PROSPECTS OF UTILIZATION OF SOLAR ENERGY FOR THERMAL DESALINATION TECHNOLOGIES

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Abstract

Energy is an important component of social and economic development. At a time when global reserves of fossil fuels are decreasing, resulting in a threat to the long term sustainability of the global economy, solar energy is an ecologically friendly alternative that can deliver national energy security. Population growth increases the demand on drinking water availability. The global desalination capacity is expected to increase significantly in the future. Furthermore, the locations that require fresh water are more likely to be disconnected from an electrical power grid. Desalination based on renewable energies is a promising solution for such locations. This paper presents a survey of the characteristics of the solar powered thermal distillation machinery that have been tested globally under different conditions. It will also discuss the latest academic work on improving the technical and economic strength of solar powered thermal desalination processes. The main focus of this study will be on technology that could be integrated with solar thermal energy systems.

Keywords: *renewable energy, water desalination technologies, sea water, solar radiation, fresh water*

1. Introduction

Desalination of seawater is a process that is becoming increasingly important due to the falling water tables worldwide as well as the fresh water shortage that is likely to occur in the near future. In all arid regions of the world, especially in the Middle East region, fresh water is scarce, as shown in Figure 1. Water resources accessibility and projections for the demand in water show that global desalination capacity is expected to double over the next 20 years. (Bouchekima, 2003) and that it will probably reach 40-50 million cubic meters around the world.

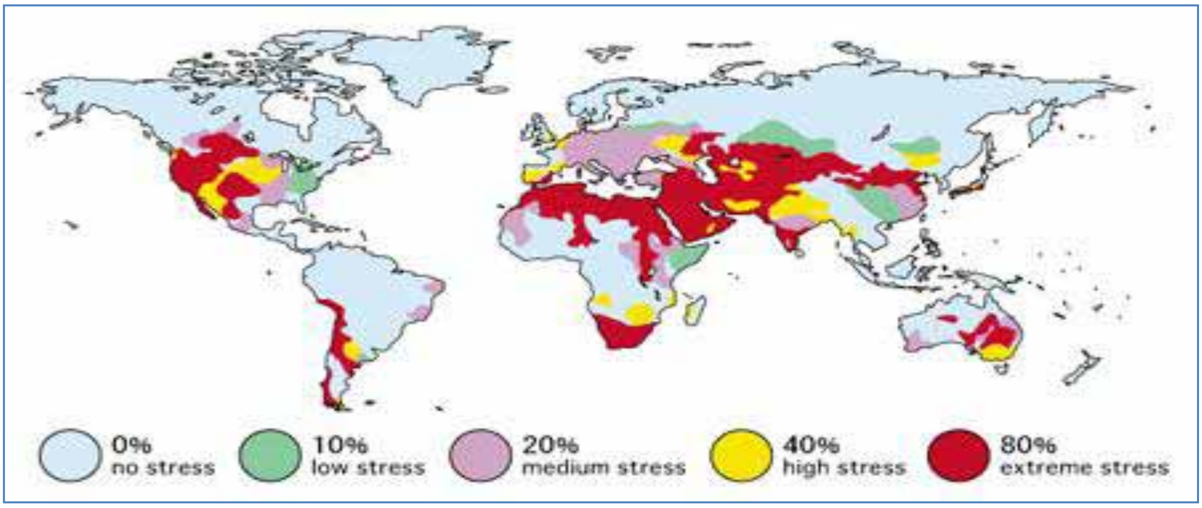

Fig. 1:This map depicts in red the "stress" areas where water is needed-note the Middle East

