المجلس الأعلى لمراكز ومعاهد البحوث
لجنة خدمة الإنتاج والجودة

دراسة تكنولوجيات تحلية المياه وأنسبها لتنمية المناطق النائية

التقرير النهائى

Introduction

The population growth in Egypt is a main reason for the problems facing the development programs in Egypt.

It is well known that 95% of the population in Egypt occupies only 5-6% of the land around the river Nile. There is a must to expand towards the desert and remote areas specially if we know that there are more than 16 million faddans ready for plantation if the water is available.

It is also a well known that the water share per capita in Egypt fell down the minimum limit.

For the above reasons the desalination of saline water, sea or brakish water, has become extremely for the development of the remote areas.

The world has given considerable attention to the development of desalination technologies. Many of them are expensive, or intensive energy consuming and may not be suitable for the applications in desert in Egypt.

This report aims at the assessment of different desalinations technologies in order to help selection and design of the most suitable and most economical desalination system.

Desalination Technologies

The desalination techniques are now expanding but can be classified to two main concepts. Thermal (which means evaporation and condensation), and electrical (which membrane systems such as RO, or electro-dialysis).

In general, a desalting device essentially separates saline water into two streams, one with low concentration of dissolved salts (the fresh water stream) and the other containing the remaining dissolved salts (the brine stream).

The device requires energy to operate and can use a number of different technologies for the separation (desalination).

-Simple operational techniques of thermal desalination, Fig. (1):

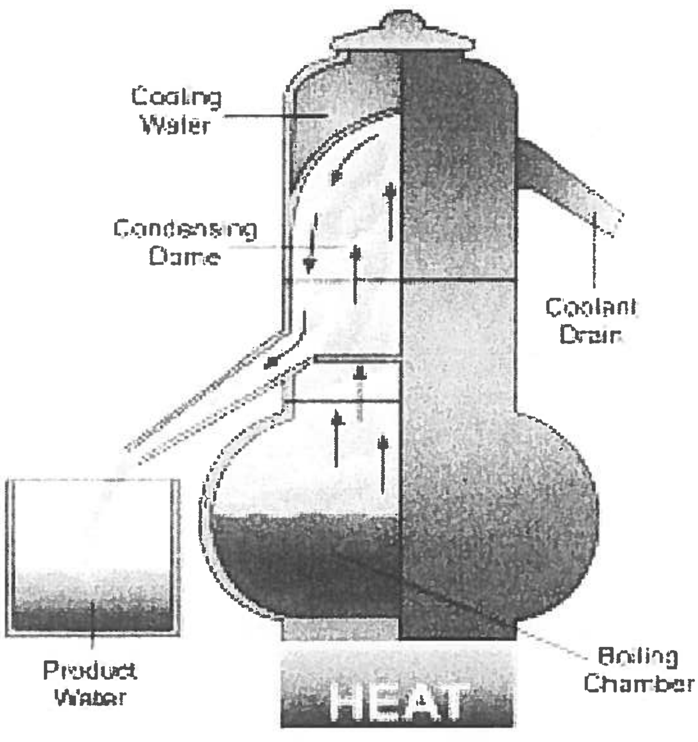

Fig (1): Operational techniques of thermal desalination

An overview of the main desalination process categories, their relationships to one another and desalination technologies (processes) are shown in Figs. (2) & (3) and Table (1).

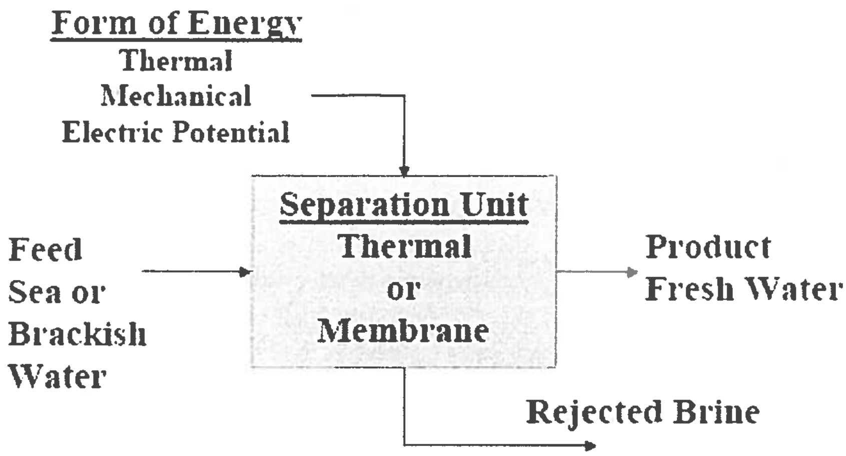

Fig. (2): Desalination process categories.

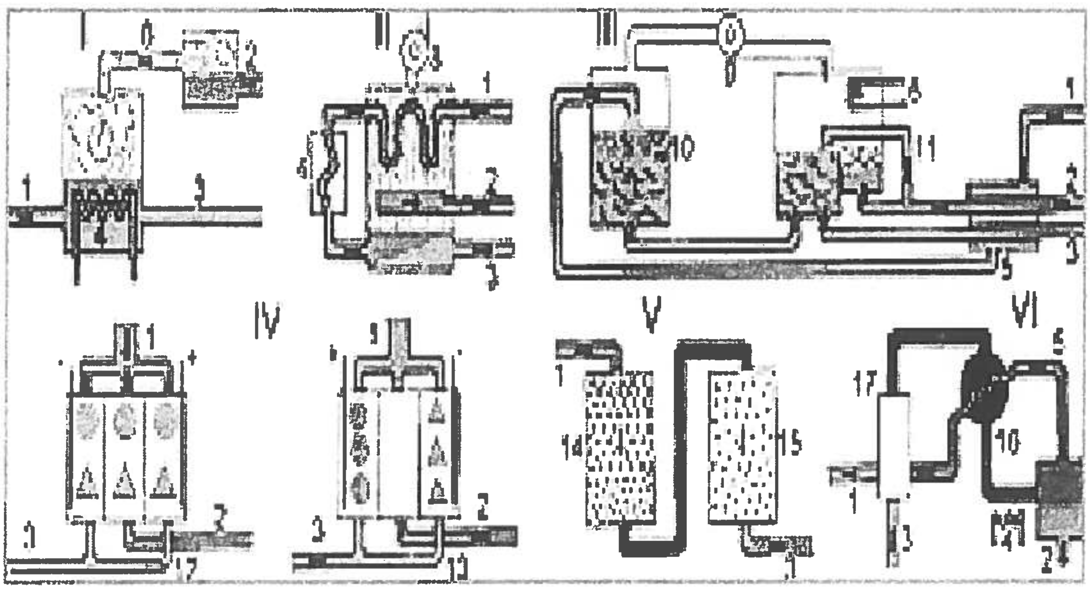

Fig. (3)

I.DISTILLATION II.EVAPORATION III.FREEZING
IV.ELECTRODIALYSIS V.IONIC EXCHANGE VI.EXTRACTION

1. Marine water 2.Fresh water 3.Brine 4.Heater 5.Heat exchanger 6. Refrigerator 7. Steam 8.Vacuum pump 9.Compressor 10. Ice - brine 11. Water for washing of ice 12.Beginning of process 13.End of process 14. Cationic exchanger 15.Ionic exchanger 16. Extract 17. Cold extract - fresh water

Table 1: Desalination Technologies and processes

Thermal Technology	**Membrane Technology**
Multi-Effect Distillation (MED)	**Electro-dialysis (ED)**
Multi-Stage Flash Distillation (MSF)	**Electro-dialysis reversal (EDR)**
Vapor Compression Distillation (VCD)	**Reverse Osmosis (RO)**
Memstill Process	**Memstill Process**

1- Thermal desalination systems

Thermal desalination technologies rely on distillation processes to remove fresh water from salty water.

Saline feed-water is heated until it boils, causing fresh water to evaporate as steam. The steam is then collected and allowed to cool (or condense) to form fresh water. Salt and other contaminants will not evaporate; rather they remain behind in a highly salty solution called brine. The brine solution is considered a waste or by-product of the desalination process and will require disposal.

There are three main thermal desalination technologies, each adopting the above process principle:

-Multistage Flash Distillation

-Multi Effect Distillation

-Vapor Compression Distillation

The above technologies vary generally by the way in which distillation is achieved. These distillation technologies are described in further detail below. The newly emerged type known as MemStill desalination unit is described.

1-1 **Multi-Stage Flash (MSF) methods:**

This process involves the use of distillation through several (multi-stage) chambers. In the MSF process, each successive stage of the plant operates at progressively lower pressures. The feed water is first heated under high pressure, and is led into the first 'flash chamber', where the pressure is released, causing the water to boil rapidly resulting in sudden evaporation or 'flashing'. This 'flashing' of a portion of the feed continues in each successive stage, because the pressure at each stage is lower than in the previous stage. The vapor generated by the flashing is converted into fresh water by being condensed on heat exchanger tubing that run through each stage. The tubes are cooled by the incoming cooler feed water. Generally, only a small percentage of the feed water is converted into vapor and condensed.

Multi-stage flash distillation plants have been built since the late 1950s. Some MSF plants can contain from 15 to 25 stages, but are usually no larger than 15 mgd in capacity. MSF distillation plants can have either a 'once-through' or 'recycled' process. In the 'once-through' design, the feed water is passed through the heater and flash chambers just once and disposed of, while in the recycled design, the feed water for cooling is recycled. Each of these processes can be structured as a 'long tube' or 'cross tube' design. In the long tube design (built at Freeport in 1961), tubing is parallel to the concentrate flow, while in the cross tube design, tubing is perpendicular to the concentrate flow.

