recovered may be unusually high, or the rate at which the biological part of the plant can be loaded may be unusually low. One noticeable difference at some sewage works receiving large volumes of strong organic wastes is the incorporation of recirculating of effluent before biological filtration to avoid ponding which would otherwise occur. For the same reason works treating particularly strong sewages have adopted the

process of alternating double filtration. At one time it was fairly common practice to add a coagulant—usually alumino-ferric—to strong industrial sewage before primary sedimentation; this practice, however, seems to be dying out and the author is not aware of any works at which a coagulant is added in solution through specially designed dosing equipment. In fact in general, where particularly difficult industrial wastes are to be received, the practice is rather to require their pre-treatment by the manufacturer than to make special modifications at the sewage works itself.

It has long been accepted that where a troublesome industrial liquor is produced with marked fluctuations in flow or composition, it should pass through a balancing tank before discharge to a sewer. This, for example, is commonly required for gas liquors, particularly when they are distilled for recovery of ammonia at a gas works which operates only intermittently. Another frequent case is the discharge from a factory of a continuous large flow of a weak liquid—say a washing water—with an intermittent discharge of a much stronger liquid; if the latter were accepted to a sewer it would usually be required that it should be discharged at a constant rate from a balancing tank. Indeed, the value of receiving at a sewage works a reasonably constant flow of liquid is now so generally agreed that the desirability of balancing fluctuating flows of sewage itself is being discussed, and at least at one large works balancing tanks have recently been installed.

Well-established methods of pre-treating trade wastes include neutralisation, this being done in some plants under manual control and in others controlled automatically. A more difficult requirement to meet is that an industrial effluent should not contain more than a certain maximum concentration of soluble sulphate (often fixed at about 1,000 ppm as SO_4) to avoid damage to concrete, particularly in small branch sewers, before the liquid receives much dilution. No economic method of reducing the concentration of sulphate (other than by neutralisation with lime which still leaves a high concentration of calcium sulphate in solution) has been discovered and the difficulties which this requirement has caused suggest that when new sewers are being designed, particularly in an industrial district, the possibility of using sulphate-resisting cement should be considered.

There is a large and important class of effluents which contain toxic substances which interfere with the biological treatment of sewage, and some of which may pass through a treatment plant and so render the effluent toxic. Most of these are from the metallurgical industries, and particularly from electro-plating, and there are well-known means of dealing with them⁸ and many pre-treatment plants in operation. For effluents containing cyanides several methods of treatment have been considered, but the practice in Great Britain is generally to oxidise the cyanide with chlorine, either as gas or as hypochlorite. Toxic metals such as zinc and nickel are removed by controlled neutralisation and sedimentation, and chromates are dealt with by reduction, usually by sulphur dioxide or a sulphite, but sometimes

by ferrous salts, followed by removal by sedimentation. Another common type of pre-treatment is for the removal of emulsified oils, for example from spent cutting oils at engineering works. Various reagents have been tried for breaking these emulsions, the commonest in use being aluminoferric applied after addition of controlled amounts of sulphuric acid. The liquid from which the oil has been removed can usually be discharged to a sewer, though it is much too polluting for direct discharge to a river. A similar method is being used for treatment of liquors from the washing of aircraft.

To a manufacturer wishing to discharge to a sewer a waste water containing organic matter it will be an advantage if he can remove part of this at a lower charge than would be made by the Local Authority for receiving it. Thus it may pay him to remove insoluble material by screening or even by sedimentation, and in some cases he may be required to do this to avoid blocking sewers. The possibility of reducing the organic load by anaerobic digestion is also being discussed at present, particularly for such strong liquors as those from slaughterhouses. Much valuable work has been done in South Africa on this process, and following somewhat similar work in England, at least two full-scale plants are at present under construction.

Where a manufacturer has to discharge an effluent direct to a surface water, and particularly of course to an inland stream, he is in a particularly difficult position and may be faced with considerable expense, both for construction and operation of a treatment plant. There is a wide range of industrial wastes which can be treated either by biological, or by chemical or physical processes, and a good deal of research has been done to evaluate their relative merits. Generally, where a biological process can be used it is likely to be cheaper than any alternative, though for some liquors it may be necessary to supplement it with some other form of treatment. One of the types of liquor which has been particularly well studied is gas liquor where the processes investigated, and in some cases operated in full-scale plant, include oxidation, removal of constituents by solvents and by base-exchange and acid-exchange processes, evaporation, absorption, and biological treatment. Work, particularly by the National Coal Board and the gas industry, has shown that the potentialities of biological action, particularly in the activated-sludge process, or in modified forms of it, in removing such constituents as phenol and thiocyanate, are much greater than would at one time have been supposed, and the National Coal Board has in operation several plants employing this process for the treatment of effluents from the purification of coke oven gas. Treatment in percolating filters is also being used to remove formaldehyde from effluents from the manufacture or use of synthetic resins and it has been shown⁹ that cyanide can also similarly be decomposed under defined conditions of treatment, though this process has not so far been adopted on a large scale.

At present the discharge to sewers and surface waters of effluents containing radioactive substances is controlled by Local Authorities and River Boards respectively, but very close supervision is exercised by the Central Government through the Ministry of Housing and Local Government. Following the publication of a report on this aspect of pollution¹⁰ a Bill is now before Parliament which would place the storage, use, and discharge of radioactive materials entirely under Government control.

EFFECTS ON SURFACE WATERS

With so large an effort on pollution prevention in Great Britain it is natural that there should be much interest in the effects which effluents, or particular constituents of them, have on surface waters and their use. Much of this field remains to be explored and research within it is at present largely confined to two aspects—the effect of oxidisable material on the distribution of dissolved oxygen in rivers, and the direct effect of toxic substances on fish.

Perhaps the most noteworthy advance made in the first of these is the direct measurement of the capacity of streams for re-aeration from the air¹¹; although this has been discussed for many years its measurement has until recently depended on an indirect and not very convincing method. Direct determination has shown that the rate varies very widely in different streams, increasing with increasing turbulence, and that it can be substantially affected under certain conditions by the presence of quite small concentrations of particular substances, as for example synthetic detergents. Further progress depends, it is suggested, on a quantitative determination of the rate of oxidation of organic matter in a river where the conditions might be quite different from those in a laboratory apparatus. Much more work is also required to determine the effect of organic bottom deposits which, at least in slow, muddy, polluted rivers in the south of England, appear to play a large part in determining the oxygen balance.

It is often complained that no serious attempt is being made to determine the effects of polluting substances on fisheries. For this there is some justification, but the enquiry would obviously be a complex one involving as it does the food of fish, their spawning habits, and the viability of eggs and young, and even the reactions of fish to the presence of polluting substances. In Great Britain a start has been made on what is no doubt the easiest line of enquiry—that is on the directly toxic action of the commoner polluting substances, an action which from time to time leads to the spectacular destruction of large numbers of fish. This limited aspect of the investigation is leading to results of much more general application than at first seemed probable. Although several factors may have to be taken into account in addition to the concentration of a particular poison, a knowledge is required of the temperature, the oxygen tension, and

possibly of the pH value and the concentration of carbon dioxide ; but given these it is possible to predict with reasonable accuracy the period which fish of a given species will survive. This work forms the background to that which is being carried out by the Ministry of Agriculture, Fisheries and Food on the development of a standard test for toxicity of effluents.

In countries of such different climate as Africa and Great Britain, the considerations which are important in discharging an industrial or sewage effluent are no doubt different. For example, it is understood that in South Africa there may be an objection to the discharge of effluents containing inorganic nitrogenous salts, or presumably inorganic nutrients, because of their effect in stimulating the growth of aquatic plants. This is not generally considered of great importance in Great Britain, except perhaps in those rivers which serve as a source of water for domestic supply, and little or no work has been done to determine the effect under different conditions of the discharge of a given quantity of inorganic nitrogen. Generally it is not suggested, for example, that nitrogenous salts should be removed from sewage effluents though oxidation of at least a proportion of the ammonia in an effluent to nitrate may be required ; this, however, would usually be for effluents to be discharged to a stream in which the concentration of dissolved oxygen is likely to fall to a low level when the nitrate would itself serve as an additional source of oxygen.

As experience in the management of streams grows, much more information on the effects of particular substances on them will clearly be required and a balanced programme of research will have to include not only work in the laboratory and at the sewage works and factory, to improve methods of purification of wastes, but equally detailed surveys of rivers and, at least in Great Britain, of estuaries, to determine how their chemistry and biology are reacting to the changing pattern of pollution.

References

1. KEY, A. River pollution and its control, present and future. Paper presented to River Boards' Association Annual Conference, 1960.
2. Ministry of Housing and Local Government. Final report of the Trade Effluents Subcommittee of the Central Advisory Water Committee. H.M. Stationery Office, London, 1960.
3. Institute of Sewage Purification. Progress towards the solution of the synthetic detergents problem. A Symposium presented at Annual Conference, June 1960.
4. River Boards Act, 1948.
5. Clean Rivers (Estuaries and Tidal Waters) Bill. House of Commons, 1959.
6. Privy Council. Sewage contamination of bathing beaches in England and Wales. Medical Research Council Memorandum No. 37. H.M. Stationery Office, London, 1959.
7. PIRIE, G. W. *Proc. Tech. Sect. Brit. Pap. Bd. Makrs. Ass.*, 1955, 36, Part 2, 265.
8. PETTET, A. E. J. *Product Finishing*, 1955, 8, No. 7, 54 and No. 8, 57.
9. PETTET, A. E. J., and WARE, G. C. *Chem. and Industr.*, 1955, 1232.
10. Minister of Housing and Local Government and Minister for Welsh Affairs and the Secretary of State for Scotland. The control of radioactive wastes. H.M. Stationery Office, 1959, London. Cmnd. 884.
11. GAMESON, A. L. H., TRUESDALE, G. A., and DOWNING, A. L. *J. Instn. Wat. Engrs.*, 1955, 9, 571.

EFFLUENT PROBLEMS OF THE PULP AND PAPER INDUSTRY

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ABSTRACT

The sources of effluents from pulp and paper mills are outlined showing their nature and possible means of disposal. Disposal is governed by the economics of recovery, as against the selection of mill sites. The degree of industrialisation of each country, coupled with increasing demands for paper products, makes the importance of effluent disposal methods a prime consideration. It is envisaged that a radically new outlook is emerging.

BY-PRODUCT RECOVERY AND EFFLUENT TREATMENT IN THE OIL FROM COAL INDUSTRY

P. R. LOEWENSTEIN

The Sasol Oil-from-Coal Plant is situated three miles south of the Vaal River in the Barrage catchment area. The Barrage is the raw water reservoir for the Rand Water Board, which is the biggest supplier of water in the country. Downstream of the Barrage are numerous towns, mines, industries and agricultural undertakings, all of which rely on the Vaal River for their water. Great care, therefore, has to be exercised by Sasol to ensure that the river is not polluted and that the effluent which is discharged to the river complies with the standards demanded by the Department of Water Affairs in terms of the Water Act.

SOURCES OF EFFLUENT

That the problems involved in effluent treatment are not small ones can be seen if one considers the types and sources of the effluent. These are: (1) Water purification sludges, (2) Water softening brines and sludges, (3) Boiler blowdown, (4) Cooling tower blowdown, (5) Gas liquor, (6) Synthesis and product work-up liquors, (7) Domestic sewage, (8) Ash handling.

Of these effluents the first three contain no organic pollution. The water purification effluent consists of about 120,000 gpd sludge containing 20 tons of solids. This effluent arises from the flocculation of the 10-11 mgd of Vaal River water which are used in the factory.

The softening plant discharges about 24,000 gpd of sludge containing 5 tons of solids and the cation exchanges use approximately 1,000 lb. of salt per day for regeneration. These effluents arise from plant providing 1,000,000 lb./hr. of softened water make-up to the power station's 600 lb./sq. in. boilers. The blowdown from these boilers is about 150,000 gpd of water containing 1,200-1,500 ppm TDS.

The cooling system gives rise to about 3,000,000 gpd of blowdown; the circulating water itself is, normally, free from oil and dissolved organic impurities, but cooling water bled off from the circuit through pump glands, etc. can be polluted, the main danger being oil.

The gasification and synthesis processes are the main sources of effluents containing organic pollution. There are 850,000 gpd of gas liquor and 350,000 gpd of synthesis liquor to be treated daily, and we will consider the problems associated with these effluents in greater detail in a few moments.

Domestic sewage from the factory and the town amounts to $\pm 450,000$ gpd (DWF).

Finally there is the ash handling system in which up to 2,000 tons per day of ash are disposed of through a hydraulic handling system which uses about 7,500,000 gpd of water.

Let us now consider the problems of gas liquor and synthesis liquor a little more closely.

BY-PRODUCT OR EFFLUENT

One of the problems which often has to be faced by an industrialist is the well-known one of "by-product or waste?" This problem arises both with the gas liquor and the synthesis liquor. In the case of gas liquor it is no new problem, being as old as the gas industry itself, and where the Fischer-Tropsch synthesis process has been employed, the problem has also had to be faced.

GAS LIQUOR

Policy

The high-pressure gasification process used at Sasol gives rise to about 225 gallons of liquor per ton of coal gasified. This is much higher than the 20-50 gallons for older, more conventional gasification processes. The main pollutants, as with other gas liquors, are ammonia and crude tar acids.

In other parts of the world phenols are sometimes recovered, sometimes ammonia is recovered, sometimes both are recovered, and sometimes nothing is recovered. The answer to the recovery problem lies partly in economics, partly in geographic considerations and partly in the volume and composition of the liquor itself.

Where phenol recovery has been practised, a variety of methods has been used. The most common methods are the Koppers distillation process and extraction processes. Both benzol and esters have been used for extraction, and extraction has been carried out in both horizontal and vertical extractors. Phenol recovery appears to be fairly common in Germany and is practised in some parts of the U.K.—notably at Bolsover. Ammonia recovery, however, does not appear to be common practice in Germany, but has been practised in the U.K. An attempt at complete recovery of all the constituents in the gas liquor has been made at Tingley, near Leeds.

In complete contrast to Nicklin's Tingley process is the proposal to oxidise phenolic wastes completely with either chlorine, chlorine dioxide or ozone. In chlorination experiments in America phenol concentrations were reduced from 150 ppm to 3 ppm but the chlorine dose was high—4,000 ppm—and nearly 4,000 ppm of lime had to be added to the effluent.

This naturally results in a high concentration of calcium chloride, and, in fact, this form of treatment merely gives rise to another effluent problem. The phenol problem has become a salinity problem. Ozonisation is best carried out at a pH of 11.5 to 12 and treatment at this pH obviously also brings neutralisation problems in its train.

Treatment of gas liquor in admixture with sewage has been commonly practised in the U.K. and it has been found that 0.5 to 3% can be treated without affecting the quality of the effluent. The higher figure of 3% has been found to apply where hot electrostatic de-tarring is practised, the lower figure referring to crude gas liquor.

