CHAPTER 2

OVERVIEW OF DESALINATION PROCESSES

2.1 INTRODUCTION

This chapter introduces the various desalination processes starting with the history of desalination and moving on to the classifications of desalination processes. A detailed study is made in the area of low temperature thermal distillation, also the principle and operation of ‘Karunya desalination system’ is given in this chapter, which is the main focus of the present study.

2.2 HISTORY OF DESALINATION

Desalination as a natural phenomenon has occurred on earth for millions of years. The natural distillation cycle of water evaporating from the sea and then condensing to form pure rain water is probably the most obvious example of this phenomenon. Aristotle describes the natural water cycle as follows: The sun, moving, as it does, sets up processes of change and by its agency, the finest and sweetest water is every day carried up and is dissolved into vapour and rises to the upper region, where it is condensed again by cold and so water is formed, which falls down again to earth as rain. The other desalination phenomenon that occurs in nature is the freezing of seawater near the polar region. The ice crystals formed are pure water, the salt being excluded from participation in the crystal growth (Al-Shayji 1998).
Desalination has been practiced in the form of distillation for over 2000 years. Evaporation of sea water to produce fresh water was known even to the ancient Greeks, while small distillation devices were first used on ships in the early seventeenth century. Desalination by selective permeation through membranes was known only in the early twentieth century (International Atomic Energy Agency 2000). Since the turn of the century, necessity has driven scientists and engineers to utilize desalination technology of varying effectiveness to produce pure water from saline water. With the development of temperature and pressure measurements, together with an understanding of the properties of gases, land desalination began to play an important role from the early 1950’s (Al-Shayji 1998).

The first commercial land-based seawater desalination plant was installed by the Ottomans in Jeddah, Saudi Arabia. This crude distillation unit was a boiler working under atmospheric pressure, but this unit suffered from severe scale deposits and corrosion problems. With the improvement in submerged-tube technology, the first evaporators with a total capacity in excess of 45,000 m³/day of fresh water were built in Kuwait in the early 1950’s. But it was not until the development of the multistage flash distillation method by Professor Robert Silver in the 1950’s, when the research and development of saline water conversion was promoted, that desalination became a practical solution to the shortage of drinking water (Al-Shayji 1998).

The turning point in the history of desalination is the introduction of multistage flash desalination (MSF) in Kuwait in 1957. Thereafter companies all over the world, especially in the USA and the UK have undertaken extensive research and development on large flash-type evaporator units to achieve lower production cost. The success of large units, proving that the MSF process could produce water economically and with greater reliability
than previous systems, set the stage for the great advances in desalination capacity that was too followed in the 1970-1980’s. Distillation was the only method available at that time (Al-Shayji 1998).

In the later 1960’s, membrane processes began to take a place in the market. In 1953, Reid and Breton at the University of Florida proposed a research program to the Office of Saline Water (OSW). They developed a membrane that was made of a cellular acetate material which had the ability to reject salt. However, the water flux through the dense membrane was too low to have commercial significance. The major breakthrough in membrane development came in a parallel research program, from 1958 to 1960, at the University of California where Leob and Sourirajan were credited with making the first high-performance membranes by creating an asymmetric cellulose acetate structure with improved salt rejection and water flux. The development of the tubular, spiral-wound, and hollow-fine-fiber modules together with the development of the polyamide membranes takes place from 1965-1970. Through the 1980’s, improvements were made to these membranes to increase water flux and salt rejection with both brackish water and seawater (Al-Shayji 1998). In the mid 1990’s large capacity MSF and MED plants were constructed. In 2000, thermal desalination process remains to be the front runner in seawater desalination (El-Dessouky and Ettouney 2002).

2.3 CLASSIFICATION OF DESALINATION PROCESSES

Desalination means the removal of fresh water from saline water. Many methods have been proposed for desalting saline water, but few were commercially used. The desalination process in vogue can be broadly classified into two categories; the first one involving phase change methods known as thermal process such as freezing and distillation and the second one non-phase change methods known as membrane process such as reverse osmosis,
electrodialysis and others. Of these the membrane filtration process using reverse osmosis and change of state process involving distillation are used worldwide. Figure 2.1 shows the different desalting processes.