Source : http://mabryonline.org/blogs/glenn/archives/2007/02/february_5-9.html

Global energy consumption has grown a lot in the last ten years and this growth has continued with the use of fossil fuels as an alternative source of energy. Provision of clean water requires energy, which is currently being provided by non-renewable fossil fuels. The total energy demand for providing the US water needs is reported as 123×10^6 MWh/ year (EPRI, 2002). It has been estimated that production of 1 m^3 of potable water requires the equivalent of about 0.03 tons of oil (Kalogirou,1998). Extraction of fossil fuels and production of energy not only place additional demands on water, but also result in pollution of water sources and air. Thus, the projected global demand for clean water supply for the future will accelerate the depletion of fossil fuel reserves as well as the concomitant environmental damage and emission of greenhouse gases. There is global concern and recognition of the fact that current energy trends aren't sustainable and that better alternatives need to be considered for the protection of the environment at large. It was reported that CO_2 emission from the fossil fuel combustion can warm up the earth's atmosphere up to 4° K. China and the U.S.A. are among major world polluters. Only India is expected to have an increase in CO_2 emissions in the next 20 years, as clearly highlighted in Figure 2.

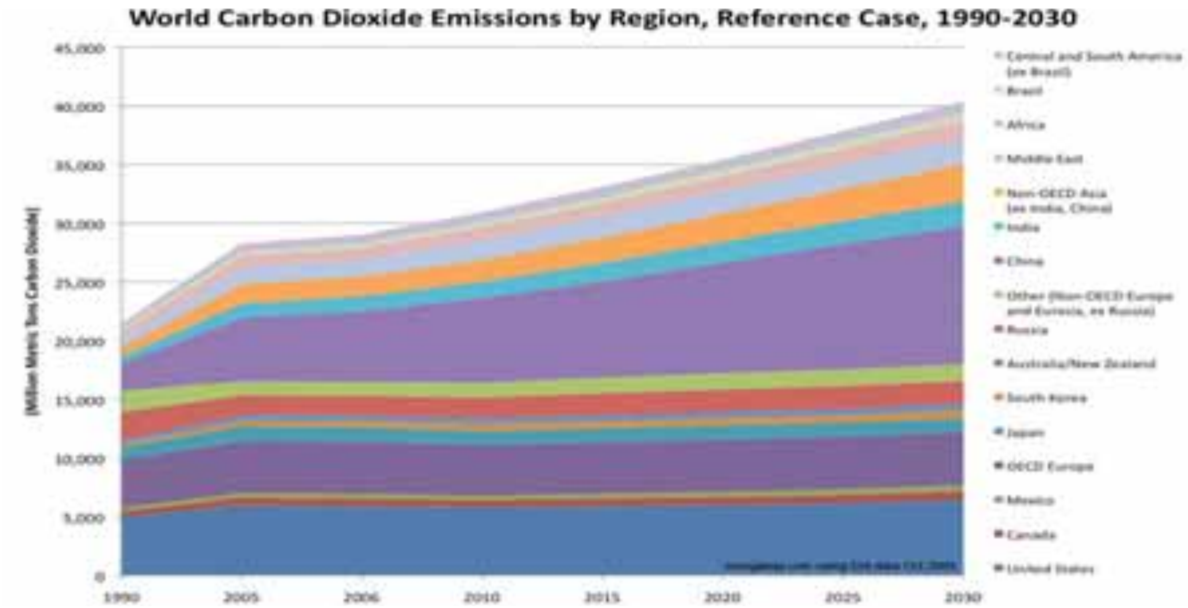

Fig. 2: Carbon Dioxide Emissions by Country, 1990-2030

Source : http://rainforests.mongabay.com/09-carbon_emissions.htm

The IPCC (Intergovernmental Panel on Climate Change) concludes that, based on scientific evidence (4th Assessment Report on scientific aspects of climate change, 2007), human activities related to large-scale fossil fuel consumption, is largely responsible for the increase in global warming by increasing emissions of greenhouse gases into the atmosphere. Solar energy is an everlasting form of energy which is clean, eco-friendly and available free of cost. The recent worldwide trends regarding the unstable prices of oil, the environmental demands of the Kyoto Protocol and the renewed calls to place more emphasis on the usage of renewable energy resources, have contributed to the development of multiple systems for the desalination of seawater. 'Renewable energy is the alternative solution to the decreasing reserves of fossil fuels'(Sofi,2001).