At Sasol the 850,000 gpd of liquor contains 4,000 ppm phenols and 1% of ammonia (of which approximately 99% is free) and the oxygen absorbed from acid permanganate at 80° F. figure (O.A.) is 4,000 ppm.

Geographic considerations make it imperative that this large volume of strong liquor be highly purified before discharge.

Treatment of the crude gas liquor in admixture with domestic sewage could not be considered because there is not sufficient of the latter to give the necessary dilution. Some other form of treatment, or some form of pre-treatment followed by purification, is obviously essential.

Both phenol and ammonia are recovered—geography and liquor composition are the dictators of the policy, not economics. Both phenol and ammonia, of course, have definite market values and their recovery can, therefore, be considered as by-product recovery; but since their recovery would be essential even if the processes showed a loss, the treatment of the liquor for their recovery can also be considered as a part of effluent treatment.

Phenol and ammonia recovery processes

At Sasol the phenosolvan process is used for the recovery of phenols. In this process the liquor first passes through tar and oil separators, and is then pumped to storage tanks with approximately two-and-a-half days capacity. The provision of this storage is essential to obviate shutting down the gasifiers for short shut-downs in the liquor treatment plant. (It is, of course, essential that no untreated liquor should be discharged.) From the storage tanks the liquor is pumped through sand filters, which remove last traces of oil and tar, to saturating towers where the pH is adjusted to ± 8.3 with CO_2 . This step is essential to avoid hydrolysis of the butyl acetate, which is used to extract the phenols from the liquor in a 7-compartment horizontal counter-current flow extractor.

The extracted liquor is passed to stripping and scrubbing towers where dissolved solvent is recovered and CO_2 made available for the saturation of the extractor feed.

The solvent, containing the phenols, passes to the solvent recovery section. Here the butyl acetate is stripped from the phenols and returned

to the extraction circuit. The crude tar acid is at present pumped to despatch, where it is drummed for export. The time may come, however, when the crude phenols are worked up at Sasol.

From the phenol recovery process, the liquor passes to a tower, in which it is stripped of ammonia. The ammonia vapours are passed to a saturator where the ammonia is converted to ammonium sulphate, which is centrifuged from the mother liquor, dried, and sold as fertiliser.

By the processes which have been described, the phenol concentration of the liquor is usually reduced to 1-2 ppm (determined colorimetrically) and the figure seldom exceeds 5 ppm. The solvent losses in the process (in which the ratio of liquor to solvent is 20:1 at Sasol) are normally well inside the guarantee figure of 250 gm. solvent/m³ liquor extracted. The ammonia stripping is equally efficient, the free ammonia in the stripped liquor being less than 150 ppm.

The extracted stripped liquor still has an O.A. of 300-400 ppm and a phenol figure slightly above the accepted standard. Further treatment is, therefore, necessary, and will be referred to later.

SYNTHESIS LIQUOR

Sasol uses both a "Fixed Bed" and a "Circulating Fluid Bed" system in its synthesis plants. These systems produce water and oxygenated chemicals in addition to hydrocarbons, but in different proportions. The "Fixed Bed" aqueous product contains 5% water-soluble chemicals, and the "Fluid Bed" product 17% water-soluble chemicals. These soluble chemicals include alcohols, ketones and organic acids. The volume of synthesis liquor is increased by the washes given to the crude oil and tail gas.

As with the gas liquor, the first step in the treatment of the synthesis liquor is the recovery of by-products. The ketones and all but 0.2% of the alcohols are stripped from the water, and are worked up into saleable products.

The stripped liquor, in addition to the residual alcohol, still contains $\pm 0.5\%$ of organic acids. This liquor presents quite a problem, the quantity of acid present is small enough to make its economic recovery a problem, but is large enough to pose a major effluent problem if pollution of water courses is to be avoided.

The present method of dealing with the stripped synthesis liquor is as follows. It is neutralised with soda ash and concentrated to a 50% solution in a triple-effect evaporator. The waste condensate from the second and third effect heaters is contaminated and is discharged to sewer, while the concentrated salt solution from the third effect is burnt in a kiln. The soda ash resulting from the combustion is dissolved and re-used for neutralisation of the incoming liquor.

It may be mentioned here that originally it had been thought that the synthesis liquor would contain only 0.2% organic acids, and the intention

had been to treat it at the sewage works. When Sasol first started producing, however, the synthesis liquors contained up to 1% acids, and the erection of an evaporation and incineration plant was decided on in preference to biological purification, as considerable expansion of the sewage works would have been necessary, and the problems associated with trying to purify a 1% acid solution biologically were unknown.

The whole question of how best to deal with the synthesis liquors is still being studied, and there is little doubt that the concentration of acid in the liquor is of extreme importance in deciding on the best procedure. Acid recovery, evaporation and incineration, or biological purification can all be used.

BASIC EFFLUENT POLICY

Now that the main effluents and their pre-treatments have been described, it is possible to consider the basic policy which has been adopted for handling them. This is to treat each effluent on its merits. To achieve this, a number of separate sewers have been constructed, viz. domestic sewers, a chemical sewer, an oily sewer, a storm water sewer and two sludge sewers. With this multiple sewer system it is possible for effluents to obtain the treatment which they require without overloading treatment units and plants with large volumes of effluent which do not require treatment in those units or plants; e.g. water purification plant and softening plant effluents with their loads of inorganic sludges, which do not require biological treatment, are kept out of the sewage works.

THE CHEMICAL SEWER AND SEWAGE WORKS

The chemical sewer carries the stripped gas liquor, the effluents of the synthesis liquor treatment plant, the drips and drains from the oxygenate working-up units and some effluents small in volume but high in oxygen demand, arising in some of the smaller work-up sections of the factory. This chemical effluent is cooled in spray ponds, and treated together with the settled sewage from the domestic sewer in a conventional sewage works. Time does not permit of a detailed description of this plant, and for further information you are referred to the paper "The Purification and Re-use of Sasol's Effluents" which appears in Part III of the *Journal and Proceedings of the Institute of Sewage Purification* (1959).

OILY AND STORM SEWERS

All effluents other than the water treating effluents which are discharged into the sludge sewer, and those effluents already referred to as being discharged into the chemical sewer, are discharged into the oily or storm sewers. The main pollution is oil, so the sewers discharge into an oil separator basin. Here the oil is recovered and returned to process, while the oil-free water is discharged into the general effluent system.

GOOD HOUSEKEEPING

Before passing on to the subjects of effluents and ash handling, a word should be said on the subject of "good housekeeping". In a factory the size of Sasol, and positioned as Sasol is, the importance of "good housekeeping" cannot be overemphasised. In some plants special sewer systems are installed which ensure that spillages are picked up and returned to process, and are not allowed to find their way to any of the sewers which discharge from the factory. Thus, for instance, spillages around the tar and oil separator group of the gasification plant, as well as all spillages in the phenosolvan plant itself, are returned to process in the phenosolvan plant. Spillages in the tar working-up plant and at the phenol loading bay in despatch are also returned to the phenosolvan plant, as are strong liquors from the naphtha hydrogenation process.

Sewers are sampled daily and any signs of abnormality are immediately followed up. By this means "illegal discharges" to sewer are, as far as is humanly possible, prevented, and unsuspected sources of pollution are tracked down and dealt with.

ASH HANDLING

As was stated at the beginning of this paper, 7,500,000 gallons of water are required to handle the 2,000 tons of ash discharged from the gasification plant and power station daily. This water is drawn entirely from the effluent system. Water from the oil separator basin, sewage works effluent, re-cycle from the final effluent dam as well as internal re-cycle within the ash handling system itself all contribute their share to the required volume of ash handling water. This use of effluents for ash handling serves a double purpose. It results in water economy, and it also permits of the complex ash handling system assisting in the purification of the effluents. The absorptive powers of the ash are used, for instance, to decolorise the sewage works effluent, which has a brown colour resulting from the large volume of gas liquor treated. The complex system of dams in the ash handling system also contribute their share to the purification of effluents.

CONCLUSION

All effluents eventually find their way to the final effluent dam. Organic effluents have been purified and matured, effluents with high suspended solids loads have been clarified, and highly saline effluents are diluted by less saline ones. The result is a final effluent which is suitable for discharge to the Vaal River below the Barrage.

THEORY OF STABILISATION PONDS AND ITS IMPLICATION ON THEIR DESIGN AND OPERATION

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SUMMARY

The paper summarises present knowledge of the biological activities taking place in stabilisation processes of organic wastes. As there exists great similarity between a series of stabilisation ponds and the various zones of purification in a flowing river receiving pollution, the biological principles underlying the processes of purification are used to formulate basic design criteria for stabilisation ponds.

Many research workers consider that planktonic algae play a very important part in the overall stabilisation efficiency of organic waste in ponds. The author, however, while agreeing that these autotrophic organisms could be of benefit to the processes by adding photosynthetic oxygen to the system during daylight hours, has found evidence that planktonic algae are of little importance to the operational efficiency of aerobic stabilisation processes.

The paper concludes by indicating that further extensive fundamental research is required before a full understanding of the processes involved can be reached.

I. INTRODUCTION

The term "stabilisation pond" is used in this paper to denote any pond which is treating either raw sewage, effluents from sewage treatment units or industrial wastes.

In a literature survey the author¹ described the rapid development of stabilisation ponds in the U.S.A. and also mentioned installations in Australia, New Zealand, Holland and Sweden. It was claimed that these ponds offered a more economical and reliable means of sewage purification in those countries than could be achieved by conventional works.

Although the results obtained overseas were claimed to be satisfactory, they were obtained empirically rather than rationally. This paper is an attempt to offer biological explanations of the processes taking place and to formulate basic criteria thereon for the design of stabilisation ponds.

In South Africa the development of stabilisation ponds did not keep pace with that in other countries. Whereas authorities in the U.S.A. and elsewhere were satisfied with a pond effluent quality equivalent to that of a biological filter, in South Africa the limited water sources made it essential that effluent qualities be of a very much higher standard in order not to overtax the self-purification capacities of rivers.

The Council for Scientific and Industrial Research, therefore, has concentrated research in the first instance on the development of stabilisation ponds for further treatment or "maturing" of existing humus tank effluents.

Stander² described experiments by the National Institute for Water

Research for the further treatment of humus tank effluent in maturation ponds, marshes and shallow algae beds.

In a later paper Stander ³ mentioned that maturation ponds, when treating humus tank effluents, were able to produce an effluent of a chemical and bacteriological quality equal to or better than that of rivers flowing through inhabited areas. Maturation ponds now form an integral part of sewage works design where the effluents have to be discharged into a public stream. No extensive research work has been undertaken in South Africa, however, on the pond treatment of raw sewage and settled sewage.

Although Clausen ⁴ and Abbott ⁵ described pond installations treating raw sewage at Allanridge and Cape Town respectively, the data supplied were insufficient for an evaluation of the design criteria.

2. METABOLIC PROCESSES AND STABILISATION OF ORGANIC WASTES

The chemical concept of stabilisation of organic wastes, viz. oxidation of organic compounds, has been superseded by a biological concept, i.e. metabolic processes of organisms.

Numerous publications have appeared on metabolism which could best be summarised in the words of Gainey and Lord⁶:

“Metabolism involves the intake, digestion and assimilation of food into tissues and the transformation of the potential energy of the food into kinetic energy with which the organisms accomplish work, together with the elimination of any waste products formed.”

Two main parallel processes are taking place in metabolism:

(a) A process of synthesis:

Food + organisms + energy → increased number of organisms and nitrogenous waste products.

(b) Respiration:

Carbohydrates + oxygen → Carbon dioxide + water + energy.

These processes run parallel to each other and the energy required by (a) is supplied by (b). Increases in (a) result in increases in (b) and in combining the above formulae (a) and (b), metabolic processes could be expressed as follows:

(c) Food + micro-organisms + oxygen → increased number of micro-organisms + nitrogenous waste products + carbon dioxide + water.

Formula (c) expresses the basic principle of all stabilisation processes, including those due to anaerobic organisms. These organisms function similarly, except that in their respiration processes other substances have to be used as an oxygen source (combined oxygen) instead of dissolved oxygen, and the end products are usually organic acids and some hydrogen-rich substance other than water, such as hydrogen sulphide and methane.

In looking at formula (c) from a physicochemical point of view it can be stated that the potential energy stored in the food and micro-organisms, on the left-hand side of the reaction, is converted into potential energy stored in the increased number of organisms and the nitrogenous waste products on the right-hand side of the reaction plus energy other than potential energy, which is necessary for the life processes of the organisms. The other products of the reaction, viz. carbon dioxide in aerobic systems and methane in anaerobic systems, under the conditions pertaining in stabilisation units could be considered to be stable products.

The efficiency of the metabolic conversion process of organic compounds present in the original organic waste into new organic compounds is of the order of 10 to 50%. This inefficiency of conversion enables the technologist to design more efficient stabilisation units by providing favourable environmental conditions in these units for the metabolism of organisms to take place to the fullest extent.

When a pure culture of a specific aerobic micro-organism is inoculated into a solution containing a large quantity of suitable nutrients and dissolved oxygen, there is a definite pattern of growth which can be divided into three phases. After a short "lag phase", the cells begin to multiply. This period of enormous increase in numbers is known as the "log growth phase". During this phase, the absorption of food material and of oxygen also increases logarithmically. At the same time there is also a logarithmic increase in the production of end products, of which the most important are the carbon dioxide and nitrogenous cell wastes.

This phase of great activity can be slowed down in five ways :

- (i) by not providing an intimate contact at all times between food, micro-organisms and dissolved oxygen,
- (ii) by using up available food material,
- (iii) by the bio-chemical oxygen demand exceeding the rate at which dissolved oxygen can be replenished,
- (iv) by the accumulation of the cell waste products which will eventually poison the cells,
- (v) by the increase of the micro-organisms above a limiting number per unit volume, above which the effects of overcrowding begin to function.

All, except factor (iii), would also apply in the case of anaerobic processes.

If nothing is done to counteract the above five factors, and especially if no further food is added, the culture will enter the "declining phase" and will eventually die out. However, this three-phase picture can be altered if the organisms are supplied with a constant source of food. Under the right environmental conditions the culture can settle down to maintaining itself at some fairly constant number of organism individuals per

unit volume, the number depending on a balance between the food available, the oxygen available and the rate of dissipation of waste products and surplus organisms. In other words, the organisms can establish themselves in equilibrium with their environment as long as conditions are not too extreme. Temperature and pH changes for instance will affect the equilibrium growth phase.

When considering the basic principle of all stabilisation processes, viz.

(c) Food + organisms + oxygen → increased number of micro-organisms + nitrogenous wastes + carbon dioxide + water, two conclusions may be drawn: the original putrescible material present in the substrate will have disappeared, and secondly, new organic material will have been synthesised in the form of an increased number of the same organisms and of nitrogenous waste products, which are both potentially putrescible materials.

If nothing further happens, a position will arise in which the original compounds in the substrate may have disappeared but may have been converted into other organic material which also has a biochemical oxygen demand.

The increased number of organisms, however, in turn provide the food-source for predators, and the second metabolic process as expressed in formula (c) takes place, followed by a third, fourth, etc.

