# Desalination - A Source of Water Supply

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*After expressing his gratitude, joy and pride at being called upon to deliver the first lecture to the Ethiopian Association of Engineers and Architects, Professor Dr. - Ing. Yehuda Peter introduced his lecture by recalling his experience as a representative of Israel in congresses of the International Association of Water Supply. This lecture, as the author put it, is based on a paper prepared at the request of the International Association of Water Supply. The part of the lecture following the introduction is reproduced here in its entirety.*

It is but appropriate to start with an explanation as to why we have turned our attention to desalination as a new source of fresh water.

You see, if you look on civilized behaviors, you may say that civilization is doing better things than nature in the sense that we always try to do something using means not given to us by nature. We clothe and house ourselves using means not directly given us: we dive into the sea to depths which are not naturally given to us and we see, hear and speak into distances much farther away than really nature has provided for us. In water supply, however, we have up to now adhered to the same source which the natural hydrological circle has provided for us, and I must say, I shall not criticize nature, but in reality it is very uneconomical.

**How do we get our water?**

You perhaps may know there is a poem of the old mariner that says: "Water! Water everywhere but not a drop to drink". Usually, a poet has a tendency for exaggeration, but in this particular case we can say he is quite right. He hit the nail on the head, because as you know 70% of the surface of the globe is covered by the oceans, i.e. salty water. Our water supply is derived mainly from the evaporation by the rays of the sun from the oceans. The precipitation, resulting from the evaporation of course, mostly goes back to the oceans, and to the dry land. As regards the latter, a good deal percolates into the ground, into depths where you cannot tap it or where it is even contaminated and unfit for human consumption, and the rest goes down usually swiftly to the ocean before you can retain it. We therefore really have very small sources of water. Of course, Man has been trying all the time to catch some of this water and store it by means of dams so as to prevent it from flowing down to the ocean immediately. You can also drill wells and pump up water that has already percolated. No matter what you do the amount of water you can retain is very small.

We in Israel, I would say, have the highest exploitation of water sources. We have between 5 and 7 billion cu.m. per year as precipitation, and by the best and most expensive means which we can think of, we can scarcely put 2 billion to use, because the larger part will always be lost by evaporation and underground percolation.

It therefore is clear why following the progress of civilization, we are now trying to find our own artificial sources.

Now comes the question why the traditional sources were sufficient up to now and why they became more scarce now. Well, the first thing is, of course, that the population of the globe is rising. This, however, accounts for a small part of the cause and is not decisive.

The next thing, which is more serious, is that the present per capita consumption is rising. Man has found new uses for water, for instance, car washing, garbage cleaning, and so on, besides the rapidly increasing need for industry. Water consumption per capita in each country goes up 2-3% per year. But the most characteristic reason is that the distribution of population all over the world takes place without regard to natural dispositions. When I was a young man, I was taught that industry, which provides most of the earnings of the men in big cities, is possible only where you have one or more raw materials, such as coal and iron in one place. These ideas have become old-fashioned. Now-a-days, a state like California where you have no natural sources at all, is the fastest growing state in the United States, just because people like it. The climate, for instance, is good. That there exist no natural resources and also no water does not matter anymore. The reason is that the whole composition of the budget of mankind has changed and is rapidly changing further. The basic needs of life are becoming a relatively small percentage of the total hudget.

I would say that the modern man spends most of his money on gadgets, (even if he does not have a wife), and now in all modern industry you need very little material, but very often much knowhow.

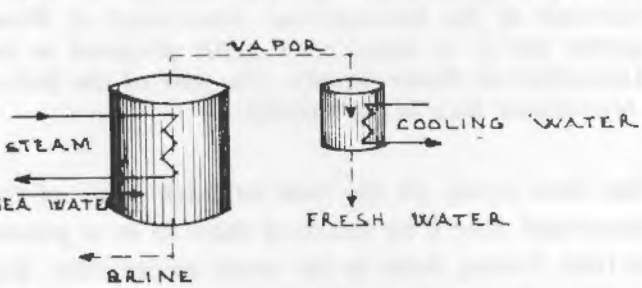


FIG. 1 SIMPLE DISTILLATION.