Solar energy is the most upcoming type of energy. It is a fact that the ever-increasing population of the world has increased the demand of water all over the world. Hence, it is essential that countries around the world do something to produce more water sources. For this reason, those countries which have abundant sunshine and seas are using the latest technology to use the solar energy to desalinate seawater, thereby producing fresh water. However, this type of technology is underdeveloped and can't be used on large scales. Desalination of seawater by using the solar energy can be done either directly or indirectly. In the indirect system, less land is required, and more fresh water is produced when compared with the direct system. However, the disadvantage of the indirect system is that it is costs more to setup, thus it is not preferred.

In fact, there are many ways to produce fresh water from seawater. Of the different available options, the MED- also called the Multi-Effect Desalination process- is perhaps the best of all as it is less costly and more effective. For this reason, we will be focusing on this particular process, for the purpose of our research.

2. Why do we need solar energy for desalination?

The application of solar powered energy in thermal desalination techniques is one with a lot of potential amongst many other types of renewable energy techniques. The non-availability of potable water resources, and the need to look for other forms of water supplies will increase in the future. In considering factors that will determine world stability, availability of water worldwide and fossil as a source of renewable energy will come tops in the nearest future. The global accessibility of renewable energies and established knowledge and technologies in this area make it quite attractive to consider the assembling of desalination plants with renewable energy production methods in order to guarantee the production of water in a sustained and environmental friendly scheme for the areas in question. The process involved in the formation of rain could also be termed as solar desalination. Thermal desalination methods are very thorough energy methods. The cost of implementing these types of methods could be as much as 40-50% of the total cost of producing water (Garcia-Rodriguez, 2003). To run a plant that desalinates seawater to give fresh water requires the use of tremendous energy. For instance, ten thousand tons of oil would be required to produce 1000 m^3 of water every day. The use of oil as a source of energy for such plants will not put the Middle Eastern countries in any spot; because they generate a lot of income from their oil exports, and will thus be able to bear the high cost. Moreover, using fossil fuels as sources of energy will pollute the environment as well. This can be seen from the fact that, according to the US EPA 2000, Inventory of the US Greenhouse Emissions and Sinks: 1990-1998, out of the total greenhouse gases produced by the United States, nearly 90% was produced by the usage of fossil fuels. The problem is that these resources will start depleting sooner, and we might not have any to use by the end of the next 100 years or so.

3. An overview of the global water problems

Figure 3 shows the population of the world from 1950 to the current year (population circa 6 billion) and the estimated population by the year 2050 (USCB, 2003). It clearly shows that the population is increasing and with this increase, the demand for water will increase as well, and with this increased demand of water, a time will come when it will not be possible to meet the requirements. This is leading to water shortages and will become a serious problem in the future.

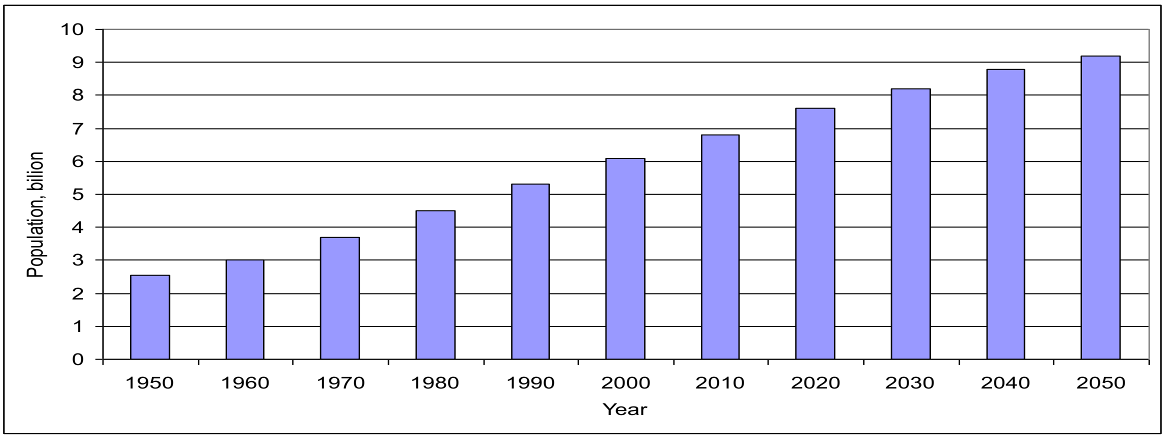

Fig. 3: Change in the world population since 1950 to 2050 (Matt, 2008)

