Desalination and the Salt Industry

Donat B. Brice
State of California Resources Agency
Department of Water Resources
Sacramento, California

ABSTRACT

Desalination of sea and brackish water to produce water suitable for municipal and industrial use has become an established practice in many parts of the world. In addition to the production of fresh water, an effluent is discharged from the plants which contains most of the salt introduced with the saline water feed. This discharge usually contains less than eight percent salt. Currently, the largest sea water desalters are capable of a daily production of only a few million gallons of desalted water. A comparable quantity of effluent brine is discharged. In the future it is expected that desalters with much larger capacity will be constructed. Those plants will also discharge like amounts of warm brine. The disposal of the brine offers certain problems, the nature of which depends on the plant location. For inland plants the disposal may be more difficult. There would appear to be an advantage to both water producers and salt manufacturers if arrangements could be made to use the brine, especially in solar salt works, in the manufacturing of salt. Such an arrangement is being studied in San Diego.

INTRODUCTION

Desalination of sea and brackish water to produce water suitable for municipal and industrial use has now become an established practice in many parts of the world. By January, 1968, there were more than 600 desalination plants, each with a capacity of at least 25,000 gallons per day. The aggregate capacity of the plants was nearly 225 million gallons of desalted water daily. About one-third of these plants produced a portion of their water for municipal use. These plants, however, represent about three-fourths of the total desalted water output.

As currently practiced, for water production for each one million gallons of desalted sea water obtained from a plant, about an equal volume of brine is discharged. The salt concentration from the sea water desalters usually does not exceed eight percent total salt, of which sodium chloride content represents about three-fourths of the total. Unlike sea water, brackish water varies widely in quality and chemical content. Consequently, the brine discharge from brackish water plants varies in chemical content and quality. However, for most of the commercial application, the brine discharge from brackish water plants usually contains not more than one percent salt.

On a world-wide basis, a considerable amount of salt is produced from sea water by solar evaporation. On the other hand, the production of salt from sea water by means of apparatus is extremely limited. Sea water desalting-type apparatus is employed in the production of salt in only a very few instances.

It is expected that as the technology and economics of desalting is improved, more plants and plants with greater capacities will be built to obtain water from sea water and brackish waters. These plants will all need to discharge a brine in which the quantity of salt is substantially that in the feed. For the distillation processes, since the product is essentially salt-free, almost all of the salt is in the brine blowdown. For the membrane processes that may be used for brackish water desalting, a substantial proportion of the salt will be discharged in the brine blowdown, but in the membrane processes some of the salt is also in the product. The disposal of the brine will offer certain problems, ending on the location. For inland brackish ;, it is expected the problem may be more diffi- than for plants located near the ocean. In any ıt, it can be anticipated that there would be an antage to both the water producer and the salt ufacturer if, in the future, the brine could e as a feed to the salt manufacturing process.

ιt the present time, for sea water desalting a tistage flash evaporator process is commercially blished, while for brackish water the electro- ysis process is the predominant process. An- er membrane process, the reverse osmosis cess, has recently reached the commercial stage.

DESALTING PLANT LOCATIONS

lany nations have active programs in desalina- ı. The largest installed capacity is in the Middle t. A list (Sachs, 1968, p. 21) of plant capacity region or country is shown in Table 1. During 57, construction was started on 45 plants in 20 ntries, with an aggregate capacity of over 58 lion gallons per day. Increase in capacity since y 1952 and projections to 1975 are shown on ure 1. Municipal plants and federal Office of

Table 1.
Desalting Plant Capacities
Planned or Under Construction.

(Producing 25,000 gallons per day or more)
As of December 31, 1967

Region or Country	No. of Plants	Capacity Million Gallons/Day
ted States	288	39.6
ited States Territories	15	7.5
th America except USA and its erritories	11	8.4
ibbean	24	16.9
ıth America	20	3.7
ope (Continental)	77	26.3
gland and Ireland	62	14.1
stralia	7	1.9
ia	18	2.1
dle East	63	50.1
ica	35	10.8
ion of Soviet Socialist epublic	7	40.9
TOTAL	627	222.3

ine Water demonstration plants located in the ited States are shown on Figure 2. The vast ma- ity of the 288 desalting plants located in the ited States are used by powerplants, industries, d the military.

