SOLAR DRIVEN MULTI-EFFECT DISTILLATION

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DEPARTMENT OF MECHANICAL ENGINEERING

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Major Project Report

Submitted in partial fulfillment of the requirements

for the Degree of

Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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Abbreviation

A_r	=	Area of the reciever pipe
A_a	=	Aperature area of the concentrator
W	=	Width of concentrator
D_{co}	=	Diameter of transparent cover
L	=	Length of concentrator
F_R	=	Heat removed factor
C_p	=	Specific heat
$H_b R_b$	=	Beam radiation intensity
U_L	=	The loss coefficient
U_O	=	The overall heat transfer coefficient
V	=	Wind velocity
q_u	=	Heat gain per unit area
t_{ci}	=	Fluid inlet temperature
t_{co}	=	collector fluid temperature at outlet
t_a	=	Ambient temperature
S	=	Absorbed solar energy

Abstract

Potable water supply has a significant role in today's developing world. A number of seawater desalination technologies have been developed during the last several decades to augment the supply of water in arid regions of the world. Due to the constraints of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. It is very important to determine the specifications of desalination systems in order to achieve cheaper water prices and better operational conditions.

The application of the direct steam generation into a solar parabolic trough collector to multi effect distillation is proposed and economically evaluated. The thermal fluid of the solar field is pure water, which boils as circulating along the solar collectors. The steam generated drives a multi effect distillation unit. This solar distillation system is compared with multi effect plants connected to a conventional parabolic trough collector field, and with fossil fuel powered distillation plants.

A special desalinization unit which utilizes solar or waste energy has been developed and tested indoors. In this unit, a relatively large fraction of latent and sensible heat of condensation is successfully recycled and utilized.

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Chapter 1

INTRODUCTION

More than two-third of the earth's surface is covered with water. Most of the available water is either present as seawater or icebergs in the Polar Regions. More than 97% of the earth's water is salty; rest around 2.6% is fresh water. Less than 1% fresh water is within human reach. Even this small fraction is believed to be adequate to support life and vegetation on earth. Nature itself provides most of the required fresh water, through hydrological cycle. A very large-scale process of solar distillation naturally produces fresh water. As the available fresh water is fixed on earth and its demand is increasing day by day due to increasing population and rapidly increasing of industry, hence there is an essential and earnest need to get fresh water from the saline/brackish water present on or inside the earth. This process of getting fresh water from saline/ brackish water can be done easily and economically by desalination.

1.1 Water: Basic Need for Human

Water is basic necessity of man along with food and air; the importance of supplying hygienic portable/fresh(less than 500 ppm) water can hardly be overstressed. Man has been dependent on rivers, lakes and underground water reservoirs for fresh water requirements in domestic life, agriculture and industries. However use of water from such sources is not always possible or desirable on account of the percentage of large amount of salts and harmful organism. The impact of many diseases affecting mankind can be drastically reduced if fresh hygienic water is provided for drinking. Further, the rapid industrial growth and population explosion all over the world has resulted in a large escalation of demand for fresh water; this invariably leads to acute fresh water shortages since the natural sources of water can meet the demand to a very limited extent. Added to this is the problem of pollution of the rivers and lakes by the industrial wastes and the large amounts of sewage. Thus there is scarcity of fresh water even in cities, towns and villages near lakes and rivers. Dangerous pollutants left on open ground also find their way into the underground reservoirs along with rain water. In fact on a global scale man-made pollution of natural sources of water is turning out to be the single largest cause for the fresh water shortage. Besides this there are several regions on the earth, e.g. the deserts, which have inhospitable climate conditions and have only brackish water sources. In such places fresh water will have to be provided not only domestic use, but also for agricultural needs. It would be no exaggeration to say that by the end of this century, supply of adequate quantities of fresh portable water could become one of the most serious problems confronting man.