If you compare a car with an old locomotive, you can immediately see what I mean. If you take radios, photo apparatus and other contrivances and gadgets of this kind, you will find that they are made mostly of cheap material, such as plastics and so on. Therefore, such industries, using inexpensive light material, involving low cost transport and very much know-how, can be established everywhere. Hence people can settle in California, Florida, etc. But then the settlers find out that there is no water. For instance, this happened in Los Angeles 50 years ago. In 1910 they were forced to bring their water from Owens Valley, a distance of 1000 Km, and now they supplement it from the Colorado River. In the meantime, the population of Los Angeles has already increased to 4 million. We have other examples: San Diego, San Francisco, and so on. People begin to ask themselves: why do we have to bring water from such distances costing a lot of money when there is an ocean here? It is perhaps possible to get water from the ocean at less cost. As a result an office of saline water was established in the US department of the Interior. At this moment this office runs five pilot plants and is spending millions of dollars on research. Desalination may be the right answer.

Now comes the question: **How can you do it?**

If you like to beat a new path and do things better than nature, it is advisable to see first how nature does it and then to improve on it.

Nature is doing it by evaporation. We may try the same thing (fig. 1). Now if you add sea water into a vessel and heat it with steam, the sea-water evaporates to form steam. This steam passes through the vessel where it is converted into fresh water. Of course, if you make a cost calculation, please remember that you need a work of 427 kg-m in order to raise the temperature of 1 litre of water by 1° centigrade. Now water consumption is calculated in cu.m. which contains 1000 litres, and work is expressed in horse-power. Therefore, in order to raise 1000 kg of water by 1° centigrade work equal to 75 kg-m per sec. is required. Using such information, you can make your own calculation to understand how expensive desalination could be. In any case such a process is in operation under conditions where water is worth its value in gold, for instance emergency water on board ships. Such conversion of saline water may cost up to U.S.$ 10 per cu.m.

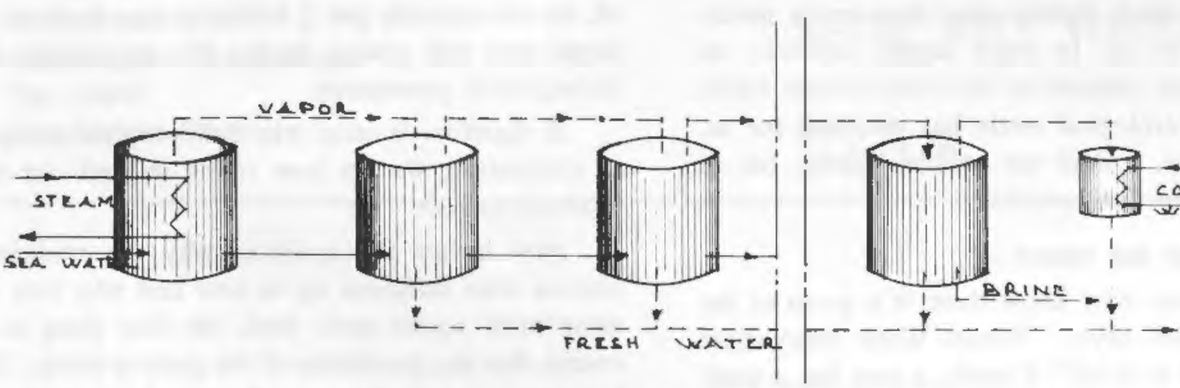


FIG. 2 MULTIPLE DISTILLATION

**How can we make the process cheaper?** (Fig. 2). It could be done, for instance, by a multiple stage process, which uses the principle of counter-flow (fig. 2). If you know how liquid air or any other liquid gas is produced, you will find that a counter-flow principle is used in order to conserve energy. Incoming air is pre-cooled by the flow of liquid air against it. We may use this principle in a multiple stage arrangement for our purpose. As in fig. 1 we put sea water into the vessel and heat it by steam. The saline water evaporates. The evaporated water is used to heat another vessel containing saline water. The saline water which is not evaporated goes into the next vessel which is heated by the steam emanating from the first, and so on. Each following vessel is, however, not heated to the same degree as the one before it.

