PRACTICE OF DESALINATION

Edited by Dr. Robert Bakish

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NOYES DATA CORPORATION
Park Ridge, New Jersey London, England
1973

Library of Congress Catalog Card Number: 72-95823
ISBN: 0-8155-0478-0
Printed in the United States

Published in the United States of America by
Noyes Data Corporation
Noyes Building, Park Ridge, New Jersey 07656

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FOREWORD

This book is based upon a series of papers presented by various authorities at St. Croix, U.S. Virgin Islands, during December 1971.

This is the first publication under the auspices of the St. Croix Corrosion Installation West Indies Laboratory, College of Science and Engineering, Fairleigh Dickinson University.

While the course was given in December 1971, the book as here constituted represents the present state of the art of the United States desalination industry in both its underlying principles and their applications. The greater portion of this material should remain valid for some time to come.

CONTENTS

INTRODUCTION

This volume is the record of a series of lectures, the first attempt by the St. Croix Corrosion Installation, West Indies Laboratory of the College of Science and Engineering, Fairleigh Dickinson University, to become involved, and hopefully to contribute to the solving of some of the problems of the Caribbean region.

Though perhaps the fact is neither widely known nor appreciated, the availability of potable water is tied intimately to the growth of the region. Inasmuch as ground water facts for the region do not offer much hope for improvement in the potable water situation, it is through desalination and through efficient and economical desalination alone that the potable water supply will increase and make possible the growth of the region. While the "fuel" for growth in the Caribbean is potable water, and while it must be provided if the region is to prosper, those involved must oversee that it is provided without endangering the region's ecology.

The objective of this presentation was to review the progress of desalination technology and to see which applications would be suitable for use in solving the desalination problems of the Caribbean. It is indeed regrettable that neither the wide range of questions asked during the course, nor the many answers provided could be made part of this record. The same is unfortunately true for the substance of the round table discussions. This information was particularly germane to the region.

The content of this volume presents the substance of the presentations given, but not quite in the order that they were in the series. It begins with a brief summary of desalination processes and considers the important aspects of operational desalination processes and some of the more promising approaches in the development stage in some detail. Presentations dealing with materials of construction and their behavior in desalination installations follow, and those dealing with the economics of desalination operations at different output levels and personnel training complete the presentations.

This was the first involvement of the undersigned in the field of desalination and as such my comments could well be disputed by veterans in the field. To me, however, the desalination business in the Caribbean has suffered most substantially from the lack of contacts and opportunity for exchange of experiences, problems and solutions among operators. I feel also that lack of appreciation of the fact that a desalination plant is basically a chemical operation and to be treated with corresponding care and precision has not helped the problem.

Another basic problem preventing carefree operations has been the lack of rugged and continuous duty monitoring instrumentation. It is certain that effort on the part of those in instrumentation to develop such devices will bring handsome returns, not only to those in instrumentation but to the desalination field as a whole.

Last, but not least, the problem indicates a basic failure in providing adequate education and training of the operating personnel on the substance of the operations. True, while many training programs will be handicapped by lack of adequate background in its trainees, at this juncture of time we should be in a position to remedy this situation.

It is the hope that the St. Croix Installation will continue and improve. The courses to follow and the personal relations developed during these courses, I am sure will begin to bear fruit in better communications, problem solving and more efficient operations. We trust that we will continue to be favored with the cooperation of those in desalination and related industries, as ultimately we all stand to gain from progress in desalination.

The Caribbean region is one of many nations and various ethnic origins. It is my belief that through cooperation in desalination work aimed at providing one of the essential components for growth of the region's potable water, a wonderful opportunity exists for establishing sound relations which should lead to more intimate cooperation in other technological problems facing the region.

