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DESALINATION APPLICATION IN WESTERN ASIA

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The theme of this conference is "Technology Transfer and Change." Before we begin to discuss the subject matters of this theme, we must ask ourselves such questions as, "What technology and to whom and why?" Some of the answers are abvious. We are talking about technology transfer to countries of western Asia. Since the selection of technology to be transferred to any region should be based on the climate, type and extent of natural resources available, density of population and cultural background of the people of the region, we must examine the unique features of western Asia for the above factors. A greater portion of this region is arid or semi-arid and is sparsely populated. However, the region is richly endowed with some of the most valuable mineral resources such as oil, natural gas, phosphate, uranium, etc. The development of these mineral resources is vital not only to the economics of the region, but also to the survival of human civilization.

Another importance of the region is its potential for settlement of projected population growth. The world's population which is now approaching 4 billion mark is estimated to grow at an annual rate of 1.9%. At this rate, world's population will exceed 6 billion within the next 25 years and may be nearer to 8 billion. To support this population, a two-fold increase in food and fiber production will be needed.

A primary requirement for proper development of the western Asian region is adequate supplies of water to support agriculture, industry, and population required to mine, manage and transport the mineral resources of the region. Because of the very limited rainfall, the region suffers from an acute shortage of water supplies. Long distance transportation of water by sea or inland is economically prohibitive and may be politically unwise. The only alternative is to efficiently utilize the ground and sea water resources available in the region. Unfortunately, these sources are highly saline and cannot be used directly for human consumption and industry without prior treatment by desalination techniques to convert them to fresh water quality supplies.

Large-scale conversion of brackish or sea waters to potable quality requires considerable amounts of energy. While some countries of Middle East do contain large reserves of oil and natural gas, substantial portions of the region are completely lacking in such fossil fuel resources. However, these areas are blessed with other energy resources such as sun and wind, in unlimited quantities. In some areas, geothermal energy resources may also be available. Therefore, the highest priority technology that needs to be transferred to western Asia is a desalination technology that is suitable for adaptation to local conditions and energy source. Though the desalination technology has been in commercial practice for nearly two decades, its use as a fresh water supply method has been limited to islands and small coastal communities. Its large-scale and world-wide application had been hindered by high energy requirements and cost. This situation has dramatically changed in recent years.

The new national goals set by the OPEC countries to rapidly industrialize their nations to absorb the increasing oil revenues has created a sudden interest in the large-scale application of desalination technology as a fresh water production method. This has created an urgent need for transfer of desalting technology from industrialized countries to oil-rich nations.

The increasing high costs of energy in oil-poor countries coupled with frequent famines in west Africa and India and recent drought conditions in Western United States and England have added further impetus to the research and development of desalting techniques that are less energy consuming and adoptable for operation with non-fossil fuel energy resources such as wind, sun, geothermal, etc.

To date, three desalination techniques have been advanced for commercial practice. These include: distillation, ion exchange, and membranes. Distillation has already gained commercial acceptance as a sea water conversion method in Middle East countries. As shown in Table 1, nearly 50 percent of the distillation plants that are in operation world-wide are located in Middle East and Africa.[1] The application of ion exchange technology is restricted to very low salinity waters (below 1,000 parts per million of salt) that are not generally available in western Asia. Membrane processes are a new development and offer a unique advantage for conversion of all types of saline waters ranging from ground brackish waters to sea water to fresh quality water supplies suitable for domestic, industrial and agricultural uses. A detailed description of the membrane processes and their potential application in western Asia is discussed in the following pages.

MEMBRANES

Major advantages of membrane processes are:

1. Ambient temperature operation
2. Requires one-third to one-half energy compared to distillation
3. No need for expensive metallic components
4. No thermal pollution

5. Amenable for operation with any source of energy--electricity, solar, wind, geothermal, etc.

6. Flexibility to obtain desired quality water

7. No restriction on plant siting

8. Flexibility in production rate to meet varying demands

9. Spare parts can be manufactured and assembled locally

10. Component manufacturing techniques are simple and capital cost of manufacturing equipment is relatively low

11. Plant capital costs are low compared to distillation

12. Plants are easy to install, maintain, and operate

13. Developing countries may be able to become familiarized in the component manufacturing techniques within a short period of time

These advantages have provided the greatest incentive for preferring membrane processes for saline waters desalination. For example, at the end of 1971, there were only 94 membrane desalting plants of 25,000 gpd or larger with a combined capacity of 23 million gallons per day (mgd) in operation,[2] while during the three-year period between 1972-1974, over 370 new membrane plants with a total capacity of 77 mgd were constructed (Table 2). Since 1974, several large plants with an estimated additional desalting capacity of 150 mgd have been either placed in operation or under construction; the largest plant that will be commissioned for operation next year is in Riyadh, Saudi Arabia. The plant will have a desalting capacity of 31 mgd.

The two membrane processes that are in commercial practice are: (1) electrodialysis (ED), and (2) reverse osmosis (RO). The ED process has been in commercial use for over 20 years, while RO has become commercial only during the past 5-7 years. Both RO and ED processes are based on the use of special membranes to achieve solute-solvent separation in saline waters. In the case of RO, fresh water diffuses through the membrane leaving the salt behind while in ED, demineralization of saline solutions takes place by the passage of salt through the membrane. The driving force employed to cause solute-solvent separation in RO is hydraulic pressure. In ED, electric current acts as the driving force.

The principles of RO and ED processes are illustrated in Figures 1 and 2.

Several types of RO membranes are commercially available. These are prepared either as flat sheets or as hollow fibers from cellulose acetate esters and aromatic polyamides.

Recent developments in RO membranes include a new family of membranes designated as "ultra-thin composites" prepared from sulfonated furfuryl alcohol, and polyethylene oxide isophthalamide copolymer.[3] These membranes have proven to be economical for sea water desalination. The ED membranes are prepared by copolymerization of styrene and divinyl benzene followed by chemical treatment to cause cation and anion exchange properties.

MEMBRANE EQUIPMENT

Several methods of packaging reverse osmosis and electrodialysis membranes have been explored over the past 10-15 years. Of these, only three configurations in RO and two in ED have been advanced to commercial application. These include: spiral wound, tubular, and hollow fine fiber in RO and tortuous and sheet flow designs in ED.

A schematic drawing of the spiral wound reverse osmosis module is shown in Figure 3. The module essentially consists of a number of membrane envelopes, each having two layers of membrane separated by a porous, incompressible backing material. These envelopes together with brine side spacer screens are wound around a water collection tube. The pressurized brine flows axially along the side of spacer screen--pure water flows through the membrane into the porous backing material and then to the central product collection tube.[4]

The tubular design combines two functions in one, in that it uses the surface of the tube as a support for the membrane and the tube wall as a pressure vessel. Normally, the membrane is placed on the inner wall of the tube, and the saline water, under pressure, flows inside the tube. Product water passes through the membrane to the tube wall, where arrangements are made to transfer the product water, now at low pressure, to the outside of the tube. Figure 4 illustrates the operation of a tubular reverse osmosis system.

Modern technology has made possible the preparation of reverse osmosis membranes in the form of fibers. The fibers are hollow and range in diameter from 50 to 200 microns (approximately 0.002 to 0.01 inch). Since they can withstand very high pressures, the fibers function both as desalination barriers and as pressure containers. In an operating hollow fiber reverse osmosis unit, the fibers are placed in a pressure vessel with one end sealed and the other end open to a product water manifold. The salt water, under pressure, flows on the outside of the fibers, and the product water flows inside the fibers to the open end where it is collected outside the vessel as shown in Figure 5.

While each of the above-described RO membrane configurations have a unique advantage of their own, economic considerations have favored construction of reverse osmosis plants based on spiral wound and hollow fine fiber designs. Except for specialized applications such as industrial wastes treatment, tubular design RO plants are not much favored because of high capital cost.

The major differences in the electrodialysis equipment designs is in the length of fluid flow path and thickness of the plastic spacer that separate the membranes. A sinuous, tortuous flow path is used in one commercial stack design. The total path length of this sinuous design is four to five times greater than a sheet flow stack which is the other hydraulic configuration commonly used. In the tortuous path design, thicker spacers up to 40 mils are used, while in the sheet flow design, spacers are approximately 20 to 30 mils in thickness.[5]

PROCESS IMPROVEMENTS

Over the past seven years significant advances have been made in reducing the capital and operating costs of brackish water desalination in both RO and ED plants. Of major importance are development of: (1) large size, high desalting capacity RO and ED modules; (2) development of membranes that provide significant savings of energy; (3) development of techniques and systems suitable for pretreatment of brackish and sea waters; and (4) optimization of plant design and operating parameters to ensure high reliability and operation by semi-skilled labor.

RO MEMBRANE MODULES AND ED STACKS

Prior to 1970, membrane equipment was generally small and their maximum product water capacity was less than 1000 gpd. Over the past five years, U.S. industry, with financial support from the Federal Government, has developed manufacturing and quality control techniques to fabricate large RO membrane modules and ED stacks with product water capacities up to 200,000 gpd.

The descriptions of the commercial RO membrane equipment are given in Tables 3 and 4.

PRETREATMENT

An inherent disadvantage of any membrane process used in solute-solvent separation is the tendency of membranes to become fouled with any particulate or collodial matter present in the feed solution. In membrane processes, the particulates form a very thin layer on the membrane surface, thereby preventing direct contact of the saline solution with the desalination barrier. This reduces the diffusion rates of fresh water (in RO) or salt (in ED) through the membranes. In addition to particulate matter, a number of salts ($CaSO_4$, $CaCO_3$, Silica, etc.) present in saline solutions reach supersaturation levels during desalination process and precipitate out as scale deposits on membrane surfaces. To maintain the plant desalting capacity at a fairly constant rate, it is critical to maintain the membrane surfaces fairly free of any deposits. This can be accomplished in two ways. First, the membranes can be chemically cleaned as frequently as required. This results in excessive plant down time, and higher plant operating costs contributed by cleaning chemicals and additional labor required for this purpose. A second approach is to pretreat the saline water prior to its use as a feed to membrane plant for removal of fouling and scale-forming constituents.

The extent of pretreatment required is also related to membrane equipment design. Hollow fine fiber systems require the most, and tubular and ED plants with polarity reversal, the least. In general, the following pretreatment schemes are generally employed:

1. Surface waters
   Chlorination-Coagulation-Sedimentation-Sand filtration

2. High hardness waters
   Lime or lime-soda softening-Sand filtration

3. Low hardness waters
   Sand and manganese-Zeolite filtration

If organics are present in excess concentrations, activated carbon is used as an additional filter. In addition to the above, the feed water is treated with sulfuric acid for pH adjustment, when required, sodium hexameta-phosphate is used to minimize $CaSO_4$, iron, and manganese hydroxides from forming scale deposits.