MSF plants are subject to corrosion unless stainless steel is used extensively. In addition to corrosion, MSF plants are also subject to erosion and impingement attack (U.S. Bureau of Reclamation, 2003). Erosion is caused by the turbulence of the feed water in the flash chamber, when the feed water passes from one stage to another.

Distillation processes produce about 3.4 billion gpd globally, which is about 50 percent of the worldwide desalination capacity. MSF plants provide about 84 percent of that capacity. Most of those plants have been built overseas, primarily in the Middle East, where energy resources have been plentiful and inexpensive.

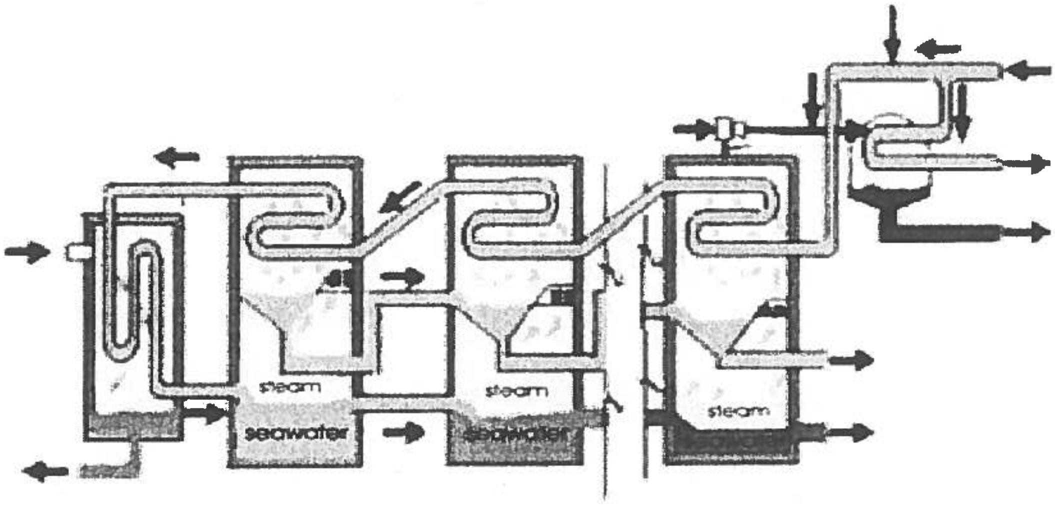

Fig. (4): Multi-Stage Flash distillation system

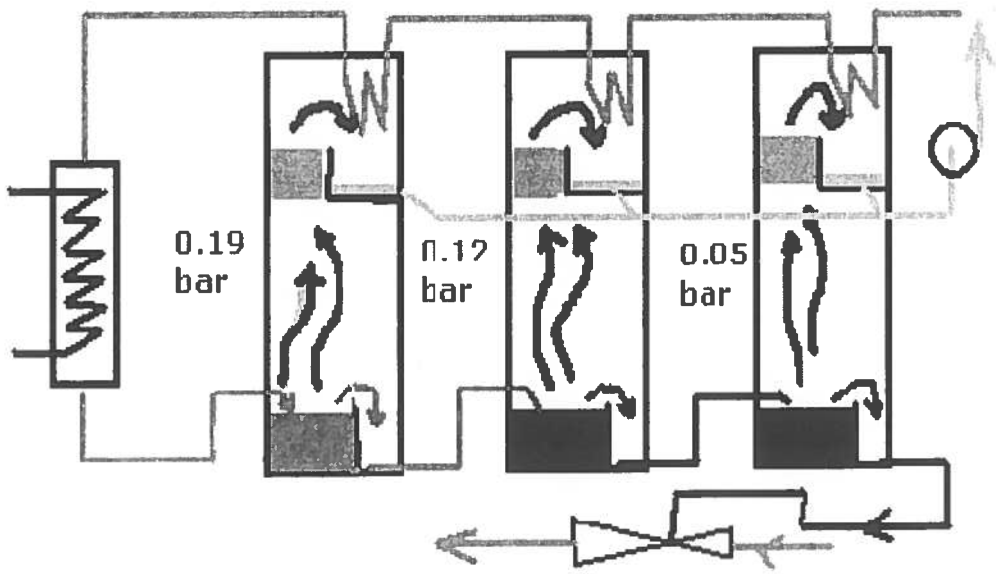

Fig. (5): Multi-Stage Flash (MSF) desalination process

Multi-Stage Flash Distillation involves the heating of seawater in a container known as a brine heater. This is usually achieved by condensing steam on a bank of tubes carrying seawater through the brine heater. Thus heated, the water is passed to another container known as a "stage", where the surrounding pressure is lower than that in the brine heater.

It is the sudden introduction of this water into a lower pressure "stage" that causes it to boil so rapidly as to flash into steam. As a rule, only a small percentage of this water is converted into steam.

Consequently, it is normally the case that the remaining water will be sent through a series of additional stages, each possessing a lower ambient pressure than the previous "stage".

As vapor steam is generated, it is condensed on tubes of heat exchangers that run through each stage.

1-2 **Multiple-Effect (MED) thin film still,**

The heat provided by exhaust of the fuel cell of the PEM type, is usually at a temperature of 80-100 °C. Other types of fuel cells produce heat as high as 800 °C, but we will choose the first-type which is sufficient for operating both MED and MSF stills.

This range of temperature can also obtain easily by solar collector, or from the waste heat in power plant.

The Multiple-Effect Still (ME) was first suggested by Dunkle (1961), which was able to give better productivity per unit area than the old known roof-type still.

Moreover, improvement of the productivity may be possible because the optimization conflict of heat collection and rate of condensation is eliminated.

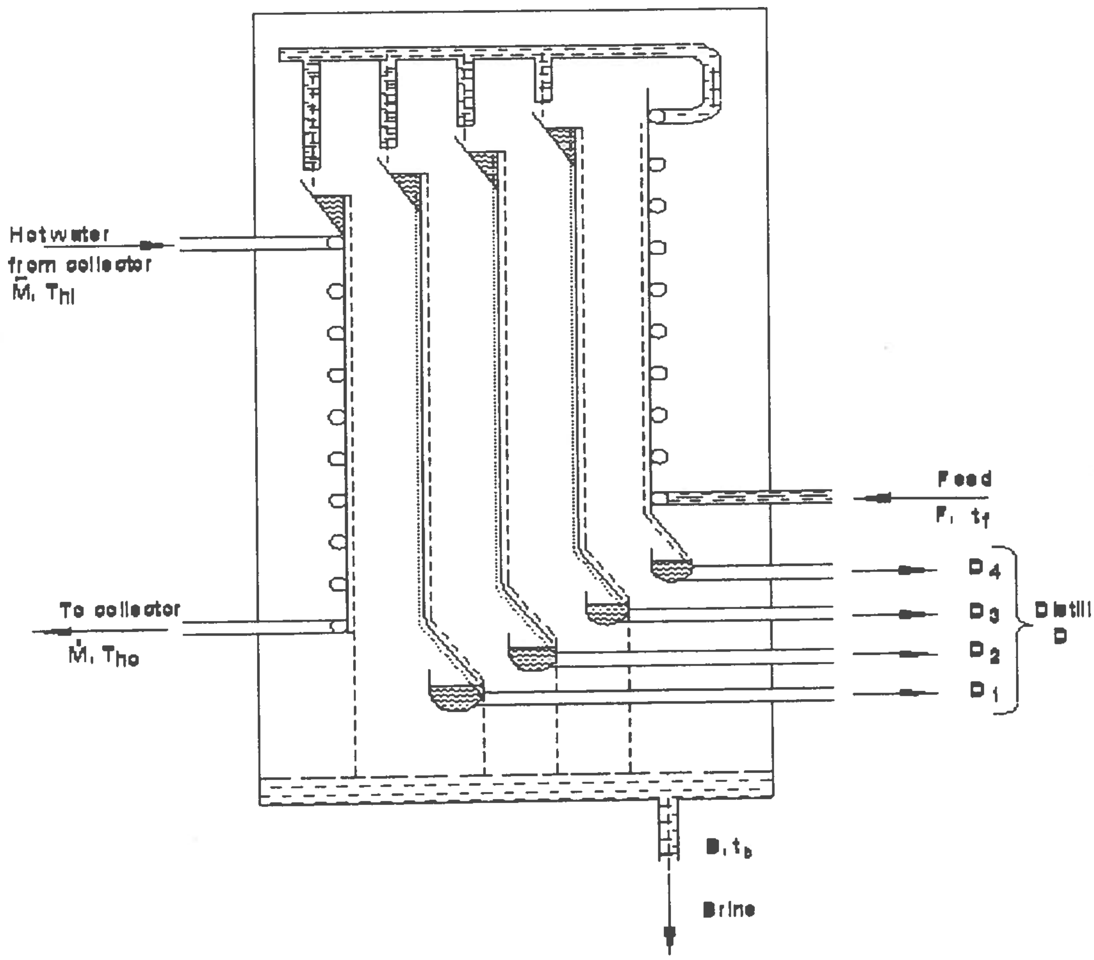

Fig. (4): Diagrammatic sketch of the multiple-effect diffusion principle

Dunkle (1961) presented an approximate steady state analysis for the diffusion still and tired to verify his analysis by experimental work (not very accurate, He used approximate relations to predict the heat and mass transfer rates between any two successive plates. No consideration was given in calculating the heat and mass transfer rates to transient conditions. The effects of the plate's temperatures, flow rates over the different plates, heat loss from the still, and the ambient temperatures had been also abandoned. No detailed measurements were made to examine the performance of the still. The only reported measurements were for the product of each effect and its approximate temperature (without referring to the method of measurement).

