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ABSTRACTS OF PAPERS

DESALINATION INFORMATION MEETING

May 27-28, 1971

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R. P. Hammond
Nuclear Desalination Program

J. S. Johnson
Water Research Program

May 1971

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
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FOREWORD

The Oak Ridge National Laboratory holds annual information meetings to report progress of work in the fields of water research and desalting technology. The meetings cover all ORNL desalination work, some of which is sponsored by the Office of Saline Water, some by the Federal Water Pollution Control Administration, some by the National Science Foundation, and some by the Atomic Energy Commission.

Proceedings of the information meeting will not be published, but some of the material is available in published form and additional publications will be forthcoming.

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NUCLEAR DESALINATION PROGRAM

R. P. Hammond

The AEC-Sponsored Program on the Application of Nuclear Energy to Desalting and Other Processes*

T. D. Anderson
Reactor Division

The Atomic Energy Commission's program on the application of nuclear energy to desalting and other energy-intensive processes has the following objectives: (1) to define and explore potential applications of nuclear energy to processes and services which may have significant potential for economic, social, or environmental improvements and (2) to cooperate with other government agencies and industry in developing the technology needed to implement the above applications of nuclear energy. Most of the AEC program is conducted at ORNL, where closely related work is supported by the Department of the Interior's Office of Saline Water.

As shown in Fig. 1, there are two major divisions of the AEC program; these are nuclear desalting and nuclear energy centers. In the field of nuclear desalting, an important function of the program is to make available to industry, government agencies, and potential desalting plant owners useful data and techniques that will increase understanding of large plant technology and allow independent evaluations of desalting plant designs and applications. Presently, the emphasis is on the practical control and coupling questions related to the design and operation of dual-purpose plants using light-water reactors. Both theoretical and experimental studies are being made.

Studies on nuclear energy complexes began at ORNL in 1967. Recent work has included evaluations of many energy-consuming industrial processes that are suitable for nuclear complexes, studies of crops and farming techniques applicable to complexes, and investigations of specific applications of agro-industrial complexes in both developed and developing countries.

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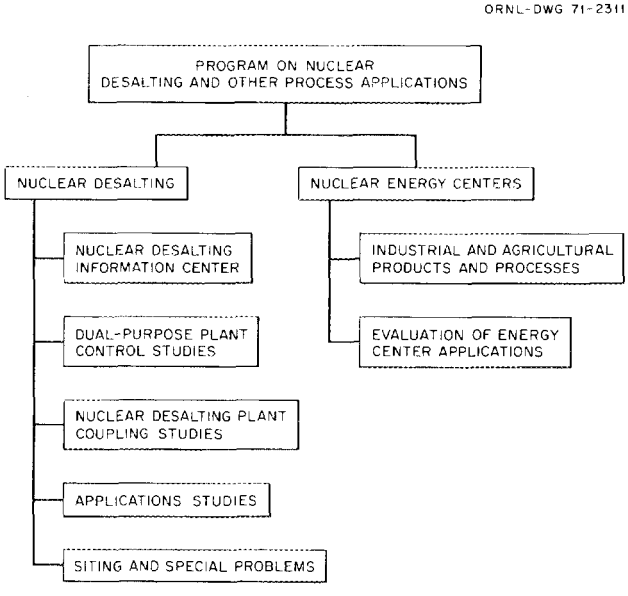

Fig. 1. Elements of program.

Nuplex Program Activities*

J. W. Michel
Reactor Division

Assistance has been given to several Nuplex study projects during the past year. These included the Energy Center Study for Puerto Rico, the Indian Indo-Gangetic Plain project, the Texas A&M research program and some of the studies being undertaken by the Southern Interstate Nuclear Board. The Puerto Rico study (performed by Burns & Roe and Dow Chemical Company) was completed. It indicated that an energy center for the south coast of the island would be a worthwhile undertaking. Work for the Indian project consisted primarily of analyzing several alternatives for providing interim power sources to drive the pumps on proposed tube wells during the construction period before electricity is available from the nuclear power station.

Under the University of Tennessee Ph.D. program, a thesis study was performed to analyze the regional economic impact which may result from building and operating an agro-industrial complex. This study utilized a computer program which allowed the selection of a viable group of energy-intensive industries and, by use of input-output tables, estimated the total energy center impact on the region in terms of employment, increase in gross regional product, costs to the public sector, etc.

Since the agricultural use of desalted water is an important segment of many proposed nuclear-powered complexes and the overall economics of its use is unproven, a study of means for increasing water use efficiency was initiated. A greenhouse experiment using a commercially available subirrigation system demonstrated that nonproductive surface evaporation can be drastically reduced, resulting in much higher water use efficiency than with surface flooding or sprinkler systems. A state-of-the-art survey of subirrigation was completed and an investigation of an improved emitter design was begun.

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The Ultimate Mineral Resource Situation*

H. E. Goeller
Chemical Technology Division

Most appraisals of mineral resources are made for the next 30 years or a little beyond. In the past year we have investigated the world mineral resource situation for all the elements using essentially an open-ended time horizon. This work, done in part with the cooperation of Resources for the Future, Inc., has attempted to provide an integrated picture showing roughly the order of runout for the various elements, and what the outlooks appear to be for recycle and for substitution for each of them.

About 20 elements have infinite resource bases in the atmosphere, in the oceans and/or in the lithosphere; even for these, however, an unlimited source of energy must be assured to convert their resources into useable products. The rest of the elements have limited economic resources with various time horizons. The most serious long range resource problem is that of perpetually supplying enough phosphate for agriculture to feed a greatly expanded world population. Others are the provision of enough reasonable cost uranium (and later thorium) to assure unlimited energy output after fossil fuels are depleted and before commercial fusion power is achieved, enough manganese to purify our steel needs, and conservation of available helium for cryogenic and superconduction uses.

Many elements, particularly the nonferrous metals, will ultimately have to depend almost completely on nearly full recycle for essential applications, use of substitutes for all dissipative uses and most nonessential uses, and the provision of a small makeup stream of high cost virgin metal from very lean ores and alternative natural sources. We will review the situation with regard to copper as representative of this group.

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In the far term magnesium, aluminum and steel will be the major metals of commerce, however, sufficient quantities of copper, lead, zinc, high alloy steels, titanium, etc., will still exist, but only if we start now to implement appropriate conservation, recycle and substitution measures. Petrochemical products will rise slowly in price as we proceed through the heirarchy of natural gas and petroleum, coal and shale oil and finally limestone as a source of carbon. Nonmetal products such as glass and ceramics with unlimited resources will undoubtedly play a much larger role in the future. Finally, the energy requirements necessary to work the leaner ores of the future and to control the pollution and land damage which will result from their exploitation will be considerably greater than for today.

Review of Water Needs in the California Region*

W. E. Thompson
Reactor Division

Conveyance of water for irrigation in California has been practiced more than 100 years. Today California has extensive aqueduct systems which supply about half the water used in the state, the remainder coming from local streams and reservoirs (30%) plus pumping of groundwater (20%). A study of California's water supply systems has been undertaken to analyze their capital and operating cost, to obtain the latest estimates of additional water needs projected for the future, and to evaluate possible applications of desalting in meeting California's future water requirements.

Water is imported from the Colorado River through the 80-miles-long All American Canal to the Imperial Valley (3850 Mgd) and the 242-miles-long Colorado River Aqueduct to the Los Angeles – San Diego area (880 Mgd). Aqueducts from reservoirs in the Sierra Nevada Range supply water to the coastal cities of Los Angeles (550 Mgd), San Francisco (300 Mgd), and the East Bay area of Oakland and surrounding communities (200 Mgd). The Central Valley Project, financed by the federal government with costs to be recovered from water sales, supplies 4500 Mgd and will ultimately supply 9500 Mgd, mainly for irrigation in the valleys of the Sacramento and San Joaquin Rivers. The state water project will deliver 3800 Mgd along the 450-mile California Aqueduct from the Sacramento River delta to southern California. This conveyance system, when completed, will supplement present water supplies to meet Southern California's estimated water requirements through 1990 at costs of 14 to 25¢ per 1000 gallons for untreated water.

Future increases in water supply will be required for population growth and the irrigation of additional crop land. The coastal mountain areas from San Francisco to the Mexican border have already fully

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*Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

exploited nearly all local water supplies. In the rough mountain terrain conveyance costs are high, and desalting of seawater may be economically competitive for future increases in water supply. The State Water Project had estimated costs of about 25¢ per 1000 gallons for untreated water delivered to San Luis Obispo through the Coastal Branch of the California Aqueduct. The joint OSW-State of California study of a seawater desalting plant at Diablo Canyon may lead to construction of a 30–50 Mgd prototype plant which will supply the San Luis Obispo area and may permit deferring construction of the $67 million portion of the Coastal Branch of the California Aqueduct, which had been scheduled to be started in 1975.