This can be proved by many examples. For instance, in 1995, a little more than 31 countries with a population of about 458 million faced a water crisis according to People Action International. However, the worrying part is that they estimate that by the year 2025 about 48 countries with a population of 2.8 billion will face the same problem (PAI, 1999). The constant industrial development coupled with factors such as increase in the population will increase the percentage of people facing the water shortage by 20% to a total of 60% by the year 2025 (El-Dessouky et al, 2002). Currently, there are about 1 billion humans who are in need of fresh water according to the world health organization (W.H.O., 2005). Angelo (2000) estimates that the percentage of the people who will be facing water shortages by the year 2050 will increase to about 63%. The Middle Eastern countries are already starved of water and if the situation continues, it could cause a water war among them; therefore, it is vital to do something to prevent any such events (Joshua, 2006). The water problem can be judged by the fact that currently contaminated water is responsible for almost 30% of deaths and about 80% to 90% of diseases in the world (El-Dessouky et al., 1999).

The countries of the Arab world have already started facing water shortages, and fresh water will most like finish in a few years (Wardah et al., 2004). Similarly, a country like China is facing water problems. For instance, there are about 40 million people in China who do not have enough water for their usage (Sci, 2000). The population of the country forms 22% of the population of the world, but this 22% has only seven percent of the world's fresh water at their disposal (Bindra et al., 2001). However, the problem of water shortage is not restricted to one part of the world. Even the region such as the UK is facing water strains (Cosgrove et al., 2000) due to dwindling lake water. One example that shows the problem can be seen from the fact that one of the largest suppliers of water to London that is using 50 percent of the rain water known as 'Thames Water' is now searching for some other sources for getting water (Stedman, 2005). Likewise, Spain faces even more problems in the summer because they have an influx of tourists during those times and that causes even more shortage for the residents of Spain (Javier, 2001). The percentage of people who have access to potable drinking water can be seen in Figure 4. Another big problem faced by the few sources of water is pollution. It contaminates the water thereby reducing the supply of fresh water because of which the demand for water cannot be met (Kufahl, 2002).

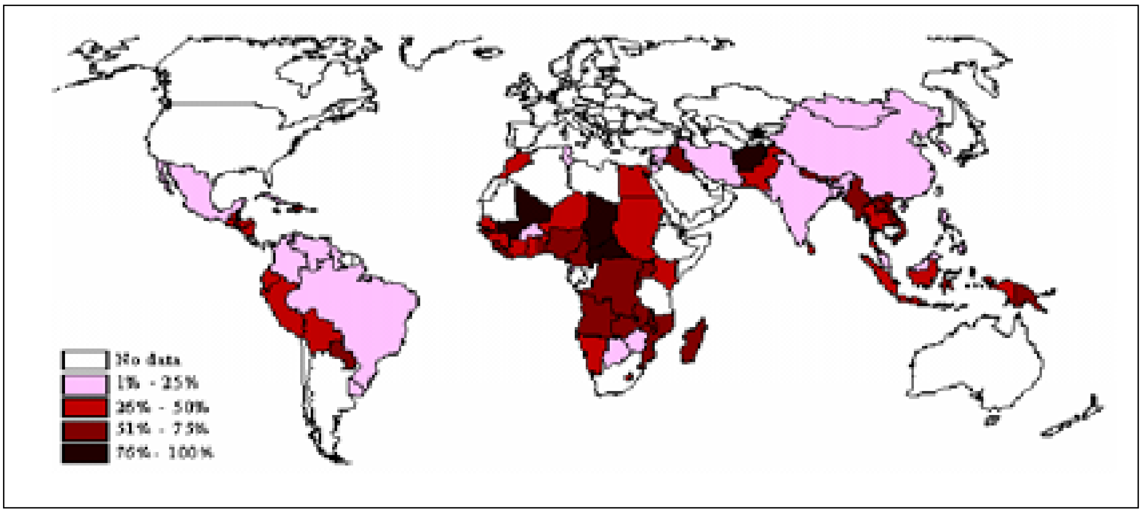

Fig. 4: Population without access to safe drinking water (Gleick, 1998)

In the light of the above, desalination of seawater has proven to be a sensible option to provide fresh water and in many cases, it is the only possible solution for many countries around the globe.