DESALTING PROCESS

For purpose of this discussion, a brief descrip- n of the multistage flash process and the electro-dialysis process will serve to describe the general technology employed in sea and brackish water de- salting.

Multistage flash distillation. A typical process flow diagram of a multistage flash distillation plant (MSF) is shown on Figure 3. Sea water, in passage through the tubes of the heat rejection section, is partially heated. The coolant portion of this stream is then returned to the ocean through an outfall line.

Dissolved carbon dioxide and air must be re- moved from the makeup sea water to very low levels to mitigate scaling, to retard corrosion, and to minimize the quantity of noncondensables which would impair heat transfer rate. To facilitate carbon dioxide (CO_2) removal, sulfuric acid is in- jected into the sea water makeup stream as shown on Figure 3. The resulting pH reduction converts bicarbonate and carbonate to CO_2 which is de- gassed in an atmospheric degassing tank and then steam stripped from the sea water feed.

From the degassing tank, the sea water makeup stream flows to a vacuum deaerator. This vessel is operated at the same absolute pressure as the

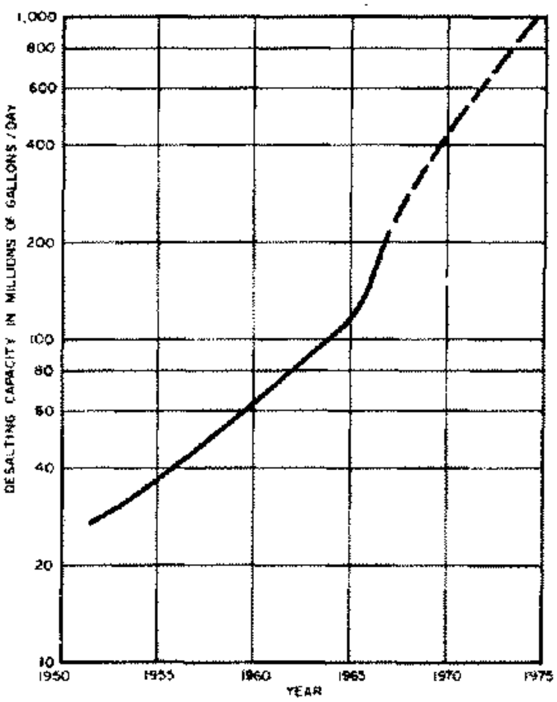

Figure 1. World-wide desalting capacity.

lowest temperature flash stage. In the deaerator, the remaining dissolved CO_2 and the dissolved air are stripped from the sea water by the combined effect of the vacuum and stripping stream. The