Although the ME diffusion still appears to be very promising as a better substitute for the roof-type still, no detailed study have ever been made to support this promise and to test the performance of the still. In addition basic information necessary to design such stills is not available and real need to develop such information exists. Data for basic process of heat and mass transfer between any two parallel plates, which represents a single effect in the still, is lacking. Answers are not known for many questions such as:

1-What are the effects of distance between two successive plates

2- What is the effect of changing the plate's temperatures on the productivity of the still?

1- How can one improve the amount of water transferred from one plate to the other?

2- What is the temperature distribution between any two successive plates?

3- What is the transient performance of the plates?

4- The main purpose of the present project is to give answers to these questions. Also, the projects may compare this method of desalination to other desalination methods such as multi-flash, reverse osmosis, vapor compression,……ect. Moreover, the project may arrive to a conclusion concerning the economic value of the multi-effect diffusion still and feasibility of its commercial option.

El-Sayed (1982) has designed and tested a Multiple-Diffusion still. His work was limited to the rate of production of the still with no correlation to the theoretical model.

In this work, the design parameters will be considered and compared in order to reach the optimal design suitable for the proposed application.

The new innovation in the design of the Multiple-Effect Diffusion (MED) still includes the following:

- A plurality of closely spaced parallel heat transfer plates spaced one half inch or less apart defining a vapor chamber having opposed evaporating and condensing faces.
- The plates being disposed at an angle to the horizontal to enable gravity flow of liquid along said faces from the upper end to the lower end.
- A method for feeding a thin film or liquid onto said evaporating face adjacent the upper end and a predetermined controlled rate.
- Establishing a heat flux across said heat transfer plates at a rate for effecting evaporation of at least a portion of liquid passing along the face for establishing a stable continuous evaporating face and condensation of vapor onto condensing face.
- A way for separately collecting said condensate at the lower edge of said plates.
- The system including means for establishing less than atmospheric pressure in the chamber.

The system plates are disposed at an angle of between 30 degree, and 90 degree, from the horizontal and means for establishing a heat flux comprises a solar heat collection panel including one of the plates.

- A method for maintaining the thin film comprises a plurality of parallel ribs extending between the top and the bottom of the plates.

1-3 Multiple Effect Distillation (MED):

A Multi Effect Desalination MED unit is an evaporator where seawater is evaporated in one or more (up to 14) evaporation stages at low temperature ($< 70°C$) in order to produce clean distillate water.

MED process is designed to produce **distilled water** with steam or waste heat from power production or chemical processes, and/or to produce **potable water.**

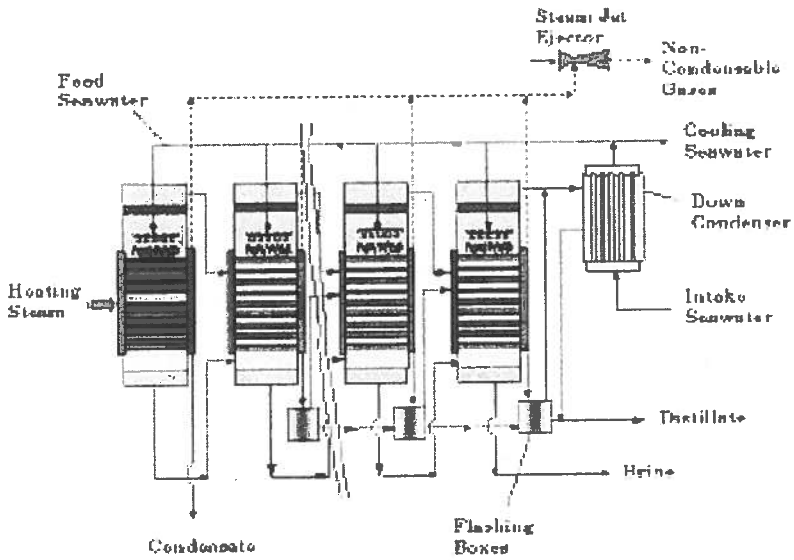

Fig. (): Parallel feed multiple effect distillation

-Case studies

1- Multiple Effect Distillation with Thermal Vapour Compression

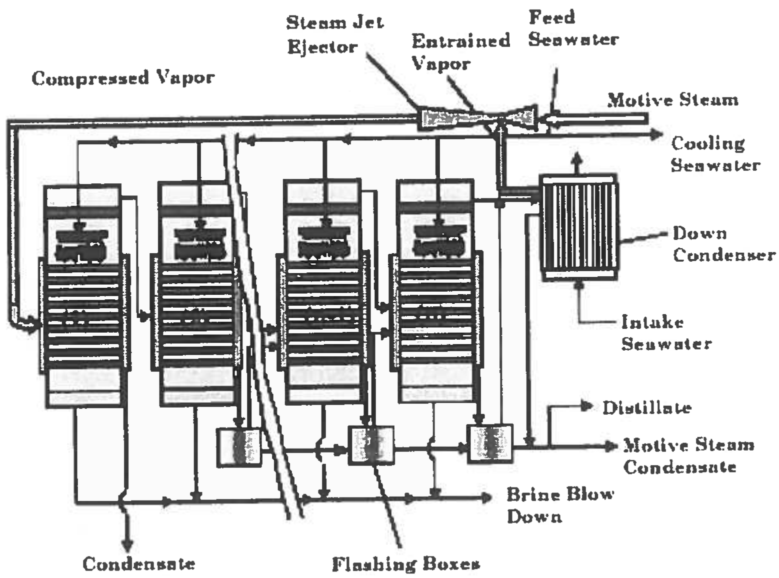

Fig. (): Parallel feed multiple effect distillation with thermal vapor compression

2- Multiple Effect Distillation with Mechanical Vapour Compression

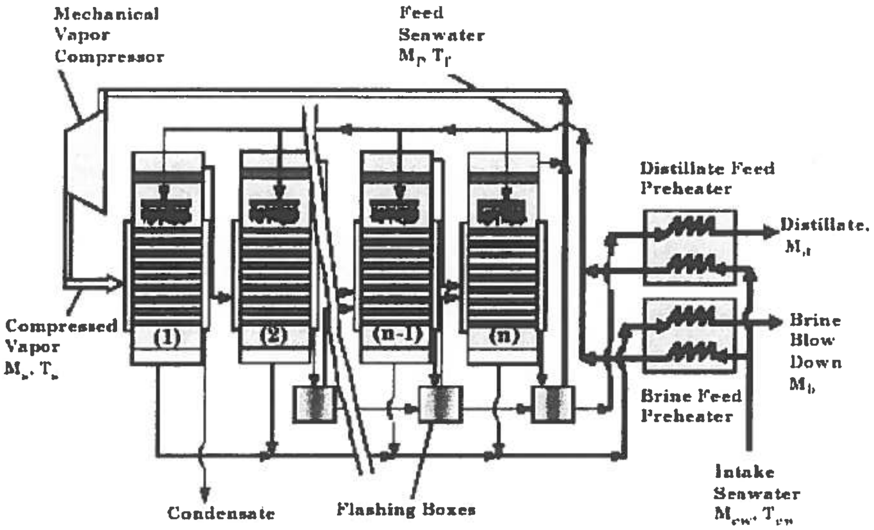

Fig. (): Multiple effect distillation with mechanical vapour compression

1-3 Multiple-Effect Evaporator method

A multiple-effect evaporator is an apparatus for efficiently using the heat of steam to evaporate water. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the last. Because the boiling point of water decreases as pressure decreases, the vapor boiled off in one vessel can be used to heat the next, and only the first vessel (at the highest pressure) requires an external source of heat. While in theory, evaporators may be built with an arbitrarily large number of stages, evaporators with more than four stages are rarely practical.

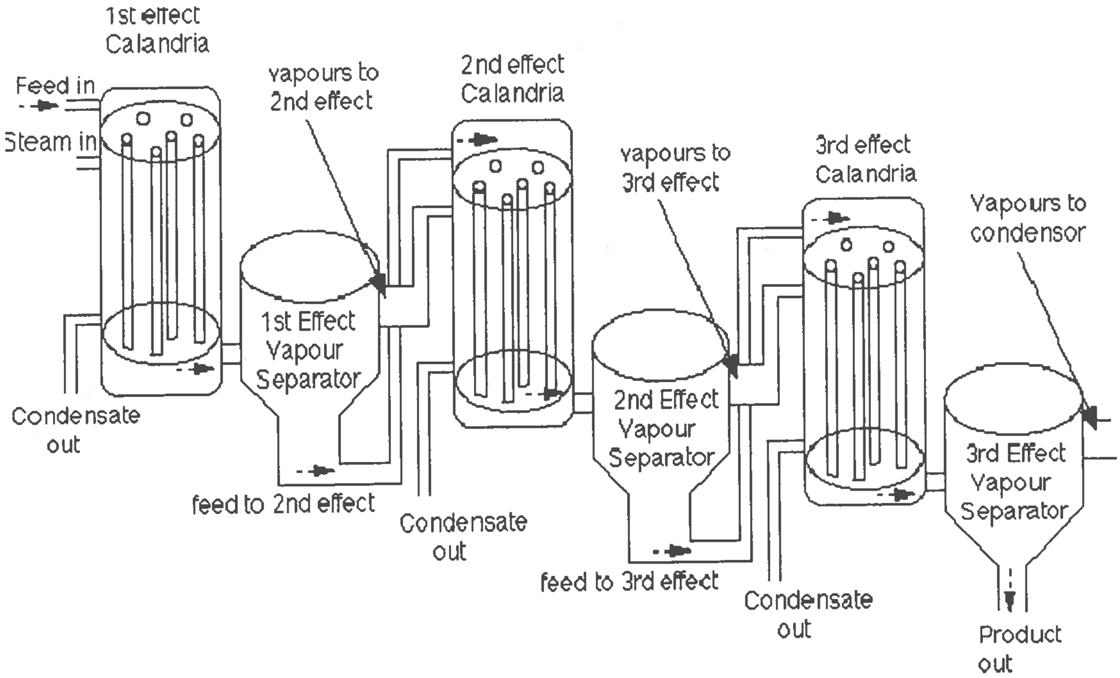

Fig. (7): Multiple Effect Evaporators

1-4 Vapor Compression Process (VC):