4. Distillation processes

4.1. Based on water evaporation :

The process of desalination is used in this method that involves a two-step process. In the first step, the water is heated to a high temperature and in the second, a vessel of decreasing pressure is used through which the heated water is passed to ensure that the amount of water vapours of fresh water produced is as much as possible. This method is called Multistage Flash Distillation (MSF). The same concept, as described above, is used in the Multi-Effect Distillation method (MED). The only difference is that in this method the temperature to which the heating is done is low. The last evaporation method used for producing water vapours by the compression of vapours results in heat. This process is used as a mixture with other processes and is called the process of Vapour Compression Distillation.

4.2. Based on water crystallisation :

Freezing processes are based on the natural phenomenon that ice crystals are formed of pure water only, even when formed from a salt solution. Hydrate processes exploit a bond between water molecules and certain chemical compounds such as $CaSO_4$ or organic gasses (e.g. methane) to recover fresh water from saline solution.

4.3. Membrane processes :

In this process, a membrane is used through which the saline water is made to pass. When the water is made to pass with force, the membrane lets the water through and traps the salt, thereby making the water free of salt. This is known as the process of reverse Osmosis. IMS (Integrated Membrane Systems): In this process, the NF and RO are used along with the Ultra filtration (UF) and Continuous Microfiltration (CMF).

5. Energy requirements

One of the most important factors in the process of desalination is the use of energy since it is a major part of the unit product cost (Darwish et al., 1997). Out of the total cost incurred for operating the MSF desalination plant, nearly 59% is the cost of energy consumed (Desalination Markets, 2004). In fact, on an average, about 30% to 50 % of the cost of operating a desalination plant consists of energy (Semiat, 2000). The ratio of consumption of the plant is the deciding factor of the amount of energy that will be consumed (Cardona et al., 2004). If the ratio is high, more energy is required. This would mean more oil is required to run the plant. However, with the oil prices touching 120 dollars a barrel (2008), oil is an expensive source of energy for many countries. It has been estimated that MSF plant consumes 48.5 kWh/m^3 energy for heat and about 1.3 kWh/m^3 for electricity (Huanmin et al., 2002). Likewise, it has been said in another study that the same plant, consumes 4-6 kWh/m^3 electrical energy and about 50-120 kWh/m^3 of thermal energy (Cardona et al). The MSF plant is also said to use about 3.8kWh/m^3 electrical power (Andrianne et al., 2002). Similarly, the place where the boiler is used to give the steam uses about 17.05MW thermal energy per1MIGD or 324 kJ/kg (Darwish et al., 2000). (Ettouney et al., 2002), have said that 4kWh/m3 is the average consumption of power at this plant. The performance ratio of the evaporation of recirculating brine in the MSF desalination plant, according to Khawji is 19 kg/1000Kcal heat input (Khawji, 2001), which proves that when Al-Sahali said that this plant uses more energy as compared to any other plant, he was right (Al-Sahali, 2007). The thermal energy which is consumed during other thermal processes is about 290 kJ/kg, which is much less than the amount of energy that the process of MSF requires when it performs the process of desalination (Al-Wizen, 2001). However, all is not lost, because it is possible to reduce the amount of energy the MSF requires. This can be done by using the dual-purpose and hybrid processes (Bruggen, 2002). Moreover, if a pre-treatment is performed, the MSF will need to do less work to produce fresh water.