With the official launching in New York, U.S.A. on 10th November, 1980, of the International Drinking Water Supply and Sanitation Decade (IDWSSD), the United Nations Organization set into motion a major initiative that should have a direct impact on at least half of the world's population by 1990. According present estimates over 2000 million people are without reasonable access to a safe and adequate water supply. Developing countries (e.g. India) have given almost priority to rural water supply in their developments plants. Major U.N. organization like UNDP, WHO and the World Bank are actively involved in promoting projects aimed at supplying drinking water in Indian villages. Between 25 to 35 percent of the UNICEF's assistance to programs for children is invested in water supply. The UNDP and World Bank have been involved in a global project aimed at low cost water supply techniques and to facilitate the testing and selection of water supply and pumps.

The only inexhaustible sources of water are the oceans. Besides, there are also several, hitherto unused, big lakes, inland seas and underground natural reservoirs containing salt/brackish water. The chief drawback, obviously, is the very large salinity of such water. One of the attractive schemes to tackle the problem of water shortage is the distillation of such water resulting in desalination; this water may be mixed with brackish water (if hygienically desirable) to increase the amount of fresh water and bring the concentration of salts to around 500 parts per million. The conventional distillation process such as multi-effect evaporation, multi-stage fresh evaporation, thin film distillation, reverse osmosis and electro dialysis are not only energy intensive but are also uneconomical for not too large demands of fresh water. However, the developments in the use of solar energy have demonstrated that is ideally suited for desalination, when the demand of fresh water is not too large. The rapid escalation in the cost of fuels has made the solar alternative more attractive; in certain remote arid regions, this may the only alternative. The least that can be said in favor of solar distillation (distillation of saline water by the use of solar energy) is that it is a viable option for providing hygienic portable water for a single house or a small community in most place of the earth. Further, the development of green houses has resulted in minimizing the water requirements for carrying on agriculture on a small scale; thus solar desalination can support small scale agriculture in regions having only brackish water sources.[1]

1.1.1 Availability of water

Water is something usually taken for granted. Like air, it is just assumed to be there, both in adequate quantity and quality. Historically Man settled near rivers, freshwater lakes, springs and, later, such shallow wells as he was able to dig. He confined his crops to areas where rainfall or, as in the case of Nile, river flooding, was at least regular if not absolutely dependable. As his need for water grew, simple artificial aids to its natural provision also developed mainly in the form of aqueducts, dams and deeper borings into the water-bearing strata. And even today, despite occasional shortages, water is generally regarded as a natural right in most of the industrially developed countries. Often people fail to realize that many branches of scientific and engineering skills must now be called on to provide it.

Science, in the sense in which the world is normally used, is a latecomer in the field; making water available has been, and still is, primarily a matter for engineers who, of course, have been adept for many years in the art of harnessing natural resources. However, assessing future water needs in terms of physical works for supplying the water is now generally regarded as a political matter. The engineer can offer alternative methods for meeting these needs. Government has increasingly to decide not so much between the commitment of capital, either to water supply development or to some other entirely different project influencing a nation's well-being.

Water use falls into one or more of the following five categories:

1. Essential domestic and public health purposes.

2. Other, less essential, public purposes.

3. Industrial.

4. Agricultural.

5. Power generation (either hydroelectric or thermal).

When offered a method of providing water for any, or all, of these uses, Government must compare the offered price with that of an alternative scheme. It must also consider how the provision of water for one kind of use many have an effect on cost, and even on the availability, of water for other uses over a substantial period. It could be that a dam would provide water at the lowest unit cost, but that its capital cost could not be supported by the economy at the time. A cheaper, smaller source might meet the immediate needs and set the scene for industrial development. Later an expanded economy could afford the more complete solution originally offered and, based on a plentiful supply of cheaper water, could continue to grow.

Desalination is not one single process: it represents the many processes for rendering water non-saline. Again it is not something on which the engineer or the scientist accurately put a price, saying “desalinated water cost so much a cubic meter”. Even if a particular process is chosen and cost figures determined for the individual case, other factor remain to be examined before the price of water per cubic meter can be worked out.