While the undersigned initiated the activities under the auspices of the St. Croix Corrosion Installation which led to this series of lectures, the series and this volume would never have become a reality were it not for the generous contributions of time and effort by the participants. Special thanks are due to the Office of Saline Water and to Mr. G.W. O'Meara, its Director, who generously provided information and suggestions during the organizational period, as well as three most competent and eloquent speakers for the course. Thanks are due to the Aluminum Association and the Copper Development Association, the metals producers and equipment manufacturers who presented talks and contributed sections of this volume. The undersigned is particularly indebted to

Mr. Richard Ahlgren of Aqua-Chem, Inc. and Mr. Bruce Watson of Grace Chemical Company for their willingness to prepare presentations on extremely short notice to replace speakers originally scheduled. Thanks are due to Mrs. Phyllis Isenberg for her efforts both during the organization of the course and in the preparation of the manuscript.

Last, but not least, thanks are due to the staff of the West Indies Laboratory, and in particular to Mr. Lowell Bingham, its Resident Manager, whose resourcefulness and efforts above and beyond the call of duty made it possible for him to provide all that was asked of him.

Dr. R. Bakish

DESALINATION PROCESSES – A BIRD'S EYE VIEW

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ABSTRACT

Desalination involves a variety of principles and processes derived from these principles. The paper to follow takes a bird's eye view of all of these and presents highlights of both principles and processes.

INTRODUCTION

Seawater can be desalinated by a steadily growing number of approaches. Some of these have been known for centuries, others have been introduced in recent years, and yet others are to be developed. In the process of developing a viable desalination technology, progress has been no different than in the development of any modern technology. Under the steady pressure of need, different processes are evaluated and gradually pass from the laboratory through pilot plant stages to commercial size operations. As in the development of other technologies, here also expensive mistakes and economic disappointments go hand in hand with progress.

Process difficulties which delay laboratory progress are quite different from those which ultimately determine the profitability or, for that matter, even the survival of a commercial process in the stringently competitive economic climate prevailing today. Success of a process rests on its economic viability under prevailing conditions. To determine it, we must consider capital investments, cost of processing, yield rates, and costs of operations including maintenance of the installation. While these will present the real costs of an operation, they alone do not determine the viability of the operation as depending on circumstances; a \$1.75/1,000 gallon cost might be entirely too expensive in one case, while on the other hand, a cost of \$7.00/1,000 gallons though appearing exorbitant, might be considered acceptable in another case. The whole matter of desalination economics will be considered later in this volume in considerable detail.

Let us now look at the four basic desalination approaches. The first and oldest of these, distillation, has given birth to five basic modifications which are competing for commercial success. These are the vertical tube, the multistage flash, the multieffect multistage, the vapor compression and the solar humidification.

The second approach utilizes membranes and has three processes competing for commercial success. They are electrodialysis, transport depletion and reverse osmosis.

The third approach based on crystallization has also three processes based on it: the vacuum freezing vapor compressor, the secondary refrigerant freeze, and the hydrate formation.

The fourth and last desalination approach, the chemical one, has only one process, i.e., the ion exchange process competing for a place in desalination technology.

DISTILLATION

This is undoubtedly the oldest principle known for the separation of fresh water from the seawater. The process simply requires the boiling of the seawater and condensing the vapor to give the product, potable water. To accomplish this one must provide thermal energy to generate the steam in order to be able subsequently to condense it. This boiling point is a function of pressure: at sea level it is 212°F. and becomes lower at pressures below one atmosphere.

If one is to have an efficient distillation process, one must use at least part of the heat recovered on condensation of the steam for the production of more steam. In addition, one must keep heat transfer surfaces free from scale. The presence of calcium sulfate, whose solubility decreases with increase of temperature, among other salts in the seawater is the main reason for scale formation.

Let us now look very quickly at the five distillation based processes. The first, the vertical tube distillation, is schematically illustrated in Figure 1. After appropriate treatment, the sea water is conducted through vertical metal tube bundles surrounded by steam to effect a heat exchange. As a consequence, the steam is condensed while converting part of the seawater to steam. In order to improve the efficiency, this is repeated in several chambers held at progressively lower pressures so that boiling can take place at correspondingly reduced temperatures, in this manner making possible the recovery of virtually all heat provided in the first chamber. The first chamber steam is provided by a steam generator plant.