**Figure 2.1  Classification of desalination Processes**

Although the main process features of these operational systems remain practically unchanged over the years, remarkable progress has been made in the last decade to optimize these plants by optimizing the selection of material, equipment design, configuration, thermodynamic design, construction etc. The experience in the operation and maintenance of these plants and advancement in technologies contribute significantly towards the quest for minimizing the cost of production of fresh water (Muthunayagam 2003a). The applicability of any process depends on the salt concentration in
the feed water and on its water unit cost. Currently the desalination industry is dominated by Multi-stage Flash Desalination (MSF) and Reverse Osmosis (RO). The market share of these two processes is more than 90% of the desalination industry. The remaining market share includes multiple-effect evaporation with/without thermal or mechanical vapor compression and single effect evaporation with Mechanical Vapor Compression (MVC) (Ettouney 2006).

2.3.1 Distillation

Dessouky and Ettouney (2002) presented a review of thermal desalination processes, which shows that the thermal processes continue to be dominated by the MSF. The MSF market share amounts to more than 90% of all thermal desalination. The study also shows that the reverse osmosis process accounts for about 50% of all desalination processes, which includes brackish and seawater. Also, it should be noted that the RO process has a much smaller share of seawater desalination - less than 30%.

Distillation is one of the oldest and most commonly used desalting techniques. In this process, the water evaporation and vapor condensation occur to obtain distillate at the end. This process produces distillate i.e., freshwater with a better quality as compared with crystallization and membrane processes. Among the processes used for desalination, distillation today remains the most widely used process which includes Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), and Vapour Compression Distillation (VCD).

2.3.1.1 Multiple Effect Distillation

Multiple Effect Distillation (MED), simply Multi-effect distillation was the first thermal process used to produce a significant amount of water
from the sea. This process takes place in a series of effects (vessels) and uses the principle of reducing the ambient pressure in the various effects in the order of their arrangement. This causes the feed water to undergo boiling in a series of effects without supplying additional heat after the first effect. Figure 2.2 illustrates the arrangement a MED. Vapour generated in the first effect gives up heat to the second effect for evaporation and is condensed inside the tubes. This continues for several effects. The seawater is either sprayed, or otherwise distributed onto the surface of evaporator tubes in a thin film to promote rapid boiling and evaporation. The condensate from the boiler steam is recycled to the boiler for reuse.

Figure 2.2 Schematic of a Multieffect Distillation Plant

The larger the number of effects, the less heat that is required as heat sources. There are vertical- and horizontal-tube evaporation effects. The vertical tubes could be of the rising or the falling-film type. The formation of falling films of water on the inner surfaces of the heating tubes affects
evaporation in the vertical-tube evaporators, so the falling films are heated by the steam passing outside the tubes. However, with horizontal effects, evaporation takes place on the outer surfaces of the heating tubes, steam for heating being condensed inside the tubes. ME distillation plants tend to come in a much greater variety of plant designs than do MSF processes. The designer could select a number of heat-transfer surface configurations and a number of flow sheet variations, thus leading to a larger number of possible combinations.

2.3.1.2 Multistage Flash Distillation

The Multistage Flash Distillation (MSF/MSFD) processes work on the principle that seawater will evaporate as it is introduced into the first evaporator (flash chamber) with lower pressure than saturation pressure. It then condenses and cools down to a saturation temperature equivalent to chamber pressure. The MSF plant consists of three sections: heat-rejection, heat-recovery, and heat input (brine heater). The heat-rejection and heat-recovery consist of a number of flash chambers (stages) connected to one another. Figure 2.3 illustrates the arrangement a MSF distillation.

In the MSF process, sea water is heated in a vessel called the brine heater. This is generally done by condensing steam on a bank of tubes that passes through the vessel which in turn heats the sea water. This heated sea water then flows into another vessel, called a stage, where the ambient pressure is such that the water will immediately boil. The sudden introduction of the heated water into the chamber causes it to boil rapidly, almost exploding or flashing into steam. Generally, only a small percentage of this water is converted to steam (water vapour), depending on the pressure maintained in this stage since boiling will continue only until the water cools (furnishing the heat of vaporization) to the boiling point.
The concept of distilling water with a vessel operating at a reduced pressure is not new and has been used for well over century. In the 1950s, a unit that used a series of stages set at increasingly lower atmospheric pressures was developed. In this unit, the feed water could pass from one stage to another and boiled repeatedly without adding more heat. Typically, an MSF plant can contain from 4 to about 40 stages. The steam generated by flashing is converted to fresh water by being condensed on tubes of heat exchangers that run through each stage. The tubes are cooled by the incoming feed water going to the brine heater. This, in turn, warms up the feed water so that the amount of thermal energy needed in the brine heater to raise the temperature of the sea water is reduced.