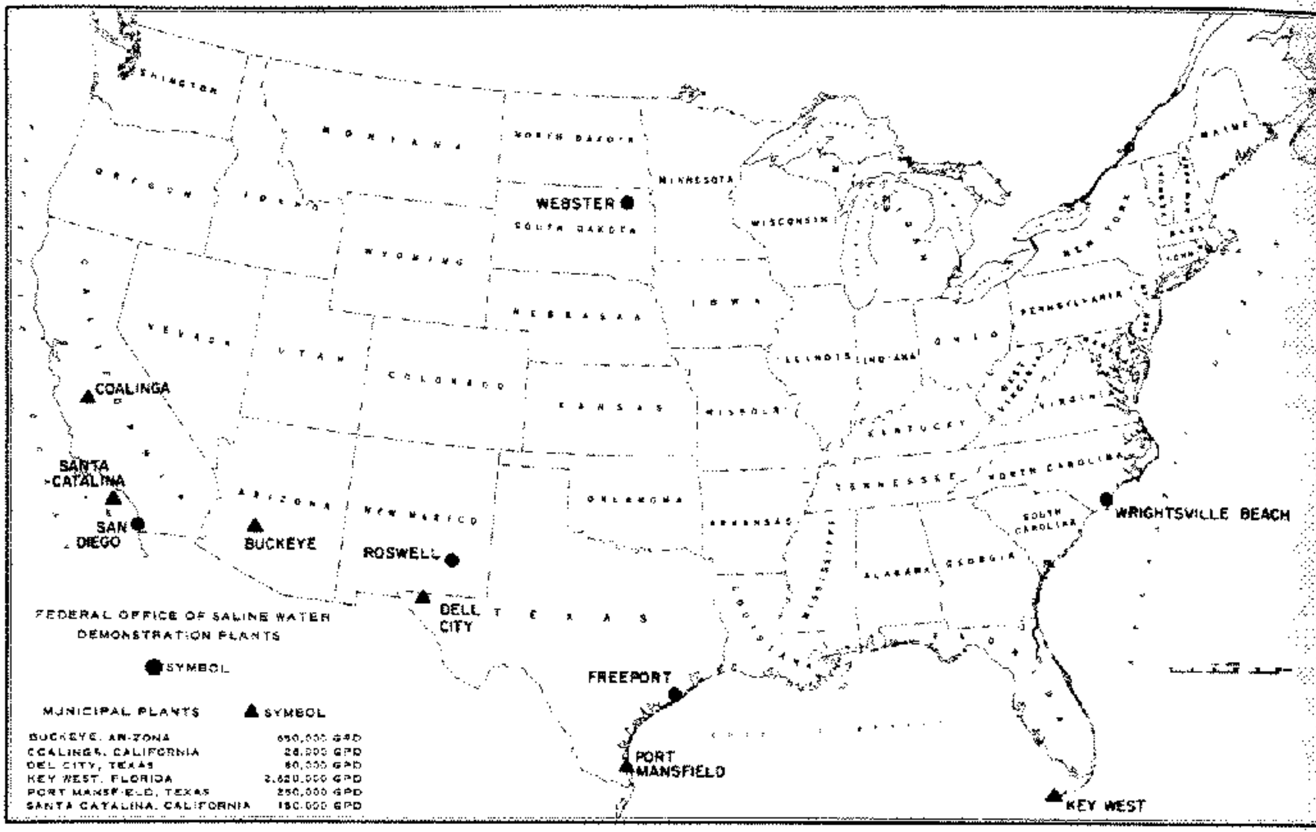

Figure 2. Municipal desalting plants and federal demonstration plants.

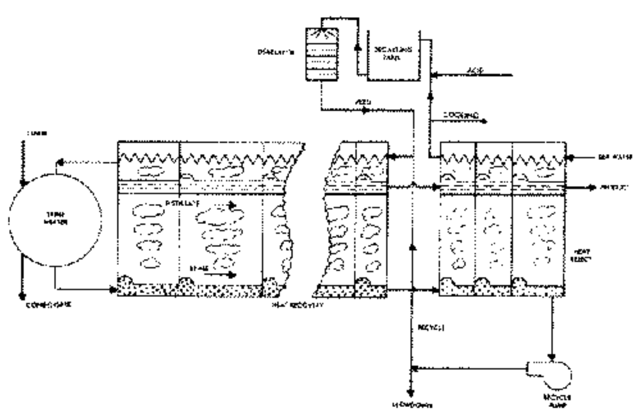

Figure 3. Multistage flash distillation.

deaerated sea water serves as the makeup to the plant. It is mixed with the recycle stream. These two streams—now combined—are pumped through the remaining tubes of the evaporators and the brine heater before being introduced into the shell side of the highest temperature stage. The shell-side brine then cascades from stage to stage as a result of the pressure differential maintained. In each stage some of the water flashes from the brine solution. It is condensed on the tubes of the evaporator and caught in troughs positioned below the tubes. The distillate also cascades from stage to stage.