California's usage of Colorado River water will have to be cut back, under a recent court ruling, as Arizona's usage increases in the next few years. The California Aqueduct will supply water to offset this cutback, but future increases in water requirements might be met by desalting plants near the Gulf of California. Increasing salinity of the Colorado River water is already causing problems in irrigated fields in the Imperial Valley and in Mexico and will worsen with the addition of saline return flows from new upstream irrigation projects. The increasing salt content of the Imperial Valley's Salton Sea will threaten sports fishing and recreation uses unless forestalled by some method of desalting. Salinity problems as well as needs for additional water will create opportunities for applications of desalting technology in this Colorado River delta region.

Dual-Purpose Plant Coupling Program*

J. E. Jones
Reactor Division

The recent "Proposed Federal Desalting Program" prepared by the Office of Science and Technology notes that "Low-cost water will be dependent on the ability of desalting plants to be closely integrated with large scale energy sources." The AEC's program on nuclear dual-purpose plant coupling is directed toward achieving this objective. The goal is to provide basic information and to demonstrate techniques which will lead to the successful integration of nuclear energy sources with large scale evaporators.

A necessary milestone in terms of hardware development in pursuing the objectives of the Federal desalting program is one or more nuclear dual-purpose demonstration plants. For the past several months we have been studying the coupling options relating to a nuclear dual-purpose demonstration plant composed of a single large [~1100 Mw(e)] nuclear power plant and a demonstration size (50 Mgd) evaporator. Since no specific demonstration plant was under consideration at the time this work was initiated the reference plant is a hypothetical one. Nevertheless, the criteria and objectives for this plant are thought to be reasonable and representative of actual prototype or demonstration plants. The major objective of such plants is to demonstrate evaporator and coupling technology applicable to large economic commercial dual-purpose plants.

Figure 2 shows simple block diagrams of three basic turbine cycle options considered for the dual-purpose demonstration plant. In evaluating these and other coupling options the following coupling criteria have been considered:

(1) Since the project's purpose is to provide experience and data applicable to future large-scale plants, the coupling arrangement should have the maximum feasible similarity to such plants.

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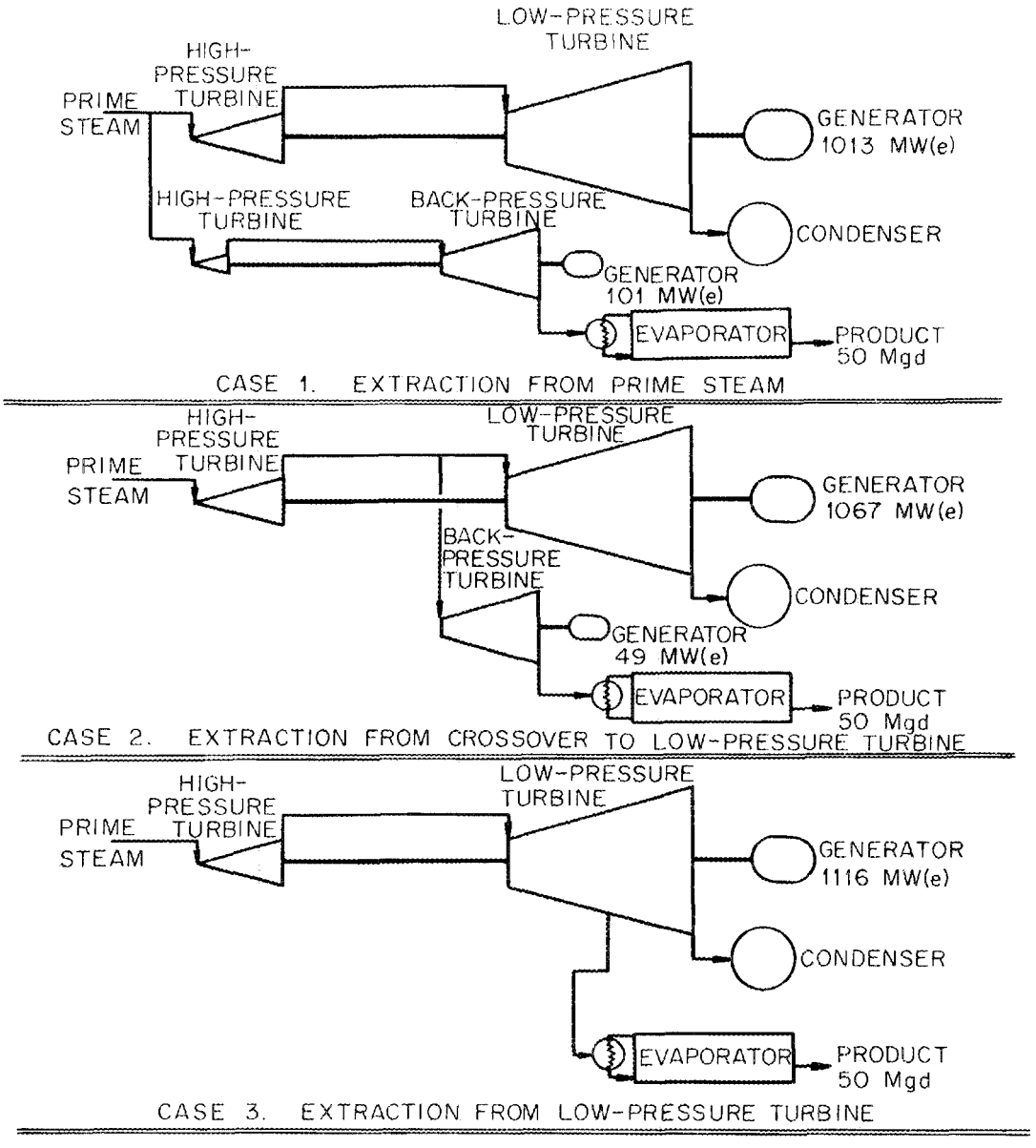

Fig. 2. Alternate Turbine Cycles for Dual-Purpose Demonstration Plant

(2) A paramount factor is the necessity for reliable power station operation, regardless of the condition of the evaporator, and for effective means of control between the two.

(3) Economics is an important factor, since our preliminary studies show substantial cost differences between some of the possible arrangements.

Detailed studies have been made for these three basic cycles with the result that Case 2, in which the water plant and its associated back-pressure turbine use steam extracted from the main steam cycle crossover, best satisfies the coupling criteria.

In addition to the basic turbine cycle layout, other interface questions are being examined. For example, considering the cycle in Case 2:

1. What provision should be made, if any, for an alternate heat sink for the back-pressure turbine during evaporator shutdown?

2. Should an alternate heat source (bypass desuperheater) be provided for the back-pressure turbine or evaporator during main turbine outage or maintenance periods?

3. Is an intermediate heat exchanger loop between the turbine cycle and brine heater needed (or perhaps required by regulatory agencies) to isolate these systems in the event of leakage? If so, what would it cost and how should it be designed?

4. With the potential for brine leakage into the turbine cycle condensate at the brine heater (assuming an intermediate loop is not used), how should condensate demineralization be accomplished? Considering the high temperature (~250°F) of the condensate, conventional demineralizer anion resins would be unsatisfactory.

The solution to these and other important questions regarding the dual-purpose demonstration plant coupling, involves a compromise between the three principal coupling criteria cited. The AEC coupling program at ORNL includes studies which will provide useful input to the analysis of these questions.

Control of Dual-Purpose Plants*

S. J. Ball
Instrumentation and Controls Division

Investigation of the problems of large nuclear desalting plant control has concentrated on multistage flash (MSF) evaporator controllability. The major objective of the work is to develop a general capacity for predicting the performance characteristics, both static and dynamic, of plants with various design features, such as the OSW 9-Stage MSF Module at San Diego and the proposed OSW-State of California 40-Mgd prototype plant.

Using the ORNL MSF digital simulator described in another paper at this meeting, we were able to pinpoint areas in which more detailed experimental data were required. For example, the predictions of overall MSF plant behavior were shown to be very sensitive to what is assumed to be the correlations for interstage orifice brine flow rate. In particular, models for stage hydraulic behavior near or in the blow-through condition (in which tray brine levels fall below the height of the orifice, allowing vapor to "blow through") were found to be crucial. More accurate expressions were also required for tray brine dynamics and nonequilibrium loss behavior.