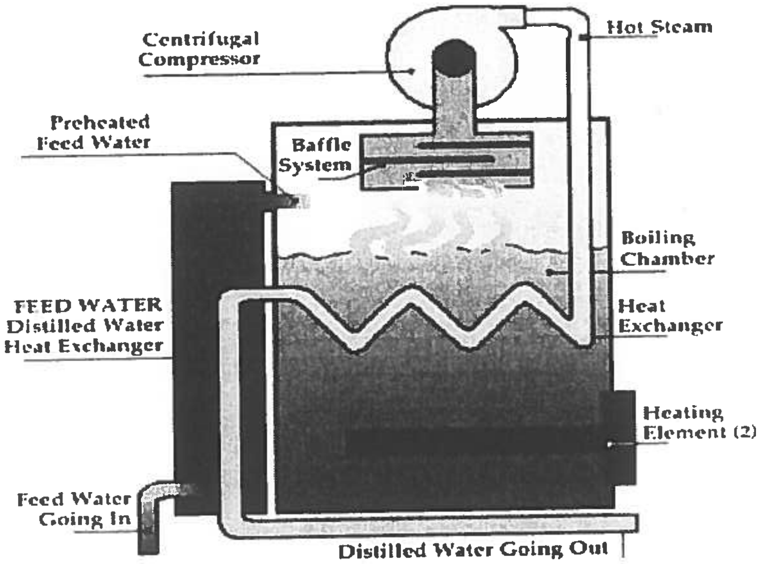

Fig. (8): Vapor Compression (VC) process.

In (VC) processes, water vapor from salty feed water is collected and compressed, thereby condensing the vapor. The heat from evaporating the saline feed water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler.

The main components of the (VC) system are the evaporator, pumps, the heat exchanger and the compressor.

In this process, the feed water enters the evaporators, where it is heated to its boiling point and some of it is evaporated. The vapor goes to the compressor, where the pressure and consequently the saturation temperature are raised.

The (VC) distillation process is generally used in small- and medium-scale sea water desalting units. (VC) units are usually built for capacities ranging from 20 to 2000 m^3 /day. They appear to be particularly suitable for tourist resorts, industrial plants, and oil drilling and mining sites where fresh water is not readily available.

2- Non-thermal Desalination systems:

2-1 Reverse Osmosis (RO) unit:

In relation to thermal processes, Reverse Osmosis (RO) is a relatively new process that was commercialized in the 1970s (Buros, 2000). Currently, RO is the most widely used method for desalination in the United States. The RO process uses pressure as the driving force to push saline water through a semi-permeable membrane into a product water stream and a concentrated brine stream. Nano-filtration (NF) is also a membrane process that is used for removal of divalent salt ions such as Calcium, Magnesium, and Sulphate. RO, on the other hand, is used for removal of Sodium and Chloride. RO processes are used for desalinating brackish water (TDS>1,500 mg/l), and seawater. The process is explained below:

Osmosis is a natural phenomenon by which water from a low salt concentration passes into a more concentrated solution through a semi-permeable membrane. When pressure is applied to the solution with the higher salt concentration solution, the water will flow in a reverse direction through the semi-permeable membrane, leaving the salt behind. This is known as the Reverse Osmosis process or RO process.

An RO desalination plant essentially consists of four major systems:

a) Pretreatment system b) High-pressure pumps

c) Membrane systems d) Post-treatment

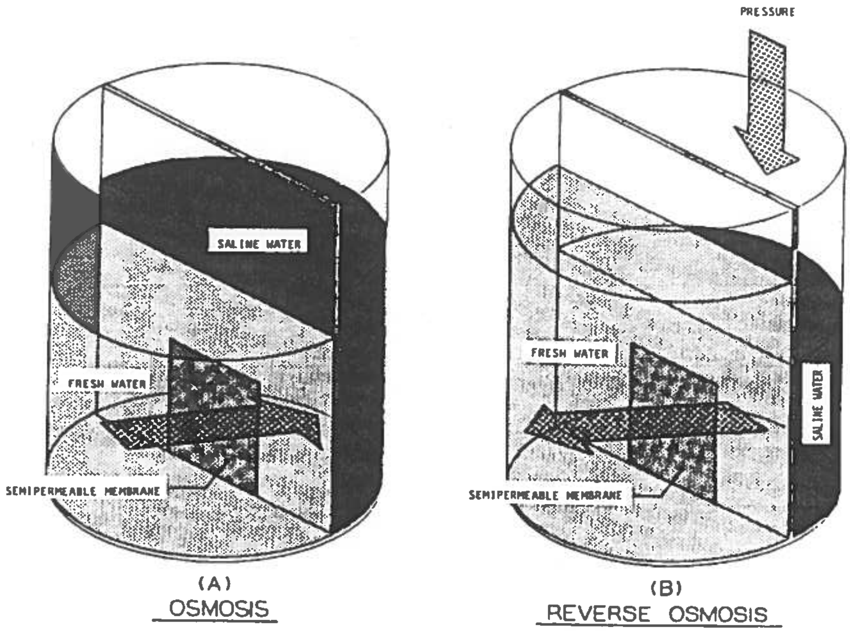

Fig. (9): Reverse osmosis principles.

Pre-treatment is very important in RO because the membrane surfaces must remain clean. Therefore, all suspended solids must be first removed, and the water pre-treated so that salt precipitation or microbial growth does not occur on the membranes.

Pre-treatment may involve conventional methods such as a chemical feed followed by coagulation/flocculation/sedimentation, and sand filtration, or pretreatment may involve membrane processes such as micro-filtration (MF) and ultra-filtration (UF). The choice of a particular pre-treatment process is based on a number of factors such as feed water quality characteristics, space availability, RO membrane requirements, etc.

High pressure pumps supply the pressure needed to enable the water to pass through the membrane and have the salt rejected. The pressures range from about 150 psi for slightly brackish water to 800 - 1,000 psi for seawater.

The membrane assembly consists of a pressure vessel and a semi-permeable membrane inside that permits the feed water to pass through it. RO membranes for desalination generally come in two types: Spiral wound and Hollow fiber. Spiral wound elements are actually constructed from flat sheet membranes.

Membrane materials may be made of cellulose acetate or of other composite polymers. In the spiral wound design, the membrane envelope is wrapped around a central collecting tube. The feed water under pressure flows in a spiral path within the membrane envelope, and pure (desalinated) water is collected in the central tube.

As a portion of the water passes through the membrane, the remaining feed water increases in salt content. A portion of the feed water is discharged without passing through the membrane. Without this discharge, the pressurized feed water would continue to increase in salinity content, causing super-saturation of salts.

The amount of feed water that is discharged as concentrate ranges from about 20 percent for brackish water to about 50 percent for seawater.

- Reverse Osmosis methods:

Reverse osmosis uses pressure on solutions with concentrations of salt to force fresh water to move through a semi-permeable membrane, leaving the salts behind, Fig. (2-5). The amount of desalinated water that can be obtained ranges between 30% and 85% of the volume of the input water, depending on the initial water quality, the quality of the product, and the technology and membranes involved.

An RO system is made up of the following basic components: pretreatment, high-pressure pump, membrane assembly, and post-treatment. Pretreatment of feed water is often necessary to remove contaminants and prevent fouling or microbial growth on the membranes, which reduces passage of feed water. Pretreatment typically consists of filtration and either the addition of chemicals to inhibit precipitation or efficient filtering to remove solids. A high-pressure pump generates the pressure needed to enable the water to pass through the membrane.

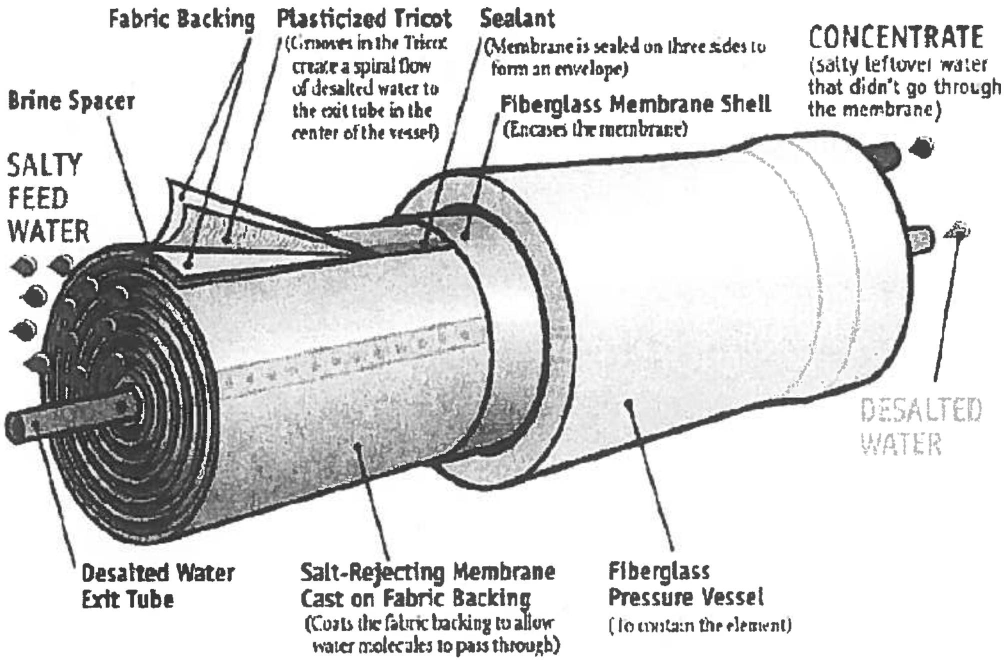

Fig. (10): Reverse-Osmosis Desalination membrane.