LOW-PRESSURE RO MEMBRANES

The commercial brackish water RO plants operate at 400-450 psi. Desalination of a 3100 ppm TDS brackish water to 240 ppm, at 70% product recovery requires about 8-10 kWh/1,000 gallons of product water. Assuming an energy cost of 2¢/kWh, this amounts to 20¢ which is about 25-30 percent of total desalting cost. Because of the soaring fossil fuel costs, in the coming years, the energy costs in RO plants may amount to as much as 50% of the total operating cost. Recognizing the need to reduce energy costs in RO desalination plants, a new family of low pressure membranes that have desalination performances (at pressures of 250 psi and below) approximately equivalent or better than those exhibited by present day commercial membranes (400-450 psi) are being developed for commercial application. Successful development of these low pressure membranes for commercial application may reduce the energy cost in RO plants by about 40%.

DRY RO MEMBRANES

To maintain desalination properties of commercial membranes, it is critical to keep them in a wet state at all times, including during shipping, storage, and plant shutdown. If allowed to dry, they tend to lose their solvent or plasticizer component by evaporation and become brittle. Because of this, commercial membranes are shipped in containers with water and are stored in a temperature and humidity controlled room until ready to use.

Because of the compactness and versatility to treat any type of water, ranging from swamp waters to radiologically contaminated waters, the U.S. Army has selected RO hardware as a major water treatment device for field use by U.S. troops.[6] The specifications call for a self-contained, packaged system, designed for air and land transport, responsive to quick start and stop operation and capable of producing potable water from sources that are close to the troops location. Commercial membranes are unsuitable for this purpose, since the equipment use is sporadic and membrane modules will have to be stored in wet state for long periods. To be responsive to U.S. Army requirements, membranes that could be shipped and stored in dry state at relatively high temperatures prevailing in desert areas without loss of their functional properties have been developed.

REVERSE OSMOSIS PROCESS FOR SEA WATER CONVERSION

Sea water with a salt concentration of 3.5% has an osmotic pressure of 350 psi. Assuming that only 30% of the incoming water is recovered as product water, the brine leaving the membrane unit will have a salt concentration of 5.2% and an osmotic pressure of over 550 psi. For practical use, membranes that provide over 99% salt rejection and withstand high operating pressures are required. Development of membranes meeting these requirements has been a challenge to polymer chemists. Recognizing the difficulties, the U.S. Department of the Interior began supporting research and development programs on sea water RO membranes as early as 1965. Earlier efforts were concentrated on improving the performance of cellulose diacetate brackish water membranes for sea water application. These early efforts were not too successful. However in 1970, Aerojet-General Company, Los Angeles, California, developed a membrane from a mixture of cellulose diacetate and triacetate. This membrane had over 99% salt rejection, but had to be operated at 1,500 psi to obtain reasonable fluxes. Since then, several sea water RO membranes suitable for commercial use have been developed. These include DuPont's polyamide hollow fine fiber, Dow Chemical Company's cellulose triacetate (CTA) hollow fine fiber, and ROGA-UOP's CTA asymmetric sheet membrane. The properties of these membranes are shown in Table 5. With the advent of these membranes, it is now possible to operate the sea water RO plants at pressures of 800 - 1,000 psi. All the membranes provide over 99% salt rejection and thus, are quite suitable for sea water desalination. The largest sea water reverse osmosis desalting plant with a production capacity of approximately 3.5 million gallons per day is presently under construction in Jeddah, Saudi Arabia.

MEMBRANE PROCESSES DESALTING COSTS

It is difficult to provide precise desalting costs. This is primarily due to wide variations in the quality of brackish and sea water available for desalting in the area. In addition, local factors such as costs of energy, labor, interest rates, distance between plant location and environmental regulations on brine disposal have a direct influence on costs. Other factors that influence desalting costs are plant size and percent product water recovery. Generalized capital and operating costs curves for RO, ED, and distillation plants are given in Figures 6, 7, 8 and 9. The costs are inclusive of membrane modules, piping, instrumentation, pretreatment, etc., but do not include costs of brackish or sea water pumping and piping to membrane plant, product water distribution and brine disposal.[8,9]

The cost estimates are based on a service life of three years for RO membranes and five and seven years for anion and cation electrodialysis membranes, respectively. Pretreatment of feed water was assumed to be sand filtration, injection of 5 to 10 ppm of sodium hexameta-phosphate for scale control and adjustment to pH of 6 using sulfuric acid.

Advancement of recent developments to commercial practice such as low pressure membranes, large desalting capacity RO and ED equipment, high flux and high salt rejection membranes, is expected to reduce the membrane desalting costs by as much as 30% from present levels.

ENERGY REQUIREMENTS

A major advantage of sea water RO system is the low energy requirement compared to distillation. Soaring energy costs have provided a further incentive for plant owners to prefer RO over distillation. For developing countries, RO offers a unique opportunity to provide drinking water supplies to rural communities that even lack electric supply. As a water supply system for military missions, RO offers many advantages. It can be packaged as a compact system and can be operated with diesel engine or gas turbine.

In Figure 10 are compared energy requirements for an MSF distillation unit with a performance ration of about 10:1 with sea water RO systems operating at 1,000 psi with various power supply systems (4). In all cases studied, RO plants require far less energy than distillation and except for the gas turbine powered RO plant, the energy for RO are well below 40 percent of the energy required for distillation. RO plants equipped with a hydraulic power recovery turbine (to recover energy from pressurized brine) appear to be the least energy consuming (about 25 percent of the energy required for distillation). Further reductions in energy costs may be possible with the development of thin-film composite membranes which may permit operation of sea water RO plants at lower pressures.

ADAPTATION TO WESTERN ASIA

Any desalination technique selected for arid areas must meet certain criteria to be economical and practical. These include: (1) flexibility for use of any available energy source; (2) short period of plant construction; (3) ease of operation; (4) high reliability; and (5) feasibility of manufacturing major components with local labor. As discussed before, membrane techniques meet all the above criteria and, therefore, are uniquely suited for arid areas.

USE OF SOLAR ENERGY

Use of solar energy for saline water conversion is not a new idea. In several parts of the world, solar distillation plants are presently in operation providing drinking water supplies to the inhabitants of many islands. (Example: Islands of the coast of Greece.) However, solar energy has never been used for large-scale conversion of sea or brackish waters. In 1974, U.S. Department of the Interior made a study to determine the technical and economical feasibility of using a solar water pumping system for operation of a 100 mgd brackish water membrane plant that will be built in Yuma, Arizona to desalt agricultural wastes. The study considered the technical and economic characteristics of all applicable solar thermal power systems, solar energy collectors performance as a function of solar flux and angle, weather conditions, collector orientation ranging from fixed position to various tilt angles and other pertinent component characteristics. A small prototype solar collector was also fabricated by Arthur D. Little Inc. of Cambridge, Massachusetts, and field tested at the planned plant location in Yuma, Arizona.[8] A preliminary analysis of several alternate storage methods was also made to determine if storage could be economically used to allow system operation through the local utility peak periods. A schematic diagram of the solar powered water pumping system studied is shown in Figure 11. Results of this study are summarized below:

1. Flat plate collectors can utilize diffuse as well as direct radiation making such systems suitable for providing energy to membrane plants in a wide range of geographical areas and climatic conditions.

2. For pumping applications, organic Rankine cycle engines can operate with high efficiency at moderate boiler temperature levels using a "once through" water-cooled condenser.

3. The power system can be assembled from components which are either already developed or in the advanced stage of development. This would permit near term utilization of these systems in arid areas.

4. The flat plate collectors can be mounted in a fixed position resulting in relatively simple mounting structures and low maintenance requirements.

5. Power system performance tend to optimize at relatively low power levels. This makes it possible to assemble systems with a range of power output levels from smaller power modules of standard design.

6. The system as shown in Figure 11 can also be used to pump water for irrigation and drainage systems.

7. The optimum economic solar thermal power module size is about 2 MW. Power costs in such a module range from 3.8¢ to 7.7¢/kWh depending upon the use of collectors array with or without reflectors, the location and prevailing labor cost. Such a system could be built at a cost of 1.4 to 1.6 million dollars (U.S.) as shown in Table 6.

8. Since the temperature of flat plate collector solar thermal module is sufficiently low, hot water thermal storage could be used.

The above findings clearly indicate that the solar energy technology is fairly well established and could be harnessed as a power source over a wide range of geographical areas and climatic conditions . Compared to climatic conditions prevailing in Yuma, Arizona, the temperatures in arid or semi-arid areas are much higher all year around and there are no constraints with regard to availability of land. More advanced concepts of solar thermal power generation concepts are also being investigated. These include: (1) "power tower" concept where a large mirror field is used to direct solar energy from a large area to a central receiving cavity placed on a tower; (2) solar powered energy systems using parabolic through solar collectors that provide heat at 500° - 600° F to organic turbines. Both these concepts when fully developed will provide an efficient and economical method of harnessing solar energy which could be used for large scale conversion of brackish waters in desert areas.

WIND ENERGY

The energy crunch resulting from rapidly depleting oil and natural gas reserves in U.S. coupled with the four-fold increase in oil prices by the OPEC countries has promoted intensive studies by the Energy Research and Development Administration of the U.S. Government to develop economical methods of harnessing wind energy.

Several types of wind energy collectors including horizontal and vertical axis turbines capable of producing any where from 100 kW to several megawatts are commercially available or under development.[10] The projected power costs as a function of power output, (in kW) for various wind velocities are shown in Figure 12, and the estimated monthly power outputs of some commercial wind generators in kW/hr. are given in Table 7. Higher capacity large wind turbines with power ratings of 500 kW and 1500 kW are presently under development. Their target performance characteristics and cost estimates are give in Table 8. The values presented in the table indicate that wind turbines could be economically used to produce power at costs as low as 1.7¢ - 2.0¢/kW in a 1500 kW capacity wind energy system. The manner of coupling wind energy system to ED and RO brackish water desalination plants is shown in Figures 13 and 14. The estimated capital and operating costs for a one mgd electrodialysis plant desalting a 2500 ppm TDS brackish water feed and operated on wind energy are given in Table 9.

In arid areas, where the wind velocities are relatively high, power could be produced at even lower costs resulting in further reduction of the brackish water desalination costs.

The foregoing discussions on the status of solar and wind energy systems clearly indicate that the technology for harnessing wind and solar energy sources could be readily used for operation of desalination plants in areas where conventional energy sources are in short supply.