In a series of tests run on the OSW/BLH Wrightsville Beach 3-stage evaporator in August 1970, several empirical correlations were obtained for a reference stage design. The test stage configuration was simply a 7-ft-long, 21-in.-wide empty chamber with rectangular orifices at either end. Several new test and analysis procedures were developed which resulted in improvements in the quality of data and correlations obtained. The "controlled-trend"test method was shown to enhance the output rate of useful information, and provide reproducible results (which checked with the data taken in conventional steady-state tests.)

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It was also found that the observation of evaporator behavior during the trend tests often makes the forms of good correlating equations readily apparent.

The test results showed that there was an important combined effect of the hydraulic and nonequilibrium loss behavior on the operational stability of a single stage. Also, suprisingly good stage efficiency and stability characteristics were noted in experiments in which there was blow through.

Analysis of Evaporator Dynamics*

N. E. Clapp
Instrumentation and Controls Division

The purpose of the evaporator dynamic tests is to obtain data that are useful in the development of a dynamic model which predicts the performance of a stage in a multistage flash evaporator. Dynamic tests were performed on the BLH 3-stage evaporator at Wrightsville Beach during August 1970, including frequency response tests and pulse tests. The frequency response tests consisted of varying one or more of the stage inputs in a coded sequence known as a pseudo-random binary n-sequence (PRBS), which contained a large number of odd harmonics. The three PRBS tests consisted of: (1) varying the recycle brine flow rate about a steady-state operating point, (2) varying the steam flow rate into the brine heater, and (3) varying both recycle brine flow rate and steam flow rate simultaneously. The pulse tests consisted of varying the recycle brine flow rate or the steam flow rate with a single pulse or a doublet (i.e., a positive pulse followed by a negative pulse) signal.

In the analysis of the frequency response data, it was determined that during each test, small drifts in temperature over the 40-min. period introduced significant errors in the individual transfer function calculation. The frequency response analysis approach was to fit the frequency response data to theoretical models, obtaining the coefficients of the models by means of an optimization routine. First, the parameters of a standard distributed-parameter model for the test stage condenser were varied to obtain good agreement with test data. From this, one could then calculate the flashing (or vaporization) rate, which was then used in the flashing tray brine dynamic model development. This method of analysis yielded good results over a reasonably wide frequency range.

The pulse test data are analyzed using the ORNL Hybrid computer. A model of the evaporator stage is set up on the analog computer.

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Digitized temperature, flow, and level data recorded during the pulse tests are stored in the digital computer. Input signal perturbations corresponding to the measured signals are sent to the analog model, and the measured outlet signals are compared with the outlet signals of the analog model. The hybrid program is written so that parameter variations may be made, either manually or automatically using a gradient search algorithm, to minimize differences between model response and measured response.

The use of coded sequences, such as the PRBS, as input signals has proved to be an efficient means of obtaining frequency response data over a wide frequency range. The use of pulse signals as input signals has proved to be an effective way of obtaining time response data. Similar results can be obtained from both frequency response and time response data; however, different analysis procedures are used. One example of the results obtained from the dynamic analysis is the discovery of a transport delay in the tray brine temperature frequency response. The transport delay was caused by channeling of brine, along the bottom, through the stage. The effect of channeling on stage performance was that larger than expected values of nonequilibrium loss were measured. The instability in brine level was also found to be dependent on the amount of channeling present.

The ORNL MSF Digital Simulator*

J. G. Delene
Reactor Division

An important aspect of the design of large seawater distillation plants is the determination of their dynamic characteristics, stability, and controllability. As an aid to understanding and predicting the response of large multistage flash (MSF) evaporator plants, a digital simulator was developed. This simulator can calculate the response of the evaporator to various types of perturbations, accurately predicting levels, temperatures, flow rates, etc., in each stage within a reasonable computer running time. Typical system perturbations currently accommodated by the code are changes in brine heater steam flow and evaporator recycle flow. Presently there are two versions of the simulator available. The first version is a general purpose simulator for the study of large evaporator designs. The second version is especially for the 9-stage MSF test module at San Diego.

Although both of the codes are operable, improvements are continually being made to them. These improvements include both changes in the representation of the evaporator components and changes in the mathematical models used to describe heat transfer and flashing flow. Where possible, attempts are made to match experimental results and simulator calculations.

In the code development, special attention has been placed on reducing computer running time while at the same time maintaining sufficient detail and accuracy. The current running times on the ORNL IBM 360/91 for the two computer code versions are about 13 and 40 times real time for the general purpose simulator (50-stage problem) and the module simulator, respectively.

Under development, but not operable yet, is an extension of the simulator to include a reactor, steam generator, and turbine-generator plant. This simulation is being developed as an aid to investigating the dynamics and possible control problems of large dual-purpose plants.

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The simulator is presently being used to determine areas in which evaporator experimentation is needed and to aid in the design of needed experiments with the 9-stage test module. The results of such experiments will further improve the mathematical models used in the simulator. It is expected that the simulator will be used in the design of control systems for large evaporators, including the proposed OSW-State of California 40-Mgd prototype plant.

Nuclear Desalination Information Center

K. O. Johnsson
Reactor Division

The Nuclear Desalination Information Center continues to provide services to both the program staff at ORNL and investigators elsewhere. The number of reports, articles, and papers from meetings in the information storage and retrieval system now approaches 1500. On request, the Center searches these 1500 references for information based on selected keywords and provides the requestor with a computer printout of the references and abstracts which are pertinent to the needs of the requestor. The Center also publishes, from time-to-time, lists of references and abstracts which have been added to the system and annually publishes complete reference data and abstracts for everything in the system. A permuted title-author-company index to all OSW R&D Progress Reports is also prepared annually. An indexed abstract listing of U.S. patents pertaining to the distillation process for desalting was prepared and issued in a preliminary form; a more complete listing is now ready for release.

Consideration is being given to including in the scope of the Center more complete coverage of information relating to the large-scale application of desalted water in agriculture.

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Summary of the OSW-Supported Development Work at ORNL*

I. Spiewak
Reactor Division

The Interagency Agreement between the AEC and the OSW provides for a broad program of research, development and engineering and laboratory services. While the bulk of the program has been in the field of distillation, significant projects have been carried out in regard to materials, program analysis, economic and feasibility studies, brine disposal and membrane processes.

Emphasis has been placed on VTE process development. A number of high-performance heat transfer surfaces have been developed and/or evaluated, including both evaporators and condensers.

During the past year, some of the noteworthy accomplishments have been the following:

1. Participation in tests of the MSF module and the VTE-X at San Diego, with comparison of predicted and observed results
2. Correlation of the fouling observed on enhanced evaporator tubes
3. Operation of the CO_2 Scale Suppression Pilot Plant at Wrightsville Beach
4. Survey of materials performance at OSW test facilities
5. Survey of the pacification of product water from distillation plants
6. Study of large VTE-MSF distillation plants as a future source of supplemental water supply for New York City.

In FY 1972, continuing work will include:

1. Heat transfer tests of high-performance tubes
2. Analysis of data from OSW pilot plants and test beds
3. Condenser bundle analysis

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*Work sponsored by the Office of Saline Water, U. S. Department of the Interior, under the Interagency Agreement with the U. S. Atomic Energy Commission.

4. Design and systems studies using computer process models
5. Component development
6. Assistance to OSW in desalting feasibility and economic studies
7. OSW Materials Information Center and Distillation Literature Survey.

Vertical Tube Evaporator Studies

Evaporator-Condenser Heat Transfer and Fluid Mechanics*

L. G. Alexander and H. W. Hoffman
Reactor Division

The heat-transfer program during the past year has explored a number of specific areas illuminated by earlier more general studies; these are considered in the following paragraphs.

Flute Geometry. We have known for sometime that the performance of doubly fluted tubes was affected by the profile shape. In examining this further, we tested first a group of nine commercially prepared corrugated (fluted) tubes (~2.0-in.-OD x 8-ft-long) with fresh water in downflow at atmospheric pressure. Nominal heat-transfer coefficients ranged from 1200 to 1750 Btu/hr·ft^2·°F with little dependence on ΔT; comparable values for a smooth tube are ~600 Btu/hr·ft^2·°F. Residual coefficients, calculated by subtracting an estimated wall resistance from the overall resistance, were found to correlate with pitch-to-penetration ratio (Fig. 3).