Finally, the shell-side brine and the distillate reach the lowest pressure and temperature stage. At this point, the distillate is pumped from the system as product. The brine in excess of that required for recycle is pumped from the system and discharged to the ocean as blowdown. A typical brine contains about seven percent salt. The remainder of the brine is mixed with the makeup and recycled through the system.

Electrodialysis. In electrodialysis the ions pass through the membranes. In this process of ion transport through the membrane the driving force is an electrical field applied across the membrane as shown schematically on Figure 4. Two types of membranes are used. Cation permeable membranes permit only positive ions such as sodium, calcium, and magnesium to pass through the membrane. Anion-permeable membranes allow only negative ıs such as chloride, carbonate, and sulfate to pass ·ough the membrane. The net result is as shown Figure 4. Alternate passages become depleted in th anions and cations, thereby becoming less ty. By proper current, flow and passages, the ɔduct salt concentration can be controlled to the ;ired level. The higher the salt concentration of : feed, the more electrical energy and the more sses are required to obtain a potable product. r these reasons, electrodialysis is more economi- for brackish water containing no more than)00 parts per million of total dissolved solids ın for sea water. Commercial units have found de acceptance for desalting brackish water :oughout the world. The first community in the ıited States to utilize this principle was Coalinga, lifornia, which has had a unit in operation since 59.

EXISTING AND PROPOSED PLANTS

Prior to 1967, the largest single-unit sea water salter had the capability of producing about

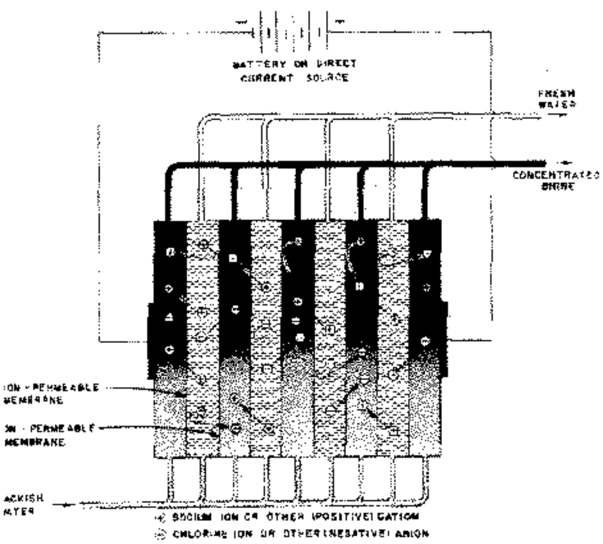

Figure 4. Electrodialysis process.

700,000 gallons per day. In 1967, a desalter was aced in operation in Key West, Florida, with a pability of producing 2,620,000 gallons per day a single-unit plant. The Key West plant was the :gest in the world until in late 1968, a plant at ɔsarito Beach, Mexico, was completed. It has a pability of 7,500,000 gallons per day from twin- ıit desalters, making this presently the largest ıgle-unit desalter at 3,750,000 gallons per day. ıte in 1968, Kuwait purchased a plant with a capability of producing 4,800,000 gallons per day in a single unit. This plant will be on line in 1970. From 1967 to 1970, the single-unit plant capacity will have increased by 85 percent.

The size of electrodialysis plants has also shown a dramatic increase since the first commercial plants were sold in the 1950s. The largest operating electrodialysis plant is the 650,000 gallons-per-day plant at Buckeye, Arizona, which has been in operation for six years. Slated for startup by mid-1969 and now under construction is a 1,200,000 gallon-per-day brackish water desalter for Siesta Key, Florida (Katz, 1969).

By comparison, studies and plans are underway in many countries for much larger desalting plants, usually in combination with power production. A nuclear reactor is the most likely energy source for these very large plants. Some of the studies that have been undertaken for the United States, all of which included dual-purpose power and water production, include the following:

BOLSA ISLAND PLANT

Proposed for construction on a man-made island offshore in Southern California. Construction start 1975; plant operation 1980. Initial capacity, 50 million gallons per day (Aqueduct News, 1968, p. 3).