The MSF water desalination process plays a vital role in the provision of fresh water in many areas of the world, particularly in the Gulf countries (Khawla A. Al-Shayji 1998). In the last four decades, a large number of desalination plants have been installed in the Arabian Gulf.
countries. Most of these plants are MSF units. Lot of effort has been done to reduce the cost of water produced from MSF plants. This have been achieved through the increase of the plant capacity, improving the thermal performance of plants, better selection of material for construction, and good practice of reliable operation and scale control (Hisham El-Dessouky 1997).

2.3.1.3 Vapor Compression Distillation

Vapour Compression Distillation (VCD) uses mechanical energy rather than thermal energy. It is based on a simple principle; saline water is sprayed over an evaporator tube bundle. The vapor formed at some temperature and pressure is then compressed either thermally in a steam ejector, or mechanically (high and low pressure) in a compressor, causing the condensation temperature and pressure to increase and the volume to decrease. Compressed vapor is passed through the evaporator bundle, where it condenses and forms distilled water. The heat of condensation could be recycled to evaporate more brine. Figure 2.4 illustrates the principle of vapor compression. Most vapor-compression plants have single effects, but a multieffect configuration could be used for a larger product capacity. The vapor-compression process consumes a small amount of energy and has a low operating cost. However, its capacity is limited, and the quality of water produced and maintenance costs do not match those by other distillation processes.
In nature, membranes play an important role in the separation of salts, including both the process of dialysis and osmosis occurring in the body. Membranes are used in two commercially important desalting processes: Electrodialysis (ED) and Reverse Osmosis (RO). Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, membranes are used differently in each of these processes. The mechanism of Membrane Processes is explained through Figure 2.5.

ED is a voltage driven process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water. RO is a pressure-driven process, with the pressure used for
separation by allowing fresh water to move through a membrane, leaving the salts behind. Scientists have explored both of these concepts since the turn of the century, but their commercialization for desalting water for municipal purposes has occurred in only the last 30 to 40 years (Buros 1990).

![Diagram of Membrane Processes]

**Figure 2.5  Mechanisms of Membrane Processes**

### 2.3.2.1 Reverse Osmosis

In comparison to distillation and electrodialysis, RO is relatively new, with successful commercialization occurring in the early 1970s (Buros 1990). RO is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane. No heating or phase change is necessary for this separation. The major energy required for desalting is for pressurizing the feed water.

In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes
through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without passing through the membrane. Without this controlled discharge, the pressurized feed water would continue to increase in salt concentration, creating problems such as precipitation of super-saturated salts and increased osmotic pressure across the membranes. The amount of the feed water discharged to waste in the brine stream varies from 20 to 70 percent of the feed flow, depending on the salt content of the feed water, pressure, and type of membrane. An RO system is made up of the following basic components: Pretreatment, High-pressure pump, Membrane assembly, Post-treatment. Figure 2.6 illustrates the Schematic diagram of a Reverse Osmosis Desalination Plant.

Figure 2.6 Schematic of a Reverse Osmosis Desalination Plant

Pretreatment is important in RO because the membrane surfaces must remain clean. Therefore, suspended solids must be removed and the water pretreated so that salt precipitation or microbial growth does not occur on the membranes. Usually, the pretreatment consists of fine filtration and the addition of acid or other chemicals to inhibit precipitation and the growth of
microorganisms. The high-pressure pump supplies the pressure needed to enable the water to pass through the membrane and have the salts rejected. This pressure ranges from 15 to 25 bar for brackish water and from 54 to 80 bar for sea water. The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the membrane. The membrane must be able to withstand the entire pressure drop across it. The semi-permeable membranes vary in their ability to pass fresh water and reject the passage of salts. No membrane is perfect in its ability to reject salts, so a small amount of salts passes through the membrane and appears in the product water. Post-treatment consists of stabilizing the water and preparing it for distribution.