This study with variously manufactured tubes indicated the desirability of a systematic investigation of the effects of flute parameters on tube performance. Accordingly, three sets of 2-in.-OD x 2-ft-long aluminum tubes were prepared: Set 1 — three tubes with sine-wave flutes of constant pitch-to-penetration ratio (P/e = 3) but with pitches of 0.150, 0.190, and 0.240-in.; Set 2 — three tubes with flat-crested flutes of 0.125, 0.167, and 0.250-in. pitch but with penetrations of 0.040, 0.060, and 0.120-in., respectively; and Set 3 — three tubes with rounded flute crests (as opposed to sine-wave) at constant penetration (0.040-in.) with pitches of 0.120, 0.200, and 0.250 in. With Set 1, $\bar{\bar{U}}_n$ decreased slightly (2150 down to 1920 Btu/hr·ft^2·°F) with increasing pitch at constant P/e. For Set 3, with approximately the same range in pitch but a two-fold variation in P/e (3 to ~6), the coefficient decrease was

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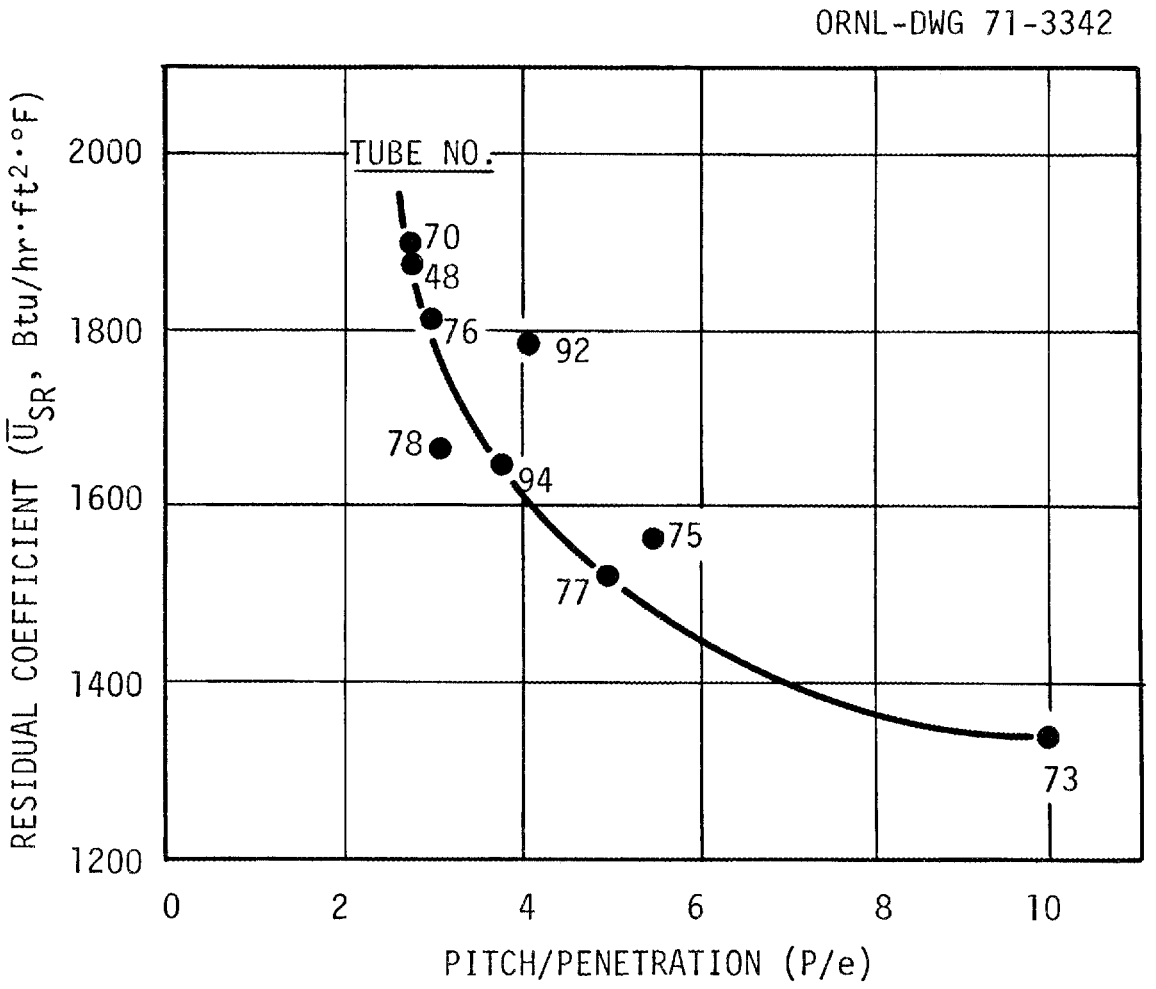

Fig. 3. Effect of Pitch-to-Penetration Ratio on Heat Transfer.

more exaggerated (1900 down to 1300 Btu/hr•ft^2•°F). With Set 2, coefficients were of the order of 2200 Btu/hr•ft^2•°F with the larger flutes (P/e = 2.78 and 2.08) but only ~1800 Btu/hr•ft^2•°F with the smallest flute (P/e = 3.13).

VTE-X Tubes. Two typical 2-in.-OD x 10-ft-long doubly fluted CuNi tubes used in the VTE-X (Anaconda-Grob profile) were tested. With fresh water at evaporating temperatures of 130, 210, and 250°F, $\bar{U}_n$ was 850, 1250, and 1200 Btu/hr•ft^2•°F, respectively; the value at 130°F is comparable to that found with the GE Profile 9 tube, but the performance at the higher temperatures is decidedly inferior. The coefficients were insensitive to variations in ΔT and in flow. With a 3.8 wt % NaCl feed and an inlet nozzle (conditions conducive to foaming), the coefficient at 130°F increased only to 1000 Btu/hr•ft^2•°F while rising to about 2000 Btu/hr•ft^2•°F at 210°F. When 20 ppm of Neodol 25-3A was added to the saltwater feed, the 210°F coefficient remained at ~2000 Btu/hr•ft^2•°F, indicating no further effect of foaming agent.

Length Effects. A series of tests with a 3-in.-OD, doubly fluted, GE Profile 9, CuFe tube revealed no effect of length (over the range 4 to 20 feet) on performance with foaming fresh-water flows. The result is consistent with earlier observations under nonfoaming conditions.

Surface Fouling. The magnitude of the fouling resistance was examined with 3-in.-OD x 10-ft-long aluminum-brass tubes of Anaconda-Grob profile exposed at the San Diego (BTE-X) and Wrightsville Beach (WB) OSW facilities. With fresh water at 210°F, $\bar{U}_c$ for a fouled VTE-X tube was 1550 Btu/hr•ft^2•°F. Cleaning of the outside surface occasioned a rise in the coefficient to 1980 Btu/hr•ft^2•°F; subsequent cleaning of the inside surface resulted in a slight decrease in $\bar{U}_n$ (~100 Btu/hr•ft^2•°F). The derived overall fouling resistance with fresh water was 0.00010 hr•ft^2•°F/Btu; saltwater data at 210°F (2200 fouled and 2790 Btu/hr•ft^2•°F clean) yield a fouling resistance of 0.00018 hr•ft^2•°F/Btu.

The fouled WB tube at 210°F with fresh water gave a coefficient of 1210 Btu/hr•ft^2•°F. With the outside cleaned, $\bar{U}_n$ was 1660 Btu/hr•ft^2•°F; and with both sides cleaned, essentially the same at 1680. The corresponding fouling resistance was 0.00023 hr•ft^2•°F/Btu. With salt water, coefficients were 1790 (fouled) and 2215 (cleaned), giving a fouling resistance of only 0.00011 hr•ft^2•°F/Btu.

Fresh-water coefficients for the cleaned tubes can be compared with a value of ~1650 Btu/hr•ft^2•°F from earlier tests with a similar clean tube. The several anomalies exhibited through these experiments need further resolution.

Experiments in the VTE-X to Observe Tube Bundle Heat Transfer Performance as Noncondensable Gas Loading and Vent Rates are Varied*

R. Van Winkle
Reactor Division

The test program of venting experiments (in which vent rates and noncondensable gas loadings were varied) and of measurement of local heat transfer coefficients was performed in the second effect bundle of the VTE-X (a large OSW facility at the San Diego Test Station) to obtain information on the following questions:

1. After making allowance for the expected parasitic temperature losses due to pressure drop and presence of noncondensable gas, will the evaporation rate be uniform in all parts of the bundle?

2. By how much will the heat transfer coefficient be impaired (locally) as the concentration of noncondensable gas increases and exceeds the values expected under normal operating conditions (with respect to vent rates and noncondensable gas loads); e.g., can criteria be established for the specification of optimum vent rates?