COLORADO RIVER AUGMENTATION

Study of staged construction of nuclear desalters between 1990 and 2010 to provide 2,088 million gallons per day of desalted water (Dominy, 1968, p. 19).

GULF OF CALIFORNIA

Study of staged construction of nuclear desalter between 1980 and 1995, on the Gulf of California. Plants proposed for construction at five-year intervals each with a capacity of 1,000 million gallons per day (Balligand, 1968).

NORTHEAST DESALTING

A study was made on the possibility of drought-proofing the Metropolitan New York-New Jersey area for the time beyond 1980. A 300 million gallons per day desalter operating primarily during drought periods was assumed to be a long-range possibility (Johnson, 1966).

From the actual increase in plant capacity for plants in operation or under construction, as well as the several studies of very large plants, it is considered likely that larger and larger plants will continue to be constructed in the future. Of course, the quantity of effluent from these plants will also become greater.

DESALTING PLANT EFFLUENTS

Quality of effluents. As was shown on Figure 3, a multistage flash evaporator plant has three effluent streams; desalted water, sea water for cooling, and warm brine blowdown. From the standpoint of salt manufacture, the warm brine stream is of interest. This stream contains most of the salts introduced with the sea water feed stream. It will contain mainly a proportionally higher concentration of the dissolved substances introduced with the feed approximately in the ratio of feed to effluent total salt concentration. Depending on the operation, various additatives and corrosion products will also be present in the brine blowdown. When sulfuric acid is added to control carbonate scale, about 120 ppm of sulfate will be added which is equivalent to about a five percent increase in the amount normally present in sea water. The addition of the acid results in the removal of most of the carbonate-bicarbonate material by evolution of carbon dioxide. Operating conditions, as well as the materials of construction, can greatly affect the type and kind of corrosion products that may be discharged with the effluent. Consequently, the amount of corrosion products addition is likely to vary widely from plant to plant.

In order to mitigate calcium sulfate scale formation on the evaporator tubes, when desalting sea water, the concentration of salt in the blowdown brine is generally maintained at no more than seven percent salt, of which about 75 percent is sodium chloride.

Most of the electrodialysis brackish water desalters utilize a feed-stream containing less than 5,000 ppm of total dissolved solids, and many plants operate with feed-streams of less than 3,000 ppm. The brine blowdown from electrodialysis plants usually contains substantially less than one percent of salt. Since the chemical composition of brackish water varies widely, no generalization can be made concerning the sodium chloride content. In any event, the concentration is unlikely to be of interest in salt manufacture unless the disposal scheme for the water desalting plant involves concentration by ponding.

Quality of effluents. On a world-wide basis, the warm brine blowdown discharged from plants desalting sea water is more than 150 million gallons per day. Except for the concentration of desalting plants in certain areas of the Middle East, the plants are fairly widely scattered so that at most only a few million gallons per day are available at a given site.

Dry salt equivalent. For each one million gallons of water produced from sea water desalting, approximately an equal amount of warm brine blowdown is discharged from the plant. This quantity of blowdown contains some 300 tons of sea salts of which the sodium chloride content represents slightly more than 75 percent of 225 tons. For the Key West, Florida plant when operated at its full capacity of 2.62 million gallons per day, the sodium chloride in the blowdown brine is equivalent to 590 tons per day. For the 7.5 million-gallons-per-day plant at Rosarito Beach, Mexico, the brine discharge at full operating capacity will be equivalent to about 1,700 tons per day. At an 80 percent capacity factor, the per annum throughput of salt discharged in the brine from these two plants would be as follows:

	Dry Sodium Chloride Equivalent Tons/Yr	Desalted Water Million gallons/day
Key West, Florida	170,000	2.62
Rosarito Beach, Mexico	500,000	7.5

From the preceding figures, it is obvious that when multimillion gallons-per-day sea water desalters are constructed, that the quantity of salt discharged in the warm brine will be very large. The dry salt production in the United States in 1967 was 16,950,000 tons (Petkof, 1968, p. 1004). A sea water desalting plant operating at a capacity factor of 80 percent and with a rated daily output of about 260 million gallons per day, would discharge a seven percent brine blowdown carrying the equivalent of the dry salt production in the United States. A plant of this capacity is about 35 times larger than the capacity of the Rosarito Beach facility.