Similarly the waste products of the first batch of organisms are utilised by different types of organisms.

Gainey and Lord⁶ said: "The statement has been made that every organic compound occurring naturally or produced biologically can be utilised as food by some micro-organisms. If some such provision for the destruction of organic matter were not provided by nature, any such compound would gradually accumulate, and the surface of the earth would eventually become so impregnated with it that life in its present form might become impossible".

Theoretically a perfect stabilisation system would consist of a unit wherein the first group of organisms, capable of metabolising the original organic compounds in the substrate, would be provided with the right environmental conditions for their metabolic processes, followed by a second unit harbouring different associations of organisms to metabolise organisms of the first unit and their waste products under their optimal conditions, and so on.

3. ORGANISMS OCCURRING IN STABILISATION SYSTEMS WITH SPECIAL REFERENCE TO ALGAE

Bacteria

The bacteria are the basic organisms in stabilisation systems. Growth of any particular species is dependent upon its competitive ability to obtain

a share of the available organic material in the system ; the species with the fastest growth rate and the ability to utilise most of the organic matter will predominate. Gainey and Lord ⁶ explain that bacteria, by exuding enzymes into the substrate, break down complex organic molecules into smaller molecules which are then diffused through the cell wall and utilised in the metabolism of the bacterium. The diverse biochemical characteristics of bacteria make it possible for them to metabolise most, if not all, compounds found in sewage.

Apart from the metabolic characteristics of the bacteria, their most important characteristic is their ability to flocculate when in the declining growth phase. As it is generally accepted that anaerobic stabilisation processes are more economical in their application than aerobic stabilisation processes, all efficient aerobic biological waste treatment systems depend on a good flocculation ability for the separation of colloidal organic solids from the liquid phase. These solids are broken down anaerobically in the bottom sediment of ponds, rivers or in digesters.

Fungi

Fungi are of secondary importance and they can, like bacteria, metabolise almost every organic compound found in sewage. The filamentous nature of some of the fungi found in wastes, however, makes them undesirable since they do not form a tight, compact floc and do not settle easily. For this latter reason, efforts should be made to make environmental conditions more favourable for bacterial predominance than for filamentous fungi, for while many of the fungi grow well at pH 4 to 5 few bacteria are able to grow well enough to compete at that pH value.

In aerobic stabilisation pond treatment of organic wastes having a biochemical oxygen demand nearing the available supply of oxygen or sometimes exceeding it, metabolism would not proceed predominantly to carbon dioxide and water, but alcohols, aldehydes and organic acids would also be produced. If the system lacks sufficient buffer the organic acids depress the pH to the more favourable range for fungi. Thus it can be seen that low oxygen tension and pH under certain conditions can be interrelated.

Under normal environmental conditions and provided the ponds do not receive too high an organic loading fungi will be present and will aid in the stabilisation of organic matter, but bacteria will predominate.

Protozoa

The protozoa are the simplest animals found in sewage stabilisation systems and they are responsible for reducing the number of bacteria. In stabilisation ponds, numerous species of protozoa are found which feed also on algal cells. The environmental conditions, the type of food, and the competition for food are the main factors which determine the predominance of protozoa species.

Higher animals

Rotifers, as well as other higher animals, occur in aerobic purification systems. They can metabolise the larger solid floc particles which the protozoa cannot metabolise.

Daphnia and other crustaceans grow well in highly stabilised aerobic effluents and feed on bacteria, fungi and algae, mainly the last, as their major source of food, resulting in a clear effluent.

Bartsch and Ingram⁷ describe higher animals which metabolise sludges on river bottoms.

It is of interest to quote the above authors⁷ on the sludge worms (Tubifex) "which feed on sludge by taking it into the digestive tract. In passing it through their alimentary canal they remove organic matter from it, thus reducing the biochemical oxygen demand. Sludge worms, $1\frac{1}{2}$ in. long and as thick as a needle, have been observed to pass faecal pellets totalling 5 ft. 9 in. through the digestive tract in 24 hours. Faecal pellets that are extruded from the anal openings have on occasion been found to have a biochemical oxygen demand of one half of that of sludge that was not worked over by them. When it is realised that from 7,000 to 14,000 of these worms may be found per square foot of bottom surface in sludges, considerable work is done in removing biochemical oxygen demand."

Tubifex worms have not been found in great abundance in experimental maturation ponds in South Africa, but they are numerous in the muds of the Apies river which receives humus tank effluent from the Pretoria Sewage Works. Larvae of Chironomid midges are often abundant in the experimental maturation ponds at Pretoria and they eat large amounts of organic matter including algae. The adults fly away and leave the system.

Algae

Algae need special reference as they cannot be considered in the same light as the aforementioned organisms. Under the influence of sunlight energy, algae, in common with higher plants containing chlorophyll, are able to synthesise from inorganic compounds such as carbon dioxide, ammonia and nitrates, etc., organic compounds similar to those which it is intended to remove from the pollutant. Their respiration processes are similar to those of the previously mentioned organisms but during daylight hours they produce more potential energy in their cells than they could convert by metabolism over the 24 hours.

As the whole process of stabilisation aims at the conversion or removal of similar organic compounds as those synthesised by algae, the impression that numerous authors seem to convey, namely that algae are the most important organisms in stabilisation processes in ponds, appears to be rather illogical. The above impression is further confused because numerous publications describe only planktonic algae which give the pond contents

the characteristic green colour. Benthic species, which are usually absent in the effluent, are seldom mentioned.

Parker *et al.*⁹ in describing the Braeside Lagoons which form a part of the Melbourne stabilisation pond system stated: "The biochemical oxygen demand removal by relatively 'algal free' lagoons would have been expected to be small inasmuch as experience at Werriby suggests a maximum removal of 25 to 30 lb. biochemical oxygen demand per acre per day. However, the actual removals achieved by Lagoon 1 at Braeside, viz. 55 to 60 lb. per acre per day in summer and the extraordinarily high figure of 267 lb. per acre per day in winter, are far in excess of the Werriby figures." Analyses of the Braeside lagoons are given in Table I.

In the following experiments conducted by the National Institute for Water Research, observations of a similar nature were made.

During experiments with sewage effluents in aquaria, it was found that glasswool or plastic mats suspended in the water resulted in the suppression of planktonic organisms in favour of benthic organisms which were encouraged by the larger surface area for attachment. The effluents from these aquaria showed excellent reductions in biochemical oxygen demand and very low turbidities. The above experiments were repeated on a bigger scale in two small concrete-lined rectangular ponds which were each dosed with humus-tank effluent and at approximately the same biochemical oxygen demand loading rate.

In one pond twenty terylene mats of curtain materials, 12 in. wide, were suspended vertically, 12 in. apart, along practically the full length of the pond. The top edges of the mats were 3 to 4 in. below the water surface and, the pond being 24 in. deep, a space varying from 9 to 8 inches was left between the pond bottom and the lower edge of the mats. Any wind-induced current could, therefore, freely assist in mixing the pond contents.

The second pond was 26 in. deep and did not have mats.

Weekly unfiltered snap samples of pond effluents were analysed and also 24 hour samples of humus tank effluent. Monthly averages are given in Table II which show that the introduction of mats resulted in effluents generally with lower turbidities and lower biochemical oxygen demand values than in the pond without mats. Green coloration of the effluent was nearly always absent in the effluent of the former.

It is of interest to note, however, that during the colder months of May, June and July the green coloration due to planktonic algae in the pond without mats disappeared, and effluents of equivalent quality or better than those in the pond with mats, were observed.

The experience of Parker⁹ and his co-authors over several years and the results of the experiments by the National Institute for Water Research seem to indicate that planktonic green algae do not contribute materially to the overall stabilisation in pond systems. However, it must be admitted that all algae through their photosynthetic oxygen production assist in

Table I.—Performance of Braeside Lagoons.
Analyses on Unfiltered Samples

Year	Season	Humus tank effluent B.O.D. (ppm)	Lagoon No. 1		Lagoon No. 2 *			Lagoon No. 3 †			
			Effluent B.O.D. (ppm)	B.O.D. ‡ load (lb./day/ acre)	B.O.D. removal (lb./day/ acre)	Effluent B.O.D. (ppm)	B.O.D. (lb./day/ acre)	B.O.D. removal (lb./day/ acre)	Effluent B.O.D. (ppm)	B.O.D. load (lb./day/ acre)	B.O.D. removal (lb./day/ acre)
1942-43	Summer	30	12	34	20	16	24	— 7	—	—	—
	Winter	33	7	73	57	—	—	—	10	1·1	— 0·4
1947-48	Summer	30	10	59	40	8	31	6	—	—	—
	Winter	29	6	110	87	—	—	—	3	1·8	0·7
1951-52	Summer	38	19	113	54	15	97	25	—	—	—
	Winter	42	16	240	149	—	—	—	4	5·9	4·4
1955-56	Summer	51	36	203	59	30	241	49	—	—	—
	Winter	54	19	415	267	—	—	—	4	9·7	7·5

* Operated in summer only.

† Operated in winter only.

‡ Effective area : summer 2·5 acres ;
winter 1·3 acres.

Adapted from Parker *et al.*⁹

Performance of Large Sewage Lagoons at Melbourne, Australia.

Table II.—Performance of Two Ponds Treating Humus Tank Effluent
Pretoria Experiments 1959

Month	Sample	pH	Temperature ° Centi- grade	Turbidity ppm SiO ₂	B.O.D. in effluent ppm	B.O.D. loading rate lb. B.O.D./ acre/day	B.O.D. removal rate lb./acre/day
January 1959	H.T.E.	7·9	25·2	23·6	23·6	—	—
	Mats	8·3	23·6	11·0	6·3	19·7	14·4
	Without	9·1	23·8	34·3	16·0	19·7	6·3
February	H.T.E.	7·9	25·5	27·8	22·0	—	—
	Mats	8·5	24·1	12·9	8·1	18·4	11·7
	Without	9·2	24·3	30·4	17·7	18·4	3·6
March	H.T.E.	7·9	23·8	20·0	15·1	—	—
	Mats	8·2	21·9	13·9	6·8	26·2	14·7
	Without	8·6	21·9	23·7	14·3	14·7	1·4
April	H.T.E.	7·9	23·1	16·0	14·9	—	—
	Mats	7·8	20·3	10·4	6·6	25·0	13·9
	Without	8·0	20·7	12·6	9·1	25·9	10·1
May	H.T.E.	7·9	19·5	9·0	24·1	—	—
	Mats	7·7	14·5	5·3	4·1	37·7	31·3
	Without	7·7	14·9	4·5	3·1	42·7	37·2
June	H.T.E.	8·0	18·4	10·5	23·0	—	—
	Mats	7·7	12·8	8·5	4·6	40·3	32·2
	Without	7·6	13·1	8·5	3·8	36·4	30·4
July	H.T.E.	7·9	17·3	15·5	28·8	—	—
	Mats	7·6	13·1	12·2	5·0	50·9	42·1
	Without	8·1	13·3	16·3	13·8	49·0	25·6
August	H.T.E.	7·7	18·9	9·1	14·8	—	—
	Mats	7·8	13·4	6·1	10·3	24·7	11·8
	Without	8·7	13·5	19·5	15·3	19·6	Negative
September	H.T.E.	7·6	20·8	13·5	22·5	—	—
	Mats	7·6	17·8	7·5	8·9	33·6	20·4
	Without	8·4	16·6	20·0	17·2	37·8	9·8
October	H.T.E.	7·6	22·9	14·3	22·5	—	—
	Mats	7·9	20·1	12·7	13·7	38·3	14·9
	Without	8·5	20·0	17·5	16·7	38·8	10·0
November	H.T.E.	7·5	23·5	20·3	28·0	—	—
	Mats	7·8	21·8	12·0	8·3	47·8	33·5
	Without	9·0	22·8	27·5	13·3	48·5	25·5
December 1959	H.T.E.	7·6	25·6	17·5	25·0	—	—
	Mats	7·8	24·5	9·0	5·6	43·2	33·7
	Without	8·4	25·5	24·5	11·4	43·3	23·6

H.T.E. . . . Humus Tank Effluent.
Mats Pond with suspended terylene mats.
Without Pond without any mats.

supplying extra oxygen which sometimes helps in keeping the pond contents aerobic, but at the same time the high turbidity caused by planktonic algae is a disadvantage as it prevents a deep penetration of sunlight. Further investigations will be necessary on the control of environmental conditions to suppress planktonic algae in order to achieve high stabilisation efficiencies in ponds. Moreover, as algae in general do not contribute to the reduction of organic matter, but rather to a synthesis of it, the reduction that takes place in ponds and the elimination in their effluents of the eutrophying elements nitrogen and phosphorus is considered far more important than mere "biochemical oxygen demand removal". Research on removal or reduction of eutrophying elements should therefore be included in a programme of investigation.

4. APPLIED BIOLOGY AND STABILISATION SYSTEMS

4.1. Self-purification processes in rivers

When an organic effluent enters a river and there are no toxic substances present, a natural process of purification begins which results in the removal or stabilisation of the polluting material. This normally takes place as follows :

- (a) The flocculation of colloids and larger particles by physicochemical processes which may be assisted by the activities of micro-organisms.
- (b) The breakdown of organic matter by micro-organisms. Unless oxygen is excluded the eventual waste products of importance will be inorganic nitrogen and phosphorous compounds; these are known as eutrophying (nutrient) substances.
- (c) The removal of micro-organisms by larger predators; these in turn might be eaten by fish.
- (d) The removal of the nitrogen and phosphorous compounds by photosynthesising plants, principally algae, which also play a part in re-oxygenating the water.
- (e) Removal of excess algal growths by algae-eating organisms including the larvae of midges and other insects. These in turn might be eaten by fish or develop into flying adults which leave the system.

The result of all this activity is that the river returns practically to normal again.

It is important to realise, however, that all these processes do not occur at one spot in the river bed but that a region of progressive change is formed. The length of this depends largely on the organic loading of the river and the speed of flow. Kolkwitz and Marsson divided up this region of self-purification into a number of zones which grade into one another. Processes (a), (b) and (c) above occur in the polysaprobic zone, where there may also

be some algal growth. Processes (*d*) and (*e*) occur in the alpha and beta mesosaprobic zones. When the self-purification is virtually complete the river is said to be oligosaprobic.

The efficiency which can be reached by these natural purification processes is seen in the case of the Swartkops River, a stream which receives the humus tank effluent from the Uitenhage sewage works. Table III gives the figures for February 1959.

Table III.—Analyses from Swartkops River, February 1959

First figure: early morning. Second: mid-afternoon.

Station	Dissolved O ₂ % saturation	B.O.D. ppm	Nitrate ppm N	Free and saline NH ₃ ppm N
Just above humus tank outfall .	35 104	0·9 1·3	0·1 n.d.	0·2 n.d.
Just below outfall . . .	n.d. 29	13·2 14·6	15·3 13·1	5·6 12·9
1 mile below outfall . .	20 100	7·7 8·6	7·0 7·0	2·1 2·1
2 miles below outfall . .	87 98	1·5 3·2	0·1 0·1	n.d. 0·2
3 miles below outfall . .	27 155	1·4 1·6	0·1 0·1	n.d. n.d.

n.d. = not determinable (Analysis by NIWR).