3. Does it make any difference whether the vent stream is withdrawn from the top or from the bottom of the vent region; will density differences between steam and noncondensable gas result in undesirable stratification?

4. If stratification occurs, would it be appreciably worse for noncondensables of higher molecular weight (CO_2 compared to air, for instance)?

5. Is there a threshold lower limit on mass velocity below which good sweeping of noncondensable gas will not be obtained?

6. Will very high mass velocities of steam at the front of the bundle affect the overall heat transfer coefficients either adversely or beneficially?

In the experiments performed to date, it appears that in the absence of gas there would be uniform heat transfer performance in all parts of

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*Work sponsored by the Office of Saline Water, U. S. Department of the Interior, under the Interagency Agreement with the U. S. Atomic Energy Commission.

the bundle, and that mass velocities of steam as high as 3800 lb/hr·ft^2 neither improve nor hurt the heat transfer coefficients. Other conclusions (in answer to the above list of questions) remain more tentative because analysis of the experimental results is complicated by the following items:

1. There was some scale formation in the bundle (equivalent to a heat transfer resistance the order of 0.00008 hr·ft^2·°F/Btu) which was not necessarily uniformly distributed.

2. There was usually a large flow of noncondensable gas, either from inleakage air or from CO_2 release, in the amount generally equal to or greater than one pound mole per hour (based on the temperature indications) which introduced sizeable uncertainty into the estimation of gas concentration in various regions of the bundle.

3. The vent vapor samples for the measurement of noncondensable gas concentrations in the vent streams appeared to give unreliable results.

4. Noncondensable gas was probably not uniformly distributed in the steam entering the bundle, apparently being higher in concentration in the lower regions.

In spite of these uncertainties, which could be reduced in additional experiments, it appears that vapor temperature measurements, when used with calculated pressure drops, afford reliable quantitative indication of noncondensable gas concentrations, which then permit useful analysis of the experimental data to give the following tentative conclusions:

1. Little stratification occurs as a result of density differences between steam and noncondensable gas, even when argon (to simulate CO_2) is used as noncondensable gas tracer.

2. There is a threshold mass velocity for effective sweeping of noncondensables, and its value is the order of 100 lb/hr·ft^2 for conditions of the VTE-X test.

3. A gas concentration in the range 1.0 to 1.5 mole percent can cause a 15% reduction in heat transfer coefficient (from a value of about 1100 Btu/hr·ft^2·°F); higher gas concentrations give much greater reductions.

4. There is little difference in performance when venting occurs from the bottom only, or from the top only, of the vent region.

Additional experiments are needed to determine more accurately the effect of noncondensable gas concentration on heat transfer coefficients, particularly at concentrations below one mole percent, and to investigate more completely threshold mass velocities for sweeping of noncondensables.

CO_2 Suppression of Alkaline Scale

D. M. Eissenberg
Reactor Division

The CO_2 Scale Suppression Process is a method of treating seawater feed to distillation desalination plants so that up to 85% of the dissolved alkalinity (the soluble form of alkaline scale) is precipitated out of the process stream and subsequently redissolved and returned to the sea. The process has been investigated using a 30-gpm pilot plant located at the Wrightsville Beach, North Carolina test facility of the OSW. The plant demonstrated that seawater carbonated by pressurization with CO_2 to a pH of 6.5 will not form scale while being heated to 290°F in conventional heat exchangers. Subsequent precipitation of the alkalinity at the high temperature was accomplished using two packed columns — one for precipitating the dissolved alkalinity from the preheated feedwater by stripping the CO_2 with prime steam, and the other for redissolving the precipitate from the packing by washing with cold, carbonated seawater which is then discharged to the sea. The CO_2 for carbonating the seawater prior to washing the column was surplus CO_2 recovered from the stripping steam used in the other column. Process design data and operation experience obtained from the pilot plant have been used to estimate the economic potential for the process when applied to current generation distillation plants (2.5-Mgd MSF), as a substitute for conventional feed treatment using sulfuric acid. For a plant operating at a top temperature of 250°F, preliminary studies indicate a one cent per thousand gallons of product water net savings in using CO_2 scale suppression when compared to an optimized acid plant, based on the ground rules of the study which include an acid cost of $45/ton. For plants with top temperatures of 270–290°F, the potential savings was 2 cents with the same ground rules.

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*Work sponsored by the Office of Saline Water, U.S. Department of the Interior, under the Interagency Agreement with the U.S. Atomic Energy Commission.

A Study of Conjunctive Operation of Nuclear Dual-Purpose Desalting Plants to Serve the New York City Metropolitan Region*

I. Spiewak
Reactor Division

A joint study team, representing the New York City Board of Water Supply, the New York State Conservation Department, Division of Water Resources, the Consolidated Edison Company, the Atomic Energy Commission, and the Office of Saline Water of the Department of the Interior, initiated a study in 1969 of the application of dual-purpose nuclear-power and desalting plants to provide the long-range (1990 and beyond) supplemental water needs of the New York City Metropolitan Region. The study, now being finalized, considered recent advances in desalting and essentially state-of-the-art power reactor technology.

Oak Ridge National Laboratory, together with personnel from Utah State University, provided staff support to the study. Our role related to study of alternatives, overall plant design, and report preparation.

Basically, the study concludes that large-scale distillation plants, operating conjunctively with the existing surface water supply system, are a reasonable method of meeting incremental water needs of New York City beyond 1990.

An increase in firm yield of 450 Mgd could best be met with a plant of 750 Mgd capacity. This plant, of the advanced vertical-tube evaporator – multistage flash process type, would have a performance ratio of 9 pounds product per 1000 Btu as compared to 10-13 normally used for base-loaded plants. Steam would be supplied by a multiunit dual-purpose nuclear power plant. The most economical type of energy supply would be "interruptible;" the steam would be used by a low-pressure turbine to generate electricity during periods of peak electrical demand but would be available to the desalting plant at other times. The low-pressure turbine would be available as spinning reserve during desalting plant operation. It is estimated that the desalting plant would have a load factor of 27 percent over its life.

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*Work sponsored by the Office of Saline Water, U.S. Department of the Interior, under the Interagency Agreement with the U.S. Atomic Energy Commission.

Preliminary Study of Geothermal Desalting*

E. C. Hise
Reactor Division

On the basis of developed wells in Mexico and exploratory wells in Imperial County, California, Robert W. Rex of the University of California estimates that a geothermal brine reserve of the order of 1,000,000,000 acre-ft exists in the Imperial Valley. It is proposed by Rex that this resource could be developed at the rate of 3.6 million acre-ft per year to generate 20,000 Mw of electric power from steam flashed from the brine.

In addition to the generation of electric power, a quantity of 1.5 to 3 million acre-ft/yr of pure water could be recovered from the system by desalting. A preliminary investigation was made of the processes which might be used in this application.

In normal seawater desalting, feed to the desalting plant is obtained cold, steam is purchased to heat the feed (to a maximum temperature of about 250°F), and the waste heat and brine are readily discharged to the sea. The geothermal feed is obtained at about 400°F. Waste heat must be rejected to the environment and waste brine must be reinjected into the ground or evaporated to dryness. It is therefore anticipated that the process equipment for geothermal brine desalting will be substantially different than that generally used for seawater desalting.

In addition, the geothermal brines may include substantial quantities of dissolved H_2S, CO_2 and silica. These constituents give rise to considerations of gas removal and silica scale control. There are also corrosion and materials selection problems that differ from the problems with seawater.

Some of the possible heat rejection methods in the area are air cooling in dry towers and evaporative cooling of the well brine in ponds, spray ponds, or wet towers. The air cooled condensers and coolers can

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*Research sponsored by the Office of Saline Water, U.S. Department of the Interior, under the Interagency Agreement with the U.S. Atomic Energy Commission.

be designed to extract product water while rejecting heat and reducing the amount of brine to be disposed of. The evaporative cooling methods reject the heat and reduce the quantity of brine but reclaim no water.

If an alternate supply of cooling water were available, it might be preferable to the well brine. However, the rejection of heat to any water results in evaporative loss.

An open geothermal power cycle would use a barometric condenser for the turbine exhaust. A surface condenser, cooled either by air or recirculated brine which is evaporatively cooled, could reclaim the exhaust as product in the amount of about 29% of the well brine.

A single effect vertical tube evaporator, placed between the well head separator and the turbine offers the attractive possibility of providing nearly gas-free steam to the turbine, and simplifying the recovering of sulphur from H_2S.