In addition, any economic assessment of a desalination scheme has to consider, for example, whether the value of land not required for a possible alternative surface storage reservoir should enter into the reckoning; and whether a debit value is to be placed on the loss of amenity and recreational facilities which could have been provided by a surface reservoir. So Government faces a decision as to whether or not desalination is a politically desirable objective, irrespective of the existence of any potential traditional sources which, on direct costing alone, could produce water at a lower unit price actually delivered to the customer.[1]

1.1.2 The water problem

Water shortage is an issue in many places of the world. The earth is rich in seawater resources, so it is an effective way to get fresh water from the sea to solve the shortage of fresh water.

Many remote areas of the world such as coastal desert areas in the Middle East or some Mediterranean and Caribbean islands are suffering from acute shortage of drinking water particularly during the summer season. Drinking water for these locations are normally hauled in by tankers or barges or produced by small desalination unit using the available saline water. The transportation of water by tankers or barges involves a lot of expense and is fraught with logistical problems which can make fresh water not very expansive when available but also its supply being very expensive susceptible to frequent interruptions.

The demand for fresh water has increased significantly since 1990 for many reasons, including, on the one hand, the increase in world population accompanied by the increase in standard of living, and, on the other hand, global warming followed by climate changes and desertification. Governments and water industries are seeking different solutions for better utilization of available water, thereby increasing the efficiency of growth crops, solutions for better wastewater treatment, and the development of new water sources and improved desalination techniques. [1]

1.1.3 Assessment of needs

To say that a particular area needs water is not helpful. There must be a careful assessment of the quantity and quality of water required, and a reasonably sound idea of the rate of growth of demand. The approach of this kind of problem has to be made either by reference to past trends in the area or by drawing upon the knowledge and experienced gained from studying conditions in other similar area and countries. The projection of past trends may not appear to give sufficiently reliable data, and it may be necessary to estimate demand by considering its separate components. This kind of approach is simplified if reference is made to the five headings listed above in relation to the applicable ways of usage:

1. Domestic: “essential” use-personal drinking, cooking, washing and sanitary.

2. Domestic: “non-essential” use-garden watering, swimming, pools, car washing, garbage disposal, air-conditioning.

3. Industrial: cooling, process, washing and transport.

4. Agricultural: animal use, crops, horticulture.

5. Power generation: hydro-electric, thermal cooling.

1.2 History of Desalination

As early as in the fourth century BC, Aristotle described a method to evaporate impure water and then condense it to obtain potable water. However, historically probably one of the first applications of seawater desalination by distillation is depicted at the drawing shown in Fig. 1. The need to produce fresh water onboard emerged by the time the long distance trips were possible. The drawing illustrates an account by Alexander of Aphrodisias in AD 200, who said that sailors at sea boiled seawater and suspended large sponges from the mouth of a brass vessel to absorb what is evaporated. In drawing this off the sponges they found it was sweet water.