**How can we bring the water in each successive vessel to its boiling point then?** According to the Law of Boyle-Mariotte, boiling point is not an absolute point. It is a point which depends on the pressure. If you decrease the pressure in the closed vessels, the water will evaporate at a lower temperature and will go to the next vessels to boil the unevaporated saline water coming from the same vessel. So you may proceed in 12 stages or more thereby achieving an economical multiple stage process. You can have an alternative to the same principle. Instead of decreasing normal atmospheric pressure, you can, right at the beginning, use overhead steam and at subsequent stages overheat the steam by compression. You can always convert mechanical energy into heat energy, and the first vessel will be under pressure which decreases from vessels to vessels until you come to atmospheric conditions.

The next method is called "flash evaporation" (fig. 3). Heated water goes through a number of vessels continuously. **How is it heated?** Sea water goes to a heat exchanger, which is heated by steam, or other means. The heated sea water enters a vessel, where it evaporates by being flashed under suitably reduced pressure. It condenses in the upper part of the vessel along a cooling element carrying incoming sea water, which is warmed up before it flows into the heat exchanger. The system is also arranged in multiple stages, making use of the counter-flow principle and different temperatures and pressures in each vessel. It is quite ingenious and you can imagine that it is economical with a tolerable loss of energy. It is already working in units up to 10,000 cu.m. per day, and plants where the order of magnitude is 100,000 cu.m. per day are envisaged. To arrive at a higher economy you may integrate the desalination plant with an energy generating plant. Energy generating plants release a lot of low temperature steam, which can be utilized in a desalination plant. You can also use the heat extracted in cooling diesel engines. In any case, using product heat from a power plant is the most economical arrangement. The figure for Kw installed and cubic metre produced per day is, more or less, of the same order of magnitude. It is one of the most modern and most productive methods.

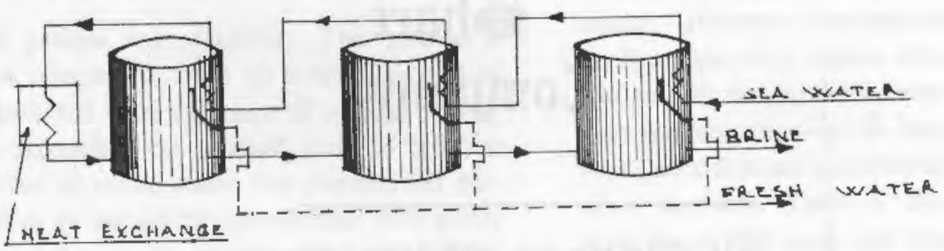


FIG. 3 MULTIPLE FLASH EVAPORATION

Now let us examine the next method. If you have a mathematical equation or formula which expresses the relation of some physical facts it is always of interest to examine the extreme cases. By assuming some of the variables to be zero, infinite or negative, you usually get the most interesting results. Following this line of thought you may ask yourself: Why should I boil the water? Perhaps it is good to freeze the water instead? Again you are following the precedent and the methods of nature. It has been known for a long time that explorers, Eskimos, polar bears and so on were living quite happily in iceberg environments. At any rate, there is no case on record of people who have died from thirst in these areas! In freezing, salty water separates into ice crystals and salt crystals. The difficulty is in the separation of the two. From a purely theoretical point of view you may say that freezing must be more economical, because the normal temperature of water is much nearer to the freezing point than to the boiling point. You know water is, say, about 20° centigrade above its freezing point but 80° below its boiling stage, so that there is roughly a 1 to 4 relation in the energy required by the different methods. There are, however, mechanical difficulties in separating the salt crystals from the water crystals. We have in Israel a plant working on this principle. The process developed by Zarchin together with the American firm of Fairbanks-Morse operates under a very low pressure, of the order of 2mm mercury. At this pressure water evaporates at a very low temperature. But all the same there are problems in this method too. Firstly it is not easy to keep such a low pressure in a vessel. Secondly, 1 cu.m. of water evaporates under