Additional water can be extracted from the remaining brine by flashing it down through a series of separators or a multistage flash evaporator provided with heat transfer surface to condense the vapor.

Very approximate cost estimates of one of the possible cycle indicates that power, water and sulfur could be recovered from the geothermal brine at reasonable costs.

Materials Information Center*

J. L. English
Reactor Chemistry Division

Upon request by the Office of Saline Water, the Oak Ridge National Laboratory has established a Materials Information Center concerned with the corrosion and performance of materials in saline water conversion processes. The Center's storage and retrieval system is computerized and has two major functions, one of which is the processing of publications for bibliographic information. Approximately 585 entries are currently in the system. The second function of the Center is the collection of information on performance of equipment in the various test-bed plants and experimental facilities operated for the Office of Saline Water. Approximately 1700 inspection-report forms have been processed thus far for computer storage for the Freeport, Roswell, and Senator Clair Engle test-bed plants.

*Work sponsored by the Office of Saline Water, U.S. Department of the Interior, under the Interagency Agreement with the U.S. Atomic Energy Commission.

NUCLEAR DESALINATION PROGRAM

Publications

Nuclear Desalination Program

Publications

(Published since 1970 Information Meeting)

AEC-Sponsored Work

1. M. M. Anderson, Jr., A Numerical Algorithm for Solving the Nonlinear Differential Equations That Describe a Multistage Flash Evaporator, thesis, University of Tennessee, NEUT 2806-7 (May 1970).

2. T. D. Anderson, "Offshore Siting of Nuclear Energy Stations," Nuclear Safety 12(1), 9-14 (1971).

3. S. J. Ball, "Nuclear Desalting Plant Control Studies at ORNL," presented at North Carolina State University, Nuclear Engineering Seminar, Raleigh, October 1, 1970.

4. H. I. Bowers, An Economic Comparison of Single-Purpose and Dual-Purpose Nuclear Plants for Supplying Widely Separated Power and Water Loads, ORNL-TM-2899 (August 1970).

5. M. R. Buckner, Optimum Binary Signals for Frequency Response Testing, thesis, University of Tennessee, ORNL-TM-3198 (November 1970). Also NEUT 2806-8.

6. D. Chapman, Income, Bias, Benefit-Cost Analysis, and the Consumers' Surplus: Logical Problems in the Evaluation of Public Benefit, ORNL-4477 (June 1970).

7. D. Chapman, "A Note on Engineering Empiricism and Economic Theory, Eng. Econ. 15(4), 243-48 (1970).

8. T. E. Cole, Subsurface and Trickle Irrigation -- A Survey of Potentials and Problems, ORNL-NDIC-9 (in press).

9. G. L. Copeland, Evaluation of Thorium-Uranium Alloys for the Unclad-Metal Breeder Reactor, ORNL-4557 (June 1970).

10. J. G. Delene and S. J. Ball, "A Digital Simulation of the Dynamics of Large Multistage Flash Evaporator Plants," Proc. 1970 Summer Computer Simulation Conference, Denver, June 10-12, 1970, pp. 346-52, (1970).

11. L. C. Fuller, Steam Turbine-Generator Cycle Efficiency for Desalting Applications, ORNL-TM-2909 (July 1970).

12. R. P. Hammond, "Energy: The Resource for the Future," presented at the 1970 National Youth Conference on the Atom, Chicago, October 22-24, 1970.

13. R. P. Hammond, "Agrar-Industrie-Komplexe," UMSCHAU in Wissenschaft und Technik (November 19, 1970).

14. R. P. Hammond, "Nuclear Power in Agro-Industrial Development," Research for the World Food Crisis (proceedings of AAAS Symposium on New Frontiers of Agricultural Research, Dallas, Texas, December 26-31, 1968), AAAS, Washington, D.C., 1970.

15. R. P. Hammond and K. A. Kraus, Abstracts of Papers, Desalination Information Meeting, May 21-22, 1970, ORNL-TM-2977 (May 1970).

16. R. P. Hammond, "Systemmatic Planning for Long-Range Energy Needs," presented at the 1971 International IEEE Conference on Systems, Networks and Computers, Oaxtepec, Mor., Mexico, January 19-21, 1971.

17. R. P. Hammond and Gale Young, "New Lands from Old Deserts," J. Amer. Med. Assn. 213(7), 1107 (August 17, 1970).

18. J. M. Holmes, The Impact of Nuclear Energy Centers on the Economy of Puerto Rico, thesis, University of Tennessee (August 1970), TID-25630.

19. J. M. Holmes, Consideration of Nuclear Power Expansion for Puerto Rico, Including Surplus Capacity Penalties, ORNL-TM-3142 (December 1970).

20. K. O. Johnsson, Indexed Bibliography of Nuclear Desalination Literature – 5, ORNL-NDIC-7 (September 1970).

21. K. O. Johnsson, Title-Author-Company Index to Reports Published by the U.S. Department of the Interior, Office of Saline Water, ORNL-NDIC-8 (November 1970).

22. K. O. Johnsson, "Operation of the Nuclear Desalination Information Center at the Oak Ridge National Laboratory," to be published in the proceedings of the International Conference on Information Science, Israel 1971.

23. J. E. Jones, "Comparative Study of Water-Only Desalting Plants," presented at meeting of IAEA Study Group on Agro-Industrial Complexes, March 29-April 2, 1971, Vienna, Austria.

24. J. E. Jones and T. D. Anderson, "A Proposed Dual-Purpose Nuclear Desalting Plant Using Single-Effect Distillation," presented at meeting of IAEA Study Group on Agro-Industrial Complexes, March 29-April 2, 1971, Vienna, Austria.

25. T. W. Kerlin, C. F. Moore, J. C. Robinson, M. M. Anderson, M. R. Buckner, C. G. Vytoyannis, and R. W. Guy, Nuclear Desalination Plant Dynamics: Modeling and Analysis of a Multi-Stage Flash Evaporator, Progress Report No. 4, June 1, 1969 - June 1, 1970, ORNL-3198 (November 1970). Also NEUT 2806-6.

26. J. W. Michel, Status and Recent Developments in Agro-Industrial Complex Studies, ORNL-TM-3019 (June 1970).

27. J. W. Michel, "Review of the Puerto Rico Energy Center Study," presented at meeting of IAEA Study Group on Agro-Industrial Complexes, March 29-April 2, 1971, Vienna, Austria.

28. J. W. Michel, "Alternatives for Storage of Desalted Water," presented at meeting of IAEA Panel on Storage and Transport of Water from Nuclear Desalting Plants, April 5-8, 1971, Vienna, Austria.

29. J. W. Michel, "Review of Recent Agro-Industrial Complex Studies at ORNL," presented at meeting of IAEA Study Group on Agro-Industrial Complexes, March 29-April 2, 1971, Vienna, Austria.

30. E. L. Mohundro, Modeling of Liquid Flows in a Multistage Flash Evaporator Tray, thesis, University of Tennessee (1970), NEUT 2806-5.

31. T. Tamura, M. J. Young, and M. M. Yarosh, Data Obtained on Several Possible Locales for the Agro-Industrial Complex, ORNL-4293 (February 1971).

32. A. M. Weinberg and R. P. Hammond, "Limits to the Use of Energy," Amer. Sci. 58(4), 412-18 (July-August 1970).

33. F. G. Welfare, The Optimum Turbine Exhaust Pressure for Use of a Single-Effect, Vertical-Tube Still Desalting Plant with a Steam Turbine-Generator, ORNL-TM-3291 (February 1971).

34. R. P. Wichner, MSF Evaporator Flow Analysis: The Submerged Jet Model and the Effect of Baffles on Flow Stability, ORNL-TM-3120 (October 1970).

35. Nuclear Desalination Program Annual Progress Report on Activities Sponsored by the Atomic Energy Commission for Period Ending October 31, 1970, ORNL-4668 (April 1971).

OSW-Sponsored Work

1. L. G. Alexander and H. W. Hoffman, Improved Heat-Transfer Systems for Evaporators — Performance Characteristics of Advanced Evaporator Tubes for Long-Tube Vertical Evaporators, ORNL-TM-2951 (January 1971).

2. L. G. Alexander and H. W. Hoffman, Data Tabulation — An Addendum to Performance Characteristics of Advanced Evaporator Tubes for Long-Tube Vertical Evaporators, ORNL-TM-3272 (March 1971).

3. D. M. Eissenberg, "Tests of an Enhanced Horizontal Tube Condenser under Conditions of Horizontal Steam Crossflow," presented at the 4th International Heat Transfer Conference, Paris, France, August 31-September 5, 1970.