2.3.2.2 Electrodialysis

ED was commercially introduced in the early 1960s, about 10 years before RO. The development of ED provided a cost-effective way to desalt brackish water and spurred considerable interest in the whole field of using desalting technologies for producing potable water (Buros 1990). Figure 2.7 illustrates the principles of electrodialysis process i.e., movement of ions. ED depends on the following general principles:

- Most salts dissolved in water are ionic, being positively (cationic) or negatively (anionic) charged.
- These ions migrate toward the electrodes with an opposite electric charge.
- Membranes can be constructed to permit selective passage of either anions or cations.
Figure 2.7 Movement of ions in the Electrodialysis process

Figure 2.8 illustrates the Schematic diagram of an electrodialysis Desalination Plant.

In electrodialysis, two types of membranes are used. The cation membrane allows only cations (positive ions) to permeate, and the anion
membrane allows only anions (negative ions) to permeate. These exchange membranes are alternately immersed in salty water in parallel, and an electric current is passed through the liquid. The cations will migrate to the cathode, and the anions will migrate to the anode. Therefore, water passing between membranes is split into two streams. One is pure water, and the other is concentrated brine. Because ED uses energy at a rate directly proportional to the quantity of salts to be removed, this process is more useful in desalting brackish water.

2.3.3 Other Desalination Processes

A number of other processes have been used to desalt saline water. These processes have not achieved the level of commercial success that distillation, ED, and RO have, but they may prove valuable under special circumstances or with further development (Buros 1990).

2.3.3.1 Freezing method for Desalination

Boiling isn’t the only change of phase that’s used to purify water. In 1786, Anton Maria Lorgna gave the first description of a working method for desalination by freezing (Khawla A. Al-Shayji 1998). Extensive work was done in this area in the 1950s and 1960s. Desalination by freezing process is carried out by cooling the saline water to form ice crystals under controlled conditions and then melting the ice to get pure water. It has several advantages such as low energy consumption, minimal potential for corrosion and low scaling probability. However, it involves handling of ice and water mixtures. In practice, the surface of the ice remains coated with brine, resulting in high salinity of the product water, to avoid this, the ice is washed with pure water. The amount of pure water required for washing is large. Several pilot plants have been built by using freezing for desalination. However, it has still not met commercial success.
2.3.3.2 Solar Humidification

The use of direct solar energy for desalting saline water has been investigated and used for some time. These devices generally imitate a part of the natural hydrologic cycle in that the sun’s rays heat the saline water so that the production of water vapour (humidification) increases. The water vapour is then condensed on a cool surface, and the condensate is collected as fresh water product. An example of this type of process is the greenhouse solar still, in which the saline water is heated in a basin on the floor, and the water vapor condenses on the sloping glass roof that covers the basin (Buros 1990).

Variations of this type of solar still have been made in an effort to increase efficiency, but they all share the following difficulties, which restrict the use of this technique for large-scale production: Large solar collection area requirements, high capital cost and vulnerability to weather-related damage. The stills themselves are expensive to construct, and although the thermal energy may be free, additional energy is needed to pump the water to and fro from the facility. In addition, reasonable attention for operation and routine maintenance is needed to keep the structure repaired, prevent scale formation caused by the basins drying out, and repair glass or vapor leaks in the stills.

2.3.3.3 Membrane Distillation

Membrane distillation was introduced commercially on a small scale during the 1980s, but it has had demonstrated no commercial success. As the name implies, the process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapour production, and this vapor is exposed to a membrane that can pass water vapor but not liquid water. After the vapour passes through the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and
collected as the output of the plant (Buros 1990). The main advantages of membrane distillation lie in its simplicity and the need for only small temperature differentials to operate. This has resulted in the use of membrane distillation in experimental solar desalting units. However, the temperature differential and the recovery rate, similar to the MSF and MED processes, determine the overall thermal efficiency for the membrane distillation.

2.3.3.4 Vacuum Membrane Distillation

Vacuum membrane distillation, like any membrane distillation process, is a thermally driven process in which the convective mass transfer is the dominant mechanism for mass transfer. The driving force is maintained by applying vacuum at the downstream side to keep the pressure at this side below the equilibrium vapor pressure. The membrane in this process is a physical support for the vapor-/liquid interface and does not affect the selectivity associated with the vapor-/liquid equilibrium (Fawzi Banat et al 2003). Schematic diagram of a Vacuum membrane distillation process is shown in Figure 2.9.