The second distillation process, seen schematically in Figure 2, as in the preceding utilizes the fact that water boils at lower temperatures at lower pressures. The heated seawater is brought into a chamber of pressure sufficiently low to cause "flash" evaporation. This evaporation leads to lowering of the temperature in the remaining brine. Just as in the first distillation process, several chambers are used here to improve the efficiency of the heat exchanger process. This process has also been designated as single effect multistage or SEMS. An effect is a complete distillation step.

The third of the distillation processes is the so-called MEMS or multieffect multistage process. It overcomes the 4°F. per stage limitation of the SEMS and makes possible the addition of more stages for each temperature level. Here there is also the opportunity of using the highly concentrated brine for by-product recovery. Schematically it is shown in Figure 3. The utilization of a number of effects, each operating at different temperatures, also greatly improves scale control.

The fourth process, the vapor compression distillation, is illustrated in Figure 4 and is based on the fact that as vapor is compressed, its temperature and pressure increase while its volume decreases. The vapor formed in the special chamber of the first effect supplies heat to the seawater being pumped through the bundles of the second effect. As the vapor loses heat to the brine, it condenses, falling to the bottom as the product water is taken away.

This schematic of the two effect unit shows the essence of this approach with the primary difference from other distillation processes being the manner by which heat is introduced into the system, i.e., here mechanical work is converted into heat of compression. The bulk of the energy here is supplied by the motor which drives the compressor.

The last of the distillation-based approaches is the so-called solar humidification process. This process is based on the fact that water evaporates from free surfaces at temperatures considerably below its boiling point. The evaporation rate here is dependent on the water temperature and the relative humidity of the space above the water. This process is usually carried out in a solar still, and is schematically illustrated in Figure 5.

While the solar distillation approach seemingly offers considerable economic advantage because of its essentially free energy source, it actually is far from economical as there are severe limitations in output. One pint of water is the maximum output per square foot of sun energy absorbing surface. Though it is an interesting concept, it certainly is no contender for large scale desalination operations.