4. D. M. Eissenberg, Analysis of Heat Transfer Fouling in Seawater Evaporators, ORNL-TM-3173 (July 1970).

5. D. M. Eissenberg and J. W. Hill, Tests of the VTE Pilot Plant Deaerator, ORNL-TM-2979 (May 1970).

6. D. M. Eissenberg, C. C. Littlefield, R. P. Hammond, S. A. Reed, and I. Spiewak, "Control of Alkaline Scale Formation in Seawater Distillation Equipment Using Carbon Dioxide Pressurization," presented at the 3rd International Symposium on Fresh Water from the Sea, Dubrovnik, Yugoslavia, September 1970.

7. D. M. Eissenberg and H. M. Noritake, Computer Model and Correlations for Prediction of Horizontal-Tube Condenser Performance in Seawater Distillation Plants, ORNL-TM-2972 (October 1970).

8. D. M. Eissenberg and I. Spiewak, "Vacuum Deaerators for Distillation Plants," presented at OSW Symposium on Treatment of Feed for Distillation Processes, Washington, D.C., April 6-7, 1971.

9. R. O. Friedrich and J. A. Hafford, ØRVE: A Fortran Code for the Calculation of a Desalination Plant Combining Vertical Evaporators with MSF Feed Heating, ORNL-TM-3149 (September 1970).

10. R. O. Friedrich and I. R. Parsley, ØVEC: A Fortran Code for the Calculation of a Desalination Plant Combining Vertical Evaporators with MSF Feed Heating, ORNL-TM-3219 (March 1971).

11. R. A. Greene, S. J. Senatore, and R. A. Ebel, Budgetary Capital Cost Estimates of 1- to 10-MGD Multistage Flash Distillation Plants for Desalting Seawater, ORNL-TM-3083 (August 1970).

12. P. H. Harley and D. M. Eissenberg, "Operation of the CO_2 Scale Suppression Pilot Plant," presented at OSW Symposium on Treatment of Feed for Distillation Processes, Washington, D.C., April 6-7, 1971.

13. J. W. Hill and E. C. Hise, VTE Pilot Plant Annual Report for the Period Ending July 1, 1968, ORNL-TM-3106 (December 1970).

14. E. C. Hise and R. Van Winkle, Horizontal Layout of 8-MGD VC-VTE-MSF Distillation Plant Based on the Design of Struthers Energy Systems, ORNL-TM-3174 (October 1970).

15. K. O. Johnsson, Abstracts of Literature on the Distillation of Seawater and on the Use of Nuclear Energy for Desalting, Office of Saline Water Research and Development Progress Report No. 589, U.S. Government Printing Office, Washington, D.C. (September 1970).

16. K. O. Johnsson, Abstracting and Indexing Guide for the Storage and Retrieval of Literature on the Desalination of Water by Distillation, U.S. Department of the Interior, Office of Saline Water, Distillation Division, Washington, D.C. (February 1971).

17. K. O. Johnsson, Title-Author-Company Index to Reports Published by the U.S. Department of the Interior, Office of Saline Water through July 1970, U.S. Department of the Interior, Office of Saline Water, Distillation Division, Washington, D.C. (1971).

18. S. A. Reed, J. W. Gregory, R. J. Kedl, F. J. Moran, J. E. Savolainen, J. A. Smith, and S. A. Thompson, Large Seawater Desalting Plants and Plant Complexes — A Preliminary Study, ORNL-TM-3167 (May 1970).

19. J. A. Smith and S. J. Senatore, Comparison of Heat and Drive Sources for Vapor Compression Plants for Seawater Desalting, ORNL-TM-3255 (February 1971).

20. I. Spiewak, Survey of Desalting Processes for Use in Waste Water Treatment, ORNL-TM-3155 (September 1970).

21. I. Spiewak, "Design of Desalting Plants for Conjunctive Operation," presented at the American Water Resources Association Conference, Las Vegas, Nevada, October 28, 1970.

22. I. Spiewak, J. K. Franzreb, and J. C. Moyers, "Flexibility in Production of Power and Water from Nuclear Desalting Plants," presented at meeting of IAEA Panel on the Storage and Transport of Water from Nuclear Desalting Plants, April 5-8, 1971, Vienna, Austria.

23. I. Spiewak, H. R. Payne, and W. E. Thompson, Report on the Status of Desalting, ORNL-TM-3227 (October 1970).

24. D. G. Thomas and L. G. Alexander, "Improved High-Performance Fluted Tube for Thin-Film Evaporation and Condensation," Desalination, 8, 13 (1970).

25. R. Van Winkle, Air Flow Tests in VTE-X Tube Bundle Model, ORNL-TM-3240 (September 1970).

26. R. Van Winkle, "Preliminary Measurements of the Performance of a Large Horizontal Condenser Bundle in the MSF Module," Proceedings of MSF Module Information Meeting, San Diego, California, October 7, 1970.

WATER RESEARCH PROGRAM

J. S. Johnson

Cross-Flow Filtration in Treatment of Municipal Sewage*

H. A. Mahlman
Chemistry Division

Development of the cross-flow filtration technique for treatment of sewage has continued, both in the laboratory and in our mobile test unit at the Oak Ridge East Sewage Plant. The effluent from primary settling is treated with a clarifying agent (hydrolyzable salt) and/or powdered carbon, and subsequently filtered under pressures typically from 5 to 50 psig. A flow is maintained parallel to the filtering surface.

The filtrate, under the more favorable conditions identified, has approximately the turbidity of tap water, 85–95% of organic carbon removed, and over 99% of phosphate removed. The product is comparable to that obtained from most projected combinations of secondary and tertiary treatment. Fluxes vary with conditions, but usually range from 50 to several hundred gpd/ft^2.

Among variables investigated are additive concentrations, pressure, cross-flow velocity, types of filtering surfaces, and regeneration techniques. The mobile unit has greatly increased the range of our studies.

The technical feasibility of this approach to sewage treatment appears established, and much information has been developed toward an economic analysis; costs cannot yet be definitively specified, however.

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*Research sponsored by the Water Quality Office, Environmental Protection Agency, under contract with Union Carbide Corporation for the U.S. Atomic Energy Commission.

Theoretical Studies Related to Ionic Transport Through Ion-Exchange Membranes*

Lawrence Dresner
Chemistry Division

Central to any theory of hyperfiltration by ion-exchange membranes is an understanding of ionic transport in such membranes. Many authors have described ionic transport with the so-called Nerst-Planck equations (ENPE). Using these equations, Hoffer and Kedem studied the rejection of a single binary electrolyte by an ion-exchange membrane. Hoffer and Kedem's study produced some startling results, verified experimentally: under not uncommon circumstances, the solute rejection could be negative, i.e., the filtrate could be more concentrated than the feed. Owing to the unexpected nature of this consequence of the ENPE, we began a study of further consequences for multi-ion feed solutions.

Generally speaking, integration of the ENPE for multi-ion solutions is difficult. No solutions in terms of elementary functions are known, and to obtain numerical solutions is time-consuming and laborious. Some methods of obtaining approximate solutions are known, but they are not generally applicable, failing for situations of interest in hyperfiltration. We have developed a new method of solving the ENPE approximately based on the assumption of good coion exclusion. Using this method, we have discovered another startling consequence of the ENPE: in the range of asymptotic rejections (high water fluxes), only one counterion accompanies the coions through the membrane, the one with the largest ratio of convective coupling coefficient to practical mobility. If this counterion is present in low enough concentration in the feed, it may be negatively rejected. Numerical solutions of the ENPE have verified this conclusion of the approximate theory.

Experiments to test this conclusion are hampered by lack of knowledge of the diffusion and convective coupling coefficients of ions in membranes,

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*Research sponsored by the Office of Saline Water and the National Science Foundation under Union Carbide Corporation's contract with the U.S. Atomic Energy Commission.

though we feel it reasonable to assume that the proton is more mobile than any other cation. Bevan observed negative rejection of trace Na^{+} from acid solution by a cation-exchange membrane, but failed to observe negative rejection of trace Mg^{++}. A paper on the theoretical aspects of this work has been written and submitted for publication.