6. Selection of desalination process

To produce fresh water from seawater, the desalination uses renewable sources such as solar, wind, geothermal, etc. However, it is not possible to use all the types of renewable sources of energy for the system of desalination. To determine the best source for the system, the geography, topography of the land and weather have to be studied in detail. Various factors that must be considered when the desalination process is being selected for a specific application are as follows (Kalogirou, 1997) :

1. The amount of fresh water required in a particular application in combination with the range of applicability of the various desalination-processes.
2. How effective the process is with regards to the consumption of energy.
3. Suitability of the process for solar-energy application.
4. The seawater treatment requirements.
5. The cost of the equipment required for this process.
6. The area of land that will be required for setting up the equipment for the plant.
7. Robustness criteria and simplicity of operation.
8. Easier ways of transportation, less maintenance, etc.

6.1. Direct solar desalination

This system is appropriate for smaller establishments where the daily freshwater requirement is less than 200 m^3. The diminished production rate is defined by the reduced functioning steam temperature and pressure. The primary solar still is basically a trough covered with a transparent solid material such as glass, which should be tilted for the whole setup to work. Seawater is placed in the trough and when it is hit by solar radiation, it heats up and evaporates. The water vapour formed mixes with the air that was originally between the water and the glass cover. Once the vapour hits the glass cover, the now humid air cools and condensation happens and the formed water trickles along the glass surface for collection at the edge (Rizzuti et al., 2007). An example of this kind of setup is shown in Figure 5.

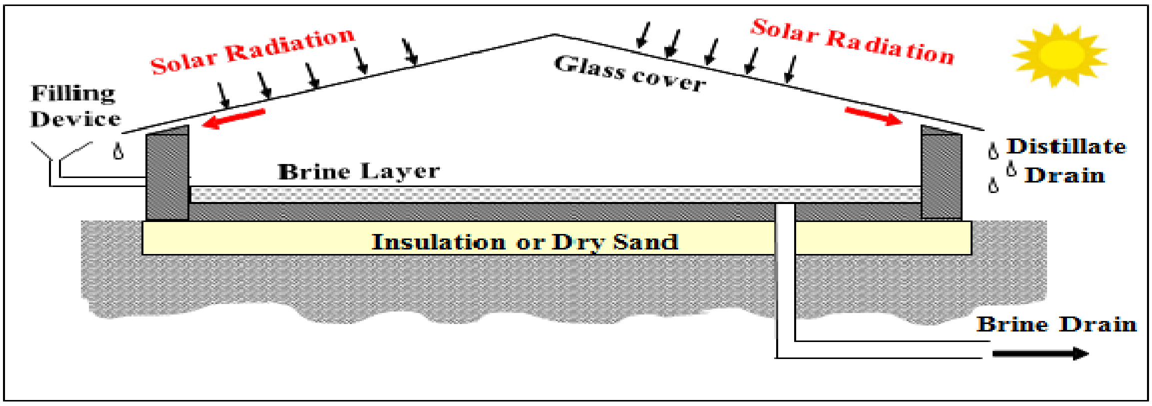

Fig. 5: A basic setup for direct solar desalination (Lindblom, 2003)

6.2. Multi-effect solar stills

These types of solar stills reuse a certain amount of the latent heat generated by the condensing vapour on the cooling panel. The latent heat is directed to either preheat the salty feed water or to heat the water inside the still (Wang et al., 2010). Preheating the feed water is achieved by combining the feed water channels and the condensation panel. In this way, the seawater is continuously heated by the heat generated by the condensing vapour, while at the same time ensuring that the condensation area is well cooled. Such a construction can produce more than 20 L/m^2 on a daily basis as shown in Figure 6.