It will be seen that within 2 miles the effects of the humus tank effluent were largely removed. The stream flowed through a series of large pools and stony rapids in which there was a vigorous growth of algae and higher plants.

Note.—Although there was considerable reduction of nitrate in the Swartkops River the author has not observed a similar reduction in ponds nor is he aware of there being any reference to it in the relevant literature. Investigations should therefore be conducted to provide the right environmental conditions in a maturation pond in order to develop the relevant association of organisms which could remove nitrates.

4.2. Stabilisation in multiple ponds in series

A system of stabilisation ponds in series would simulate the self-purification processes of rivers, with the added advantage that environmental conditions in each pond could be controlled to ensure a more efficient biological activity per unit area in each pond than that which the equivalent zone in a river could produce.

Although it is impracticable to maintain the group of micro-organisms in the optimum logarithmic growth phase in each pond, it is possible, by

controlling the food supply and other environmental conditions, to maintain the groups of organisms in each pond in a state of equilibrium with each other. Effluent from such a system would be well stabilised as all the various organisms would have had the opportunity of playing their part to the full.

4.3. Stabilisation in a single pond system

A single pond system, designed to maintain in equilibrium the full association of organisms necessary for stabilisation, must be large enough to provide a retention period long enough for the slower rate of assimilation by the higher organisms and to provide sufficient water to dilute the effluent entering it. If the effluent is insufficiently diluted the biological association will be upset and purification will be incomplete.

4.4. Stabilisation in conventional units

Complete stabilisation of organic wastes, namely, the complete destruction or removal of organic compounds, can occur only if the full cycle of organisms can play their part. It is, therefore, obvious that in biological filters or activated sludge plants where the environmental conditions are not suitable for the development of a full biological cycle, no complete stabilisation can occur.

5. THE FATE OF FAECAL BACTERIA IN STABILISATION PONDS

Most of the available literature on stabilisation ponds fails to mention the bacteriological quality of effluents. A few authors report most probable numbers (M.P.N.) of coliform organisms and the available figures show that reductions in the M.P.N. vary from 70% to 99.9% irrespective of whether the ponds are treating raw sewage, settled sewage, biological filter effluent or effluents from stabilisation ponds. Although the percentage reduction is of a similar order in all cases, it is obvious that the quality of the effluent of a pond will depend on the quality of the inflow. For instance, a 90% reduction of M.P.N. of coliforms present in raw sewage will result in a poor effluent, whereas a similar reduction in the case of sand-filtered effluent would result in a water of a reasonable quality.

Although coliform organisms do give an indication of the bacterial quality of effluents, it is considered that a determination of the M.P.N. of faecal bacteria would give one even a better picture. Coliform organisms need not all be of faecal origin whereas faecal streptococci and faecal *E. coli* are.

In Table IV which was adapted from Stander,³ it may be seen that the M.P.N. of faecal *E. coli* in the effluent of the first maturation pond and that of the final effluent also became less when the respective M.P.N.s in the relevant influents decreased.

Table IV.—Reductions in the M.P.N. per ml. of faecal *E. coli* and *Streptococcus faecalis* in maturation ponds

Effluent from :	<i>Streptococcus faecalis</i> M.P.N./ml.	Faecal <i>E. coli</i> M.P.N./ml.		
	No humus tank nor sand filter	No humus tank nor sand filter	After humus tank	After humus tank and sand filter
Biological filter. . .	9,460	40,000	10,000	4,000
Maturation pond No. 1 .	840	660	240	Not determined
Maturation pond No. 2 .	80	8	6	1

Adapted from G. J. Stander,³ *Trans. S.A. Inst. C.E.*, 8, No. 10 (October 1958).

Stander³ also showed that the above counts in the effluent from maturation pond treatment were as good as, or better than, those from various rivers in South Africa. Further investigations are proceeding as it is realised that the information on the faecal bacteria mentioned does not give an indication on the fate of individual pathogens in stabilisation pond treatment.

6. DISCUSSION ON CONSIDERATIONS FOR DESIGN AND A RESEARCH PROGRAMME

From the information available in the literature on biological principles, stabilisation ponds and self-purification processes in rivers, there appear to be two main considerations which should be taken into account in the design of stabilisation ponds. It must be made clear, however, that these considerations are still being tested by controlled experiments and should therefore not be accepted as statements of facts.

6.1. Consideration 1

Stabilisation pond systems should contain several ponds in series

In the earlier chapters of this paper, it was shown that, to achieve complete stabilisation of organic wastes, it would be necessary to provide the right environmental conditions for complete prey-predator food cycles. When an organic effluent enters a river self-purification takes place in a series of intergrading stages. The ideal stabilisation system is one in which such a series of stages can develop without mutually interfering with one another. If, therefore, ponds are used, several should run in series so that in each the biological association relevant to the stage of purification can develop and play its part to the full. Practical and economical considerations would tend to restrict the number of ponds which, however, should be determined by the desired quality of the effluent.

6.2. Consideration 2

In each stabilisation pond environmental conditions must be controlled as much as possible in order to achieve the best operational efficiency and to prevent a nuisance from developing

This general consideration could be subdivided into the following components.

6.2.1. In each pond turbulence should be developed to the greatest extent without having recourse to mechanical means. The latter would detract from the simplicity of operation especially in areas where no power is available.

Turbulence in a pond could be increased by the following :

- (i) Jet inlets.
- (ii) Exploiting to the full wind-induced currents, i.e. areas open to all winds and no trees to surround ponds.
- (iii) Adopting a depth of 3 to 5 ft. to prevent rooted aquatic vegetation from obstructing wind-induced currents in the pond.

Turbulence in a pond ensures good mixing which in turn will satisfy the previously described requirements for optimal biological activities, namely :

- (a) by providing intimate contact at all times between food, micro-organisms and dissolved oxygen,
- (b) by increasing the atmospheric oxygen uptake in relation to stagnant water,
- (c) by removing waste products and surplus organisms which might interfere with metabolic processes.

6.2.2. B.O.D. loading rates should be controlled for each pond so as not to cause serious overloading.

Parker *et al.*⁹ stated that at Braeside (see Table I) no smell or other nuisances were observed when Lagoon 1 was overloaded. The reports of the Mojave experiment,^{10, 11} however, mentioned that high overloading in the first pond caused the development of a considerable amount of unsightly scum and smells.

It is evident from the literature, however, that unless extreme overloading occurs in the first ponds, the biochemical quality of effluents from succeeding ponds is not seriously affected, although a lower efficiency of B.O.D. removal is observed in the first pond.

The following B.O.D. loading rates for aerobic ponds have been reported as successful in the literature.

- (a) Treatment of raw sewage :

250 lb. B.O.D./acre/day at Mojave.^{10,11}

(b) Treatment of settled sewage or effluents equivalent to settled sewage :

100 lb. B.O.D./acre/day—Parker *et al.*^{8, 9} and Myers.¹²

(c) Treatment of partly stabilised effluents :

Up to 50 lb. B.O.D./acre/day depending on the B.O.D. strength of the influent and environmental conditions. An influent with a comparatively higher B.O.D. would allow a slightly higher loading rate than that with a low B.O.D.

Whether the above B.O.D. loading rates would be applicable under South African conditions only experiments can prove. Furthermore, in designing any aerobic stabilisation pond system for the treatment of raw sewage in this country, the engineer will probably adopt a B.O.D. loading rate for the first pond somewhat below 250 lb. per day per acre. However, he will be completely in the dark as to his calculations of sizes of the second and other ponds.

B.O.D. loading rates of anaerobic stabilisation ponds for treatment of raw sewage and settled sewage have been given by Parker *et al.*^{8, 9} :

600 lb./acre/day in summer and

450 lb./acre/day in winter.

Since such high loading rates would be economically attractive, experiments should be conducted to investigate if any nuisance arises and to ascertain loading rates compatible to conditions in this country.

6.2.3. To prevent mosquito and fly breeding, grass and weeds at and below the water's edge of the ponds should be cut regularly and the cuttings should be removed.

6.2.4. Other controllable environmental conditions which may become evident from further hydrobiological, bacteriological, chemical and biochemical fundamental studies should be taken into account.

Two examples are quoted to illustrate how such studies could aid in promoting a higher operational efficiency in stabilisation ponds.

(a) Kreft *et al.*¹³ showed in laboratory experiments that by raising the pH to figures over 8.5, in made-up solutions and in sewage effluents, ammonia nitrogen was given off to the atmosphere. As it is very important to reduce the concentration of nitrogen in effluents to prevent secondary pollution in impounding reservoirs and dams, the control of pH in ponds should be investigated.

(b) The experiments at Braeside⁹ and at Pretoria, previously described in this paper, indicate that, by suppressing planktonic algae, higher stabilisation efficiencies can be obtained. Further studies will be necessary to find ways and means to achieve these conditions economically.

6.3. Research programme summary

In the text of this paper it was mentioned that to improve our knowledge with regard to stabilisation ponds, further investigations would be required. With this objective in mind, the CSIR has established a Sanitation Research Unit consisting of civil engineers, bacteriologists, hydrobiologists, and chemists. This group will investigate various sanitation problems in Southern Africa. In particular, however, one aspect which will be studied specifically is the stabilisation pond. In this connection the investigations which are envisaged will be of a technological nature and also fundamental, as follows :

A. Technological studies

- (i) Ascertaining B.O.D. loading and removal rates.
- (ii) Study of the influence of topographical, climatological and meteorological conditions on the operational efficiency of ponds.
- (iii) Evaluation and control of environmental conditions to obtain best pond performance.
- (iv) Application and testing of results from fundamental studies where these would indicate an improvement in pond performance.
- (v) Formulation of design criteria for the construction and operation of stabilisation ponds.

B. Fundamental studies

- (i) Study of the fate of faecal bacteria, with special reference to pathogens.
- (ii) Identification of the organisms constituting the associations which occur in stabilisation ponds.
- (iii) Physiological studies on identified organisms.
- (iv) Study of chemical and biochemical changes in the ponds and especially of the organic compounds present.
- (v) Study of the inhibitory or toxic effects of organic and inorganic materials on organisms.
- (vi) Study of the role which pond sediments play in the overall purification processes.
- (vii) Study of the environment which, under natural conditions, encourages the development of a specific association of organisms which seem to perform a specific function in the self-purification processes in natural waters.
- (viii) Study of methods to remove or reduce the eutrophying elements, phosphorus and nitrogen, in effluents.

CONCLUSION

The stabilisation of organic wastes is brought about by the metabolic processes of organisms whereby the potential energy in the wastes is

transformed into kinetic energy and into potential energy synthesised into newly formed tissues and present in the waste products of organisms. However, the potential energy of the latter two products is very much less than the potential energy contained in the original organic waste.

From biological principles, a set of technological design considerations are formulated to provide the right environmental conditions for the necessary metabolic processes of various associations of organisms to take place. Algae synthesise organic compounds from inorganic elements, and they do not metabolise organic material to a great extent. Evidence has been quoted that planktonic algae do not contribute to the stabilisation efficiency per unit area of stabilisation ponds; however, no figures are available as to the function of benthic algae.

Further fundamental biological, bacteriological and biochemical studies are required for the formulation of comprehensive design criteria for the construction of stabilisation ponds.

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References

1. VAN ECK, H. Sewage Stabilisation Ponds—A Critical Review. *Trans. S.A. Inst. C.E.*, 8, No. 7, July 1958. Reprinted *Jour. Inst. S.P.*, Part 3, 1959, p. 320.
2. STANDER, G. J. Preliminary Results of Experiments on the further Biological Purification of Sewage Effluents. *Jour. Inst. Mun. E.* (S.A. Chapter), Ninth Ann. Conference.
3. STANDER, G. J. Watervoorsiening en Riolwatersuiwering — Oorwegings in verband met Volksgesondheid en Openbare Vooroordeel. *Trans. S.A. Inst. C.E.*, 8, No. 10, October 1958.
4. CLAUSSEN, H. T. Some Observations on the Action of Algae on Sewage in Ponds. *Jour. Inst. S.P.*, Part 3, 1959, p. 345.
5. ABBOTT, A. L. Discussion on Papers 1 and 4 above. *Jour. Inst. S.P.*, Part 3, 1959, p. 349.
6. GAINNEY, P. L., and LORD, T. H. Microbiology of Water and Sewage. Prentice-Hall Inc. Englewood Cliffs, N.J.
7. BARTSCH, A. F., and INGRAM, W. M. Stream Life and the Pollution Environment. *Public Works*, July 1959.
8. PARKER, C. D., JONES, J. H., and TAYLOR, W. S. Purification of Sewage in Lagoons. *Sewage and Ind. Wastes*, 22, No. 6, June 1950, p. 760.
9. PARKER, C. D., JONES, H. L., and GREENE, N. C. *Sewage and Ind. Wastes*, 31, No. 2, Febr. 1959, p. 133.
10. Anon. Report on Continued Study of Waste Water Reclamation and Utilization. Publication No. 15. Calif. State Water Pollution Control Board, 1956.
11. Anon. Report on Continued Study of Waste Water Reclamation and Utilization. Publication No. 18. Calif. State Water Pollution Control Board, 1957.
12. MYERS, J. Studies of Texas Sewage Lagoons. *Public Works*, December 1949.
13. KREFT, G., VAN ECK, H., and STANDER, G. J. A Short Note on the Possibility of Removing Ammonia from Sewage Effluents by Varying the pH. *Water and Waste Treatment Jour.*, July/August 1958.

A SCHEME FOR THE TREATMENT OF RAW SEWAGE BY MEANS OF OXIDATION PONDS

A. ABBOTT

ABSTRACT

The development of oxidation ponds described briefly. The evolution of the Wynberg-Retreat-Muizenberg sewage treatment scheme outlined with particular reference to the applicability of oxidation pond methods to this instance.

Operating experiences in connection with starting up the first phase of the scheme, including recirculation of algal effluent, are described. An interim report on operating results including chemical and biological performance data is given.

RECENT PROGRESS ON WATER SUPPLIES IN THE WESTERN REGION OF NIGERIA

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This paper deals with the development of water supplies in the Western Region of Nigeria, a territory lying between 4° N. and 9° N. and between 2° W. and 7° W. The area of the region is approximately 45,000 square miles, and it is inhabited mainly by the West African Yoruba race. The population is some 7,500,000 with twenty-one towns of between 20,000 and 600,000 inhabitants, and a further 140 with population above 5,000. The rural population live in scattered villages, often accessible only along bush paths, and some are many miles from motorable roads.

POPULATION

Population density in the towns is high, and past development has taken place without any regard for planning. Town planning and rehousing of population to clear slum areas is only beginning to make its appearance, and access to individual houses is often through a labyrinth of buildings. Growth of population is of the order of 2% per annum, although infant mortality rate is high and expectation of life low.