CONCLUSIONS

At no time in history, the human race has been presented with a challenge of the magnitude and complexity as we are facing today. The inhabitable areas of our planet are becoming overcrowded and known reserves of mineral resources are rapidly dwindling. Since we have no new frontiers to conquer, we must make the most efficient use of all the available land and natural resources to support both the present and projected population growth. The world's population is expected to double to 8 billion in the next 25-30 years and this means we will have to double or triple the world-wide food and fiber production to meet the minimum demands of projected population.

Global climatic changes are becoming another serious threat to human survival. While their effect was less obvious in the past, they have caused serious impact on human lives in recent times.

To improve the economic standards and to provide a better world for future generations, we must take steps to bring more areas under cultivation. The only vast areas that are available for expansion are arid areas, which cover a quarter of our planet.

While nature has "stored" some of the most valuable mineral resources useful to mankind such as oil, phosphate, uranium, etc. in arid areas, they are not blessed with adequate supplies of water, a basic requirement for human settlement and for food and fiber production. Because of the limited rainfall, they have little or no dependable surface water supplies. Long distance transportation by sea or inland is economically prohibitive and is politically unwise. The one and only alternative is to efficiently utilize the limited surface and ground water resources available in the areas. Unfortunately, these sources are highly saline and have to be treated with desalination techniques to prepare them for human consumption and industry.

Desalination methods based on membrane processes appear to offer the best promise for conversion of saline water resources to fresh quality water supplies in western Asia and other similar arid areas. The basic advantage of these techniques is that they are adaptable for use of any energy source--oil, natural gas, solar, wind, and geothermal. While some areas of western Asia contain vast reserves of oil, all arid regions are blessed with abundance of sun and wind which can serve as energy sources for water resources development. Additional advantages of membrane techniques include: (1) low-energy requirements, (2) short plant construction period, and (3) ease of operation.

The harnessing of solar and wind energy has always been a challenge to mankind. Because of our rapidly depleting fossil fuel energy resources, a concentrated effort is being made by many nations to develop these energy resources for practical application. As a result, some advances have been made in developing commercial equipment capable of generating power from a few kilowatts to as high as several megawatts.

The technical and economic feasibility of coupling solar and wind energy power to membrane desalting plants is under intensive study. Preliminary cost estimates indicate that with the current state of development, power could be generated from solar and wind energy at a cost ranging from 1.7¢ to 7¢/Kw/hr. depending upon the size of the plant, location, wind velocity, prevailing temperature levels, etc. Technological advances in the next 5-10 years are expected to significantly lower these power costs.

Based on the current technology, desalination costs range from U.S. 0.70¢ to $1.00/1,000 gallons for brackish water and for sea water U.S. $3.00-$3.50/1,000 gallons depending upon the chemical composition of the saline feed, plant size, plant location, interest rates, etc. Several technological advances are currently in progress that are expected to reduce the present day costs by 30% - 40%.

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TABLE 1

DESALTING PLANTS BY LOCATION

Region	Number of Plants	Plant Capacity (mgd)
United States	346	68
United States Territories	26	20
North American (Except USA and Territories)	41	12
Caribbean	39	32
South America	24	6
Great Britain and Ireland	69	16
Europe	149	68
Africa	104	57
Arabian Peninsula and Iran	153	146
Asia and Indonesia	68	68
Australia and the Pacific	10	2
Union Soviet Socialist Republics	7	30
Total	1036	526*

* Individual region totals do not add to 526 because of rounding

TABLE 2

DESALTING PLANTS BY PROCESS AS OF JANUARY 1, 1975

Type of Process	Number of Plants	Plant Capacity (mgd)
Distillation		
Single-stage flash	57	8
Multi-stage flash	285	352
Thin film vertical tube	104	51
Vapor compression	67	5
Thin film horizontal tube	12	5
Combination vertical tube - multi-stage flash	1	3
Submerged tube	138	23
	664	447
Membrane		
Electrodialysis	75	26
Reverse osmosis	268	45
Electrodialysis - reversing	27	6
	370	77
Freezing		
Vacuum freezing - vapor compression	2	*
All types of process	1036	526**

* Less than one million gallons per day
** Individual Process totals do not add to 526 because of rounding.

TABLE 3

STATUS OF REVERSE OSMOSIS MODULES FOR BRACKISH WATER DESALINATION

Module configuration	Commercial				Under development	
	Dimensions	Design capacity (gpd)	Dimensions	Design capacity (gpd)	Dimensions	Capacity (gpd)
Cellulose diacetate spiral wound modules[1,2]	4"Ø X 36"L	1000-2000	8"Ø X 36"L	4800	12"Ø X 60"L	17,280 (70,000)[2]
Cellulose triacetate hollow fiber module	6"Ø X 48"L	4000	10"Ø X 48"L	20,000	12"Ø X 96"L	50,000
Polyamide hollow fiber module[1]	4"Ø X 48"L	2500	8"Ø X 48"L	15,000	--	--
Polyamide ultra-thin composite module[1,3]					8"Ø X 36"L	7,500 (45,000)[3]
Cellulose acetate blend modules[3]	4"Ø X 37"L	1400	--	--	6"Ø X 37"L	2,900[3] (13,200)

1 Initial RO capacity based on desalting 1500 ppm NaCl at 400 psi and at 25°C.
2 Up to four elements in series housed in a single pressure vessel.
3 Up to six elements in series housed in a single pressure vessel.

TABLE 4

STATUS OF REVERSE OSMOSIS MODULES FOR SEA WATER DESALINATION

Module configuration	Commercial				Under development	
	Dimensions	Design capacity[2] (gpd)	Dimensions	Design capacity[2] (gpd)	Dimensions	Design capacity[2] (gpd)
Cellulose acetate blend spiral wound element[1]	4"Ø X 37"L	450[5]			6"Ø X 37"L	1100[5]
Cellulose triacetate spiral wound element[1]	4"Ø X 36"L	800[4]			8"Ø X 36"	3000[4]
Polyamide hollow fine fiber module	4"Ø X 48"L	1900[3]	8"Ø X 48"L	4000[3]		
Cellulose triacetate hollow fine fiber module			8"Ø X 48"L	2500[3]	12"Ø X 48"L	7500[3]
Cellulose triacetate composite spiral wound element[1]					4"Ø X 36"L	1200[4]
Polyamide composite spiral wound element[1]					4"Ø X 36"L	1500[4]

1 Up to six elements in series housed in a single pressure vessel
2 Design capacity based on 35,000 ppm sea water, 25°C, 30% recovery
3 Operating pressure - 800 psi
4 Operating pressure - 1000 psi
5 Operating pressure - 1500 psi

Table 5

SEAWATER MEMBRANE PROPERTIES

Polymer system	Flux[2,3]	Salt rejection[2] percent	Operating Pressure psig
Cellulose acetate blend flat film	8 -10	99.3	1500
Cellulose triacetate flat film	10 -12	99.2	1000
Polyamide hollow fine fiber[1]	0.8- 1.0	99.0	800
Cellulose triacetate hollow fine fiber	0.8- 1.0	99.5	800
Cellulose triacetate composite flat film	14 -16	99.5	1000
Polyamide composite flat film[1]	20 -25	98.9 to 99.3	1000

1 Sensitive to Chlorine
2 35,000 ppm Seawater, 25°C
3 Flux after 24 hours at 25°C

TABLE 6

ESTIMATED POWER COSTS USING A SOLAR ENERGY SYSTEM GENERATING ELECTRICITY FOR USE IN THE DESALINATION PLANT

	Collector Array Without Reflectors	Collector Array Using Reflectors
a) Power Module Cost:		
Collector Panels	$ 975,000	$ 700,000
Reflectors	–	88,000
Collector Support	64,500	46,000
Feeder Line Piping	44,700	32,000
Rankine Cycle Engine	390,000	390,000
Generator, Switchgear and Power Lines	127,000	127,000
	$1,601,200	$1,383,000
b) Annual Power Produced (effective)	3,340,000 Kw-hr	3,360,000 Kw-hr
c) Cost of Power:		
Capital Costs	Power Cost (¢/Kw-hr)*	
8%	4.3	3.8
10%	5.3	4.6
15%	7.7	6.7

*Including operational costs of 0.5 ¢/Kw-hr

TABLE 7

Estimated Monthly Power Output of Selected Wind Generators in Kw-hr

	Rated Output (Watts)	Average Windspeed (mph) 8	12	16
Windcharger	200	10-14	19-26	26-36
Sencenbaugh	1000	70-110	130-220	190-300
Dunlite	2000	80-125	160-250	235-370
Electro	6000	200-310	400-620	600-930
Aerowatt	(24	8	11	15
	(130	45	55	80

TABLE 8

Anticipated Performance

Characteristics of

500 and 1500 Kw MOD-1 Wind Turbines

	500 Kw		1500 Kw	
	General Electric	Kaman	General Electric	Kaman
Mean Wind Speed	12	12	18	18
Rated Power, Kw	500	500	1500	1500
Rated Wind Speed, mph	16.3	20.5	22.5	25
Energy Captured, Kw-hr/yr	1.88×10^6	1.3×10^6	6.6×10^6	5.7×10^6
Rotor diameter, feet	183	150	190	180
Rotor Solidity, percent	3	3	3	3
Rotor Speed, rpm	29	32.3	40	34.4
Energy Cost, cents/Kw-hr*	4.2	5.5	1.7	2.0
Capital Cost, dollars/Kw	974	901	449	481
Wind Turbine Cost, dollars	486,000	450,670	674,000	720,800
Plant Factor	0.42	0.29	0.51	0.43

*Assumed 16 percent of capital cost for interest, operations, maintenance, taxes, etc.