In order to be able to make a better comparison of theory, we must measure the diffusion and convective coupling coefficients of ions in ion-exchange membranes. Nelson, Phillips, and Shor are using the radiometric porous-frit method to measure diffusion coefficients. A membrane is equilibrated with a solution containing a radioactive tracer. Then a solution containing no tracer but otherwise the same is circulated past the membrane, eluting the tracer. The tracer diffusion coefficient is related to the half-time of elution of the radioactivity from the membrane. This relation is a simple one if the tracer ions being eluted are swept away as soon as they reach the membrane surface, i.e., if the buildup of a concentration boundary layer is ignored. Corrections to the simple theory have been calculated for boundary layer buildup for several laminar flows (Poiseuille, Blasius) and for fully developed turbulent pipe flow; both developing and fully developed concentration boundary layers have been considered. Experiments have been carried out to test these corrections to the elementary theory. A paper describing the theory has been published as ORNL-4667.

Using the thermodynamics of irreversible processes, we have analyzed electro-osmotic water transport through ion-exchange membranes under conditions of good coion exclusion. We find that the electro-osmotic coefficient is related in a simple way to the ratio of convective coupling coefficient to practical mobility of the counterion. Electro-osmotic measurements may allow us to identify the penetrating counterion in a multi-ion solution, and together with an independent measurement of the diffusion coefficient provide a value of the convective coupling coefficient. Such measurements are being made by R. Bevan.

All of the above work has been concerned with ionic transport through homogeneous ion-exchange membranes. This is a kind of hyperfiltration process called piezodialysis in which a heterogeneous (charge-mosaic) membrane is used. In this process the filtrate is enriched rather than

depleted in salt. A schematic theory of this process has been formulated with detailed consideration of the effects of geometric heterogeneity. A paper describing this work has been written and submitted for publication.

Recent Developments in Dynamic Membranes and Their Practical Applications*

R. E. Minturn
Chemistry Division

Since the first preparation of dynamic membranes six years ago, we have been engaged in delineating factors whose manipulation would result in high-flux membrane systems practical for desalting brackish waters. At the same time, we have investigated other water treatment problems which seemed more amenable than desalination to the dynamic approach at its early state of development. We reported last year what appeared to be a substantial step toward both objectives – the preparation of a two-layer membrane, both layers dynamically formed, of hydrous oxides and polyacrylic acid.

Work during the past year has increased our optimism concerning this development. Our major efforts have been directed toward finding the conditions of formation and operation which give the best flux and rejection. We have also looked for porous supports more promising for incorporation in practical modules than the experimental test sections we have used, typically 0.45 μ Acropor wrapped around porous stainless steel tubes.

With these experimental test sections, we are able in short-term tests to routinely form membranes of 90 to 95% rejection with 0.05 M NaCl feed and fluxes usually over 100 and up to 160 gpd/ft^2. With ceramic and carbon tubes, which are possible candidates for practical modules, performance is usually not as good. However, we have, for example, prepared membranes of 90% rejection on 0.27 μ Selas ceramic tubes with fluxes of 112 gfd. On carbon tubes, at 60°C, 94 to 97% rejection at fluxes near 100 gfd has been attained.

We reported last year good rejections by dual-layer membranes on Acropor with feeds of compositions typical of natural brackish waters.

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*Research supported by the Office of Saline Water and the National Science Foundation under Union Carbide Corporation's contract with the U.S. Atomic Energy Commission.

We have now obtained similar performance with more practical supports. For example, with carbon tubes, 900 psig, 8 ft/sec circulation velocity at 60°C, we observed with synthetic Coalinga water 96% rejection of total anion and 99% rejection of Ca(II) + Mg(II) at 56 gfd.

In tests for other applications, hydrous Zr(IV) oxide membranes have been tried with Kraft pulp-mill wastes, and hydrous Zr(IV) oxide-PAA membranes with textile dyeing wastes. Particularly with the latter, results were promising.

Hydrodynamic Effects on Fouling*

D. G. Thomas
Reactor Division

During the past several years we have made fouling studies with cellulose acetate hyperfiltration membranes using as feed both Tennessee River water and effluent from the primary stage of the Oak Ridge East Sewer Plant. Initial membrane fluxes covered a range from 5 to 150 gal/ft^2·day, and axial velocities were in the range 1 to 30 ft/sec. With this range of operating conditions, we have observed flux declines which varied from mild to catastrophic; flux declines which followed either a power law or exponential function of time and some cases in which there was little flux decline but marked decreases in rejection.

Although membrane fouling is quite complicated, we are now able to discuss some trends which appear to be relatively reproducible within broad limits. In general we find that operation at higher fluxes requires higher axial velocities to prevent catastrophic flux decline.

*Research sponsored by the Office of Saline Water, the National Science Foundation, and the Water Quality Office, Environmental Protection Agency, under Union Carbide Corporation's contract with the U.S. Atomic Energy Commission.

WATER RESEARCH PROGRAM

Publications

Water Research Program

Publications

(Published since 1970 Information Meeting)

1. L. B. Yeatts and W. L. Marshall, "Apparent Invariance of Activity Coefficients of Calcium Sulfate at Constant Ionic Strength and Temperature in the System $CaSO_4$-Na_2SO_4-$NaNO_3$-H_2O to the Critical Temperature of Water; Association Equilibria," J. Phys. Chem., 73, 81 (1969).

2. "Application of Hyperfiltration to Treatment of Municipal Sewage Effluents," Final Report for the Federal Water Quality Administration by the ORNL Water Research Program, ORNL-CF-70-1-61; identical with Water Pollution Control Research Series ORD 17030EOH01/70, Federal Water Quality Administration, U.S. Department of the Interior.

3. "Water Research Program Biennial Progress Report for the Period March 15, 1964 to March 15, 1966 - Properties of Solutions," compiled by R. J. Raridon, ORNL-CF-70-6-30.

4. L. Dresner, "Theory of the Porous-Frit Method of Measuring Self-Diffusion Constants," ORNL-4667, March 1971.

5. A. E. Marcinkowsky and H. O. Phillips, "Diffusion Studies. II. Tracer Diffusion Coefficients of Cu(II) in HCl and $HClO_4$ at 25°C," J. Chem. Soc., London, (A), (No. 1), 101 (1971).

6. R. E. Meyer, M. C. Banta, P. M. Lantz, and F. A. Posey, "Chronopotentiometry and Voltammetry of the Ag-AgCl Electrode in Flowing Streams. I. Experimental," J. Electroanal. Chem., 30, 345 (1971).

7. F. A. Posey and R. E. Meyer, "Chronopotentiometry and Voltammetry of the Ag-AgCl Electrode in Flowing Streams. II. Theoretical," J. Electroanal. Chem., 30, 359 (1971).

8. R. J. Raridon and K. A. Kraus, "Properties of Organic-Water Mixtures. XII. Activity Coefficients of Sodium Chloride at Saturation in Aqueous Solutions of Some Oxy-Oxa Compounds at 25°," J. Chem. Eng. Data, 16, 241 (1971).

9. D. G. Thomas, W. L. Griffith, and R. M. Keller, "The Role of Turbulence Promoters in Hyperfiltration Plant Optimization," Desalination, 9, 33 (1971).

Papers Submitted for Publication:

1. L. Dresner, "Geometric Effects in Piezodialysis through Charge-Mosaic Membranes," submitted to Desalination.

2. L. Dresner, "Some Remarks on the Integration of the Extended Nernst-Planck Equations in the Hyperfiltration of Multicomponent Solutions," submitted to Desalination.

3. J. A. Dahlheimer, K. A. Kraus, and J. S. Johnson, Jr., "Hyperfiltration XIX. Dynamically Formed Membranes in Treatment of Municipal Sewage Effluents," submitted to Environ. Sci. Technol.

4. H. O. Philipps, A. E. Marcinkowsky, S. B. Sachs, and K. A. Kraus, "Properties of Organic-Water Mixtures. XI. Self-Diffusion Coefficients of Na^+ in Polyethylene Glycol-Water Mixtures at 25°," J. Phys. Chem. (in press).

5. J. D. Sheppard and D. G. Thomas, "Increased Concentration Polarization Caused by Permeable Films on the Feed Side of Hyperfiltration Membranes," A.I.Ch.E.J. (in press).

6. D. G. Thomas, "Dry Limestone Injection: Factors Affecting the Reaction of SO_2 with Limestone Particles," submitted to Environ. Sci. and Technol.

7. D. G. Thomas, "Estimation of Concentration Polarization for Ion-Exclusion Hyperfiltration Membranes with Turbulent Flow," submitted to Ind. Eng. Chem.

8. D. G. Thomas and W. R. Mixon, "Effect of Axial Velocity and Initial Flux on Flux Decline of Cellulose Acetate Membranes in Hyperfiltration of Primary Sewage Effluents," submitted to Ind. Eng. Chem.

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