such conditions into not less than 40,000 cu.m. of steam. You will therefore have a lot of pumping to do. The plant in Israel is producing about 1000 cu.m. per day at an acceptable price under certain conditions.

Another freezing method uses immersible refrigerants (isobutane). As you know a refrigerator works by turning the cooling medium from liquids into gases. When added to salt solution, these refrigerants form crystals with water at a temperature slightly above the freezing point, leaving a brine at the bottom. Warming the crystals yields pure water. The gas can be used again. Here again the counter-flow principle is used, that is the incoming sea water warms the crystals and is itself pre-cooled. It is proving to be a very promising method, although so far it is at the pilot plant stage.

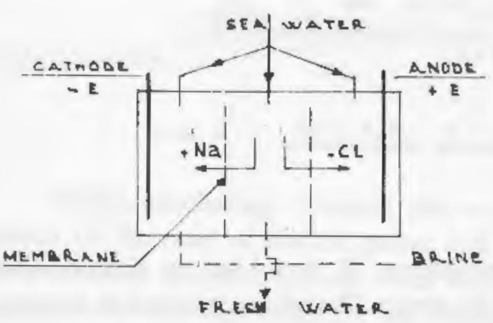


FIG. 4 ELECTRO - DIALYSIS

Another process uses electricity. This method is generally not competitive from an economic point of view. The so-called base exchange of sodium is only used in the laboratory on a small scale to produce sweet water out of saline water. For commercial purposes you have to use electricity together with partly permeable membranes in the so-called electro-dialysis. You can use membranes which work like a non-return valve or even as a selective valve. This means such membranes will allow certain ions to pass and even prevent them from going back. Fig. 4 shows sea water going-into three compartments which are separated by permeable but selective membranes. If you now pass electric current of opposite signs (anode and cathode) into the outer compartments, the sodium and chlorine ions will leave the middle compartment in different directions, leaving behind sweet water while increasing the salt concentration in the outer compartments. This is also an attractive possibility. The problem here is the availability of the right quality of membranes, but I will return to this later. This method is quite different from the previous one, because in the latter the water is taken out from the salt, and therefore it is entirely independent of the amount of salt in the original water. But when you remove salt from the water, as in electro-dialysis, then it is quite clear that the amount of electricity, and therefore that of the cost is related to the amount of salt. For this reason the method is restricted mainly to brackish water. Brackish water is defined by the order of magnitude of several thousand parts per million chlorides, while sea water contains some tenths of thousand parts per million. We have quite a lot of brackish water in the world. It occurs along coastal areas where ocean water comes in contact with natural ground water. It is also found in the interior where ground water passes through soil strata containing salt. The Salt Lake City in the middle of the United States is an example in point.

Another method is that known as "reverse osmosis". **How does this work?** (fig. 5). If you have a vessel divided into two parts by a membrane, and you fill the first part with water and the second part with salt water, fresh water will enter the salt solution under what is called osmotic pressure. This pressure amounts to about 25 atmospheres. However, in order to achieve equilibrium you have to apply a counter pressure of this order on the salt solution side. If you now increase this pressure, water will leave the solution through the membrane into the sweet water compartment. The most economical pressure for this purpose is about 100 and 150 atmosphers. This method is attractive since you do not need any boiling or heating. You have only to apply mechanical means. However mechanical problems involving pumps, pipes and vessels which have to stand up to 100 to 150 atmospheres create difficulties in operation and construction; in short, you have some advantages and some disadvantages, compared with the other methods. There is one pilot plant having a capacity of 1000 cu.m. per day working in the United States. It is not yet developed to such a degree that you can use it on a large commercial scale.