Figure 2.9 Schematic diagram of a Vacuum membrane distillation process
2.3.3.5 Ion exchange Process

Ion exchange is described as the removal of one type of ion from the solution and its replacement by an equivalent quantity of another ion of the same charge. This process is widely used for water treatment for process application, boiler feed water and in semiconductor industry. The use of ion exchange for desalination systems is technically feasible but commercially not viable so far.

2.3.3.6 Low Temperature Thermal Desalination

Desalination plants operate under very low temperatures comes under the category of Low Temperature Thermal Desalination (LTTD). These types of desalination plants can be an integrated desalination system with power from Ocean Thermal Energy Conversion (OTEC) Plants or with power plants, where Low temperature waste heat from nuclear research reactors and condenser outlet of power plants is an abundant source of low cost energy for those desalination technologies, which can operate effectively at low temperatures. Such a system is called as Low Temperature Thermal Desalination (LTTD) or otherwise called as Low Temperature Vacuum Evaporation (LTVE).

The temperature difference between the upper (warm) and bottom (cold) layers ranges from 10°C to 25°C, with the higher values found in equatorial waters. To an engineer this implies that there are two enormous reservoirs providing the heat source and the heat sink required for a heat engine. A practical application is found in a system (heat engine) designed to transform the thermal energy into electricity. This is referred to as OTEC for Ocean Thermal Energy Conversion. Several techniques have been proposed to use this ocean thermal resource; however, at present it appears that only the closed cycle (CC-OTEC) and the open cycle (OC-OTEC) schemes have a
solid foundation of theoretical as well as experimental work. OTEC, through the use of a binary cycle with cold water from the ocean depths, was originally conceived mainly as a means of generating electrical power. However, it has been recognized that the combination of cold and warm water from ocean can itself be of value (Dylan Tanner 1995). Even though the practical application of utilizing the temperature difference between the upper and bottom layers water is pointed, no practical system was developed.

In 2002, Muthunayagam (2003a), introduced a new concept for the production of fresh water by spray flash evaporation technique, to utilize the available temperature difference of the upper and lower strata of the ocean and named as ‘Karunya Desalination System”. The Ocean’s enormous potential of stored solar energy can be used to design reliable and economic desalination systems by evolving systems with technologies to maximally utilize the stored solar energy in the upper strata of the ocean, designing and incorporating thermodynamic systems which utilize the temperature difference existing between different layers of the ocean and gainfully utilizing the enormous quantity of the salt water available in the ocean to produce fresh water. A detailed study about Karunya desalination system is given below, which is the main focus of the present study.

In Karunya desalination system, warm ocean water from the upper strata of the ocean in the ambient temperature is flash evaporated in a vaporizer at low pressure and the resulting water vapour is condensed in a condenser, also maintained at low pressure, using cold ocean water, taken from the depth of the ocean. The vacuum in the vaporizer and condenser is maintained by means of a vacuum pumping system and barometric seals. The barometric seal, provided by the long duct connecting the vaporizer to the ocean enables to maintain the vacuum in vaporizer and also to discharge large volume of water which is not vaporized in the vaporizer without any pump.
Similarly the barometric seal provided by another duct connecting the condensate side of the condenser to the fresh water collection reservoir enables to maintain the vacuum in condenser and also to discharge all condensed fresh water from the condenser without any pump.

Vaporization, the process of phase change of the water from liquid to vapour can be achieved by reducing the ambient pressure below the saturated vapour pressure corresponding to the temperature of the liquid and by the conventional method of heating water to boiling point and adding external energy. During the former process of Vapourisation at low pressure the energy for phase change is taken from its own body and consequently the process leads to reduction in energy requirement.

The design of the desalination plant by incorporating barometric seal helps to discharge large quantities of water from a low pressure environment in the system to the ambient by gravity and at the same time provide seals for maintaining low pressures. Such designs eliminate the need for pumps for discharging large quantities of water and lead to reduction in energy requirements. The distribution of a given quantity of water in the form of large number of fine particles results in the increase in the surface area available for vaporization and consequently increases rate of the quantity of vapour generated.