TABLE 9

Estimated Desalting Costs for 1 mgd

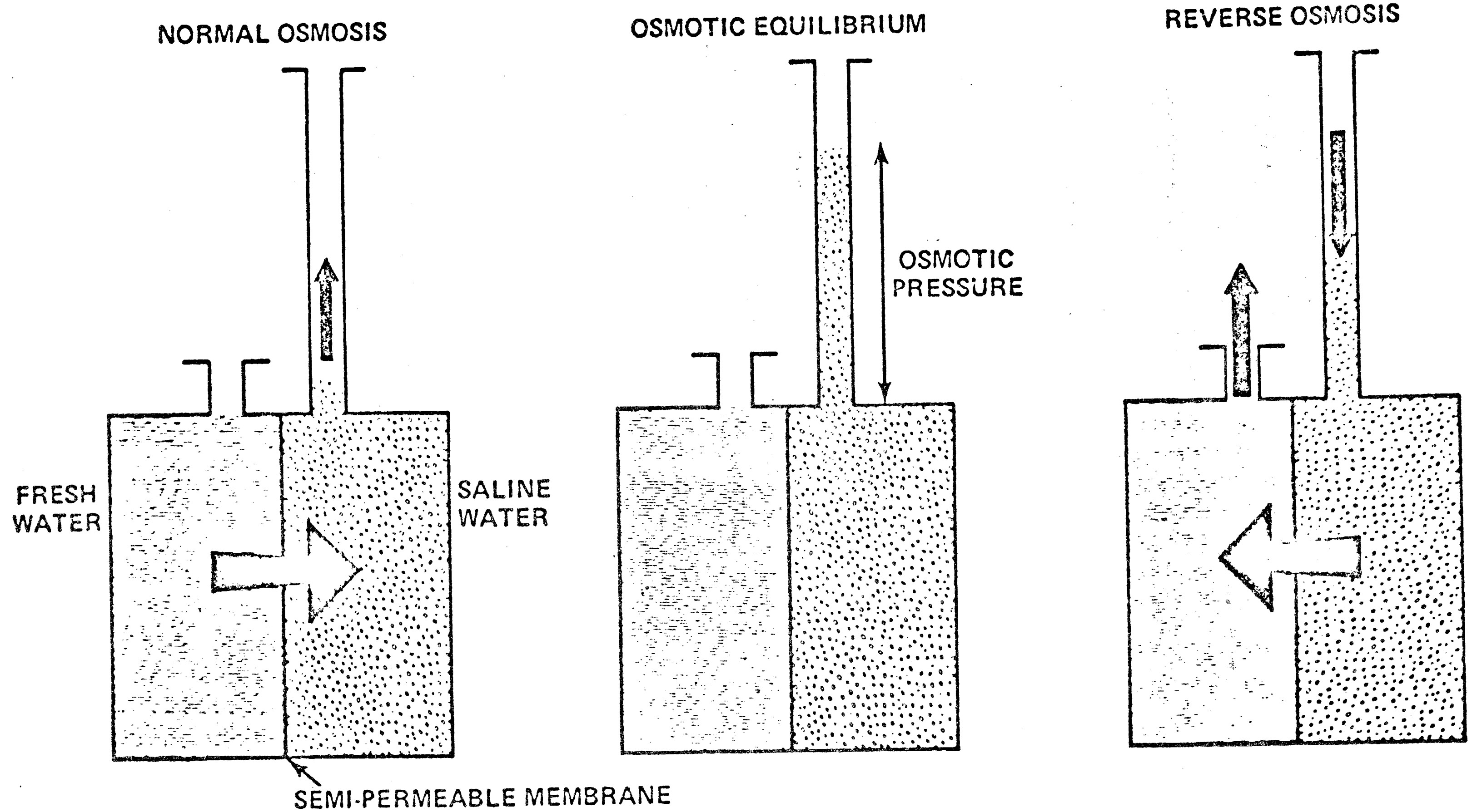
Electrodialysis/Wind Energy Brackish Water Desalination Plant

Ground Rules

Capacity = 1 mgd, Capital Cost $700,000, Feed 2500 ppm TDS
Product Water, 500 ppm TDS, 350 day operation/year
Production, 340,000,000 gallons/year
Average Daily Production, 930,000 gallons

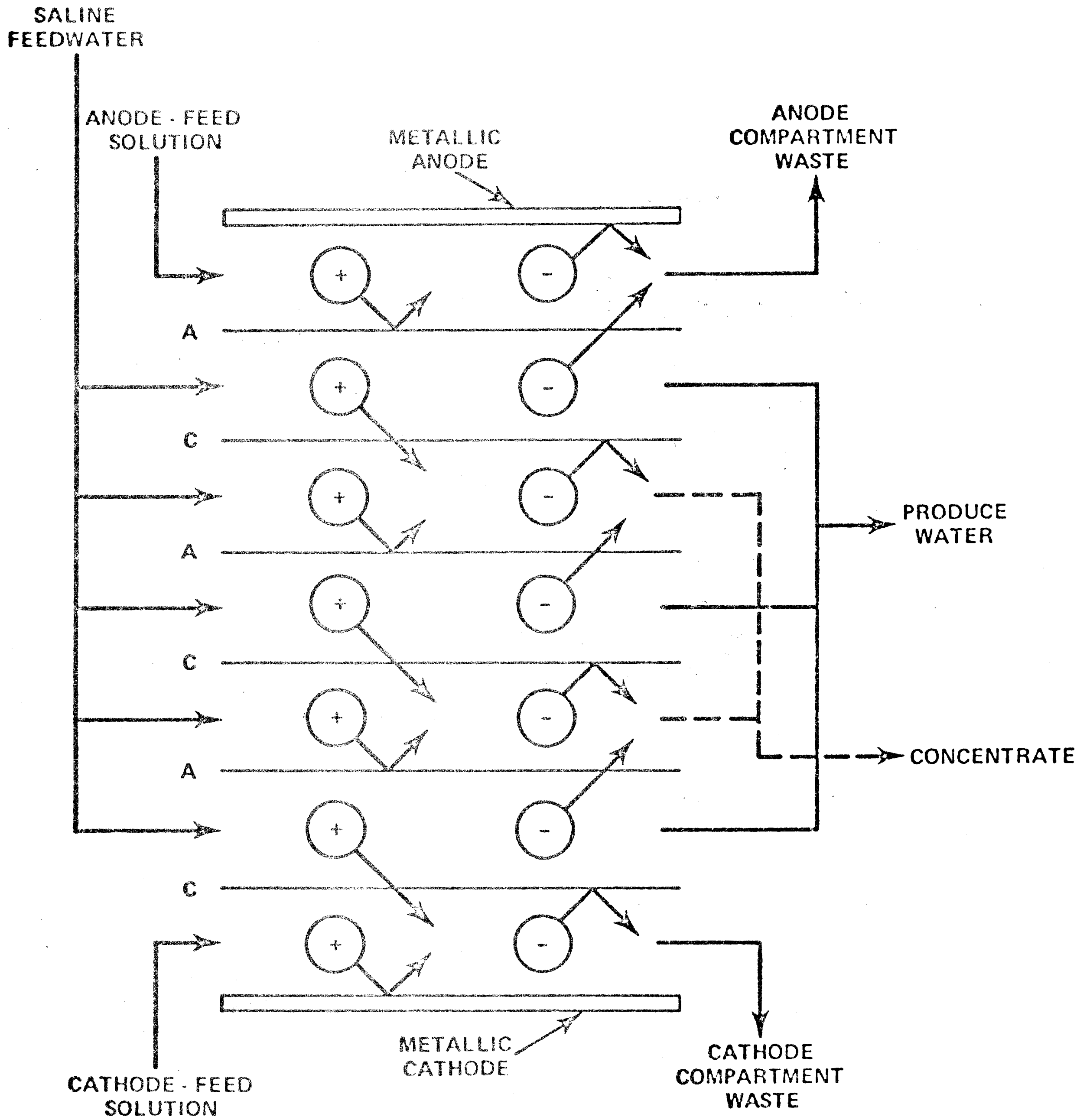
Energy Source - Two 500 Kw G.E. Wind Turbine
Estimated Amount of Energy Produced - 3.76 x 10^6 Kw/hr/yr.
Cost of Energy - 4.2¢/Kw/hr.
Plant Service Life - 20 years
Interest Rate - 8%

Item	¢/1000 gallons of desalted water
Amortization	12
Energy	40
Operation and Maintenance	10
Contingencies	8
Total:	70



PRINCIPLE OF REVERSE OSMOSIS

FIGURE 1

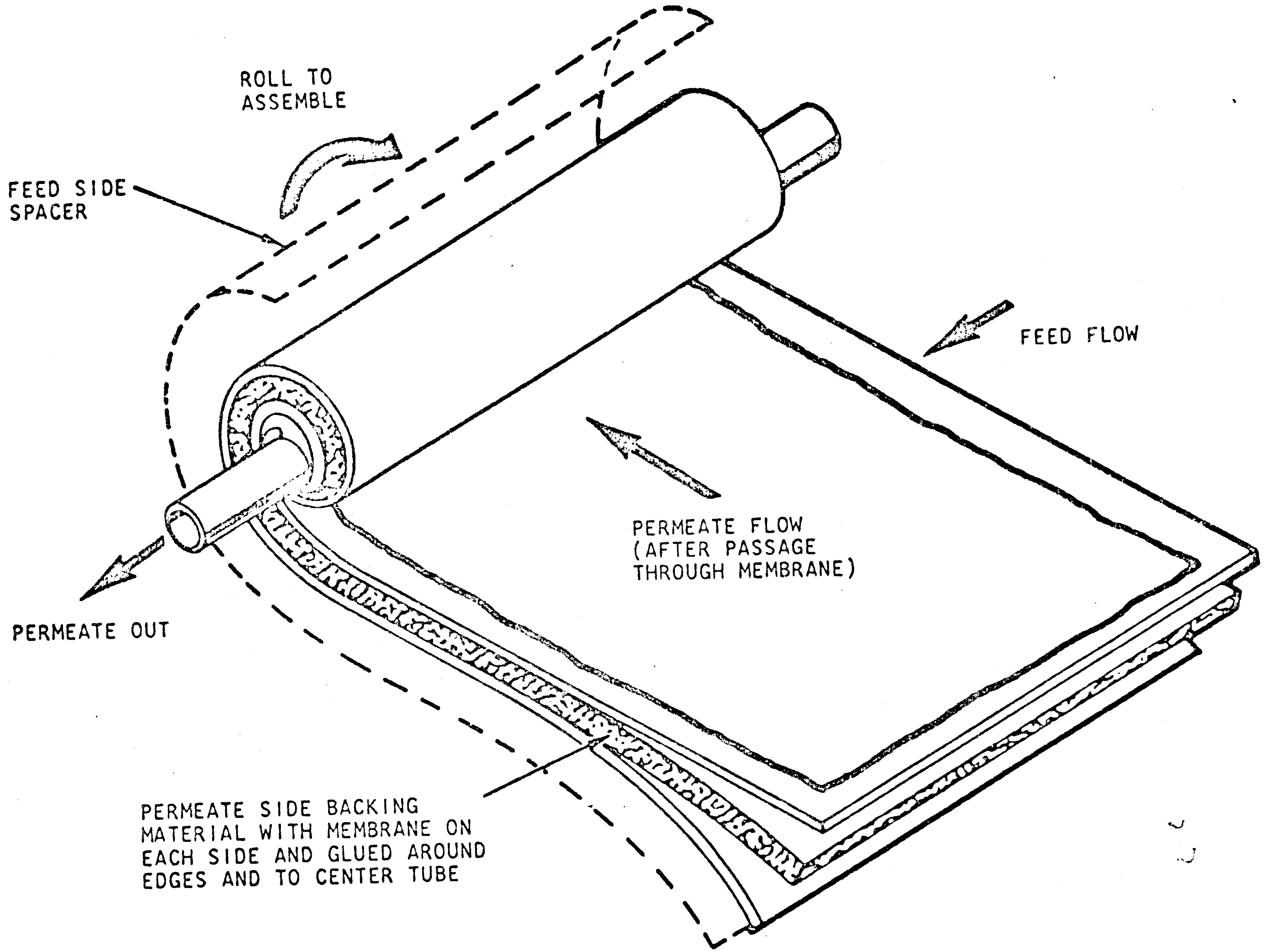


LEGEND

- A MEMBRANE PERMEABLE TO NEGATIVE IONS ONLY
- C MEMBRANE PERMEABLE TO POSITIVE IONS ONLY
- \+ ANY POSITIVE ION, SUCH AS Na^+
- \- ANY NEGATIVE ION, SUCH AS Cl^-