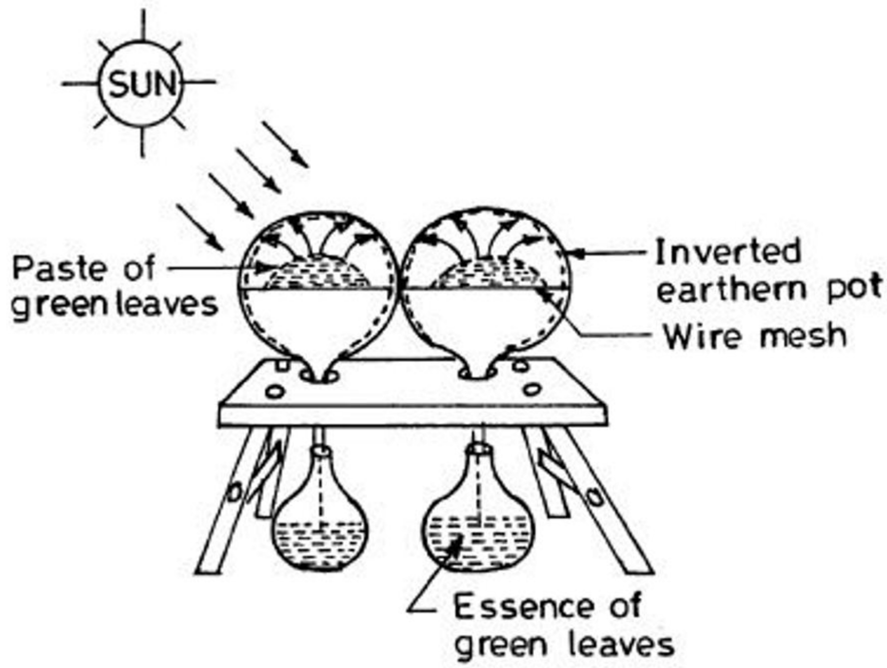

Figure 1.1: Producing fresh water with seawater distillation.[2]

Until medieval times no important applications of desalination by solar energy existed. During this period, solar energy was used to fire alembics in order to concentrate dilute alcoholic solutions or herbal extracts for medical applications, to produce wine and various perfume oils.

1.3 Desalination and Energy

The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. Therefore, it would be attractive to tackle the water-shortage problem with desalination of this water. Desalinize in general means to remove salt from seawater or generally saline water.

According to World Health Organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm) and for special cases up to 1000 ppm, while most of the water available on earth has salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000– 45,000 ppm in the form of total dissolved salts. Excess brackishness causes the problem of taste, stomach problems and laxative effects. The purpose of a desalination system is to clean or purify brackish water or seawater and supply water with total dissolved solids within the permissible limit of 500 ppm or less. [3]

Desalination processes require significant quantities of energy to achieve separation of salts from seawater. This is highly significant as it is a recurrent cost, which few of the water-short areas of the world can afford. Many countries in the Middle East, because of oil income, have enough money to invest in and run desalination equipment. People in many other areas of the world have neither the cash nor the oil resources to allow them to develop in a similar manner. The installed capacity of desalinated water systems in year 2000 is about 22 million m^3/day, which is expected to increase drastically in the next decades. The dramatic increase of desalinated water supply will create a series of problems, the most significant of which are those related to energy consumption and environmental pollution caused by the use of fossil fuels. It has been estimated that the production of 22 million m^3/day requires about 203 million tons of oil per year (about 8.5 EJ/yr or 2.36×10^{12}kW h/yr of fuel). Given concern about the environmental problems related to the use of fossil fuels, if oil was much more widely available, it is questionable if we could afford to burn it on the scale needed to provide everyone with fresh water. Given current understanding of the greenhouse effect and the importance of CO_2 levels, this use of oil is debatable. Thus, apart from satisfying the additional energy demand, environmental pollution would be a major concern. If desalination is accomplished by conventional technology, then it will require burning of substantial quantities of fossil fuels. Given that conventional sources of energy are polluting, sources of energy that are not polluting will have to be developed. Fortunately, there are many parts of the world that are short of water but have exploitable renewable sources of energy that could be used to drive desalination processes.

Solar desalination is used by nature to produce rain, which is the main source of fresh water supply. Solar radiation falling on the surface of the sea is absorbed as heat and causes evaporation of the water. The vapour rises above the surface and is moved by winds. When this vapour cools down to its dew point, condensation occurs and fresh water precipitates as rain. All available man-made distillation systems are small-scale duplications of this natural process.