CONSUMPTION

The main industries of the country are agricultural and forestal, with cocoa, palm oil and timber as the principal exports. Local industries such as cement manufacture, light metal work, carpentry, plastics, canning and bottling of fruit and fruit juices, and manufacture of soft drinks, are emerging as consumers of water in quantity, and the demands of schools, hospitals and other social services are increasing in marked degree. It will be many years before water-borne sanitation becomes general, as the capital expenditure on this and consequent augmentation of the water supply will be prohibitive.

Average urban demand is 10 gallons per head per day, which low figure has proved adequate in practice. It is notable that when a new supply is put into service, the consumption is much less than this figure, a fact only explained by the hereditary economy of the people in water conservation, and it takes several years to change this point of view.

PLANNING

The importance of water supply is receiving increasing recognition and the demand of all sections of the community is becoming more insistent, as the advantages of potable water become apparent. Not only from the point of view of public health but also from sheer need of water, it is evident that these demands should be met to help development of the country and raise living standards. This is fully appreciated by Government, and successive development plans allocate a reasonable proportion of available money for this purpose.

There is still a tremendous leeway to make up, but a great deal has been achieved, considering the limitation of resources, both financial and technical, from which the Region has suffered for almost three decades, and the tempo is increasing.

Prior to the construction of water supply schemes, the population, both urban and rural, depended entirely on the rivers, streams, springs and subsurface wells for their needs. In the dry season from December to March, over much of the area, this entailed considerable hardship, as sources dried up and became increasingly polluted. Often long distances had to be covered on foot to obtain meagre supplies, and the provision of village and town needs meant a tremendous wastage by people who could have dedicated their labour to more productive work.

By present standards most of this water is polluted and enteric diseases, typhoid, hookworm and yaws were and still are prevalent in some areas. The standards of health were depressed in consequence with all the ills consequent on this condition.

Against this background twenty-six Urban Water Schemes have been constructed since 1927, five are under construction, five more are in the planning stage, and are included in the present development programme of 1960-65. These cater for 2,500,000 people or some 33% of the total present population. In addition a large number of small schemes, not all of which supply treated water, such as boreholes, impounded streams, spring development and surface wells, have been constructed to supply villages, schools, agricultural establishments and hospitals, which cannot be linked to the Urban Schemes.

RAINFALL

Rainfall in the Region varies from 40 inches in the north to 110 inches in the coastal belt, and falls between April and November, with two peaks in July and September. Variation in rainfall intensity is high and is often localised in squalls and line storms. Precipitations of 6 inches in an hour and a half have been recorded in one area where the average annual rainfall is 45 inches. Hydrological and meteorological information is sparse, though increasing year by year, and not nearly enough points are gauged to provide the complete local records required for the design of supplies.

GEOLOGY

The geology of the Region is roughly as follows. Fully half of the Region, the northern half, is of the Pre-Cambrian series, composed of gneisses, granites, schists, pegmatites and quartzites. These are generally overlaid by laterites up to 40 feet in depth but with rock outcropping in many places.

South of this area, in the western half of the Region, there is a broad band of Eocene of the Tertiary age, thinning out in width as it approaches the Niger to the east. A Post-Eocene formation, known locally as the Benin Sands, with which is interspersed the lignite series, occupies the south-eastern section. This formation is of great thickness and very porous. The lignite series appears in shallow lenticular beds of shales and clays, and where they outcrop are often the sources of springs.

Finally the Delta deposits of the Pleistocene series extend in a coastal belt round the Bight of Benin, in a strip of from 10 to 40 miles in width, being particularly prominent at the delta of the River Niger.

RUN-OFF

Over the Pre-Cambrian series run-off varies from 10% to 40% of the total rainfall with peak discharges in rivers at the latter end of the rainy season, i.e. August to November. Soil erosion is relatively heavy and silt content is of the average order of 200 to 400 ppm. Sources for water schemes in this area are invariably impounding reservoirs based on 180 days' ultimate requirements.

The Eocene series yield supplies from rivers, streams and boreholes. Silt control is lower, the discharge is more constant throughout the year, and headworks installations are simpler.

The Benin sands yield supplies from boreholes but more generally from the springs, and streams which make their appearance at approximately the flood plain level of the Niger. The water, though of low pH value, is generally very clear, of constant flow, but as a large portion of the populated area is from 700 to 1,600 feet above river levels the pumping heads are relatively high.

Over the Delta series the ground is, in general, waterlogged and covered with swamp vegetation. Supplies are easily obtained though brackish.

DESIGNS

As far as Urban schemes are concerned, designs follow conventional practice, and are suited to the particular sites, whether impounding reservoirs, barrages, river intakes, or boreholes. Owing to the difficulties encountered in the staffing and maintenance of headworks, and referred to later under Maintenance and Control, the policy is to supply diversified

populations from one source, as area schemes, though these may entail very extensive reticulation and separate boosting plants. For dams, earth banks with concrete or clay puddle cores are preferred on the score of cost, but concrete gated dams are built where important rivers are involved with high sediment content and high flows. Barrages, one under construction and one planned, are the two most important structures to date and are sited on rivers which although discharging some 20,000 cusecs in the rainy season, have been known to dry completely in January/February.

Intake structures must cater for flood conditions of up to 40 feet rise in river levels, but present no particular problem.

Borehole supplies are often derived from water whose pH is as low as 4.5 and casing and pump design must receive special attention. Screens are either gravel packed or the inserted sand bonded type, the latter proving superior in the Eocene and Delta areas.

TREATMENT

The twenty-two Urban schemes constructed and projected since 1952 have been designed to supply water to the British Ministry of Health requirements, in that these should show no coliform bacteria in 100 ml., and it is the aim of the water undertaking to provide water of this quality at the take-off points. Schemes built prior to this date are gradually being modernised to the same standard. In the presence of coliform organisms other than *B. coli* I, if the confirmed presumptive coliform count exceeds 3 in 100 ml. then the sample is unsatisfactory, while if less, then the sample is below standard.

All Nigerian surface sources are polluted to a greater or lesser degree but perhaps not to the extent of the industrialised countries where in some cases control of effluent is inefficient. There are no water-borne sanitation systems in the towns except those better-class houses which are provided with septic tanks, and the larger institutions with small sewage disposal plants. The result is that pollution of streams draining the towns is high and particularly noticeable during the early part of the wet season. Subsoil conditions in the town areas, around stand pipes and public latrines, are particularly bad, and in general sanitation lags very far behind the provision of potable water.

Treatment works are designed as simply as possible, and provide for coagulation, rapid gravity or pressure filtration control of pH value and chlorination. Practically all surface waters in the Western Region coagulate satisfactorily with aluminium sulphate on dosages of from 50 to 100 ppm and only in isolated cases is it necessary to give pre-treatment. Upward flow hopper bottomed type sedimentation tanks are in common use, followed by rapid gravity filters. Lime slurry pH correction is universal with chlorination by gaseous chlorine or chlorine of lime.

Chemical Treatment

As far as impounding reservoirs are concerned there is a considerable difference in quality of water referred to depth below surface. Comparing surface conditions with samples taken at 30 ft. deep, typical analyses are as follows :

Free and saline ammonia	. . .	increase 15 times
Albuminoid ammonia	. . .	doubled
Total alkalinity as CaCO ₃	. . .	increase of 80%
Total iron as Fe	. . .	increase of 25 times
Total solids	. . .	doubled
Organic matter	. . .	increases by 3½ times
pH value	. . .	reduced by 10%
Acidity cc. of 0.5% NaCO ₃ per 100 cc.	. . .	increases 8 times.

The high iron content at depth is due to anaerobic action on decomposing vegetation and, reaching as it does the figure of 25 ppm, precautions have to be taken to draw off supplies from the aerated surface layers. This sometimes presents problems at a time of reservoir turnover, and although all reservoir supplies are passed through a forced draft aeration prior to sedimentation, and reduction is obtained, filter sand becomes ferruginised, leading to frequent replacement and excess backwashing.

Manganese content in the raw water, which in some schemes varies between 0.1 ppm at the surface and 3 ppm at depth, is precipitated by the action of the lime and chlorine in the clear water tanks, is carried through and deposited in reservoirs and pipe walls, and so far no economical solution has been found.

The standard aimed at in the treated water is to limit the iron and manganese together to less than 0.3 ppm. Nitrates and fluorides are generally low and do not present any particular problem.

Apart from aeration no pre-treatment of the raw water is in use, and post-treatment is necessarily made as simple as possible, a point referred to later.

Bacteriological Treatment

Analyses of raw water surface supplies reveal that the colonies per cc. growing on nutrient agar at 37° C. in two days, run to hundreds and sometimes thousands, that the probable number of coliform organisms per 100 cc. exceeds 180 and that *B. coli I*, *B. coli II* and aerogenes are isolated.

Simple chlorination of the filtered water is practised, no chloramine or break-point chlorination being used, but in some smaller supplies, for simplicity's sake chloride of lime is employed. Owing to the fact that there is only one laboratory in the Region, and to the large distances between some of the plants and this laboratory, it is not possible to sample water as frequently as is desirable. The addition of a mobile laboratory has not filled this deficiency and recourse has had to be made to making presumptive tests at the headworks when, if a sample shows both acid and gas, further samples are sent to the laboratory.

Although it is safe to say that all water leaving the treatment works and passing into supply is potable, this often cannot be said of the product arriving in the consumers' home. When it is realised that distribution systems pass through subsoils where excretal pollution is high, the possibility of entry of bacteria is present, due to repairs to mains, suction at air valves, handling of standpipe taps, and in the receptacles used by the consumers themselves to carry water.

MAINTENANCE AND CONTROL

This is one of the greatest problems affecting the provision of ample potable water in the region. While it is possible to design structures and install equipment of a high standard, the operation and maintenance of these often leaves much to be desired. Close supervision by experienced water-works superintendents has in the past been stretched to the limit, and it is felt that the position will deteriorate further in the future. With the emergence of Nigeria as an independent country, there is a natural tendency to employ their own nationals, many of whom have not the experience or initiative to maintain a high standard. Facilities for training operatives is limited to the particular plant on which they are engaged and specialist courses for laboratory technicians are not readily available.

Water schemes when completed become the property of District Councils who are responsible for financing them. These bodies are not necessarily public spirited, rivalry and partisanship are common, and control of public funds is haphazard. While all are insistent that Government should give their particular area special attention, when provided, they are apt to forget that water supplies cost money to run. Most schemes run on a bare minimum with hand-to-mouth supplies of fuel, chemicals, spares, and replacements. Maintenance staff are not interchangeable between schemes, and are sometimes ousted for political reasons and replaced by inexperienced operators.

Attempts to replace the human element by introducing automatic control in part or all of the installations fails, due to shortage of skilled maintenance staff, the inherent desire to interfere with mechanisms which only skilled men should touch, and failure to keep up a reasonable standard of maintenance.

The solution of these problems would appear to lie in the formation of a Regional Water Board to take the supply away from local factions, allow the training of operatives, enhanced supervision, central control of consumable stores, and self-accounting. Although this was proposed some years ago, very little progress has been made in implanting it, and meanwhile, with the multiplication of schemes, the problem is becoming more pressing.

CONCLUSION

With the provision of easily accessible and potable water the pattern of urban and, to some extent, rural life is changing. The morning and evening exodus of people in search of water, employing in some cases hours in covering several miles of road and path, is gradually being translated into home, factory, or agricultural pursuits. Capital investment in the country, previously hindered by lack of water, is increasing, and the standard of health, particularly in infant mortality, is improving.

In the Western Region of Nigeria we are not faced with the problem of lack of water, rather its conservation during the period of the dry season, and the treatment and translation to the areas of demand, and in this respect the only impediments are financial and technical.

We are fortunate, too, in that pollution of the raw water, both bacteriologically and chemically, is not serious, and can be kept under control. Demineralisation or distillation is applicable only to special industries and does not affect the public supplies, which form the subject of this paper.

The maximum demand during any one day is 30 to 35 per cent greater than the annual average and on 15 October 1959, the Board supplied over 200 million gallons in 24 hours.

TREATMENT OF UNDERGROUND SUPPLIES

Most of the water obtained from the underground sources was free of bacterial contamination, and apart from certain crude attempts to remove iron and manganese from some of the water obtained from Zwartkopjes and some intermittent chlorination, no treatment was considered necessary. About 6 million gallons per day is still being obtained from the Zuurbekom boreholes and the water is of remarkable purity and could be sent into supply without treatment. As a purely precautionary measure it is now chlorinated before being pumped into supply.

The purification of the Vaal River water therefore presented the Board with an entirely new problem.

THE VAAL RIVER

The catchment area of the Vaal above the Barrage is about 17,000 square miles. The whole area is savannah type country and is entirely devoid of natural forest. Except for the mining and industrial complex of the southern Transvaal and northern Free State, which is drained by tributaries entering the Vaal within the Barrage reservoir, the country is sparsely populated and mainly used for pastoral and agricultural purposes. Like most South African rivers the flow varies greatly not only seasonally but also yearly. In most years the flow is less than 100 million gallons per day for a considerable portion of the year and at the end of an exceptionally dry season has been known to cease entirely. In some years the maximum flow has not exceeded 5,000 million gallons per day but floods of 15,000 mgd are fairly common and the maximum floods, which occur at rare intervals, exceed 60,000 mgd. The annual run-off has varied from under 100,000 to over 3,000,000 million gallons. Table I gives particulars of the discharge of the Vaal River. It should be noted that since the construction of Vaaldam in 1937 the flow at the Barrage is controlled except during periods of high floods.

As is to be expected with such large variation in flow the composition of the water also varies greatly.

The greatest variation is in respect of suspended solids and dissolved salts, and these variations follow a general pattern which depends almost entirely on the incidence of rainfall and run-off.

Under natural conditions large flows in the highly saline tributaries draining the mining and industrial areas of the Witwatersrand usually coincide with high flows of the low-electrolytic water of the Vaal River—

Table I.—Discharge of Vaal River

Hydrographic year 1 October to 30 Sept.	Total yearly discharge	Maximum discharge in 24 hours (million gallons)	
	Million gallons		
Discharge at Vereeniging			
1900-01	218,438	— Records incomplete	
1901-02	226,100	—	
1902-03	101,150	—	
1903-04	484,888	—	
1904-05	35,413	— Records incomplete	
1910	417,112	— Records incomplete	
1910-11	536,082	—	
1911-12	259,087	—	
1912-13	158,416	—	
1913-14	90,628	—	
1914-15	949,035	—	
1915-16	636,006	—	
1916-17	287,564	— Records incomplete	
1917-18	3,253,954	—	
1918-19	521,504	—	
1919-20	178,845	—	
1920-21	363,658	—	
1921-22	478,476	—	
1922-23	805,165	—	
Discharge at Vaal River Barrage			
1923-24	178,502	—	
1924-25	1,083,796	35,000	
1925-26	184,439	5,600	
1926-27	263,816	10,500	
1927-28	199,844	4,800	
1928-29	375,606	15,400	
1929-30	648,110	28,500	
1930-31	172,219	6,372	
1931-32	157,243	3,672	
1932-33	95,256	3,599	
1933-34	911,587	34,560	
1934-35	615,085	32,805	
1935-36	397,677	37,368	
1936-37	1,094,818	41,040	
1937-38	79,455	1,980	Vaaldam filled
1938-39	857,792	37,260	
1939-40	494,595	14,243	
1940-41	583,712	18,900	
1941-42	233,357	2,790	
1942-43	756,658	22,950	
1943-44	1,691,236	66,746	
1944-45	428,360	9,180	
1945-46	286,729	6,567	
1946-47	200,618	1,696	
1947-48	208,179	2,444	
1948-49	190,524	2,557	
1949-50	383,361	5,480	
1950-51	142,771	2,465	
1951-52	222,374	2,557	
1952-53	447,206	19,884	
1953-54	212,111	1,286	
1954-55	699,347	25,837	
1955-56	292,058	3,649	Vaaldam raised
1956-57	976,189	67,822	
1957-58	1,006,790	45,538	
1958-59	290,555	2,088	

so the water at Vereeniging during most of the wet (summer) season is highly turbid and has a low dissolved solids concentration.