The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the semi-permeable membranes. The membranes are fragile and vary in their ability to pass fresh water and reject salts. RO membranes are made in a variety of configurations. The two most commercially successful membrane configurations are spiral wound and hollow-fine fiber. Post-treatment prepares final product water for distribution, removes gases such as hydrogen sulfide, and adjusts pH.

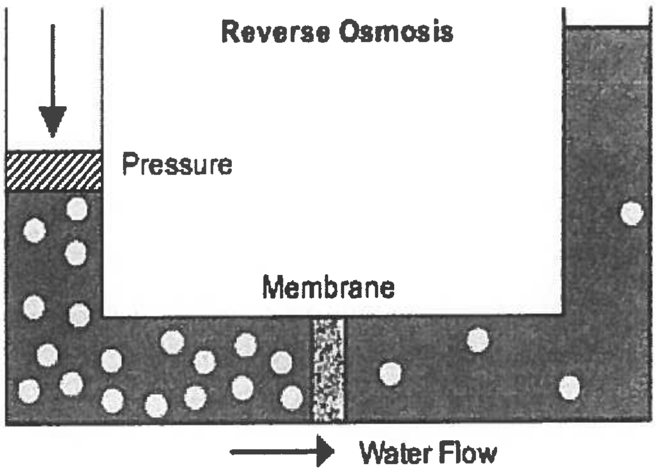

Fig. (11): Reverse Osmosis process.

The energy requirement for RO depends directly on the concentration of salts in the feed water. Because neither heating nor phase change is necessary for this method, pressurizing the feed water accounts for the major use of energy. As a result, RO facilities are most economical for desalinating brackish water and increase in cost as the salt content of the water increases.

RO has become a relatively mature technology and membrane approaches are experiencing fast growth. Some of the largest new desalination plants under construction and in operation use RO membranes. The largest RO plant in the world desalinates seawater for municipal purposes with a capacity of 100 million gallons per day (MGD), or 395,000 cubic meters per day (m^3/d) (Wang nick/GWI 2005). Among the needed improvements in RO systems are better pretreatment of feed water to reduce the use of chemicals that often end up in the brine and cause a disposal problem; improved membranes that are more durable and increase the flux of pure water; new approaches to reduce befouling in membranes; more effective energy recovery and use; and development of less expensive materials.

2-2 Membrane Distillation methods:

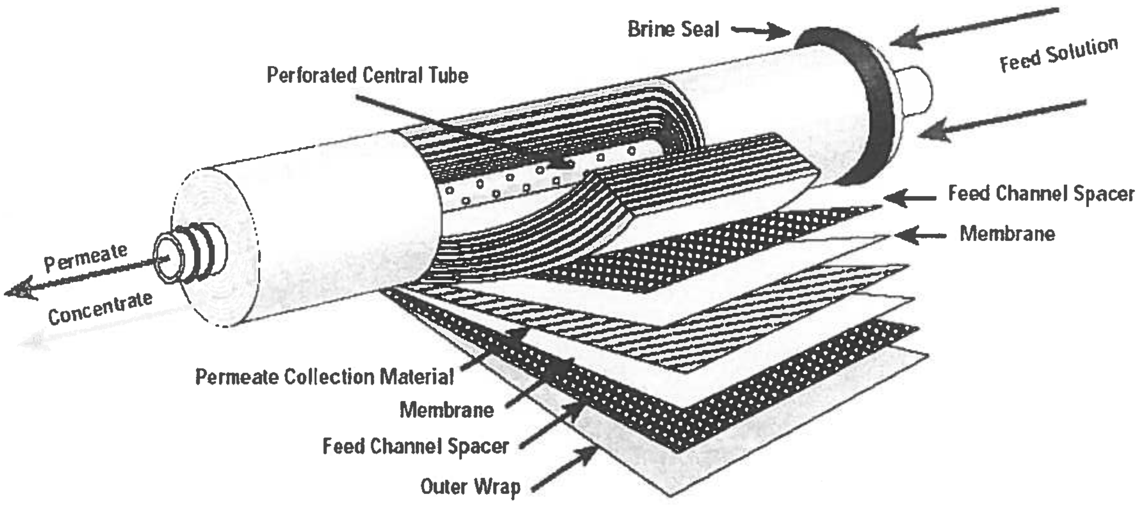

Fig. (12): Spiral Membrane

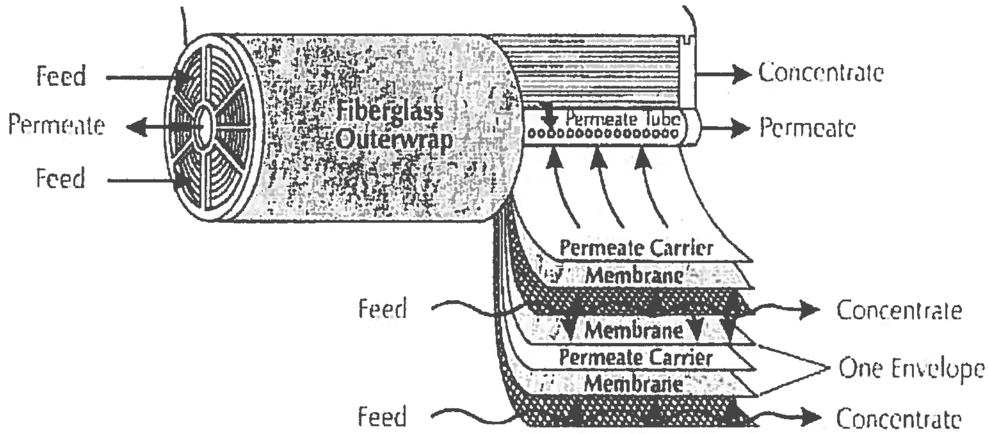

Fig. (13): Section of spiral Membrane

It is possible to concentrate aqueous solutions of non-volatile dissolved substances by micro porous membranes impermeable for water but permeable for water vapor. Driving force for this "membrane distillation" is a vapor pressure difference on both sides of the membrane due to a corresponding temperature gradient across the membrane.

The distillation is performed at ambient pressure and at a maximum temperature of 80°C (175°F). Operating costs are extremely low because the process can be driven by low temperature heat sources e.g. solar heat or waste heat from diesel engines. The system is employing spiral wound desalination modules. Inside the distillation modules a thin micro porous hydrophobic PTFE-membrane is used with pore diameters between 0.051 and 0.2m. This material shows the surprising property of allowing easy passage of water vapor, but of completely blocking the flow of liquid water. The high surface tension of water prevents the passage of liquid water through the sub-micron pores up to a pressure of typically 0.5MPa (72.5psi). In the process one surface (hot side) of the flat sheet membrane is in contact with the process solution while the opposite surface (cold side) is in contact with distillate.

Thus the diffusion gap between evaporating and condensing surfaces is reduced to the thickness of the membrane that is only about 30 mm. With an actual pore fraction of 80% high specific evaporation rates are possible. The recovery of the heat of condensation is done by utilizing the heat of condensation to preheat the feed water.

2-3 Osmotic pressure:

When a semi-permeable membrane that will pass solvent is placed between two solutions of different concentrations containing the same solvent at identical temperatures, the solvent must pass from the less concentrated to the more concentrated solution as shown in Fig. (8).