The energy requirement is minimized since the energy for vaporization is taken up from its own body and the condensation is by using cold water from ocean. No external energy is supplied for heating or cooling. The solar energy stored in the ocean is gainfully used. However energy is required for injecting water into vaporizer and circulating cooling water in condenser and maintaining vacuum. The system operates between the
temperature in the ocean upper strata and lower strata. It is different from the commercially operated desalination process by distillation viz., Multi Effect Distillation (MED) and Multi Stage Flash (MSF).

This Karunya Desalination System can be barge mounted and moored at required water depth or shore / shelf-mounted with necessary piping system to supply the required warm ocean water from the upper strata of the ocean to the vaporizer and the required cold water from lower strata of the ocean to the condenser. The barge mounted configuration can be moored in deep waters and co-located with any Ocean Thermal Energy Conversion (OTEC) barge, deriving power and other support services from the OTEC system. Alternately the Desalination system can be integrated with the OTEC system. The fresh water produced shall be transported to shore through pipes or transport barges.

The feasibility of barge mounted floating seawater desalination plant is seen from the literature (Klaus Wangnick 1982). A 18 stage MSF plant is installed in the first barge mounted floating seawater desalination plant was built for commercial use in 1982, in Abu Dhabi. This plant, consisting of a self-propelled pontoon-like hull carrying two centrally positioned desalination units of 1250 m³/day each, Which supply islands, coastal towns and major construction sites in the United Arab Emirates with drinking water and will also be deployed in the event of breakdown of stationary desalination plant, to provide an emergency water supply and to alleviate plantation water shortages. Two 1,250-kVA diesel generators are used to generate the electric power for the desalination units and the vessel’s auxiliaries.

It is realized that islands have very favorable bathymetry where deep water is available in short distances from the shore. Hence warm ocean water from upper strata of the ocean and cold ocean water from depths can be taken economically through pipes to the desalination plant established on
shore, which could meet the fresh water requirements for many islands. The multi benefits of thermo-cline driven system are Power generation, Desalination, Aquaculture and Air-conditioning system or a combination of all the above is possible. The cold water pumped used in the condenser can subsequently is used for air conditioning as the return temperature of this water is around 17°-18°C. This water being pumped from the lower levels of the sea is rich in minerals & plankton and when discharged on sea surface becomes a potential breeding area for fish and other marine life. The main features of Karunya Desalination System are:

a) Use of renewable energy. No pretreatment of feed water required and no high technology elements like membrane, fine filters etc.

b) Adopts proven technologies, Simple System configuration, Operational simplicity and easy maintenance. Equipments Commercially available and fabricated through Conventional Processes.

c) Operation and maintenance simple and highly skilled operators not required.

d) Low temperature operations, eliminating scaling and associated problems.

e) Assured consistent quality water fit for drinking as per World Health Organization (WHO) standards.

f) Highly nutrient cold water available which can be used to enhance marine life.

g) The cold water pumped used in the condenser can subsequently be used for air conditioning.
The temperature difference between warm water at surface of the ocean and cold water at its depth is used for producing electricity by the principle of Ocean Thermal Energy Conversion (OTEC). An integrated OTEC system consists of 30 kW OTEC plant using UAHARA cycle with spray flash desalination plant started by Saga University, Japan (Yasuyuki Ikegami 2003) for the condition the inlet warm sea water temperature is taken at 28°C, inlet cold water temperature is 8°C.

In the year 2005 a LTTD plant was installed by National Institute of Ocean Technology (NIOT), India; to produce fresh water of 100 m³ per day at Kavaratti, one of the Lakshadweep groups of Island. Also a Barge Mounted LTTD plant was installed by NIOT at Tuticorin, India; to produce fresh water of 100 m³ per day. Such larger rating barge mounted plants are producing at very low cost. In the year 2006, another floating desalination plant of 1 MLD capacity successfully demonstrated in Chennai, India; the reported yield ratio was in the range of 1-1.4% (Raju Abraham 2007).