FIGURE 1: SCHEMATIC OF A VERTICAL TUBE DISTILLATION PROCESS

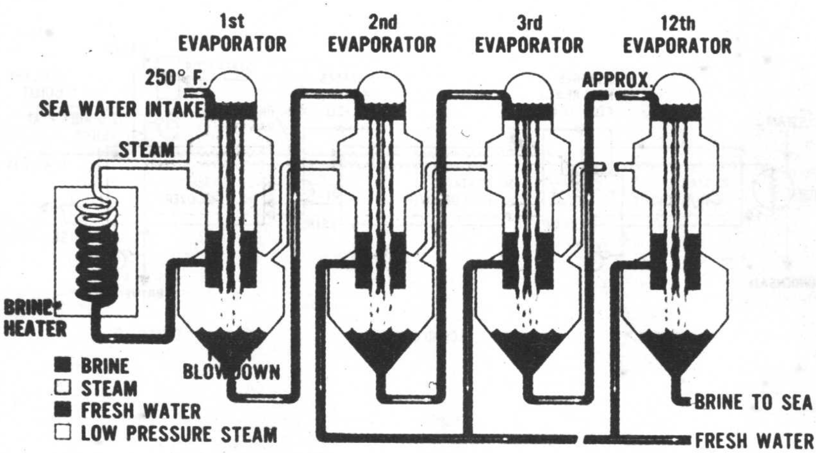


FIGURE 2: SCHEMATIC OF MULTISTAGE FLASH DISTILLATION PROCESS

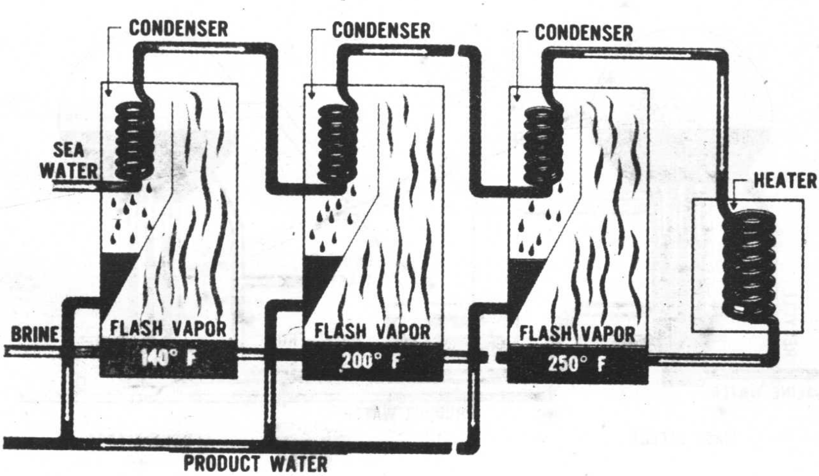


FIGURE 3: SCHEMATIC OF MULTIEFFECT MULTISTAGE DISTILLATION PROCESS

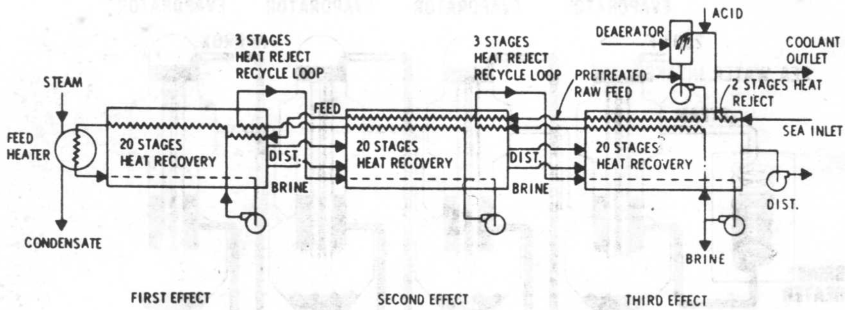


FIGURE 4: SCHEMATIC OF VAPOR COMPRESSION DISTILLATION PROCESS

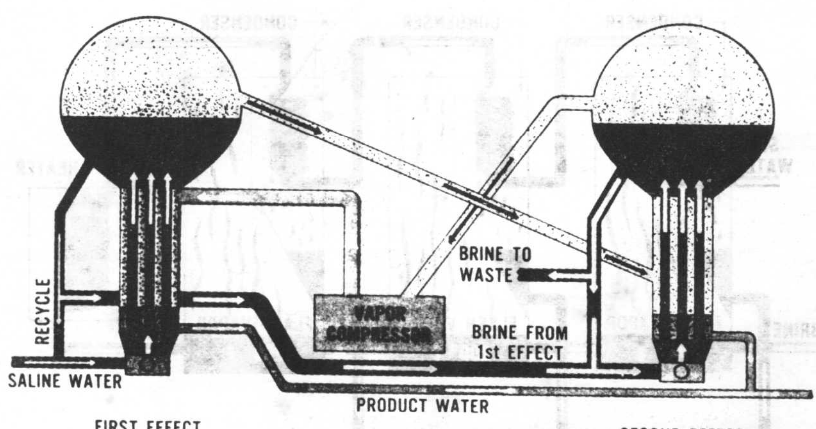
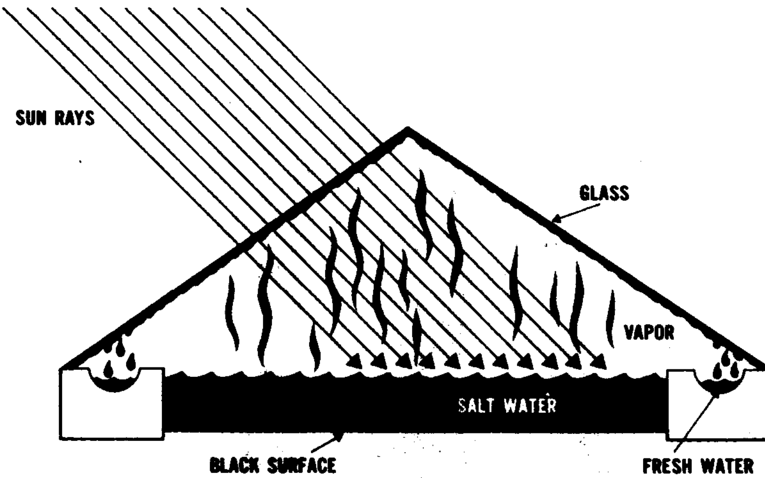