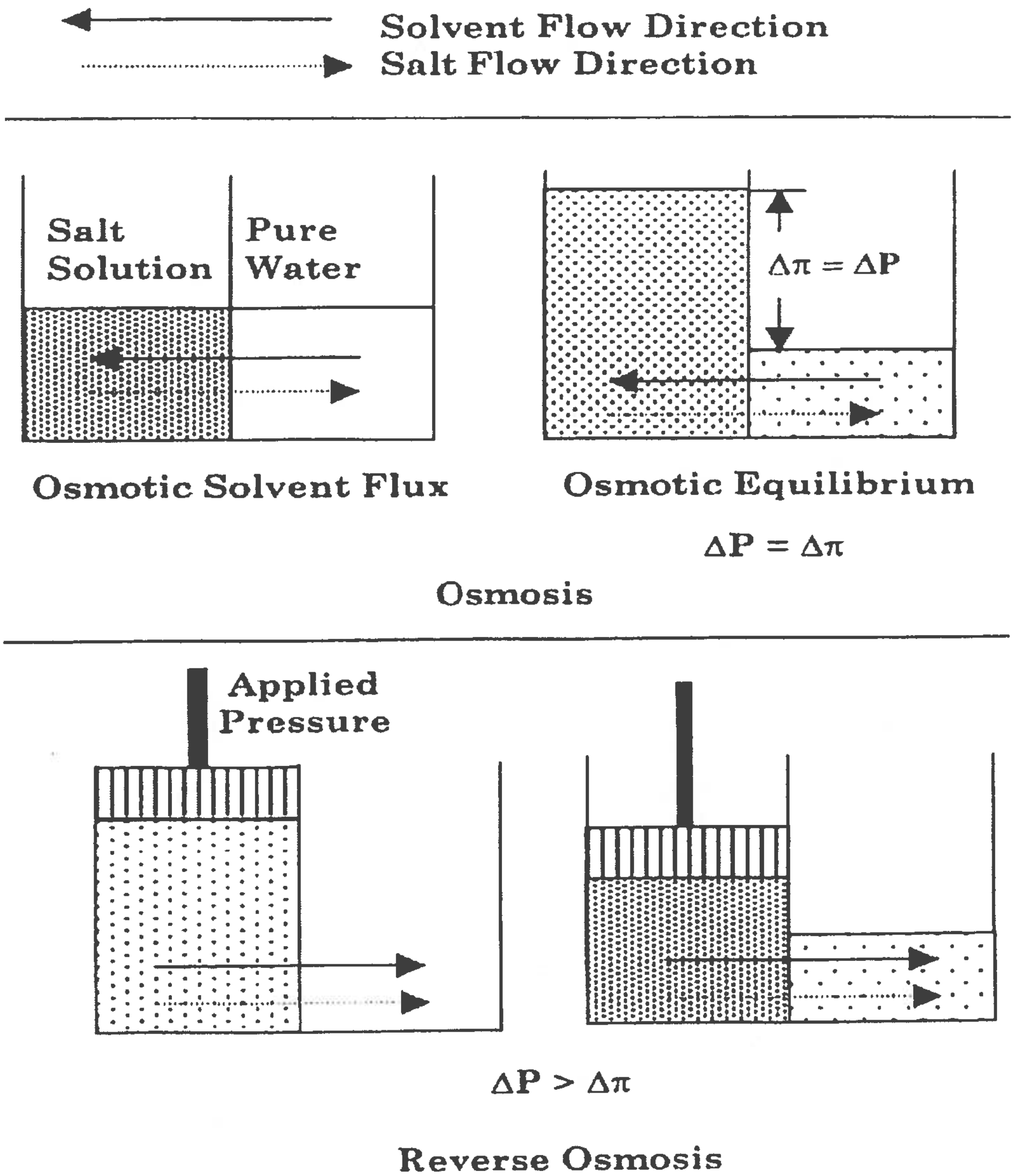

Fig. (14): Reverse Osmosis vs. Osmosis

- Reverse Osmosis processes

- Pre-treatment
- Improved flux rate
- Improved rejection – Boron
- Fouling resistance
- Energy consumption
- Flow distribution
- Chlorine resistance
- Larger diameter modules

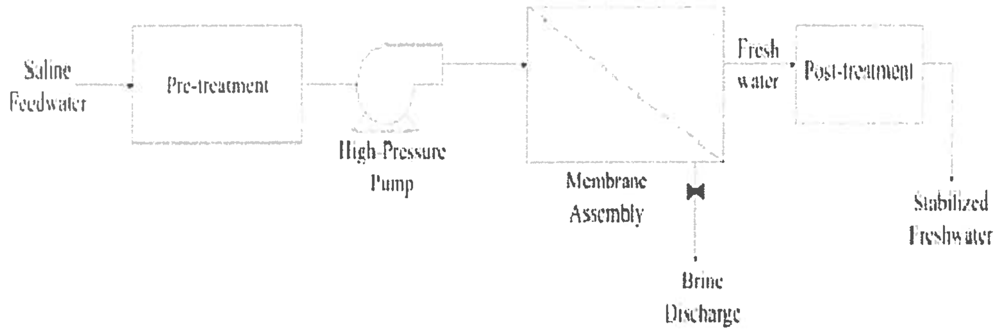

Fig. (15): Basic components of a reverse osmosis

2-4 Forward osmosis (FO):

This proposal presents an extensive review of Forward Osmosis (FO) and closely related membrane processes. The review begins with an introduction of the basic principles of the FO process, including comparison to other closely related processes. Special aspects of mass transport in the process as well as the membranes used for the process are described. Strengths and limitations of the FO process in a broad spectrum of applications are reviewed and discussed. And last, the future of FO technology is considered.

Osmotic processes

Classification of osmotic processes

Osmosis is the transport of water across a selectively permeable membrane from a region of higher water chemical potential to a region of lower water chemical potential. It is driven by a difference in solute concentrations across the membrane that allows passage of water, but rejects most solute molecules or ions. Osmotic pressure (π) is the pressure which, if applied to the more concentrated solution, would prevent transport of water.

A schematic drawing of the novel ammonia–carbon dioxide (FO) process is illustrated in Fig. (8). Water is extracted from seawater and dilutes the ammonia–carbon dioxide draw solution.

Upon moderate heating (near 60 ∘C), the draw solution decomposes to ammonia and carbon dioxide. Separation of the fresh product water from the diluted draw solution can be achieved by several separation methods (e.g., column distillation or membrane distillation (MD)). The degasified solution left behind is pure product water and the distillate is a re-concentrated draw solution available for reuse in the (FO) desalination process.

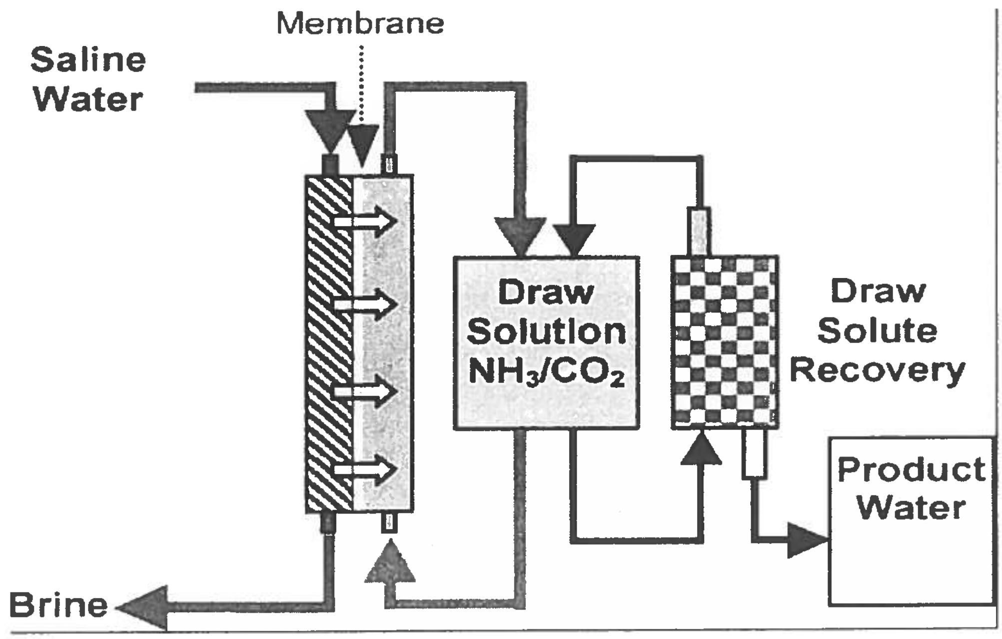

Fig. (15): Schematic drawing of the novel ammonia–carbon dioxide Forward Osmosis (FO) process

The main advantages of using (FO) are that it operates at low or no hydraulic pressures, it has high rejection of a wide range of contaminants, and it may have a lower membrane fouling propensity than pressure-driven membrane processes.

Because the only pressure involved in the (FO) process is due to flow resistance in the membrane module (a few bars), the equipment used is very simple and membrane support is less of a problem. Furthermore, for food and pharmaceutical processing, (FO) has the benefit of concentrating the feed stream without requiring high pressures or temperatures that may be detrimental to the feed solution. For medical applications, (FO) can assist in the slow and accurate release of drugs that have low oral bioavailability due to their limited solubility or permeability.

2-5 Membrane distillation:

It is a combination of thermal and membrane technologies, where water vapor, usually produced as a result of the application of low grade energy, is separated and collected through a membrane. Commercially it is of little significance.

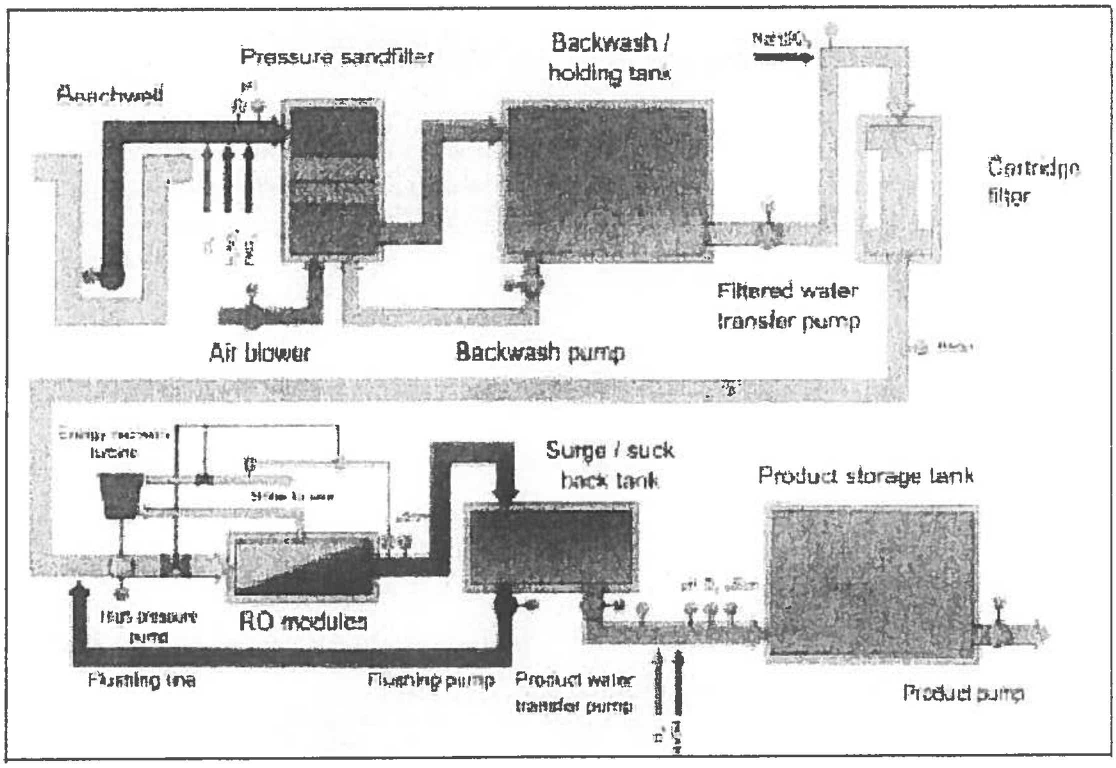

Fig. (16): Membrane distillation process

2-6 Electro-dialysis (ED) Desalination:

Electro-dialysis (ED) is a voltage-driven membrane process. An electrical potential is used to move salts through a membrane, leaving fresh water behind as product water. ED was commercially introduced in the 1960s, about 10 years before reverse osmosis (RO), Although ED was originally conceived as a seawater desalination process, it has generally been used for brackish water desalination.

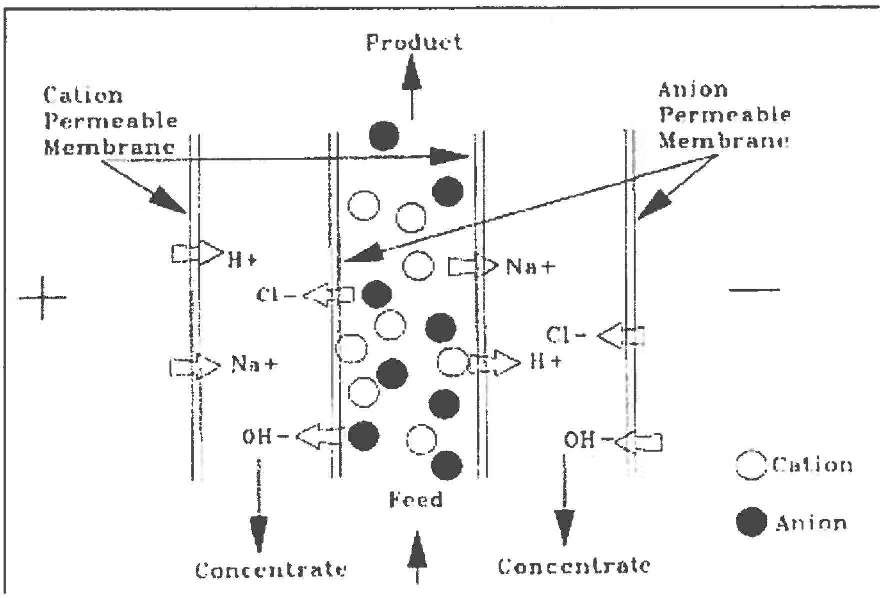

Fig. (16): Ion transport in electro-dialysis

ED depends on the following general principles:

- Most salts dissolved in water are ions, either positively charged (cations), or negatively charged (anions).
- Since like poles repel each other and unlike poles attract, the ions migrate toward the electrodes with an opposite electric charge
- Suitable membranes can be constructed to permit selective passage of either anions or cations.

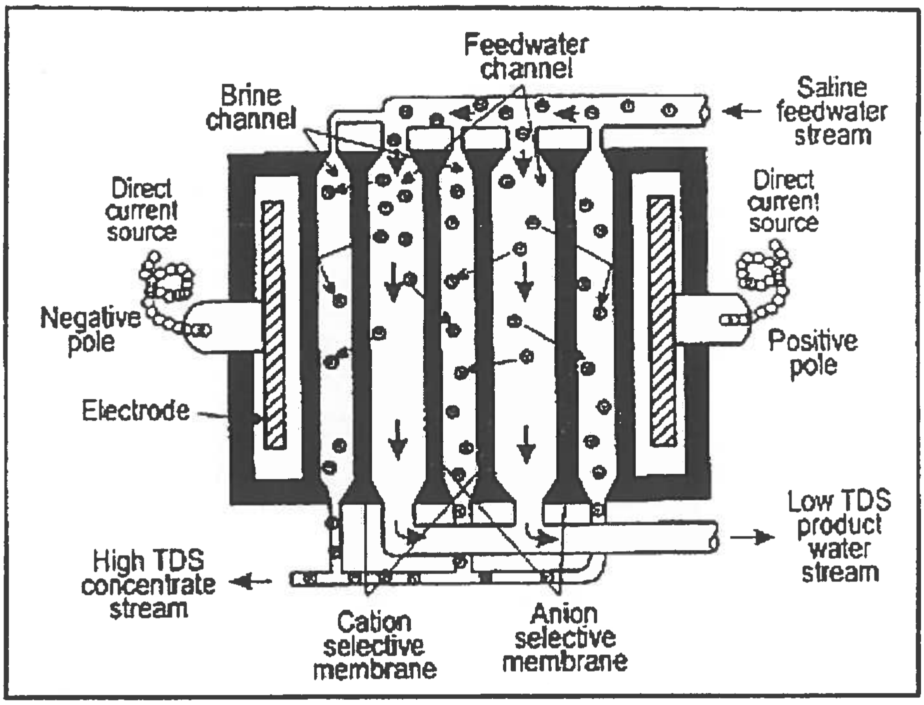

Fig. (17): Electro-dialysis methods.

ED works on the principle that salts dissolved in water are naturally ionized and membranes can be constructed to selectively permit the passage of ions as they move toward electrodes with an opposite electric charge. Brackish water is pumped at low pressure between stacks of flat, parallel, ion-permeable membranes that form channels. These channels are arranged with anion selective membranes alternating with cat ion-selective membranes such that each channel has as an anion-selective membrane on one side and a cat ions-selective membrane on the Figure. Water flows along the face of these alternating pairs of membranes in separate channels and electric current flows across these channels, charging the electrodes. The anions in the feed water are attracted and diverted towards the positive electrode. These anions pass through the anion-selective membrane, but cannot pass through the cat ion-selective membrane and are trapped in the concentrate channel. Cat ions move in the opposite direction through the cat ion selective membrane to the concentrate channel on the other side where they are trapped. This process creates alternating channels, a concentrated channel for the brine and a diluted channel for the product water.

ED membranes are arranged in a series of cell-pairs, which consist of a cell containing brine and a cell containing product water. A basic ED unit or “membrane stacks” consists of several hundred cell-pairs bound together with electrodes on the outside. Feed water passes simultaneously in parallel paths through all of the cells to produce continuous flows of fresh water and brine

2-4 Electro-dialysis Reversal method:

A modification of ED was introduced Electro Dialysis Reversal (EDR). An EDR unit operates on the same principle as a standard ED plant except that both the product and the brine channels are identical in construction. Several times an hour, the polarity of the electrodes is reversed, and the brine channel and product water channel flows are switched. Immediately following the reversal of polarity and flow, the ions are attracted in the opposite direction across the membrane stack and product water is used to clean out the stack and lines. After flushing for a few minutes, the unit resumes producing water. The reversal process breaks up and flushes out scale and other deposits in the cells. Flushing also allows the unit to operate with fewer pretreatment chemicals and minimizes membrane fouling.

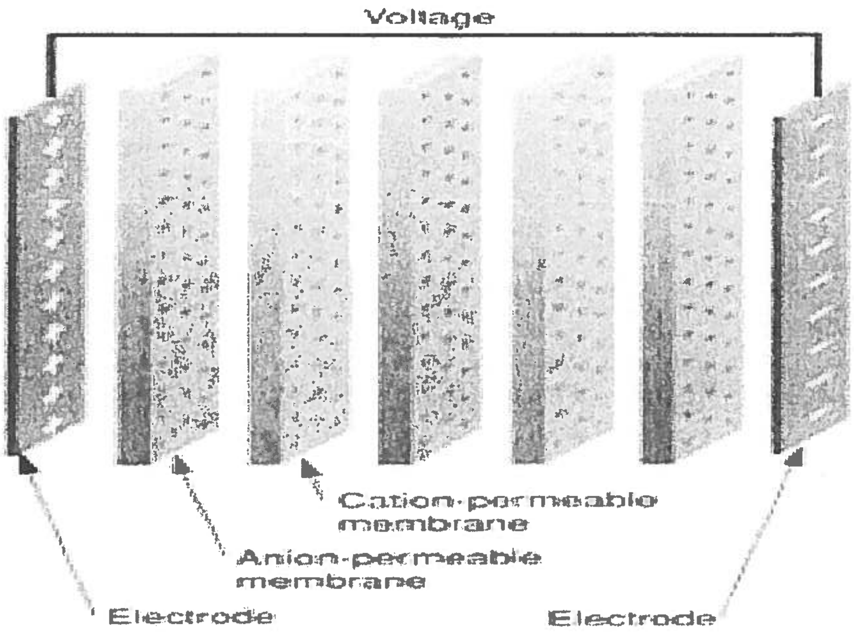

Fig. (18): Electro-dialysis Reversal methods.