Desalination of brackish water and seawater is one of the ways of meeting water demand. Renewable energy systems produce energy from sources that are freely available in nature. Their main characteristic is that they are friendly to the environment, i.e. they do not produce harmful effluents. Production of fresh water using desalination technologies driven by renewable energy systems is thought to be a viable solution to the water scarcity at remote areas characterized by lack of potable water and conventional energy sources like heat and electricity grid. Worldwide, several renewable energy desalination pilot plants have been installed and the majorities have been successfully operated for a number of years. Virtually, all of them are custom designed for specific locations and utilize solar, wind or geothermal energy to produce fresh water. Operational data and experience from these plants can be utilized to achieve higher reliability and cost minimization. Although renewable energy powered desalination systems cannot compete with conventional systems in terms of the cost of water produced, they are applicable in certain areas and are likely to become more widely feasible solutions in the near future.

Only methods, which are industrially matured, are reviewed. There are, however, other methods, like freezing and humidification/dehumidification methods, which are not included in this work as they are developed at a laboratory scale and have not been used on a large-scale for desalination. Special attention is given to the use of renewable energy systems in desalination. Among the various renewable energy systems, the ones that have been used, or can be used, for desalination are reviewed. These include solar thermal collectors, solar ponds, photovoltaics, wind turbines and geothermal energy.

1.4 Desalination Processes

Desalination can be achieved by using a number of techniques. Industrial desalination technologies use either phase change or involve semi-permeable membranes to separate the solvent or some solutes. Thus, desalination techniques may be classified into the following categories: [3]

I. Phase-change or thermal processes; and

II. Membrane or single-phase processes.

All processes require a chemical pre-treatment of raw seawater to avoid scaling, foaming, corrosion, biological growth, and fouling and also require a chemical post treatment. In Table 1.1, the most important technologies in use are listed. In the phase-change or thermal processes, the distillation of seawater is achieved by utilizing a thermal energy source. The thermal energy may be obtained from a conventional fossil-fuel source, nuclear energy or from a non-conventional solar energy source or geothermal energy. In the membrane processes, electricity is used either for driving high-pressure pumps or for ionisation of salts contained in the seawater.

Table 1.1: Desalination processes

Phase-change processes	Membrane processes
1.Multi-stage flash (MSF)	1. Reverse osmosis (RO)
	• RO without energy recovery
	• RO with energy recovery (ER-RO)
2. Multiple effect boiling (MEB)	2. Electro dialysis (ED)
3. Vapour compression (VC)	
4. Freezing	
5. Humidification/Dehumidification	
6. Solar stills	
• Conventional stills	
• Special stills	
• Cascaded type solar stills	
• Wick-type stills	
• Multiple-wick-type stills	

Commercial desalination processes based on thermal energy are multi-stage flash (MSF) distillation, multiple effect boiling (MEB) and vapour compression (VC), which could be thermal (TVC) or mechanical (MVC). MSF and MEB processes consist of a set of stages at successively decreasing temperature and pressure. MSF process is based on the generation of vapour from seawater or brine due to a sudden pressure reduction when seawater enters an evacuated chamber. The process is repeated stage by stage at successively decreasing pressure. This process requires an external steam supply, normally at a temperature around 100°C. The maximum temperature is limited by the salt concentration to avoid scaling and this maximum limits the performance of the process. On MEB, vapours are generated due to the absorption of thermal energy by the seawater. The steam generated in one stage or effect is able to heat the salt solution in the next stage because the next stage is at a lower temperature and pressure. The performance of the MEB and MSF processes is proportional to the number of stages or effects. MEB plants normally use an external steam supply at a temperature of about 70°C. On TVC and MVC, after initial vapour is generated from the saline solution, this vapour is thermally or mechanically compressed to generate additional production.

Not only distillation processes involve phase change, but also freezing and humidification/dehumidification processes. The conversion of saline water to fresh water by freezing has always existed in nature and has been known to man for thousands of years. In desalination of water by freezing fresh water is removed and leave behind concentrated brine. It is a separation process related to the solid liquid phase change phenomenon. When the temperature of saline water is reduced to its freezing point, which is a function of salinity, ice crystals of pure water are formed within the salt solution. These ice crystals can be mechanically separated from the concentrated solution, washed and re-melted to obtain pure water. Therefore, the basic energy input for this method is for the refrigeration system. Humidification/dehumidification method also uses a refrigeration system but the principle of operation is different. The humidification/dehumidification process is based on the fact that air can be mixed with large quantities of water vapour. Additionally, the vapour carrying capability of air increases with temperature. In this process, seawater is added into an air stream to increase its humidity. Then this humid air is directed to a cool coil on the surface of which water vapour contained in the air is condensed and collected as fresh water. These processes, however, exhibit some technical problems which limit their industrial development.