FIGURE 5: SCHEMATIC OF A SINGLE SOLAR STILL



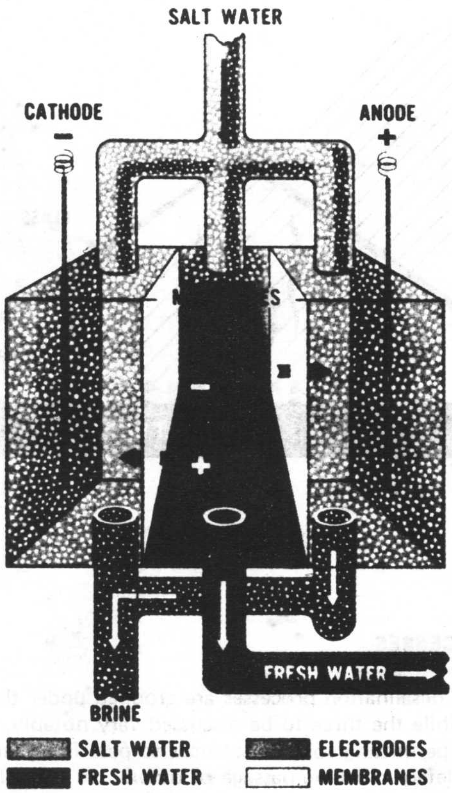
MEMBRANE PROCESSES

The next family of desalination processes are grouped under the title of membrane processes. While the three to be discussed vary notably, they all utilize porous membranes permitting some substances to pass freely under given conditions while completely blocking passage of others. In two of the three, we are concerned with ion migration under applied current and are essentially operating under the laws of electrochemistry.

The process in this group which is most advanced in principle is the so-called electrodialysis process. It utilizes an electrolytic cell with two different ion elective membranes (see Figure 6), one each permitting passage of anions and cations. The imposed current drives the ions through the membranes leaving fresh water between them. In addition to the membrane costs, the cost of such processing is directly related to the salt content of the water, with current costs at present making it uneconomical for salt water conversion.

Efforts in progress to operate such cells at elevated temperature where the electrical resistance of the electrolyte (seawater) is reduced show promise for the future. Work also continues on membrane development, which also can have important effects on the economics.

FIGURE 6: SCHEMATIC OF AN ELECTRODIALYSIS CELL



The second of the membrane processes, the so-called transport depletion process, is based on the fact that there is a difference in the ion transport numbers in bulk solution and within an ion selective membrane. While in a simple electrolytic cell the sodium ion carries 40% of the current with the balance being carried by the chloride, by contrast, in a cation permeable membrane, the sodium will carry just about all of the current.

The principle of this process is schematically shown in Figure 7. Here the seawater enters the top of the cell and passes into the compartment separated by a nonselective membrane each bounded by a cation permeable membrane. Current drives the cations through the cation selective membrane while the anions pass through the nonselective membrane, depleting one of the compartments of