The suspended solids consist mainly of finely divided clay, silt particles and organic debris.

During periods of low flow (May to August each year) the raw water is generally fairly clear and contains greater amounts of dissolved salts, much of it derived from the more constant flowing tributaries, the Klip and the Suikerbosrand Rivers.

The specific electrical conductivity, which is a measure of dissolved electrolyte, increases steadily during the winter months and as all electrolytes induce coagulation it was notable that after the Barrage was built a considerable amount of settlement took place in the reservoir area. In fact, at the end of the dry season, the water in the vicinity of the Barrage became remarkably clear.

The bacterial quality of the Vaal water is good and this aspect of the treatment has never provided any real difficulty.

The construction of Vaaldam profoundly influenced the nature of the Vaal River below the dam. Not only was the river converted to a perennial stream with a minimum flow of over 300 mgd but the composition of the water was changed greatly.

Because the first and most turbid run-off in the Vaal catchment area is retained and strongly diluted in Vaaldam at the commencement of each wet season, the maximum quantity of suspended solids in the water entering the Barrage is considerably lower than before the construction of the dam. Also, due to silting in the dam, the total quantity of suspended solids carried in the water during the year is very much less than before the completion of the Vaaldam.

Before the construction of Vaaldam the highly mineralised tributaries draining the Witwatersrand contributed an appreciable proportion of the flow into the Barrage reservoir during the dry season, so the dissolved salts in the reservoir were higher than now. During the wet season, however, the position is reversed. Formerly, increased flow in the tributaries was usually accompanied by a greater increase in the Vaal flow so the concentration of dissolved salts was reduced. Now it frequently happens that the tributaries are in flood without any increase in the flow in the Vaal and under these conditions the concentration of dissolved salts in the reservoir is considerably increased.

The specific electrical conductivity (in micro mhos per cubic centimetre at 20° C.) and the suspended solids (in parts per million) of the Vaal River water at Vereeniging for the period from 1924 to 1960 are given in Table II. It is noteworthy that for the fourteen-year period before the dam was built the average electrical conductivity of the water was 192. For the next eighteen years the average was 215 and for the five years since the dam has been raised the average is 266.

Table II.—Vaal River water at Board's intake—Vereeniging

Year	Electrical conductivity micro-mhos per cc. at 20° C.			Suspended solids parts per million			Ref.
	Average	Maximum	Minimum	Average	Maximum	Minimum	
1923-24	239	345	120				
1924-25	205	330	75				
1925-26	236	375	85				
1926-27	188	320	60				
1927-28	174	355	88				
1928-29	199	325	75	606	1,900	40	
1929-30	165	325	68	684	1,500	45	
1930-31	221	510	75	268	1,400	15	
1931-32	200	335	60	340	2,010	15	
1932-33	152	250	52	534	1,600	60	1
1933-34	168	270	62	1,006	7,480	30	
1934-35	155	260	75	492	7,030	31	
1935-36	216	350	75	462	4,270	25	
1936-37	184	310	80	294	2,430	11	2
1937-38	208	850	128	57	898	6	
1938-39	204	600	95	135	620	26	
1939-40	155	450	90	228	1,120	90	
1940-41	171	385	125	201	2,240	80	
1941-42	190	650	110	229	350	18	
1942-43	202	600	130	146	992	15	
1943-44	163	480	95	288	1,478	82	
1944-45	234	650	165	116	618	8	
1945-46	233	750	130	146	618	10	
1946-47	203	450	130	158	1,182	45	
1947-48	215	685	130	136	563	24	
1948-49	203	440	130	154	305	22	
1949-50	211	1,000	120	231	2,204	27	
1950-51	225	725	110	252	1,416	15	
1951-52	261	835	145	151	559	6	
1952-53	253	810	115	220	1,870	8	
1953-54	230	645	110	241	602	12	
1954-55	216	775	125	245	1,536	18	3
1955-56	282	700	125	167	685	10	
1956-57	281	680	130	150	3,148	12	
1957-58	240	870	105	294	1,165	16	
1958-59	268	650	150	152	626	12	
1959-60	261	775	125	60	435	14	

1. The maximum and minimum suspended solids up to 1933 are monthly readings : after 1933 daily readings.
2. Vaaldam completed 1937.
3. Vaaldam raised 1956.

Most of the dissolved salts consist of sulphates with the result that the hardness of the water sent into supply is high during these periods. The periods are usually only of comparatively short duration but nevertheless numerous complaints were received from consumers, particularly industrial consumers. It was for this reason that the Board in 1949, when the provision of increased supplies was being considered, decided to construct a new pumping and purification station at Zuikerbosch above the confluence of the tributaries with the Vaal. The difference between the water produced at Vereeniging and Zuikerbosch is shown in Table III. The water from the two stations is mixed at Zwartkopjes so that a water of more constant composition is supplied north of Zwartkopjes.

ORIGINAL VEREENIGING WORKS

When the original works at Vereeniging were being designed little was known about the treatment for potable purposes of large volumes of highly turbid water. Most large water undertakings obtained their supplies either from controlled upland catchments where no treatment was required or from large relatively clear rivers. In the latter case treatment plants were required, but these were designed primarily for the removal of bacteria rather than large volumes of suspended solids. The only town in South Africa using turbid water was Kimberley. The water was obtained from the lower Vaal at Riverton and after being dosed with alum was led into large settling dams. The water was allowed to remain in a dam for some days to enable the suspended solids to be deposited and was then drawn off and pumped to Kimberley. This method of treatment was not very satisfactory and the quantity treated was small.

Alexandria in Egypt had had for some years a fairly large plant treating water obtained from the river Nile, and as the composition of the Nile water was similar to that of the Vaal the design of the original plant at Vereeniging was based on that of Alexandria.

The plant was designed to treat 5 mgd by single-stage sedimentation and consisted of four long, shallow, flat-bottomed sedimentation tanks and a battery of eight rapid gravity filters. To produce a settleable floc, aluminium sulphate was introduced into the flume feeding the tanks. The settled water was continuously drawn off over weirs into a collecting flume at the other end of the tanks. The retention time in the tanks was about 15 hours and the filters were rated at 80 gallons per square foot per hour. There was no provision for rapid mixing of the alum, for floc conditioning or for continuous withdrawal of the settled sludge. During the winter months when the raw water was low in turbidity and high in specific electrical conductivity the plant was satisfactory, but it was quite incapable of treating the high turbidity and low conductivity water that occurred in the summer months. Even with an alum dosage exceeding 80 ppm the filters had to be washed every three or four hours and the filtered water was often turbid.

Table III.—Composition of water supplied during the year ended 31 March 1960
(parts per million)

	From Zuur- bekom wells	From Vaal River source					
		Zuikerbosch Station			Vereeniging Station		
		• Lowest	• Highest	• General	• Lowest	• Highest	• General
Solid residue on evaporation	158	92	168	127	118	490	182
Alkalinity (calcium carbonate equivalent)	120	73	135	90	26	91	68
Hardness (calcium carbonate equivalent)	143	60	126	78	50	266	95
Calcium (Ca)	26	17	32	19	15	67	25
Magnesium (Mg)	19	4	13	7	3	24	8
Sodium and potassium (expressed as sodium)	3	9	21	15	15	76	24
Bicarbonate (HCO ₃)	146	89	165	110	32	111	83
Sulphate (SO ₄)	20	9	14	10	12	233	50
Chloride (Cl)	5	6	10	7	11	99	20
Silica (SiO ₂)	14	6	13	10	7	15	9
Iron and alumina (R ₂ O ₃)	1	2	5	4	1	3	2
Fluorine	0.09	0.11	0.25	0.19	0.12	0.20	0.17
Oxygen absorbed from acid permanganate	Nil	1.6	2.8	2.1	0.9	2.8	1.4
pH	7.71	7.45	8.90	8.30	8.0	9.8	8.43
pHs	8.00	7.80	8.30	8.16	8.0	8.7	8.35
Electrical conductivity (micro-mhos, 20° C.)	250	150	250	176	160	720	246

* The individual lowest or highest value of each separate constituent did not necessarily occur at the same time. The highest values were exceptional and occurred over short periods.

Attempts were made to improve precipitation by introducing baffles in the tanks but these had little effect.

MODIFICATIONS AT VEREENIGING

When the output of the station was increased to 10 mgd sixteen vertical flow and four more horizontal flow tanks were constructed. The whole system was converted to two-stage sedimentation, the vertical tanks being used for the primary stage and the horizontal flow tanks for the secondary stage. During the summer months milk of lime was used as a coagulant in the primary stage and aluminium sulphate in the secondary stage. The lime dosage varied from 50 to 200 ppm and the alum from 10 to 30 ppm. During the winter months alum alone was used at rates varying from 10 to 50 ppm.

The results were fairly satisfactory and some saving in the cost of chemicals was effected, but the turbidity of the water delivered to the filters was still high at times and there were other troubles. When lime was used for long periods severe calcium carbonate encrustation of the filter sand resulted. This was corrected to a certain extent by the addition of sodium bi-sulphate at the entrance to the secondary tanks. When alum alone was used the aluminium hydroxide floc was of such a nature as also to clog the filters, and the low pH value of the water resulted in corrosion in the distribution system.

For some years extensive experiments were carried out to determine the best solution of these problems and study was also made of the plant treating Missouri and Mississippi river water at St. Louis, U.S.A. As a result of these investigations it was decided that two-stage lime and alum treatment offered the best solution of the problem, but that it was essential that the high pH value of the water coming off the primary tanks should be reduced before the water entered the secondary tanks.

It was also found that rapid and adequate mixing immediately after the addition of the chemicals was most important and that time should be given for the floc to form before the water entered the settling tanks. Once in the tanks the flow of water should be slow and uniform and eddies should be avoided as much as possible. The continuous collection and removal of sludge in the primary tanks was also important.

EXISTING VEREENIGING SEDIMENTATION SYSTEM

When the final 5 mgd unit of the 20 mgd Vaal River Scheme was designed in 1934, the whole plant was revised and the design based on the experience gained during the previous ten years. Since then there have been no radical alterations in the basic design of the plant, but many minor modifications and improvements have been effected as additional units have been added to meet the ever increasing demand for water. In 1940 a 2½ mgd pilot plant was built to enable further experiments to be carried out and in particular to determine the most economical size of primary and secondary tanks having regard to both capital and working cost. When not required for research this plant forms an integral part of the system which now has a total nominal capacity of 105 mgd. During seasons of high demand, however, up to 125 mgd has been satisfactorily treated.

The raw water is pumped from the river intake stations into mixing chambers where maximum turbulence is created to ensure rapid and thorough mixing of the added lime. The lime reacts with the calcium and magnesium bicarbonates present in the raw water to form calcium carbonate and magnesium hydroxide. The water then passes through a conditioning bay where the velocity is gradually slowed down from about 50 to 21 feet per minute. The water is retained for about twenty minutes in the mixing

and conditioning bays and during this time a heavy settleable floc is formed. From the conditioning bays the water is delivered through inlet flumes to the primary sedimentation tanks: the inlets from the flumes to the tanks are in the form of wide chutes so as to disturb the floc as little as possible and to induce it to settle in the tanks. The tanks are about 100 feet long, 30 feet wide and 12 feet deep to the top of the hoppers. They are free of baffles or other obstructions but to minimise wind action the surface of the water is broken by three traverse beams. The nominal time of retention is eight hours. The bottoms of the tanks are constructed in a series of hoppers from which the settled sludge can be drawn off. From 85 to 90 per cent of the suspended solids are removed in the primary stage.

The water is drawn off from the tanks over adjustable weirs into a collecting flume. At the end of this flume aluminium sulphate is added and immediately afterwards the water passes into the carbonation chamber where carbon dioxide gas is bubbled through the water in sufficient quantity to reduce the pH value to about 0.2 above pHs. This chamber also acts as the mixing chamber for the aluminium sulphate. The water then passes through the secondary conditioning bay where the aluminium sulphate hydrolyses to aluminium hydroxide and sulphuric acid and the hydroxide floc is built up to a size that will settle in the secondary sedimentation tanks. These tanks are similar to those in the primary stage except that the tanks are flat bottomed and the sludge is removed only during annual cleaning. The number of secondary tanks is less than the number of primary tanks and the time of retention is about six hours. About 5 per cent of the total suspended solids is removed in the secondary stage.

ZUIKERBOSCH SEDIMENTATION SYSTEM

The plant at Zuikerbosch was designed on similar lines to that at Vereeniging but as the water to be treated has a lower average electrical conductivity and is more turbid, certain modifications were made. To improve mixing, a conical flash mixer followed by an hydraulic jump was constructed and the time of retention in the primary tanks was increased to $9\frac{1}{2}$ hours and that in the secondaries reduced to $3\frac{1}{2}$ hours. As the station was to be operated on electric power, carbon dioxide gas could not be obtained from boiler flues and it was necessary to build a lime-burning plant to produce calcined lime and CO_2 gas. This also enabled the cost of lime handling to be appreciably reduced.

After the station was brought into service it was found that even with the modifications that had been made the quantity of lime required was high, and even with heavy dosage there were times when satisfactory coagulation could not be obtained.

Before the war, experiments had been conducted at Vereeniging on the use of activated sodium silicate as an aid to lime coagulation. At that

time this chemical was not manufactured in South Africa and with the comparatively high conductivity of the Vereeniging water its use was not considered economical. When trouble was experienced at Zuikerbosch the use of sodium silicate was reconsidered and it was decided to install plant to introduce it into the water immediately before the lime. The result was most successful, as a heavy readily settleable floc was formed and the reduction in the amount of lime required effected an overall reduction in the cost of chemicals.

Recently a similar plant has been installed at Vereeniging. It is probable that this plant will be little used during the summer months when the conductivity of the raw water is high : during the winter months when the conductivity of the water is relatively low, it is expected that the plant will effect an appreciable saving in chemicals.

Particulars of the suspended solids removed in the Vereeniging and Zuikerbosch plants are given in Table IV.