The other category of industrial desalination processes does not involve phase change but membranes. These are the reverse osmosis (RO) and electro dialysis (ED). The first one requires electricity or shaft power to drive the pump that increases the pressure of the saline solution to that required. The required pressure depends on the salt concentration of the resource of saline solution and it is normally around 70 bars for seawater desalination.

ED also requires electricity for the ionization of water which is cleaned by using suitable membranes located at the two appositively charged electrodes. Both of them, RO and ED, are used for brackish water desalination, but only RO competes with distillation processes in seawater desalination. The dominant processes are MSF and RO, which account for 44 and 42% of worldwide capacity, respectively. The MSF process represents more than 93% of the thermal process production, while RO process represents more than 88% of membrane processes production.

Solar energy can be used for seawater desalination either by producing the thermal energy required to drive the phase change processes or by producing electricity required to drive the membrane processes. Solar desalination systems are thus classified into two categories, i.e. direct and indirect collection systems. As their name implies, direct collection systems use solar energy to produce distillate directly in the solar collector, whereas in indirect collection systems, two sub-systems are employed (one for solar energy collection and one for desalination). Conventional desalination systems are similar to solar systems since the same type of equipment is applied. The prime difference is that in the former, either a conventional boiler is used to provide the required heat or mains electricity is used to provide the required electric power, whereas in the latter, solar energy is applied. The most promising and applicable renewable energy systems (RES) desalination combinations are shown in Table 1.2[4]

Table 1.2: RES desalination combinations

RES technology	Feed water salinity	Desalination technology
Solar thermal	Seawater	Multiple effect boiling (MEB)
	Seawater	Multi-stage flash (MSF)
Photovoltaic's	Seawater	Reverse osmosis (RO)
	Brackish water	Reverse osmosis (RO)
	Brackish water	Electro dialysis (ED)
Wind energy	Seawater	Reverse osmosis (RO)
	Brackish water	Reverse osmosis (RO)
	Seawater	Mechanical vapor compression (MVC)
Geothermal	Seawater	Multiple effect boiling (MEB)

1.5 Solar Energy

1.5.1 Sun: as a Source of Energy

From many centuries, sun has been the primary source of energy for the globe. Technically, solar energy can be defined as Electromagnetic energy transmitted from the sun (solar radiation). The amount of energy that reaches the earth is equal to one billionth of total solar energy generated. But is that small? No. The amount of energy which strikes the surface of earth in one day exceeds daily consumption by 10,000 to 15,000 times. In other words, the amount of solar energy intercepted by the earth every minute is greater than the amount of energy the world uses in fossil fuels each year.

Strictly speaking, all forms of energy on the earth are derived from the sun. However, the more conventional forms of energy, the fossil fuels received their solar energy input eons ago and possess the energy in a greatly concentrated form. These highly concentrated solar energy sources are being used as such at a rapid rate that they will be depleted in not-too distant future.

Sun's energy has been used by both nature and man throughout the time to grow food, to see by, to dry clothes, it has also been deliberately harnessed to performed a number of other 'chores'. Solar energy is used to heat and cool buildings, to heat water and swimming pools, to power refrigerator; and to operate engines, pumps and sewage treatment plants. It powers cars, ovens, water stills, furnaces, distillation equipments, crop dryers, and sludge dryers powered by solar energy. Stoves and cars run on solar-made methane gas, power plants operate on organic trash and sewage plants produce methane gas. The sun powered evaporation, in combination with gravity, powers machines and electric turbines. Solar electrolyzes convert water to clean hydrogen gas (a fuel).[5]

1.5.2 Application of Solar Energy

- Heating and cooling of buildings.
- Solar water heating and solar air heating.
- Salt production by evaporation of sea water or inland brines.
- Solar distillation on a small community scale.
- Solar drying or agricultural products.
- Solar cookers.