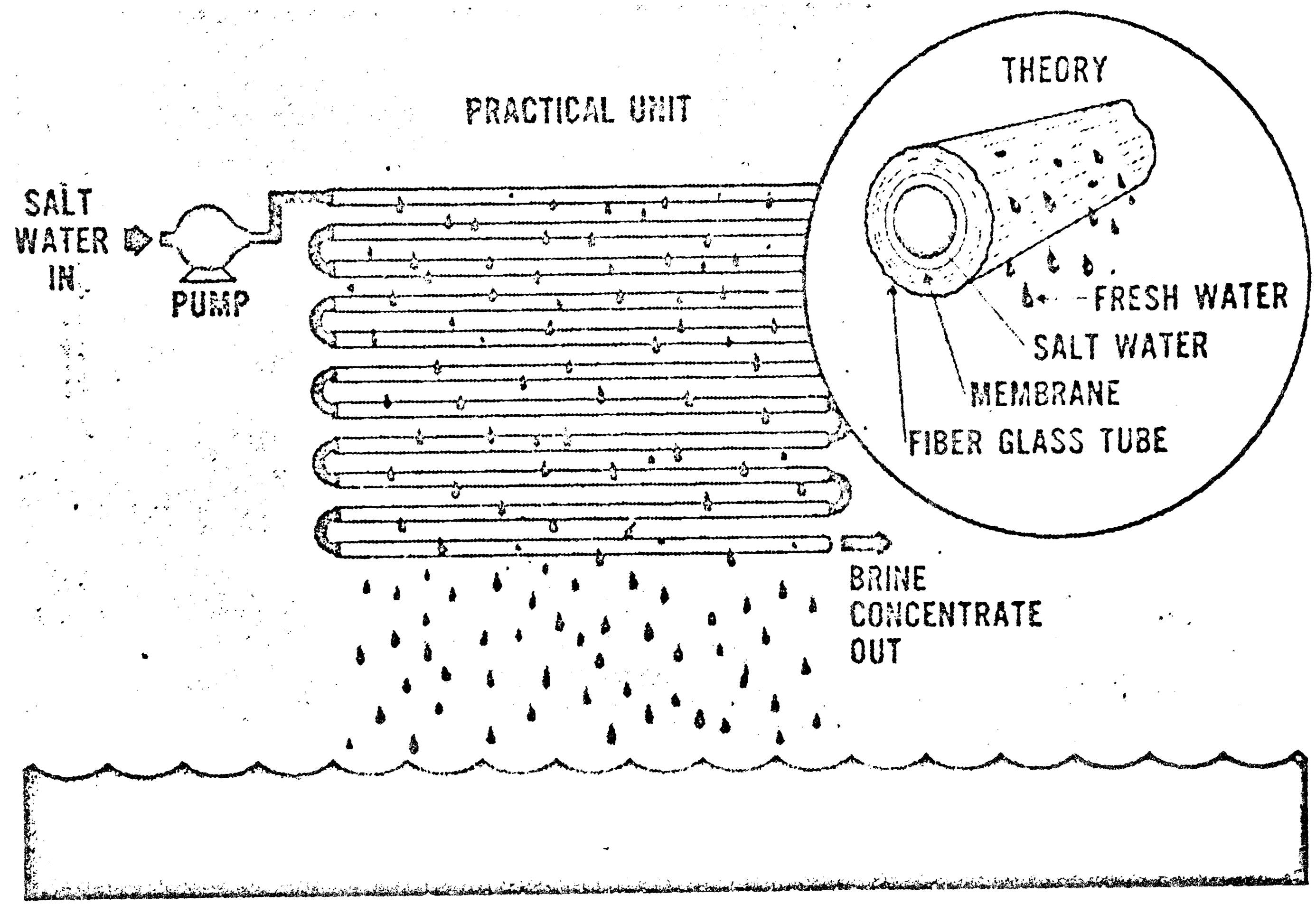
ELECTRODIALYSIS STACK SCHEMATIC

FIGURE 2



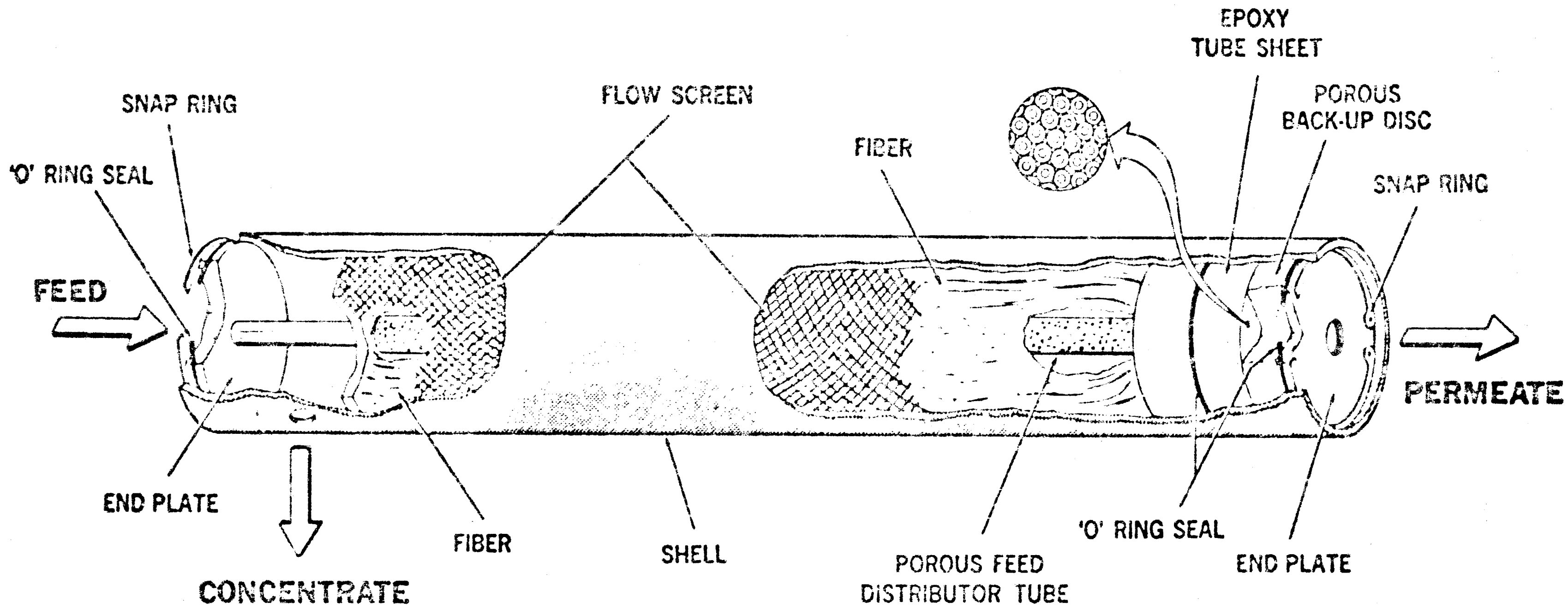
SPIRAL WOUND REVERSE OSMOSIS

FIGURE 3



TUBULAR REVERSE OSMOSIS

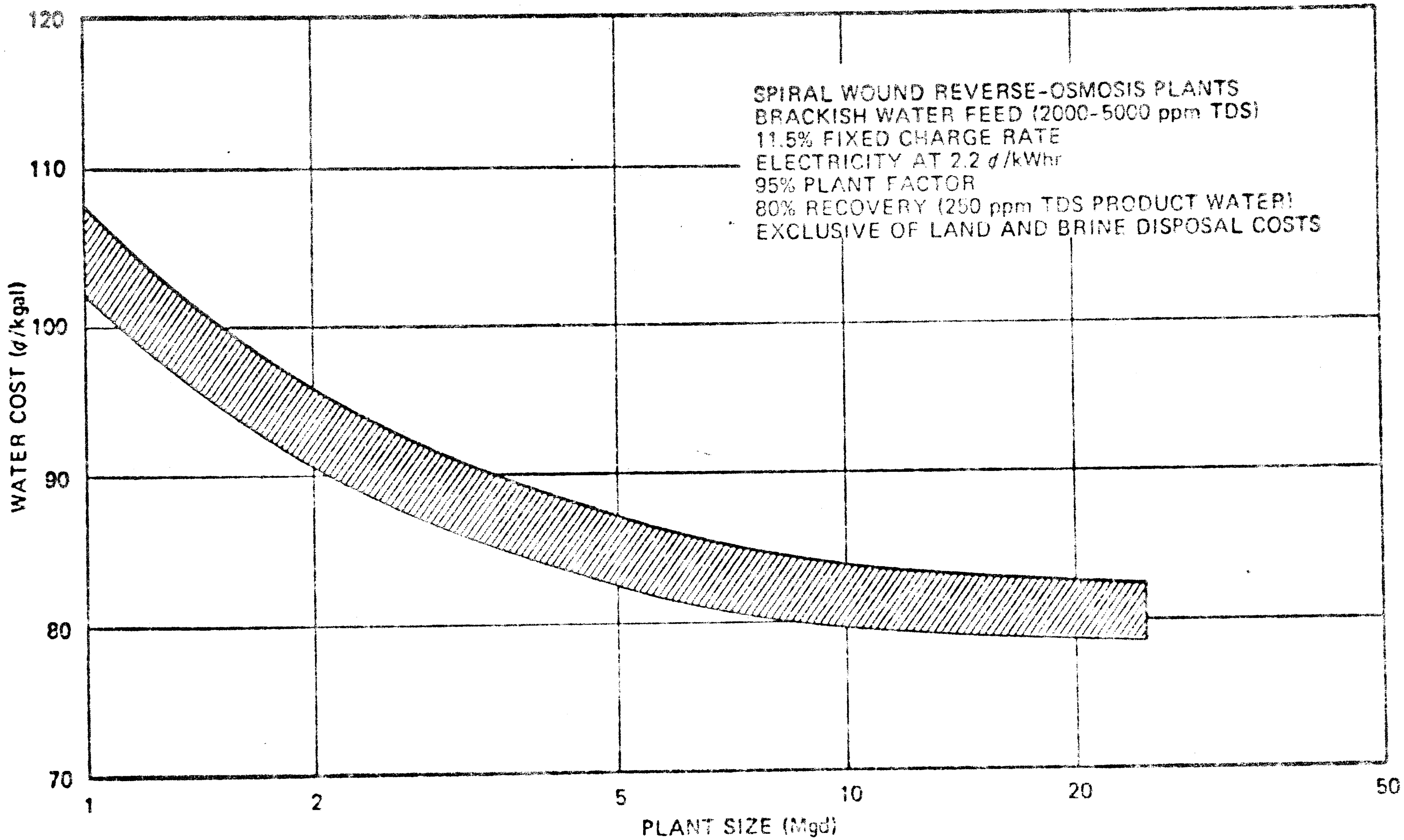
FIGURE 4



CUT AWAY DRAWING OF PERMASEP® PERMEATOR

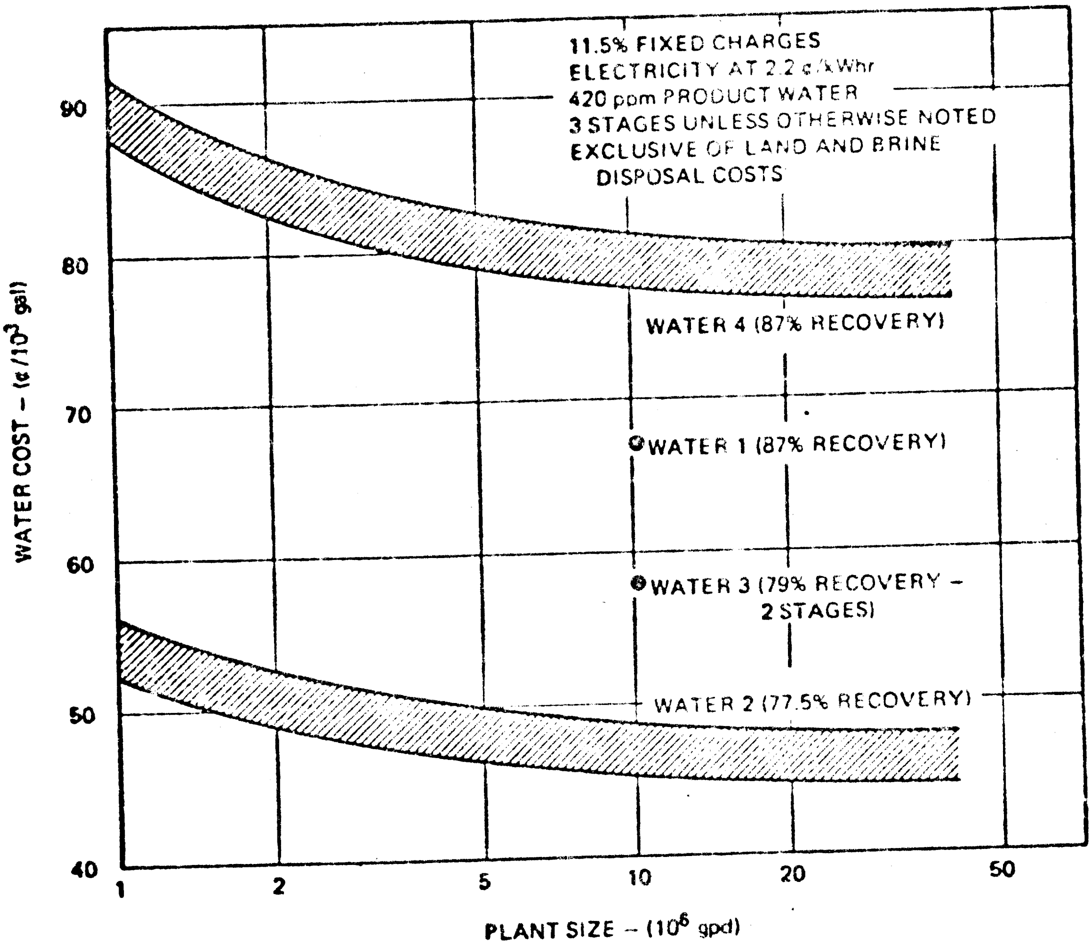