Disposal of effluents. For sea water desalters, the warm brine and sea water cooling streams are discharged back to the ocean either through an outfall line or discharge canal separated from the sea water intake system, in order to allow adequate mixing so that short-circuiting does not occur. Disposal of the brine effluent from inland sites poses more difficult problems. Depending on the local situation, several means, including ponding, deep-well injection, transportation out of the basin, and ntroduction into the drainage system down-eam from the plant, have all found application. rger-capacity plants of the future will pose more ficult disposal problems. Hence, any use by salt nufacturers of the warm brine discharge would p mitigate the disposal problem.

Since the very large-capacity plants, if built, are st likely to desalt sea water, consideration of disposal problem into coastal waters is of erest. Unfortunately, it is not possible to gener-ze the solution to the problem. Each proposed ility will have to consider the environmental ef-t on an individual basis. Because of the inade-ate knowledge of the temperature requirements many important organisms in the various ecolog-l communities, the inadequate knowledge of the ults of past temperature changes along major astal areas and the inability at the present time predict the magnitude or pattern of natural anges, it does not appear feasible to describe a neral temperature range for coastal waters which uld protect existing aquatic life in all situations. lditionally, one cannot predict a change which uld be particularly beneficial or only slightly ad-se over extended periods (Dunham, 1968, p.).

Salt recovery. The brine blowdown from multi-ge flash sea water desalting plants operating in wait has provided feed since 1963 for a force-culation evaporator plant to produce sodium loride from the waters of the Arabian Gulf ardi, 1968). The salt plant is a conventional type th calandria evaporators and a calcium sulfate arator. The practicability of the process has en well demonstrated with the daily production 22 tons of salt. In the future it is anticipated s process for salt manufacture will be applied on much larger scale for the economic production of lium chloride in Kuwait.

In Japan salt has long been produced from sea ter by other than solar evaporation. Partial con-tration by solar energy followed by thermal cesses, have been employed for the manufac-e of salt. The application of the electrodialysis cess to salt manufacture was commercialized in 66 (Suwa, 1968). In most world-wide applica-ns of salt separation by electrodialysis the object to obtain potable or industrial water. In Japan emphasis is on the production of brine of suit-e concentration for salt manufacture.

The federal Office of Saline Water Test Facility San Diego is adjacent to the Western Salt Com-ny which manufactures salt from solar evapora-n ponds. Since last year, several million gallons per month of the 85°-90°F. brine discharged from the test facility has been conveyed to the evapora-tion ponds (personal communication, D. Miller, March 13, 1969). The brine has a concentration of one and one-half to two times sea water. This is an experimental operation in which information will be obtained on the effect of using brine from the desalting plant on crystal size and impurities in the salt. While it is too early to tell what the results will be, the chief advantage is expected to be a reduction in time for evaporation of water from the brine. The initial results are expected by the end of the year.

SUMMARY AND CONCLUSIONS

Desalting capacity is increasing rapidly on a world-wide basis. The majority of the plants are of modest capacity. By January 1968, the total com-bined rated capacity of desalting plants was nearly 225 million gallons per day. The rate of growth in total capacity during the past few years has aver-aged about 22 percent per annum. The total desalt-ing capacity by 1975 is projected to be about one billion gallons per day.

The dry salt equivalent of the salt contained in the brine discharges from all of these plants by 1975 is expected to be equivalent to over 65 mil-lion tons per annum of sodium chloride. The major portion of this brine, because of economic consid-erations including the many discharge locations, will continue to be discharged back to the environ-ment. As larger capacity facilities are built, brine disposal problems will become more formidable. The utilization of the warm brine discharge from desalting plants by salt manufacturers, especially in solar salt works, may in the future work to the mutual advantage of both products.

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