Later in the year 2003, Muthunayagam (2003) extended the above concept to produce fresh water in thermal stations without affecting its normal operations. In thermal power stations, large quantities of sea water at ambient temperature are taken from sea for condensing the exhaust from turbines and other cooling purposes. After completing the intended use, this sea water is discharged back to the sea. During this process of cooling the sea water picks up heat and its temperature is raised minimum by 10°C. Thus large quantities of warm sea water are available in the Thermal Power Station. The warm seawater discharge to sea, carrying waste heat from thermal stations is injected into a vaporizer at low pressure and vaporized. This vapour is condensed as fresh water in a condenser, using the cold seawater intake to the Thermal station, also maintained at low pressure. From marine environmental considerations, it is desired that the temperature of the warm sea water discharged back to the sea is
close to the ambient temperature and does not exceed around 5°C. The temperature of the warm sea water discharge to sea is reduced by this process and promotes preservation of marine ecosystems. The main features of Karunya Desalination System used in power plants are:

a) Use of renewable energy. No pretreatment of feed water required and no high technology elements like membrane, fine filters etc.

b) This Desalination Process utilizes waste heat energy from the power plant condenser and does not affect the normal operations of power plant.

c) With existing warm water and cold water resources in thermal stations, the boiler feed water needs of thermal power stations can be met. The desalinated water (with low dissolved salt content) can be directly used as boiler feed water with fine polishing.

d) Zero environmental Pollution i.e., Desalination operations and associated waste water treatment and environmental issues in power plants can be eliminated. Reduced temperature of warm water discharge to sea helps to promote marine ecosystem.

e) Communities and industries around power plants can get fresh water economically.

Utilization of waste heat from a steam turbine for production of fresh water through a vacuum desalination process was first reported by Tay et al (1966). A multi-effect distillation process and multistage flash process (Al-Wazzan and Al-Modaf 2001), which use recovery of heat from the vapor produced in the initial stages for heating the saline water in the subsequent stages, is particularly promising and has been applied for large scale
desalination. The multi effect distillation process, despite the heat recovery, is still energy intensive and there is an urgent need to evolve means for producing fresh water at lower energy levels. The seawater is either sprayed, or otherwise distributed onto the surface of evaporator tubes in a thin film to promote rapid boiling and evaporation.

The vaporization of water at relatively low temperature is not new. The Ashodad MED desalting plant in Israel (Fisher 1985) used water at 62.5°C from a power plant condenser, and circulated through the flash evaporation chamber. The vapor is passed through the tubes of the first effect where it condenses giving up its latent heat to warm up the feed water flowing over the tubes. The plant has been demonstrated to be very effective with energy consumption being about 5.7 kW-h/m³, here the vaporization is effected at low temperatures and pressures in evaporator tubes using steam.

It is known that power stations use seawater for condensation of steam from turbines. In this case the temperature of seawater in condensers increases by 10-20°C. A large quantity of heat is lost in condensers. The energy can be used for desalination of seawater in a plant, which includes a low temperature vacuum desalting installation and a heat pump. In the heat pump the temperature of seawater increases by 60-80°C and is then transported to a vacuum desalting installation. Desalted water is then utilized by the power station. This scheme of a desalination plant is widely known and has practical application (Slesarenko 1999).

Dario Breschi (1999) described the operational results of an experimental project aimed for the exploitation of very low temperature differences (associated with many waste streams commonly available in industrial environments) for the distillation of seawater. The case described is relevant to the engineering, construction and operation of a seawater desalination plant, called Low-Temperature Flash (LTF), able to utilize as
prime energy source the cooling seawater discharged by a turbine condenser, at only 8°C above ambient seawater temperature. The project was developed in the early 1990s by the Italian company Sowit, with a grant from the European Community. The desalination plant is presently in operation at the Piombino power station (owned by ENEL, the Italian Electricity Board) for the production of high-purity distillate for boiler make-up. Plant operational results confirmed the feasibility and the technical economical convenience of this process. From the design point of view, the most critical aspect is related to the vent system of non-condensible gases released in the evaporator, while plant operation showed various advantages, such as a good reliability, a very high purity of produced distillate, reduced environmental impact and a competitive operation cost.

A Low Temperature Vacuum Evaporation process desalination plant utilizes waste heat in the form of hot water (50°C) or low-pressure steam (0.13 bar) to produce pure water from seawater. Apart from the electric power requirement for the pump, no other energy or fuel is required. The probability of scale formation is practically eliminated by operating at low temperature and permissible brine concentration. Vacuum is maintained, and excess brine is drained by water jet ejectors having no moving parts (Tewari and Rao 2002).