HOLLOW FINE FIBER REVERSE OSMOSIS

FIGURE 5



Water cost as a function of reverse-osmosis plant size.

FIGURE 6



Water cost as a function of feedwater composition and electrolysis plant size.

FIGURE 7

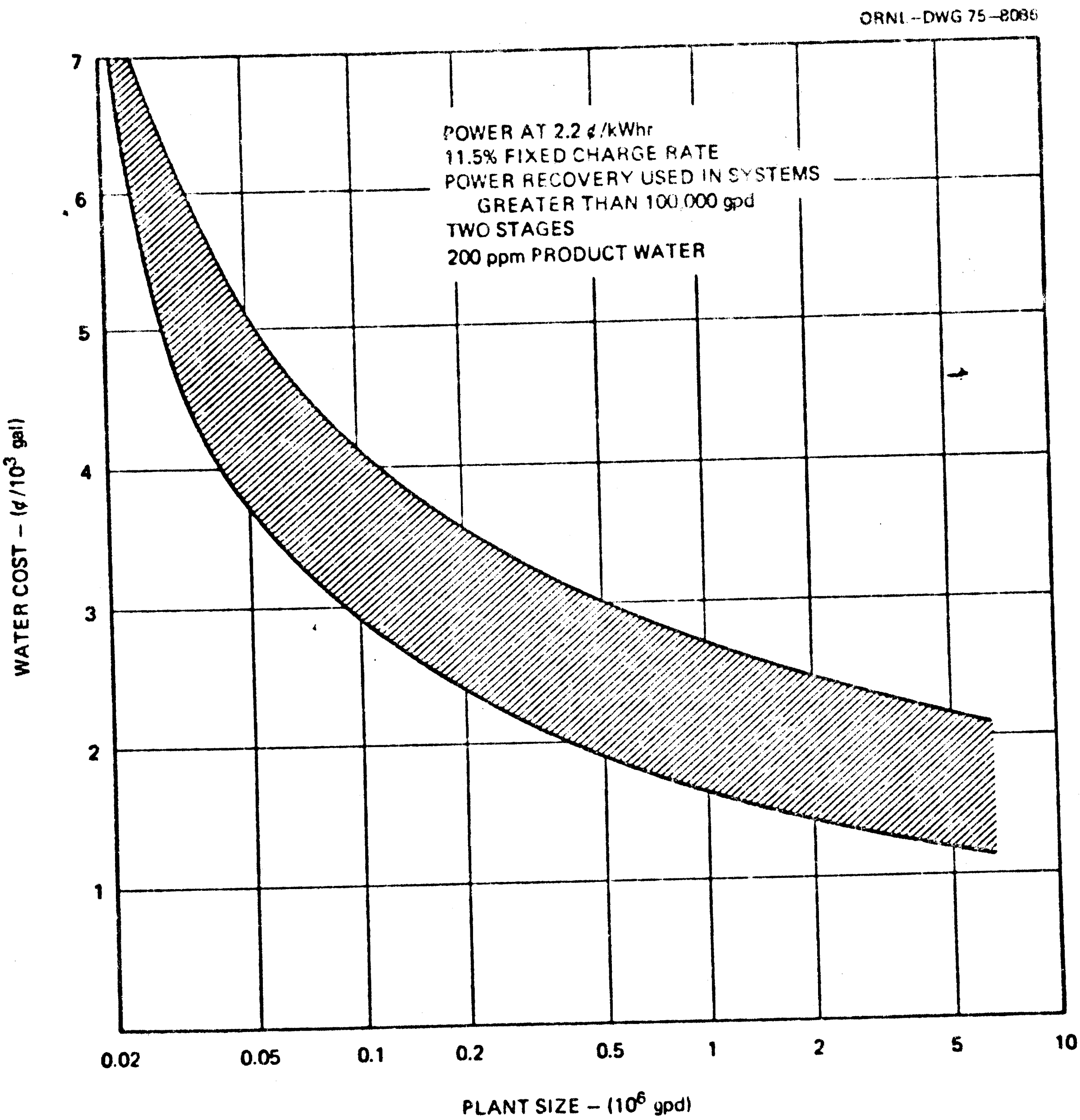


Fig. 8. Estimated cost of desalting sea water via reverse osmosis.