FILTRATION

After sedimentation the water is passed through a battery of rapid gravity filters, 102 at Vereeniging and sixty-four at Zuikerbosch. The filters are of the conventional air scour and backwash type and have a nominal capacity of 60 gallons per square foot per hour. Great attention is paid to having a uniform distribution of air over the filter bed and the quantity of wash water required is reduced by a surface flush in which the incoming settled water displaces the dirty water remaining after backwashing.

The backwashing of filters is controlled manually as under the Board's conditions automatic control is not justified. The running time between washes used to be limited to 84 hours but for some years now the limit has been 200 hours. This figure is frequently obtained. Filter performance for the year 1959-60 is given in Table V.

STERILISATION

The original intermittent sterilisation of underground supplies at Zwartkopjes was done with chlorine produced in an electrolytic cell containing a brine solution. This system was not used at Vereeniging where chloride of lime was used at first. This, however, was soon replaced by liquid chlorine supplied in 150-lb. steel cylinders. For many years the chlorine had to be imported from overseas, but fortunately just before the outbreak of the war in 1939 local supplies became available. When Zuikerbosch station was built the plant was designed to handle 2,000-lb. cylinders then obtainable and this effected an appreciable reduction in cost. Recently a central chlorine plant was built at Vereeniging to handle 2,000-lb.

Table IV.—Suspended solids in Vaal River, year ended 31 March 1960

At Zuikerbosch Station

Month	Suspended solids in parts per million			Total removed in the purification plant at Zuikerbosch (tons)
	Highest	Lowest	Average	
April 1959	95	79	87	575
May	107	67	82	566
June	87	55	67	451
July	65	47	56	390
August	67	43	53	393
September	71	35	47	414
October	55	31	47	441
November	63	48	53	459
December	77	57	68	622
January 1960	118	57	77	701
February	61	45	54	456
March	63	43	53	480
Year 1959-60	118	31	62	5,948

At Vereeniging Station

Month	Suspended solids in parts per million			Total removed in the purification plant at Vereeniging (tons)
	Highest	Lowest	Average	
April 1959	98	73	85	1,414
May	88	16	62	928
June	78	39	59	894
July	67	19	45	673
August	59	29	45	759
September	56	37	46	774
October	435	37	81	1,428
November	62	16	44	618
December	84	14	54	734
January 1960	79	28	62	1,021
February	398	25	88	1,394
March	80	24	52	791
Year 1959-60	435	14	60	11,428

cylinders and except at Zwartkopjes and Zuurbekom the 150-lb. cylinders are no longer used. The obsolete chlorine feed plant from Vereeniging is being installed at Zwartkopjes so that when it is considered necessary rechlorination can be effected at this point.

TYPE AND QUANTITY OF CHEMICALS USED

At Vereeniging most of the water is treated with hydrated lime containing about 64 per cent of available calcium oxide. A portion is treated

Table V.—Filter performance—Year ended 31 March 1960

Zuikerbosch Station

Month	Suspended solids removed by filtration (tons)	Rate of filtration gal./sq. ft./hour	Filter running time (hours)		
			Average	Maximum	Minimum
April 1959 . . .	45	69·8	131	186	90
May	51	70·2	100	160	42
June	49	70·5	88	132	47
July	44	72·2	94	138	64
August	54	41·6	112	202	55
September	58	47·4	122	199	74
October	70	48·3	125	195	49
November	64	47·2	141	201	60
December	78	46·2	170	211	66
January 1960	62	47·4	165	200	88
February	62	46·8	166	196	72
March	61	46·2	158	200	94
Year 1959-60	58	54·5	131	211	42

Vereeniging Station

Month	Suspended solids removed by filtration (tons)	Rate of filtration gal./sq. ft./hour	Filter running time (hours)		
			Average	Maximum	Minimum
April 1959	139	61·4	98	200	47
May	117	53·8	106	200	48
June	121	55·6	109	200	49
July	113	54·7	112	200	38
August	136	61·3	99	190	55
September	124	63·1	91	200	38
October	138	62·7	73	197	32
November	77	52·3	133	200	58
December	99	48·5	184	200	66
January 1960	124	57·9	140	200	50
February	128	60·0	124	200	43
March	105	54·1	140	200	51
Year 1959-60	118	57·1	117	200	32

with calcined lime produced at Zuikerbosch. The quantity of lime required depends on the condition of the raw water, the determining factors being turbidity, electrical conductivity and alkalinity. Before Vaaldam was built lime was not used during the winter months, but during the summer months the quantity required varied from about 50 to over 200 parts per million. Since Vaaldam came into service lime is used throughout the year and generally the quantity required varies from about 80 to 120 ppm. For short periods during high floods in the Vaal, the quantity may have to be increased

to about 180 ppm. At Zuikerbosch calcined lime containing about 85 per cent of available calcium oxide is used. Before being aided by sodium silicate the quantity required varied from 100 to 160 ppm and poor coagulation was frequently obtained. With activated-silica-aided coagulation the dose has been reduced to 60 to 80 ppm.

During the initial operation with sodium silicate, silicon dioxide was added at rates varying from 0.5 to 2.0 parts per million. It was found that the most effective and economical dosage was 1.5 ppm and this quantity is now added irrespective of the quantity of lime being used.

At both Vereeniging and Zuikerbosch aluminium sulphate containing about 17 per cent of available aluminium oxide is used for secondary coagulation and conditioning of the water for filtration. The quantity required at Vereeniging is usually from 2.5 to 5 ppm but for short periods, when the raw water is both turbid and coloured, may have to be raised to 10 ppm. At Zuikerbosch the rate of application is between 3 and 4 ppm.

At Vereeniging the CO_2 required is obtained from the boiler flue gases, the concentration of CO_2 being about 9 per cent. At Zuikerbosch the gas from the lime kiln contains from 18 to 25 per cent of CO_2 . With the comparatively small amount of CO_2 required with activated-silica-aided treatment the gas is diluted with air down to a concentration of about 15 per cent CO_2 before being passed through the water.

The water is sterilised by the addition of chlorine immediately before the water is pumped into supply. The dose depends on the condition of the water coming off the filters and may vary from 0.5 to 1.5 ppm. A residual of about 0.3 ppm of free chlorine as hypochlorous ion 10 minutes after the application of the chlorine is the determining factor. During the summer months spore formers and other after growths are apt to appear in the distribution system. To combat these growths intermittent chloramine sterilisation is adopted for a few days. Ammonium sulphate at the rate of about 0.15 ppm ammonium nitrogen is added immediately before the chlorine. The dichloramine thus formed, although not a strong bactericide, is more stable than free chlorine and remains active to the end of the distribution system.

Copper sulphate is occasionally used to destroy freshwater molluscs and various species of algae which may grow in the secondary sedimentation system and the filters. It has been found, however, that growth of algae can be greatly retarded by raising for a few hours the pH value of the water in the secondary system.

Sodium carbonate is also used occasionally for pH correction of the water sent into supply. The material is added at the rate of about 3.5 ppm immediately after filtration.

Chloride of lime is not used in the treatment process but is regularly employed for the sterilisation of new filters, reservoirs and pipelines before they are put into service.

STORAGE AND HANDLING OF CHEMICALS

Hydrated lime is delivered to Vereeniging in 50-lb. paper bags and is stored in weatherproof lime sheds. As required, the bags are emptied into hoppers over the lime feeders. Both continuous weighing and volumetric feeders are in use. It has been found that due to the flow characteristics of the lime the weighing machines are apt to choke and are unreliable particularly at high loads. The volumetric feeders are very reliable and are sufficiently accurate for practical purposes. The handling of the bagged lime is a messy business and requires a large amount of labour. There is also appreciable wastage due to broken bags and other causes. It is hoped in time to discontinue the use of hydrated lime.

Limestone 3 to 5 inches in size is delivered to Vereeniging. It is offloaded from the railway trucks on to a stock pile by a mechanical grab crane. As required it is reloaded by the crane into tip trucks for delivery into bunkers at Zuikerbosch. Two vertical gas-fired lime kilns, one standby to the other, have been erected. Each kiln has its own producer, the fuel used being anthracite coal or gas coke. To produce one ton of burnt stone requires about 1.7 tons of limestone and about 0.27 tons of fuel. The available calcium oxide in the limestone is about 95 per cent and, depending on the efficiency of burning, the availability in the burnt stone is from 82 to 87 per cent. From the kiln the burnt stone is delivered by belt conveyor to overhead bunkers, from where it is fed into rotary crushers and reduced to $\frac{1}{4}$ to $\frac{3}{8}$ inch size. The crushed stone is then conveyed to storage bunkers over the slakers. From these bunkers the stone is fed over automatic weighing machines into rotary drum slakers and the milk of lime produced is fed directly into the water. At every stage of the process the material is mechanically handled and comparatively little labour is required.

Sodium silicate is delivered into storage tanks at the works by road tankers. As required it is forced out of the storage tanks by compressed air into open tanks over the water inlets. It is then diluted down to a strength of 1.5 per cent of silicon dioxide, and carbon dioxide gas bubbled through the solution till 90 per cent of the sodium hydroxide has been converted to bicarbonate. This partly neutralised solution is then allowed to stand for an hour to become activated, that is for a silicic acid solution to form, and is then further diluted to a concentration of 0.5 per cent of silicon dioxide before being added to the water. The amount of activation is somewhat critical, as if the solution is over activated it will gel and block the feed pipes. Apart from the tendency to gel the handling of the material is simple.

At Vereeniging the carbon dioxide gas is obtained from the boiler flue gas which has to be cleaned by passing in through cyclones and flannel bag filters before it enters the blowers for delivery to the carbonation bays. The temperature of the gas in the bag filters is critical as, if it is too hot, it will char the bags, and if below the dew-point, condensation takes place and sulphurous acid is formed which not only destroys the flannel bags but

also damages the blowers and the pipe system. The temperature is regulated by drawing the gas partly from the back of the boilers and partly after it has passed through the economisers. Recently, glass fibre cloth has been used to replace the flannel bags, with encouraging results. At Zuikerbosch CO₂ gas is obtained direct from the lime kilns. The gas is comparatively free of impurities but it has to be cooled and a certain amount of lime dust removed by scrubbers before it is passed to the blowers.

Aluminium sulphate is delivered to Vereeniging in 200-lb. bags and is stored in sheds. As required it is transported by road to Zuikerbosch. The material is in lump form, 1 to 3 inch size; to use, a certain weight of material is dumped into a fixed quantity of water in a wooden box. Air is then bubbled through the water to speed up the dissolving of the alum, a solution of known concentration being obtained. The solution is fed into the water at a rate depending on the dosage required, the rate being controlled by passing the solution through a constant level box and variable head nozzle feed tubes. The solution is highly corrosive to both metals and concrete. For this reason the wooden dissolving boxes are placed in lead trays and all pipework, cocks, etc., are made either of glass, rubber or plastics.

Chlorine is delivered to Vereeniging in steel cylinders containing 2,000 lb. of liquid chlorine. The cylinders are stored in an open-sided but roofed shed and those required at Zuikerbosch are transported there by road. When in use the cylinders are placed on a scale, to check the amount of chlorine used, and connected to a chlorine feeder. From the feeder chlorine gas is delivered under vacuum through steel pipelines to where required. The vacuum is produced by a water ejector at the point of application. The evaporation of the liquid chlorine entails a considerable absorption of heat and to maintain the cylinders at a uniform temperature it is necessary to blow hot air around them.

EXAMINATION AND CONTROL

The Board's main laboratories are at Vereeniging but small laboratories for routine work are also maintained at Zuikerbosch and at Head Office.

In addition to routine work of controlling purification, the personnel of the laboratories are responsible for the inspection of the catchment area and obtaining and examining samples for the purpose of detecting and controlling sources of pollution. Some forty different points in the catchment are regularly sampled and over 700 examinations made during a year. Sampling and testing of materials supplied to the Board whether for purification or other purposes is regularly done to ensure that these materials comply with the relative specifications. A considerable amount of research, both fundamental and applied, is also done in the Board's laboratories.

For the purpose of ensuring efficient control of the purification process nearly 3,000 bacteriological and more than 150,000 chemical and physical routine tests are carried out during a year. The importance of efficient routine control cannot be over emphasised as such control not only ensures that the quality of the water sent into supply is maintained at a satisfactory standard, but also ensures that this standard is maintained at a minimum cost.

Regular sampling is done at the following points: raw water intakes, outlet of primary sedimentation system, inlet of secondary system, inlet and outlet of the filters and pumping mains delivering water into supply.

In addition regular samples are taken at Zwartkopjes and other points in the distribution system which are submitted to the South African Institute for Medical Research for bacteriological examination and to the Government Chemical Laboratories for chemical and physical examination. An independent check is thus maintained on the quality of the water being sent into supply. Table VII gives the results of the independent bacteriological examinations for the last ten years.

In addition to the present routine tests it is hoped in the near future to institute tests to determine the radioactivity of the raw water.

COSTS

Table VI shows the cost and dosage of chemicals used during the year ended 31 March 1960.

To the average unit cost of 0·71d. per 1,000 gallons for chemicals must be added 0·50d. per 1,000 gallons for labour and overhead charges, bringing the total cost of purification to 1·21d. per 1,000 gallons. The total working costs at five-year intervals since 1935 are given in Table VIII.

It is notable that compared with the great reduction in the value of money during this twenty-five year period, the increase in the unit costs of purification are moderate. This is partly due to the great increase in the volume of water treated, but improvements in the method of purification have also contributed to the result.

In addition to working costs there is also the cost of meeting interest and redemption charges on capital expenditure. It is difficult to determine an exact figure, as many capital works, such as roads, housing, etc., serve other purposes as well as purification. At Zuikerbosch the total cost of purely purification units was about £1,900,000. Taking interest and redemption at 8 per cent this represents an annual charge of £153,000 or about 1·25d. per 1,000 gallons of water produced. As an indication of the rise in costs that has taken place during the last ten years, the sedimentation tanks built in 1950 cost £280,000, while similar tanks built in 1955 cost £412,000.

Table VI.—Water purification chemicals : dosage and cost
Year ended 31 March 1960

	Weight, tons	Average rate part/s per million	Total cost, £	Cost in part of a penny per 1,000 gallons
Zuikerbosch Station : (19,468·911 million gallons)				
Calcined lime	5,632·90	57·9	33,721	0·511
Hydrated lime	6·28		27	
Sodium silicate	491·66	1·52	7,764	0·086
Aluminium sulphate	356·80	3·67	6,961	
Ammonium sulphate	1·50	*	44	0·044
Chlorine	79·00	0·81	3,521	
	—	—	52,038	0·641
Vereeniging Station : (36,479·681 million gallons)				
Hydrated lime	13,559·00	104·6 †	66,476	0·634
Calcined lime	4,885·49	92·7 ‡	29,901	
Aluminium sulphate	677·30		13,003	0·086
Ferrous sulphate	5·27	3·74	25	
Copper sulphate	0·21	*	12	0·055
Ammonium sulphate	4·14	*	207	
Chlorine	169·99	0·93	8,199	
	—	—	117,823	0·775
Zwartkopjes Station : Water repumped (51,947·520 million gallons)				
Chlorine	12·98	0·04	1,090	0·005
Zuurbekom Station : (2,115·719 million gallons)				
Chlorine	1·05	0·10	83	0·010
Total water : (58,064·311 million gallons)				
	—	—	171,034	0·707

* Intermittent treatment.