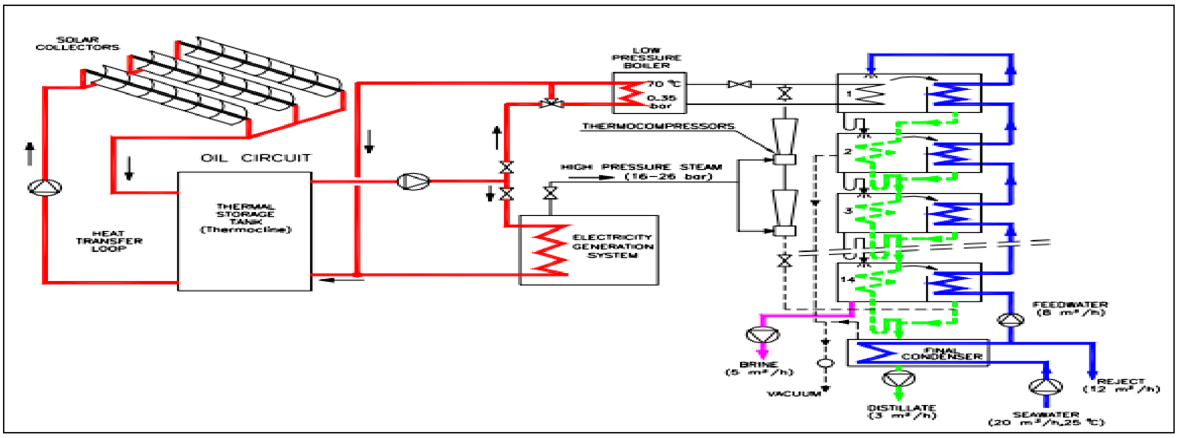

Fig. 6: Schematic Solar still with MED system

6.3. Indirect solar desalination

Desalination plants of the multistage flash type, reverse osmosis type and the multi-effect type have been set up on large industrial scales because of the amount of fresh water that they can provide (Garcia-Rodriguez and Gomez-Camacho 2002). In fact, according to statistics, 236 m^3 of fresh water is produced by this industry (Garcia-Rodriguez and Gomez-Camacho 2002). However, all the above systems are not cheap to run at all. This is because the energy that they demand for producing electrical power can only be generated from burning of fossil fuels. However, the solution to this problem is the usage of renewable energy, such as the solar power. This type of energy is not only cheaper, but easy to maintain as well.

6.4. Multi-effect desalination

The multi-effect desalination system is currently the most reliable of all other techniques. In the past, this system was only used for production of over 100 m^3 per day. However, the usage of solar systems to generate the required electrical energy to power the plants has made the systems more economically viable. This system performs the work of producing fresh water by evaporation of the saline water. When the water is heated, it produces steam. This steam that condenses is made to pass through a number of tubes which are basically arranged in bundles. The heat from this steam results in evaporation that takes a total of about twelve different steps (Seimat 2000). In the second stage, the steam is produced at low temperatures and pressures by evaporating the brine. Once this has been done, the saline water is evaporated by using it. As of now, many different studies are going on at different levels, each with the single focus of making a multi-effect system that can run on the solar power (Manwell and McGowan 1994).

7. Characteristics of solar powered thermal distillation machinery

The characteristics of the machinery used for the thermal distillation which is powered by the solar energy are based on two types of heat absorbers, namely copper and aluminium. Copper is less frequently used because its ability to conduct the thermal energy is less than that of aluminium. Some more characteristics of this machinery are as follows: **1-** how much thermal conductivity does the material used for conduction possess? **2-**The thermal conductor cross-sectional area, which is responsible for determining how much the exposure from the sun, will the conductor get as the amount of the thermal energy that is absorbed by the conductor will depend on how much it has been exposed to the sun. **3-**The radiosity that depends on the place where the desalination plant is situated. There are some other characteristics such as the effects of heat and the input fluid's capacity to sustain and trap heat.

8. Low temperature multi-effect distillation (LT-MED)

The efficiency of the Low Temperature Multi-Effect Distillation (LT-MED) has been tested, evaluated and economically proven to be efficient. An important characterizing element is its good thermodynamic functionality. That is coupled with low pressure drops accompanied with high volumetric efficiency of vapour flows providing an economic feasibility of using low cost durable materials (Barron, 1992). The technical construction of the system using aluminium alloys that provide an efficient transfer of heat within the system ups its operational efficiency. That is typically due the fact that the thermal conductivity of aluminium is higher than that of copper, making the material specifically suitable in providing superior thermal functionalities (Office of Saline Water, 1971).