1.6 Global Status of Solar Distillation

As per documented literature survey, most of distillation systems have been abandoned due to very slow production rate. However, research in the area of solar distillation is limited in the following academic organizations namely IIT Delhi, CAZRI, Jodhpur, and SPRERI, Anand (India); UNAM Ciudad Universitaria, Coyoacáan (Mexico); RYUKYUS, NAGOYA and CHUO Universities (Japan); BEN-GURION University of the Negev (Israel); TECHNISCHE Universitat Bergakademie Freiberg (Germany); ALEXANDRIA University (Egypt); Jordan University of Science and Technology, Irbid (Jordan); University of Ouargla (Algeria); XiAn Jiao Tong University (China); University of Foggia (Italy); NCSR "DEMOKRITOS"Laboratory for Solar and other Energy Systems (Greece).[6]

1.7 Need for Research

The road to truly low-cost desalinated water is beset with many problems. Their solution will be forthcoming only by the development of basic data and information applicable to all desalination processes or phenomena which conceivably might be used in separation processes. The irreversibilities associated with all existing processes cannot be significantly reduced by use of currently available information. Some increase in efficiencies can be obtained, but marked additional progresses in desalinations become more and more difficult. Much needs to be learned regarding the properties of water and aqueous solutions, transport processes, and the properties of membranes which permit movements of salts or water through them.

In practically all desalination processes, rate processes (which include all transport processes) dominate the process. Such separation processes involve mass transport through the use of appropriate potentials and, in general, transport is the principal source of energy degradation. Desalination involves transport of salt molecules, water, ions, and ion complexes in aqueous solutions, organic liquids, gases, and solids. There fundamental research in this area is needed. Water is very unusual substance. Any research that might help achieve a better understanding of its behavior will in the long run lead to the development of new advances in desalination. The best assurance of success in the development of the fields of aqueous solutions, transport, synthetic and living membranes, novel separation techniques, and in other relevant areas of the natural sciences.

Chapter 2

LITERATURE REVIEW

2.1 Desalination Techniques

Many desalination processes were proposed over the years; only a few survived the crucial road to produce the cheapest, yet most valuable, product on earth – water. The most successful techniques are summarized briefly below:

2.1.1 Membrane Processes

Membrane techniques for water desalination are based on different types of molecular level filters – membranes. The most common technique that aims at taking over the entire market of desalination processes is reverse osmosis.[7]

2.1.1.1 Reverse Osmosis (RO)

Desalination with reverse osmosis membranes is a process whereby saline water under pressure is transferred along a membrane. The pressure applied is high enough to overcome the osmotic pressure of the dissolved salt in feed solution. The osmotic pressure of a solution is proportional to the concentration of the dissolved matter, salts in water, starch or sugar, etc. (Faller, 1999). Salts rejected by the membrane are removed from the membrane with the flow of concentrated solution while fresh salt solution is fed to the membrane. The permeate – the fresh water product – exits the lower pressure side of the membrane.

A.H.H. Al-Sheikh discussed in the reverse osmosis (RO) process, the osmotic pressure is overcome by applying external pressure higher than the osmotic pressure on the seawater. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behind with an increase in salt concentration. No heating or phase separation change is necessary. The major energy required for desalting is for pressurizing the seawater feed. A typical large seawater RO plant consists of four major components: feed water pre-treatment, high pressure pumping, membrane separation, and permeate post-treatment. Raw seawater flows into the intake structure through trash racks and traveling screens to remove debris in the seawater. The seawater is cleaned further in a multimedia gravity filter which removes suspended solids. Typical media are anthracite, silica and granite or only sand and anthracite. From the media it flows to the micron cartridge filter that removes particles larger than 10 microns.[8]