† 25,935 million gallons treated with hydrated lime.

‡ 10,545 million gallons treated with calcined lime.

Table VII.—Independent bacteriological examination of samples of potable water collected from the Board's distribution system

Year ended on 31 March	Number of samples examined	Number of samples giving counts of viable organisms growing on milk-nutrient agar at 37° C. within the limits stated			100 ml. samples in which faecal coliform organisms were found
		0-25	26-100	Over 100	
1951	494	480	11	3	0
1952	500	451	43	6	0
1953	500	416	59	25	4
1954	503	434	45	24	0
1955	898	882	11	5	4
1956	1,886	1,858	18	10	9
1957	1,887	1,840	40	7	4
1958	1,892	1,818	61	13	6
1959	1,878	1,857	15	5	1
1960	1,911	1,866	26	19	3

Table VIII.—Total working cost of purification

<i>Year ended 31 March</i>	<i>Cost : pence per 1,000 gallons sold</i>
1935	0·92
1940	0·84
1945	0·74
1950	1·02
1955	1·24
1960	1·21

Table IX.—Daily average quantity of water sold

<i>Year ended 31 March</i>	<i>Million gallons</i>
1906	2·332
1911	7·007
1921	11·315
1931	17·139
1941	51·344
1951	92·482
1956	123·696
1960	155·546

As a matter of interest the following were the unit costs (pence per 1,000 gallons of water sold) of the Board's operations for the year ended 31 March 1959.

Total quantity of water sold 53,526,000,000 gallons.		d.	d.
Pumping		2.67	
Purification		1.26	
Maintenance		1.11	
Administration		0.51	
Staff funds		0.16	
Total working costs			5.21
Reserve fund		0.90	
Renewals fund		0.25	
Total appropriations to funds			1.15
Interest on capital		2.52	
Redemption on capital		1.87	
Total capital charges			4.39
Total cost to consumers			11.25

The detail unit costs for the year ended 31 March 1960 are not yet available, but the total cost to consumers remains at 11.25 pence per 1,000 gallons sold.

FUTURE TRENDS

The one outstanding problem still to be solved is the satisfactory and economical disposal of sludge derived from the sedimentation and filter systems. At the present time the volume of sludge water is about 2,500 million gallons per annum, containing over 45,000 tons of suspended solids. These quantities are of course increasing at the same rate as the demand for potable water.

Up to the present the sludge has been delivered through gravity pipelines on to so-called depositing sites. The sites are relatively small and, owing to the fluid nature of the sludge, little is retained on the sites and most of it finds its way back to the Barrage reservoir where large mud banks are formed. This practice is obviously undesirable but until recently caused little concern as a flood of 25,000 cusecs or more in the rivers would wash out the whole of the accumulated deposits.

Before the doubling of the capacity of Vaaldam, floods of this magnitude could be expected fairly frequently, the time between floods rarely exceeding five years. Now, however, the time between major floods may well exceed ten years and the mud banks are likely to become a serious problem.

Many attempts have been made to find a practical and economical way of drying the sludge so that it can be dumped. None of these attempts have

been successful. At Zuikerbosch the sludge is being deposited in a sludge dam where it is partly settled. The relatively clear water from the surface of the dam is drawn off and returned to the purification system and the thicker sludge from the bottom of the dam, still in a fluid state, is pumped into a slimes dam where the remaining water is evaporated. The method offers some hope of success but will be difficult to apply at Vereeniging as the necessary area for a slimes dam is not available.

Except for the sludge problem it is difficult to forecast what other changes will occur. As previously mentioned it is probable that calcined lime will be substituted for hydrated lime at Vereeniging; also with the use of sodium silicate to aid coagulation the time of retention in the secondary tanks can be reduced so that further extensions will probably provide only for primary tanks and the rating of the existing secondary tanks will be raised. It is also possible that one or more of the polyelectrolytes now being developed will in time be substituted for chemicals used at present.

It has been suggested that the Board should medicate the water by the addition of fluorides for the prevention of dental caries. As a very small proportion, less than 1 per cent, of the water supplied by the Board is ingested, and as much of the water is used for industrial and mining purposes, it is unlikely that this will be done. It is maintained that if municipal consumers consider medication desirable they should themselves undertake this treatment.

Apart from the above possible changes it appears probable that only minor modifications and improvements will be made for many years to come.

THE RE-USE OF SEWAGE EFFLUENTS IN SOUTH AFRICA

N. P. NICOLLE

The ever increasing demand for water in South Africa has called for a study of the necessity for re-use of sewage effluents. It will help to maintain the limited supplies of our rivers when recycling and re-use of purified effluents is practised. Authorities should endeavour wherever possible to prepare future plans containing schemes embracing the re-use of sewage effluents. As towns and cities increase in size, and modern reticulation systems grow with the corresponding sewerage network, the volumes of sewage increase. Expensive treatment plants must be made available which will provide the final effluents for re-use.

In South Africa it is necessary to examine the supplies of water available to the large cities, in order to evaluate the greatest need for re-use. Undoubtedly the Rand dependent on the Vaal River must be the area which most justifies careful examination. Lessons learned from a study of this area will be used by all other areas of South Africa which are faced with the water shortage problem.

THE VAAL RIVER CATCHMENT BASIN

A brief study of the area is not misplaced when considering the huge quantity of water supplied each day from the Vaal Catchment Basin. The Vaal River Catchment Area is responsible for the supply of water to industry, mines, farmers, power stations and domestic dwellings, plus enormous losses by evaporation. The Natural Resources Development Council in its report on the Water Supplies of the Vaal River in relation to its future development, clearly fixes the volume of water available from the area. It is therefore imperative that before the limits of the system are reached, plans for the restriction of growth, for obtaining additional water, for the re-use of water and for efficient use of water must be tabled.

EFFLUENTS FOR RE-USE

Industrial effluents

Though this paper deals with the re-use of sewage effluents, some mention must be made of industrial effluent re-use and its effect on the re-use of subsequent sewage effluents when discharges are made to the sewers.

Many large industries are today finding the value of effluent re-use and of the investment in a simple treatment plant for recycling. Such large corporations as Sasol have a carefully planned and operating system for

re-use of industrial effluents, coupled sewage treatment plants and water purification processes.

Wherever industries are established an effluent discharge problem has to be faced and if this effluent is discharged to the sewer the admixture with domestic sewage is an added burden on sewage purification works.

The largest single use of water by industries is undoubtedly for cooling purposes. In this field re-use has so far found its most important role.

Sewage effluents

A short description of the processes involved after standard purification methods at a sewage works have operated, is necessary to understand to what extent careful handling of sewage effluents for re-use should take place. Any well designed sewage works will produce a stable, well-oxidised humus tank effluent. This effluent requires to have the last small amounts of suspended material removed by sand filtration and, dependent upon its re-use, further treatment in stabilisation ponds will greatly help to reduce the bacterial population and balance the association of organisms in the water. For effluents requiring to be pumped some distance, such as to a power station, chlorination is necessary to limit the growth of slime-forming bacteria which can greatly affect pumping rates and quickly close large pipelines.

Many effluents may have substances which are toxic, or may give rise to toxic conditions. These must be removed before re-use.

Sewage effluents discharged from Sanatoria must be treated with respect, and planning allows for separate treatment, if subsequent re-use of effluent is contemplated.

When effluent is to be re-used it should be remembered that if the original supply of water was taken from a watershed, the ultimate return should, as far as possible, be to that source in order to maintain the water supply cycle intact.

In dealing now with the re-use of sewage effluents in South Africa the details will be described under two headings: (a) Direct re-use; (b) Indirect re-use.

(a) Direct re-use

The direct re-use of sewage effluent is strongly recommended wherever possible as much better control can always be exercised in the handling of the effluent before it reaches the consumer. The effluent is purified on a sewage works under supervision, to a known chemical and bacteriological analysis. Every care is taken to provide exactly what is required for the consumer who is to re-use. At any time throughout the period of supply variables can be checked and direct representation made to the supplier by the consumer if the effluent is unsatisfactory.

Under the heading of direct re-use, the following uses are important :

1. Supply of effluent to power stations

Requirements for such an effluent are that the water should be well oxidised and 100% stable, the ammonia content as low as possible and the suspended solids should be kept below 10 parts per million. Such a water has proved to be completely satisfactory.

2. Irrigation of grasslands for grazing

The effluent should be as well treated as possible and certainly sand filtered, as every endeavour must be made to keep to a minimum the level of infection in animals grazing on such intensively cultivated lands. Most of the available sewage effluents are used today for such grassland irrigation and it is hoped that where possible consideration will be given in the future to the re-use within industry of these effluents, as requirements become known, rather than for irrigating grasslands.

3. Irrigation of Poplar deltoides for matchwood

Several municipalities have undertaken the growing of Poplar deltoides trees for sale as matchwood. The trees are easy to propagate and absorb an extremely large amount of water. Sludge can be used at the same time to further growth. The project is a long-term one and no return for ones efforts can be expected under 12 to 15 years, but with careful supervision and if no untoward troubles occur, an extremely profitable result can be obtained. The whole problem of poplar-tree growing is of course dependent on correct soil and a large enough available area.

4. Controlled cattle fattening on irrigated grasslands

A most interesting method of sewage effluent re-use is the rapid fattening of certain breeds of cattle on rich grasslands, maintained thus by irrigation. The scheme is notable in so far as it renders a national service, that of providing much needed prime beef at a reasonable figure.

5. Agricultural purposes

Much purified effluent is used for irrigation of crops, especially vegetables and flower growing. It is sad to say that the control in many cases of these effluents is very poor. When one considers that vegetables which will be consumed, often in the raw state, are flooded and irrigated with badly treated effluents, it is clear that the time has come to educate culprits and force them if necessary to examine the system of purification, before being allowed to provide the effluents for re-use. This position is rapidly being adjusted, thanks to the control now exercised by the National Institute of Water Research. Such provisions as stabilisation ponds are becoming an essential requirement before discharge.

Table

Town	Effluent Re-use	Volume gal./day	Purification	Quality 4 hours OA
Johannesburg 23/5/60	Crop irrigation, power station cooling, irrigated grasslands, cattle fattening, discharge of effluent to river courses.	38,000,000	Sand filtration Stabilisation ponds	12 8
Pretoria 22/6/60	Power station cooling, golf course, zoological gardens, irrigation poplar deltoides, discharge of effluent to river courses.	12,000,000	Humus tank effluent Sand filtration	12 9
Germiston 13/6/60	Irrigated grasslands, crop irrigation, discharge of effluent to river courses.	8,300,000	Humus tank effluent	20
Spring 1/6/10	Paper making industry, crop irrigation.	7,000,000	Sand filtration	5
Krugersdorp 24/5/60	Crop irrigation, grasslands, cattle fattening.	2,500,000	Bio-filter effluent	16
Benoni 8/6/60	Crop irrigation, market garden irrigation, via series of dams for power station use.	1,900,000	Humus tank effluent Stabilisation ponds	4 18
Brakpan 30/5/60	Power station cooling, recreation, lake overflow to water course.	1,500,000	Sand filter effluent	7
Kempton Park 23/5/60	Discharge to water course.	870,000	Sand filter effluent	10
Westonaria 23/5/60	Irrigation of grasslands, golf course.	634,000	Humus tank effluent	21
Randfontein 23/5/60	Grassland irrigation.	300,000	Humus tank effluent	22
Welkom 23/5/60	Crop irrigation, irrigated grasslands, use by reduction works on goldmines.	5,000,000	Humus tank effluent Sand filter effluent Stabilisation ponds	— 15 10
Parys 25/5/60	Discharge to river (future development).	30,000	—	—
Pietermaritzburg 10/6/60	Crop irrigation, poplar deltoides.	4,000,000	Humus tank effluent	13
Bellville 24/5/60	Grassland irrigation, proposed 1961 supply to board making mills, river discharge.	916,000	Humus tank effluent 1961 Sand filter effluent Stabilisation ponds	9
Worcester 6/6/60	Crop irrigation and grasslands.	1,000,000	Sedimentation tank effluent	
Kimberley 23/5/60	Crop irrigation, golf course, diamond washing purposes.	1,000,000	Humus tank effluent	
Grahamstown 24/5/60	Discharge to river.	450,000	Sand filter effluent	26

6. Watering of golf courses

Most local authorities have effluent of a good standard available and are able to supply golf courses with water to maintain the fairways and greens. The well nitrated, ammonia-carrying effluent is admirably suitable to the growth of grass. The outlay necessary to pump, or distribute the effluent, definitely pays dividends.

Much domestic water purified to drinking standards at high cost can be conserved and made available for other uses if golf courses are provided with sewage effluents for watering.

7. Supply to manufacturing and processing concerns

Sewage effluents are re-used in several concerns such as box board manufacture from waste paper. They are also re-used in the paper making industry and in special cases where they are ideally suited, such as for diamond washing purposes. Some mine reduction works also make use of limited quantities of effluent.

This field of supply is as yet undeveloped and in the near future new industries and expanding old industries must be prepared to use sewage effluents in order to continue manufacturing. Our limited natural water supply will impose this practice. It is therefore time the municipalities and authorities purifying sewage prepare and examine the implications of future sewage effluent supply for re-use.

(b) Indirect re-use

1. The feeding of natural watercourses

By far the largest quantity of water that passes through the sewage works of South Africa returns to the rivers to be caught up in conservation dams, to be re-used lower down from the rivers, or to pass down to the sea.

Self-purification undoubtedly takes place as an effluent moves on its journey to the sea down the river. It would seem that by the time water lower down the river is removed its condition would be highly satisfactory. This is, however, not always the case. Secondary pollution from industries and town wastes often causes the well-purified sewage effluent discharged at the sewage works finally to have a much worse analysis than when it commenced its journey.

Increasing mineral pollution causing high dissolved solids from unknown discharges makes later biological purification almost impossible. Even the vleis through which these streams often flow are powerless to purify them when inorganic salts, heavy silt and clay loads are carried. Toxic substances further add to the subsequent difficulty of water re-use. It is therefore hoped that interest will be taken in the re-use of effluents directly after they are discharged from a works, and before they have become polluted.

2. Recycling for domestic use

Nowhere in South Africa has effluent yet been directly introduced from a sewage works into the cycle of domestic water supply. However, it seems likely that this will eventually be commonplace in the future.

The natural river supply, conserved in a catchment basin, will be enhanced with a well-oxidised, sand-filtered and stabilised effluent from a sewage works. Dilution will be an enormous factor and the valuable effluent supply will be integrated in the body of the catchment water to become unrecognisable and will finally be brought back for service many times over.

Finally a survey presented in table form gives the actual re-use of effluent in South African cities and towns and, as far as possible, as comprehensive a picture is given as can be obtained.

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