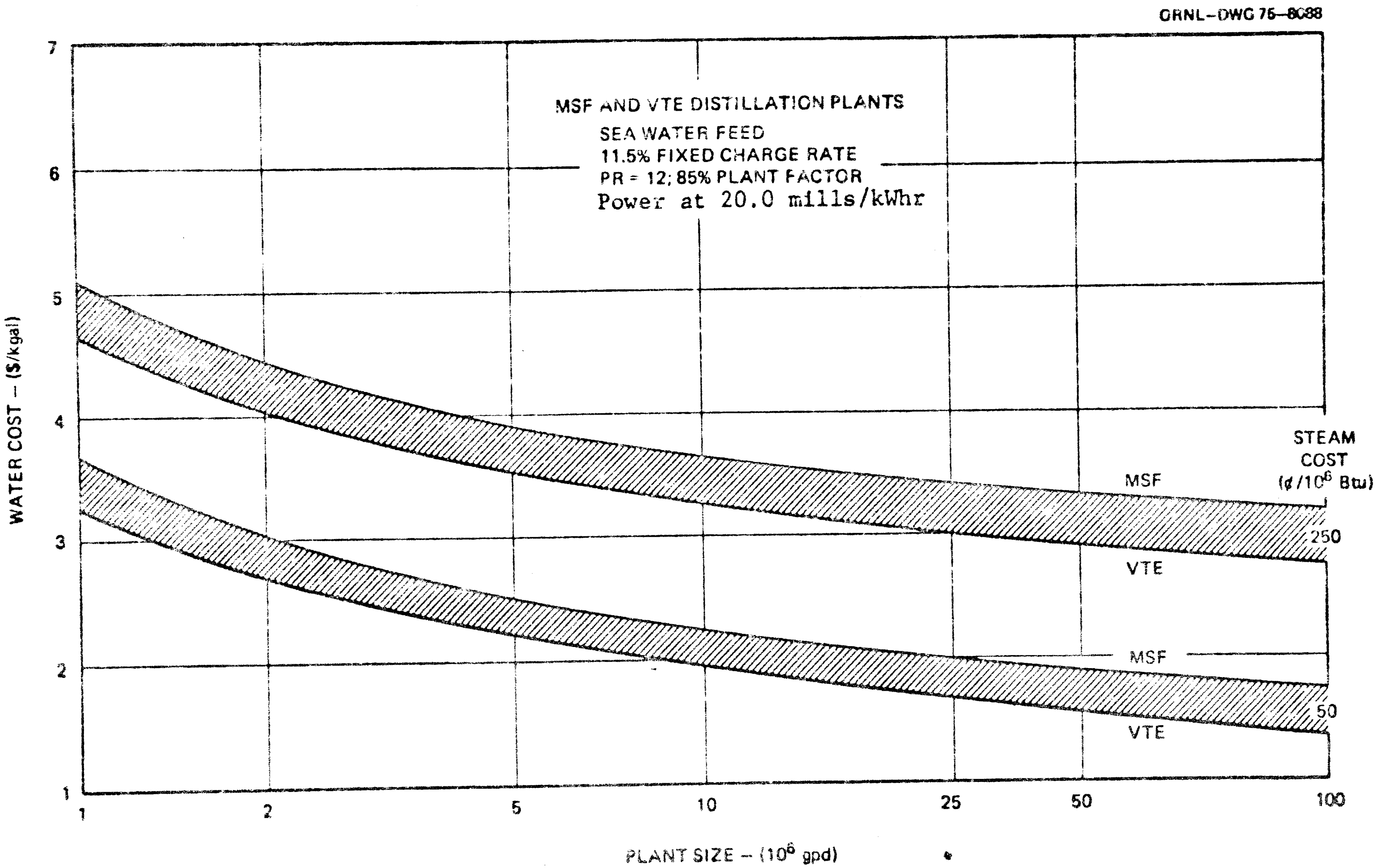
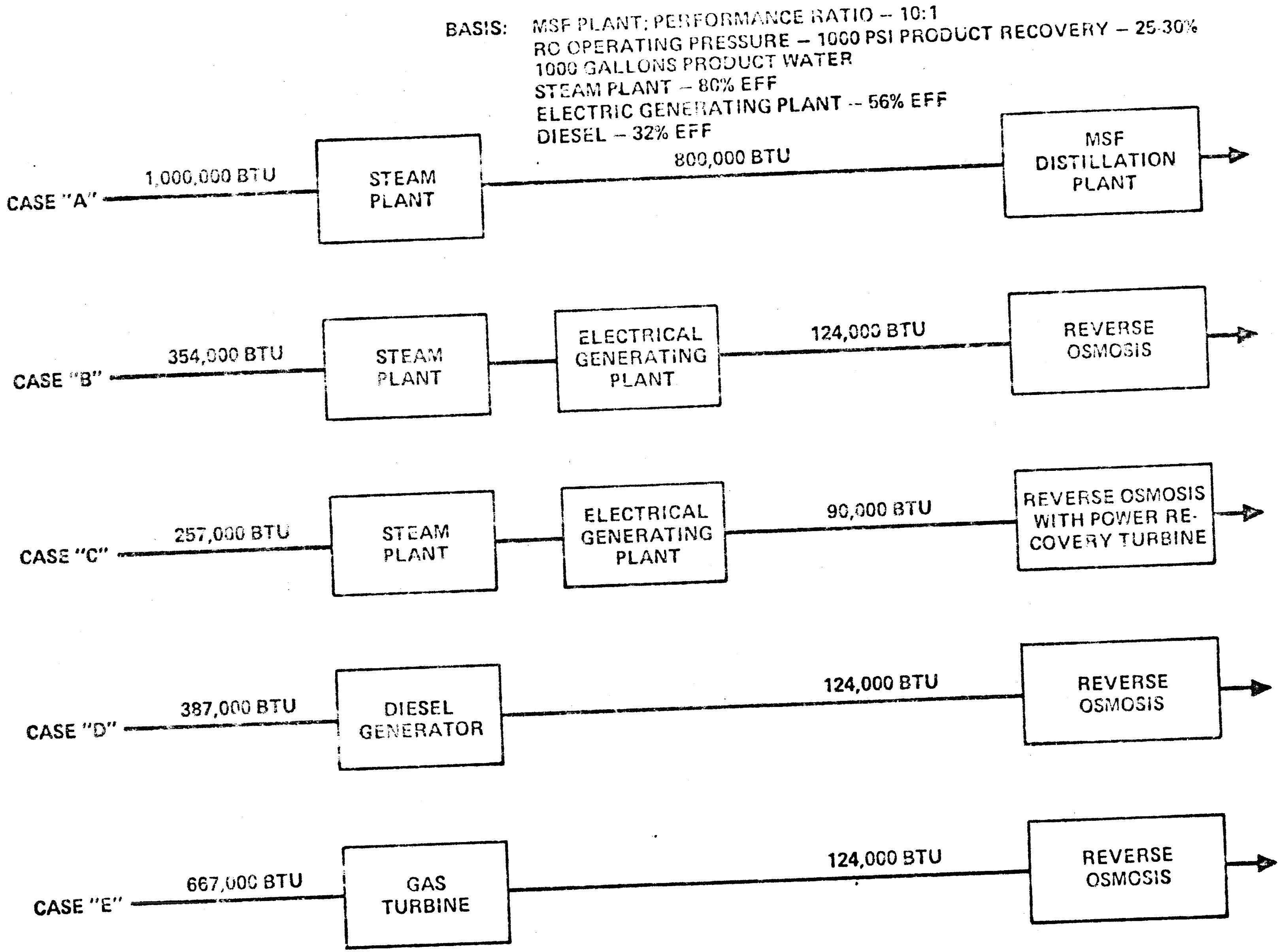
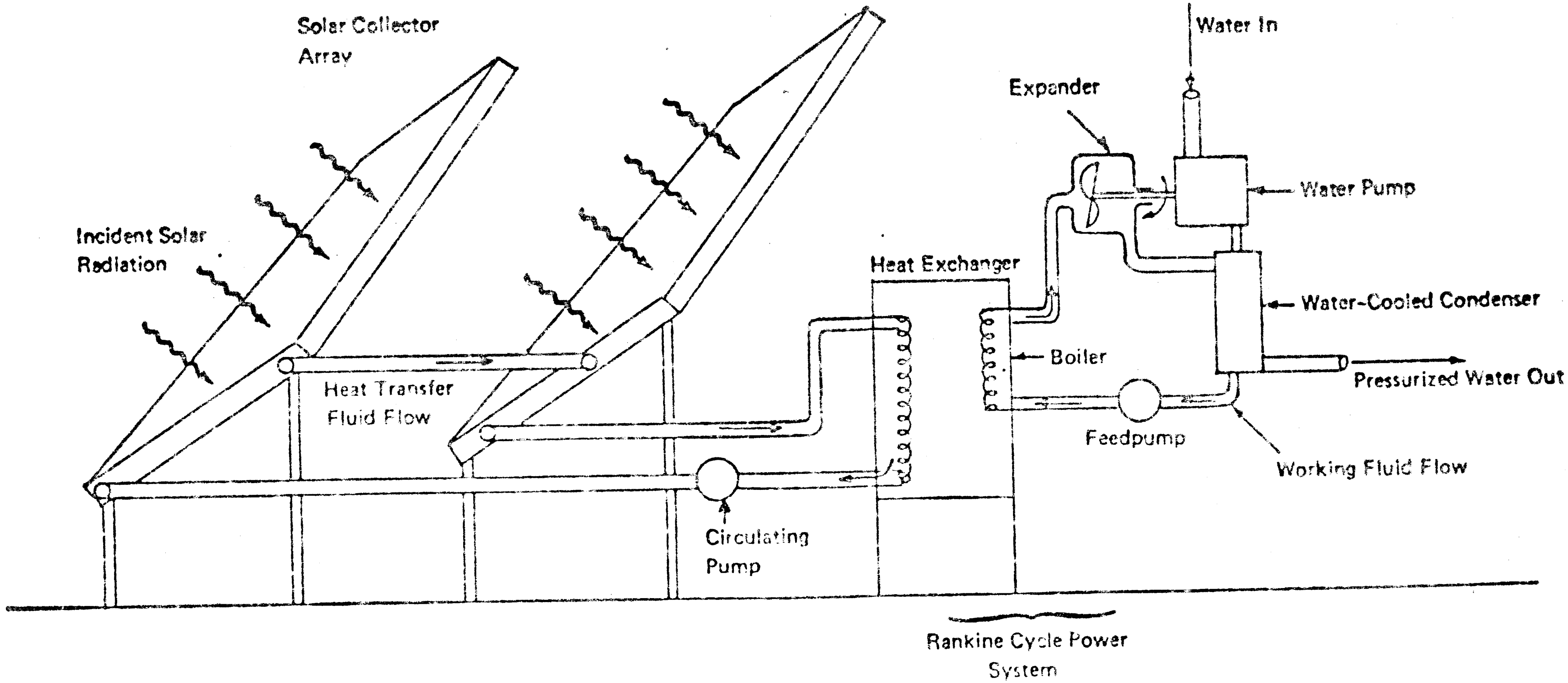


Fig. 9. Water cost as a function of distillation plant size.