Lastly, I come to the methods using the "solar still' for heating. Strictly this is not really a technological process. It is, as shown in fig. 6, so simple that you can construct it in your back yard. It consists of a shallow basin filled with saline water and covered by a slanting glass roof. When heated by the sun the evaporated water condenses on the glass and drops into channels on the outer sides of the basin. The depth of the basin cannot exceed 20 to 30 cm, so as to create sufficient penetration of the sun rays. This device of course ceases to operate at night and in cloudy weather, which thus restricts its use to areas with sufficient sunshine. Its very simple operation is however offset by its low efficiency and high cost. One sq.m. of floor area costs about 20 to 25 U.S.$, and, depending on the climate, it produces between 3 and 5 litres per sq.m. per day. A big plant is under construction in Florida. It extends over an area of several square kilometers, and uses plastic material. The designers hope to decrease the cost considerably. One plant is working already in South Africa, producing about 35 litres per capita per day. In terms of floor area this is about 10 sq.m. per capita and costs of about 200-250 U.S.$ per capita. Under severe water supply shortages, such a high cost might be justified.

construct, as well as to maintain. In the case of the latter, it steadily decreases with the membrane becoming gradually clogged. In a water plant you need a certain guaranteed efficiency. You have to serve the customer with a steady quantity and quality of water. This is the difficulty with this method up to now. Industry will of course attempt to produce cheaper, better and longer lasting membranes.

As in the case with the electro-dialysis method, the question of membranes is important in reverse osmosis. The membrane has to stand pressures up to

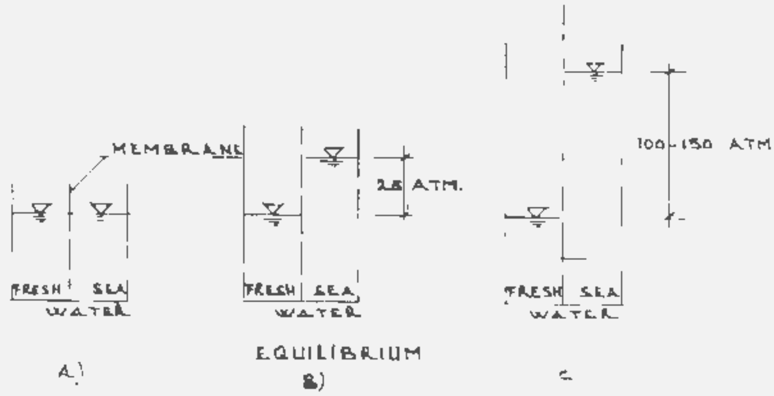


FIG. 5 : REVERSE OSMOSIS

Now we come to the evaluation of all these methods.

In the first method (i.e. evaporation) you get the water free from all minerals, because steam consists of pure water only. Nevertheless, this process is not without its disadvantages, sea-water is corrosive and scale forming. The scale formed in pipes and on the walls of the vessels acts as heat insulator thereby lowering heat transfer; efficiency is lowered. Corrosion is like a chemical process; its action increases with increasing temperature. The question of corrosion and scale formation is a serious problem. A great deal of research work is being conducted, and progress is being achieved every day. In the case of the freezing method corrosion is much less and scale formation non-existent. The sweet water obtained by the freezing method will contain some minerals because the separation between salt crystals and ice crystals cannot be 100% effective. This is not a disadvantage as pure distilled water is usually not required. You have generally a tolerance of several hundred parts per million.