2-7 MEMSTILL PROCESS:

Triggered by the worldwide fresh water scarcity problem and the need for low cost water supply, The Memstill technology is the development of a membrane-based distillation concept which radically of existing desalination technology for sea water and brackish water.

This so-called "Memstill technology" combines multistage flash and multi-effect distillation modes into one membrane module.

Because a Memstill module houses a continuum of evaporation stages in an almost ideal countercurrent flow process, a very high recovery of evaporation heat is possible.

The process promises to decrease desalination costs to well below 0.5 USD/m3, using low grade waste steam or heat as driving force.

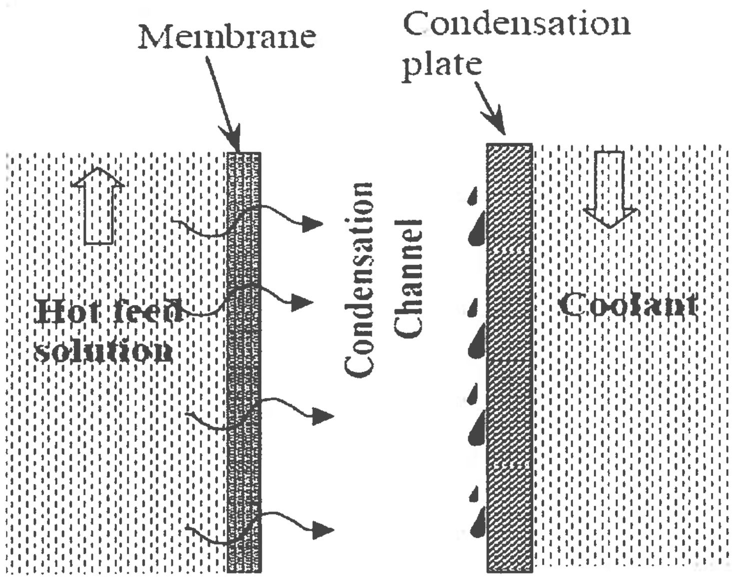

Fig. (19): Heat transfer in Memstill process

The patents have been applied for the principle of the technology is shown in the following Figure.

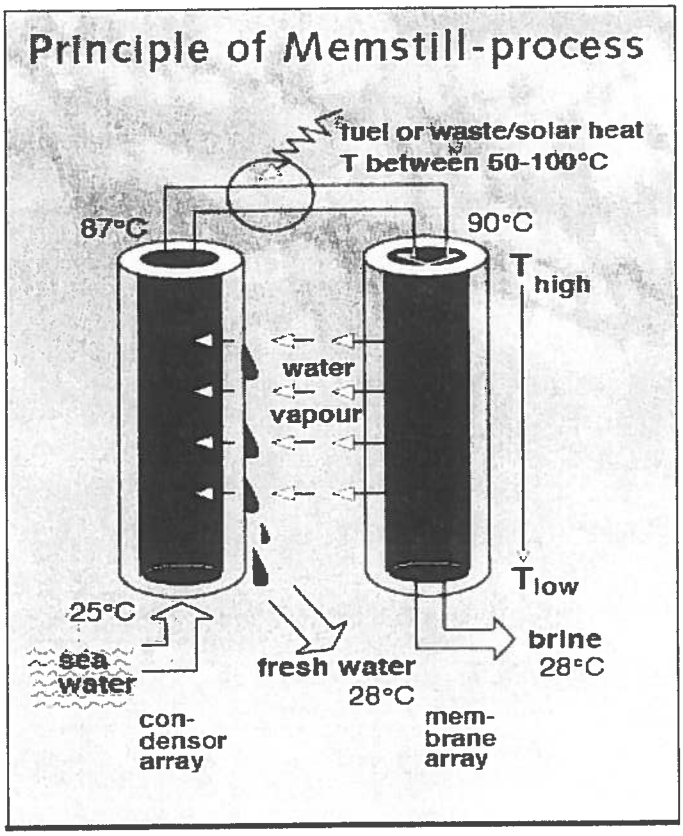

Fig. (20): Memstill principle

In this system, the wall of evaporator consists of a micro-porous hydrophobic membrane through which water vapor can diffuse and by which liquid water (with dissolved salts) is retained. The condenser and the membrane can either be tubular.

The Memstill concept can best be classified as air gap Membrane Distillation (MD), in which the cold surface is cooled by the feed flow which is preheated by the condensing water vapor. Reduction of air gap width or air gap pressure or both will lead to a reduction of this resistance to mass transfer.

In the Memstiil process, the applied driving force is the temperature difference between the hot and the cold water flow. The direct driving force that makes the water molecules diffuse across membrane and air gap, is the water vapor pressure difference between the hot water surface at the inner membrane radius and condense layer surface. At both surfaces local vapor-liquid equilibrium is assumed.

In this system, the feed water at 25 °C inlet temperature passes through the condenser channel, from its inlet to its outlet, while warming up at 65 °C outlet temperature.

The hot feed solution (T_{high} =80 °C ^{inlet} temperature) is directed along this membraine, passing the evaporating channel from its inlet to its outlet, while cooling down (T_{low} = 40°C evaporator outlet temperature). The input heat, necessary to achieve the required temperature gradient between the two channel (e.g., 80-65 °C =15 °C), is introduced into the system between the condenser outlet and the evaporator inlet, by the medium.

The major energy requirement is for low-grade thermal energy to confirm this technology. Low cost desalination of sea water and brackish water is expected with Memstill.

With waste heat as an energy source, the cost with Memstill process will be very lower than that with other technologies. The Memstill technology is in operation on pilot plant scale and must still be proven on a large scale.

-Advantages of Memstill Technology:

The Memstill technology reveals important advantages in comparison with classical desalination techniques like MSF and MED, comprising

– Low energy consumption

– Simple construction based on prefabricated modules

– Lower total cost price

– Potential of very high salt separation factors

– Limited corrosion and easy maintenance

– Small footprint.

-- Current state of the Memstill technology

Measurements with hollow fiber membranes with variable air gap width, at a hot water entrance temperature of 65°C show that, for air gaps of around 1.5 mm or smaller, the energy efficiency of the process decrease with more than 20%. This is due to thermal conduction taking place across product water, which forms water bridges between the membrane and the condenser wall. For large air gaps of 3 mm energy efficiencies of typically 85-90% were obtained.

The highest fluxes are obtained at the lowest possible pressures in the air gap. This lowest pressure is equal to the saturated water vapour pressure of the hot water entering the module. At this pressure, the air gap width is of negligible influence on the water vapor flux.

-Potential of the Memstill technology

he energy consumption of the Memstill is low (average 73.75 MJ/m3) compared to MSF (147.5 MJ/m3) and MED, because in the Memstill® technology, low grade heat, with a temperature of 50 - 100°C, or solar energy can be used to heat up the feed. Since Memstill operates in counter-current mode efficient use of the energy supplied is obtained. Also in comparison with RO, the energy consumption is low. RO requires electrical energy for the high pressure pumps and MD only uses heat.

- Cost comparison

The present and expected costs for several desalination processes are shown. From this figure, it can be seen that the RO costs have decreased dramatically. The main reasons for this are the lower module costs, the development of energy efficient RO membranes and energy recovery systems, which recover about 50% of the energy required for RO.

The process characteristics for the Memstill process are:

• Specific flux: Js = 1.5·10-10 m3/m2.s.Pa

• Heat energy: 80 – 240 MJ/m3

• Production: 25 – 50 m3/day.module • Recovery: 50%

In the following Figure, the expected costs for several desalination methods.

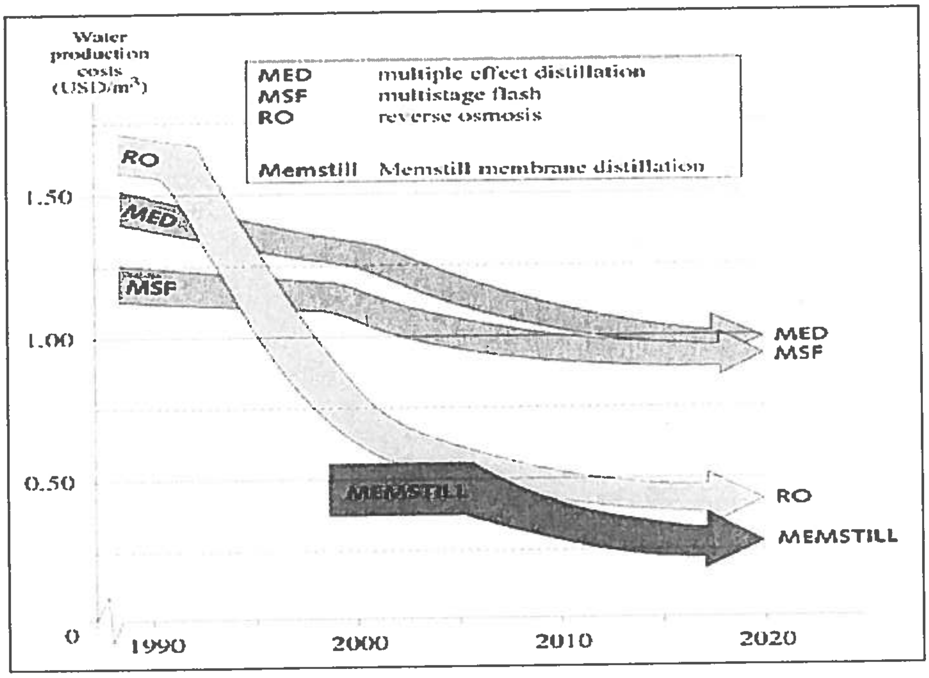

Fig. (19): Cost of the different desalination methods

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