RELATIVE ENERGY REQUIREMENTS - CONVERSION OF SEAWATER TO POTABLE WATER

FIGURE 10



SOLAR-POWERED WATER-PUMPING SYSTEM

FIGURE 11

PROJECTED POWER COST FROM HAWT

WIND ENERGY SYSTEMS

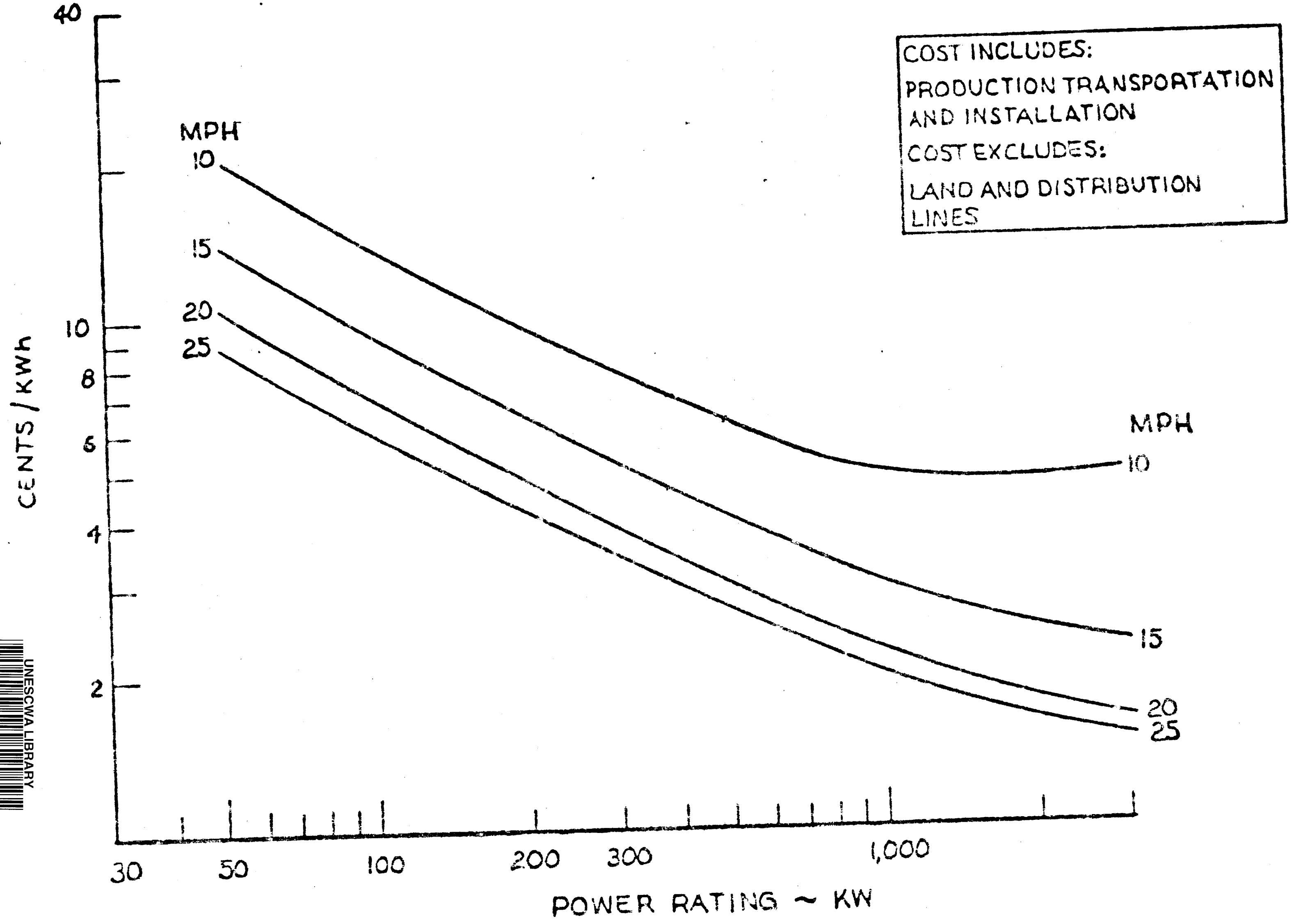
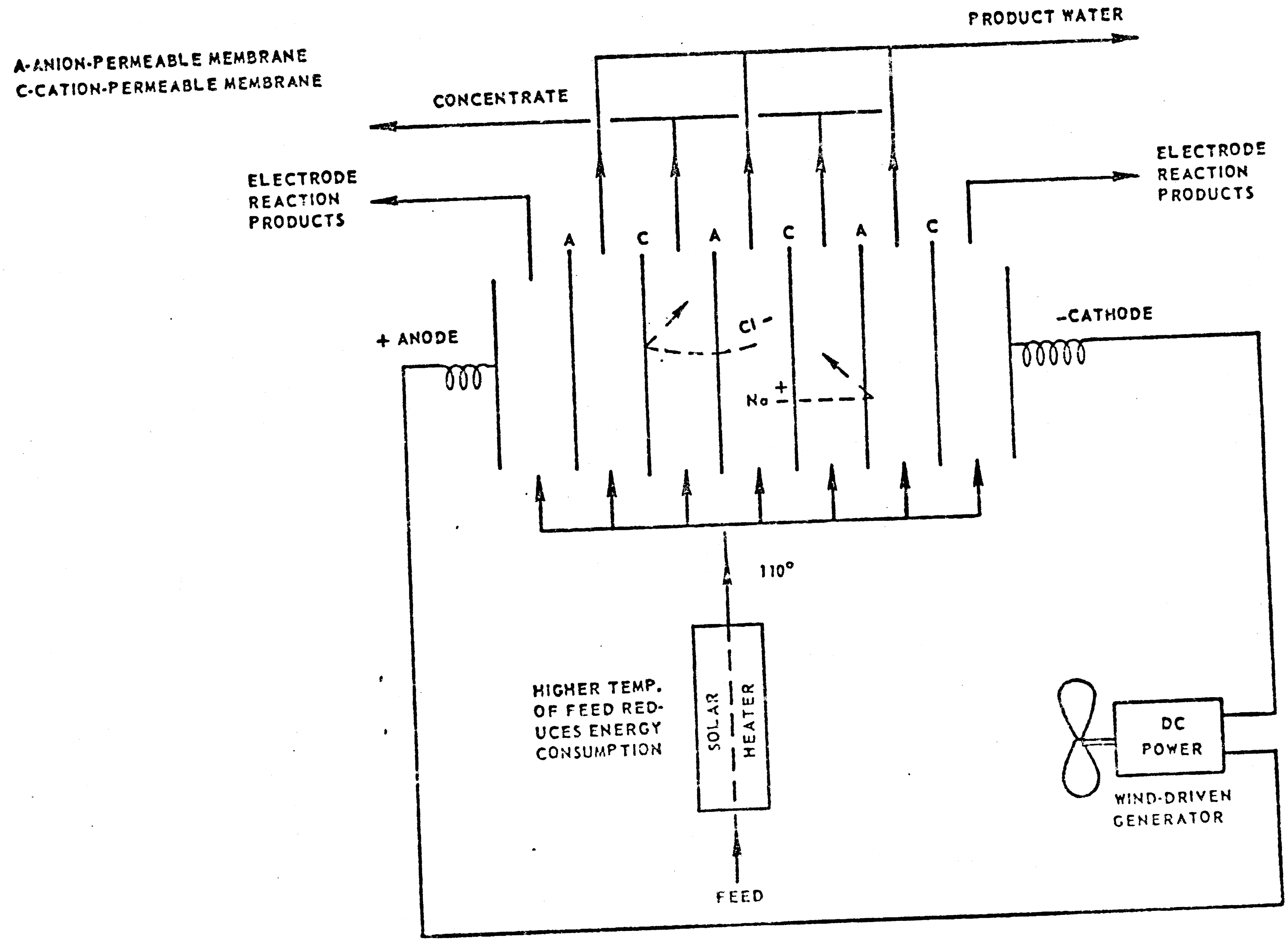
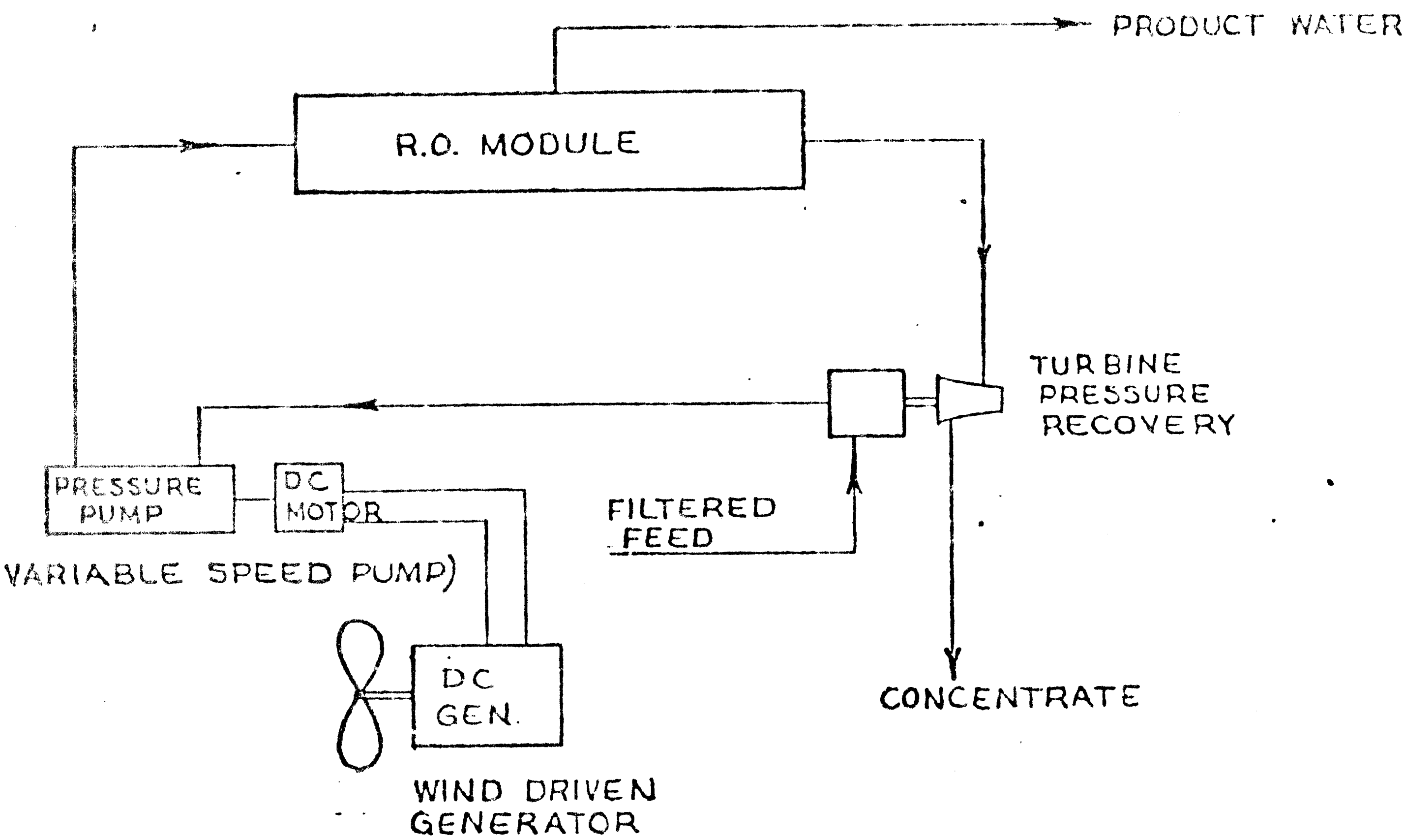


FIGURE 12



CONVENTIONAL ELECTRODIALYSIS WITH WIND POWER

FIGURE 13



CONVENTIONAL REVERSE OSMOSIS WITH WIND POWER

FIGURE 14