The electro-dialysis method is economically feasible up to a certain concentration of salt, because electric consumption increases with increasing salt concentration. In addition there is the problem of the membranes. Imagine a membrane constructed in such a way so as to let through only sodium ions and in one direction only. It is not so easy and cheap to

100-150 atmospheres. It is subject to deterioration and can not be cheap. The whole installation (pumps, pipes and valves) working under high pressure restricts its application. A pilot plant with a capacity of the order of several hundred cu.m. per day is under operation. This method may be used on a commercial scale in the future.

Finally comes the question: **where can you use desalination to advantage?** The use of this method is advisable in arid places with high density of population who can pay, California for instance; I would say Israel too. Availability of cheap power, as in the oil producing part of Arabia, is another factor. The largest plant I know, for instance, up to now is in Kuwait. There are four streams working a multiple stage method, each producing 5,000 cu.m. per day. An American group of experts from the Office of Saline Water has been invited to devise a plant with a capacity of 40,000 cu.m. per day in the first stage and 70,000 cu.m. per day later. As oil in Kuwait costs practically nothing the question of thermal efficiency is not important. The Isle of Gurensey in the British Channel is an example of another type of place where desalination can be used to advantage. This is a small island which derives its livelihood from tourists and vegetables, which they sell to the market of London during a certain part of the year at very good prices. This island depends for water on the natural hydrological cycle. On a small island precipitation and what can be stored therefrom can be very erratic. When a dry year comes, the island can lose its livelihood completely. Therefore, the inhabitants of the island have found out that it pays them to build a desalination plant, even if it does not work all the year round. There may even be years of plentiful precipitation where they do not need it at all, but then they can be sure that each year they can accomodate tourists, and even use this expensive water which costs up to 20 cents per cu.m. for irrigation, because vegetables bring such a good price at the right season in London. So these are three different possibilities where desalination finds its place.

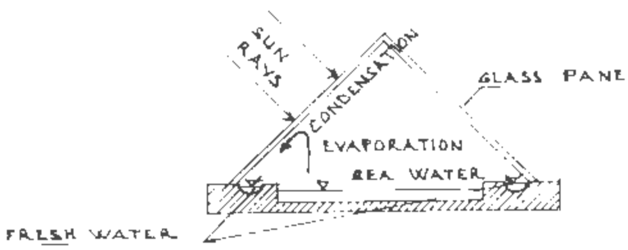


FIG. 6 1 SOLAR STILL

Before concluding, I would like to say a few words on the need of electric power and the general uses of water. Theoretically the lower limit for electric power is 0.7 kilowatt-hours for the desalination of 1 cu.m. of sea water. Of course, no practical arrangement can be so efficient. But 20-30 years ago 50 to 80 kilowatt-hours per cu.m. were used. Now there are plants which do this quite easily with 20-30 kilowatt-hours per cu.m., and at the blueprint stage there are some which assume 10-15 kilowatt-hours per cu.m. According to presently available means the ultimate practical goal, I would say, will be between 5 and 15 kilowatt-hours per cu.m.

Well, at this expected minimum input of electric power water could be rendered available for municipal use at attractive prices. Even here in Addis Ababa, you know, water is quite expensive, and a price based on the lower side of energy required would be acceptable even for some industries. For instance, mineral water, beer and dairies can pay such a price. The beer industry uses about 5 - 10 litres of water per litre of beer and the dairy industry the same quanaity for one litre of milk. In both cases the final product is so expensive that the price of water does not influence it very much. Of course, if you take other industries, paper for instance, where for each ton of paper several hundred cu.m. of water is required, a desalination plant for the same could not be economically justified. I would, however, say that for general municipal use and for some selected industrial uses desalination will, in the not too distant future, become a source of water. It will not, of course, become cheap enough for irrigation which demands several thousand cu.m. of water per acre of land. Water policy should have as its aim to reserve the cheaper sources for irrigation, the more expensive for industry, and the most expensive for domestic use.

I hope that the talk has been of interest to you even if you are not directly concerned with water. Thank you.