The study conducted by Cohen et al (2002) has shown that the LTF desalination technology is a viable solution both from technical and economical point of view, and can be effectively installed in steam power station located on the Mediterranean shore and operating at base load with a minimum seawater temperature increase of 8°C.

A vacuum desalination system has been designed for utilizing power plant waste heat and was studied theoretically to produce fresh water by Senthil Kumar et al (2005). This technique takes advantage of a drop in the
water boiling point at reduced pressure. This vacuum is created by a jet pump. By dropping the saturation pressure exerted on the seawater to about 0.05622 bar, a condenser outlet temperature could be used as an external heat source for boiling the seawater, and the condenser inlet temperature could be used for condensing water vapour.

The Desalination system works on Low Temperature Vacuum Evaporation process, had been operating since 2004 in BARC, India (Rakesh Ranjan et al 2007), which utilizes waste heat from nuclear research reactors. Such a system operates at around 710 mm of Hg (gauge) vacuum and 41°C, which is close to the reject heat temperature of a typical power plant.

LTTD produces fresh water having less than 10 ppm TDS from seawater without any chemical pretreatment of the feed water. However, the overall efficiency of LTTD is low owing to low temperature operation. Therefore, the capacity of these systems tends to be low. Nevertheless, the LTTD process shows good potential for small capacity applications such as supplying the in-house water requirements of coastal industries and commercial centers.

2.3.4 Other aspects of Desalination

2.3.4.1 Co-generation

In some situations, it is possible to use energy so that more than one use can be obtained from it as the energy moves from a high level to an ambient level. This occurs with co-generation where a single energy source can perform several different functions. Certain types of desalination processes, especially the distillation process, can be structured to take advantage of a co-generation situation. Most of the distillation plants installed in the Middle East and North Africa have operated under this principle since 1960s and are known in the field as dual purpose plants. These units are built
as part of a facility that produce both electric power and desalted seawater for use in a particular country. Cogeneration units producing electricity and desalinated water by evaporation have been used since the late 1960s with success (Jacques de Gunzbourg 1999). In today's water shortages context which threaten many industrial countries, this cogeneration system should therefore have an important impact.

The main advantage of a co-generation system is that it can significantly reduce the consumption of fuel when compared to the fuel needed for two separate plants. Since energy is a major operating cost in any desalination process, this can be an important economic benefit. This type of power and water production installation is commonly referred to as a dual-purpose plant. Since many of the oil producing countries of the Middle East and North Africa were engaged in building up their total infrastructure, these types of installations fit in well with the overall development program in these countries. Other types of co-generation facilities benefiting desalination can derive lower-cost steam from heat recovery systems on gas turbine exhausts, heat pumps, or various industrial processes including burning solid wastes in an incinerator (Buros 1990).

2.3.4.2 Hybrid Desalination systems

There are many ways to improve the efficiency and cost of product water of desalination plants. One means is to combine two or more desalination systems resulting in a hybrid plant. Hybrid systems can offer performance improvement, savings in pretreatment and overall water cost reduction (International Atomic Energy Agency 2000). Such hybrid systems are not applicable to most desalination installations, but can prove to be an economic benefit in some cases. A hybrid system is a treatment configuration made up of two or more desalination processes.
An example is using both distillation and RO processes to desalt seawater at one facility and to combine the different characteristics of each process productively. Hybrid systems provide a better match between power and water development needs. Few examples of a hybrid system are integration of MSF and RO or MED and RO systems at the same location offers the opportunity to reduce cost and meet diverse requirements for product water quality when industrial plants are part of the customer base. The hybrid MSF-RO and MED-RO systems offer several interesting prospects for water cost reduction and, therefore, deserve further exploration. The coupling of vapour compression to any distillation process offers the possibility for increasing the GOR. Several such schemes have been proposed in this regard. A number of hybrid VCD plants are operating throughout the world for industrial and municipal use. Other combinations like VC and RO technologies can be integrated into a hybrid system with the same set of advantages as offered by the hybrid distillation and RO plant. Other combinations are also possible but at present are not economical for low cost water production (International Atomic Energy Agency 2000).