In the construction of a typical system, aluminium provides a higher heat transfer per ton of water than copper when the same investment cost is calculated for the two materials. In practice, the economy ratio is very high as has been proven with similar plants that have been used at the Virgin Island plants (Barron, 1992). The technology incorporates inexpensive centrifugal compressors which demand minimum inputs for pre-treatment machines (Barron, 1992). Consider a Multi-Effect Desalination (M.E.D.) plant. Established MED plants are constructed using horizontally arranged aluminium alloy tubes with an evaporative condenser that consists of falling films in a serial arrangement (Al-Shammiri et al., 1999).

The tubes are serially arranged to optimize the production of multiple amounts of distillate in a repetitive process involving evaporation and condensation. Technically, the temperature difference between the steam and the inlet temperature of seawater affects the overall number of effects. The minimum temperature difference allowed for each effect is also influenced by the arrangement of the aluminium tubes (Barron, 1992). Operationally, the input seawater is divided into two streams at the inlet after it has been deaetreated and preheated. At this point, one stream is allowed to flow into the sea as a coolant and the other acts as the input source for desalination. The heating process is done at the heat rejection condenser. Afterwards, the water to be distilled is allowed into the lowest temperature compartment, referred to as backward feed flow. That is influenced by the need to optimize the thermodynamic efficiency of the system which is achieved by controlling the mixing of colder seawater with the higher temperature effects (Barron, 1992).

9. The economic rationale

The studies that have been done on whether desalination plants which are thermally powered are technically and economically feasible show that, by using desalination plants that are solar powered, the cost of producing water has gone down by 8% to 17% (Mireles, 1991). Furthermore, it came to light that if the Multi-effect distillation system was used for the solar powered thermal desalination plants, the cost of the fresh water produced with it would reduce even more (Swift, 1988). By using multiple wetting techniques for the usage with pumps which are intermediate and work on the solar power, and by using antiscalants, the efficiency of MED and LED-MED techniques can be improved (Glueckstern, 1995). When the cost benefit analysis was done on these techniques, the internal rate of return was found to be about 8.5 % more costly if gas was being used as a source of energy, particularly in those countries which have longer and colder winter months (Mireles, 1991). But, when the decision to use a technology is being made, it is essential to analyse what effect this desalination will have on the environment (Morton, Callister & Wade, 1996).

10. Limitations to the use of solar desalination processes in the MENA region

The fact that desalination requirements are mostly high in those countries which have the oil wealth makes the use of the expensive solar technology not feasible for them. The funds required to carry on the study and the research on the solar technology do not meet the requirements. Another problem is the instable electricity supply. When these plants were built, they were designed to run on uninterrupted supply of the electrical power. When the power goes out, it affects the efficiency of the system. Different problems are faced by different desalination systems. For instance, when the vapour compression system is used, it requires a lot of energy to get to the optimum level of working. Therefore, there must be some kind of a system which can store the energy and supply it to the plant when the power gets disrupted. However, this system is workable only on a small scale where the system that use this stored power is also small. Another option is to store hot oil or hot water as a source of thermal energy for the thermal system. However, this option is very expensive and thus not feasible economically. Likewise, the problem with the reverse osmosis system is that the membrane which is used in this system is sensitive to scaling and fouling.

11. Conclusion and recommendations

The solar systems have a very low rate of fresh water production, and also not efficient enough to be used on a large scale. Therefore, they are mostly being used for a small scale production of fresh water. Because of this very reason, the amount of fresh water, which is produced by the use of the solar energy around the world, is only 0.025%. The demand for fresh water is increasing day-by-day with the increase in the population. Farmers are now doing irrigation-based agriculture as compared to agriculture which is based on rainwater. Moreover, fossil fuels are used to supply the energy for the rest of desalination plants. As a result, with the increasing demand, this trend of producing water from the solar energy will increase in the near future. The best option available now is to combine the traditional desalination system with a renewable energy. In the end, we would like to recommend that the MED system should be the subject of further study so that it can be determined if this process is more effective and economically feasible as compared to other processes of desalination.

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