2.1.1.2 Nano-Filtration

Nano-Filtration is based on a loose membrane that allows partial passage of monovalent ions (mainly Na^+ and Cl^-) while partially rejecting the bivalent ions. It is used mainly in the desalination of brackish water of low salt concentration. Currently, the cost of these membranes is similar to the cost of RO membranes, so there is not much incentive to prefer these membranes over RO membranes.[9]

2.1.1.3 Ultra-Filtration and Micro-Filtration

Ultra-Filtration and Micro-Filtration membranes contain large pores that allow the passage of free salts while preventing the passage of different sized suspended matter, down to nano-sized particles and colloids passing through the membranes, depending on pore size. These membranes are used mainly for wastewater treatment and have started to take their place in the pre-treatment of water along with other desalination techniques.[9]

2.1.1.4 Electro-dialysis

Electro-dialysis is based on the application of an electrical field across a pair of ionselective membranes, causing the different ion salts to move through the membranes into a concentrated solution, leaving behind a diluting solution. Here, unlike other desalination technologies, the salts are removed from the feed water. The feed water should be free of suspended solids, organic matter and non-ionic contaminants that accumulate in the product. [9]

While reverse osmosis may be used for all types of salt water, the nano-filtration and electro-dialysis techniques are more suitable for brackish water.[9]

2.1.2 Evaporative Techniques

Traditionally, evaporation techniques, especially MSF, have controlled the market of desalination techniques. Since 2004,, this trend has changed since reverse osmosis has proven to work properly and consume less energy. The question is still the final cost of the product, while preserving the environment. Evaporation techniques not only stand alone, but are now being considered as membrane evaporation techniques on the one hand and possibly a second stage for increasing recovery following RO desalination,approaching zero discharge. These trends still have long way to go before implementation.[10]

2.1.2.1 Multi-Stage Flash (MSF)

Multi-Stage Flash (MSF) distillation is based on condensing low-pressure steam as a heat source for the evaporation of seawater. It is still considered the simplest and most common technique in use. It has been in operation commercially for more than 60 years (Awerbuch, 1997). The technique is based on passing seawater through long, closed pipes passing through a series of flash chambers where hot seawater allows flashing along the bottom of the chambers. Vapor from the flash chambers heat the feed water flowing in the pipes. More heat is added in order to increase the temperature of the feed water to the initial high temperature, around 110ºC. This is done with the use of lowpressure steam, usually taken from a back-pressure turbine in a power station. The vapor condenses on the heating pipes and is pumped out as product. Usually, the concentrated brine is recycled with the feed to improve recovery ratio. Part of it is pumped out to sea.[10]

2.1.2.2 Multi-Effect Distillation (MED)

Multi-stage evaporation comes from the chemical industry where water or solvent must be removed in order to concentrate a product in solution (Figure 2.1; McCabe et al., 2001). The evaporated liquid in the chemical industry is usually not the product, except for cases where the solvent is recovered from a certain reaction. The evaporation process consumes a great deal of energy. The need to save energy was the basis for the development of this multi-stage process, whereby more equipment (investment) is required in order to reduce the overall amount and cost of energy consumed. In most cases, the process involves 2-4 stages, sometimes called effects, and has been used for more than a century for solution concentration, crystallization, solution purification, etc. Since 1950, it has been used for seawater desalination, yet in the water industry it requires between 2-16 stages. Multi-Effect Distillation (MED) is more energy efficient than other evaporation techniques, including the Multi-Stage Flash system (Awerbuch, 1997). It is also considered to be more sophisticated. A low-temperature source of energy is used in most cases to feed the process. In most industrial cases, this is spent steam at a slightly elevated pressure exiting from a steam-operated power station, a source of heat that is available in refineries, or any low-level steam or hot fluid from other sources (Ophir & Lokiec, 2004).[10]

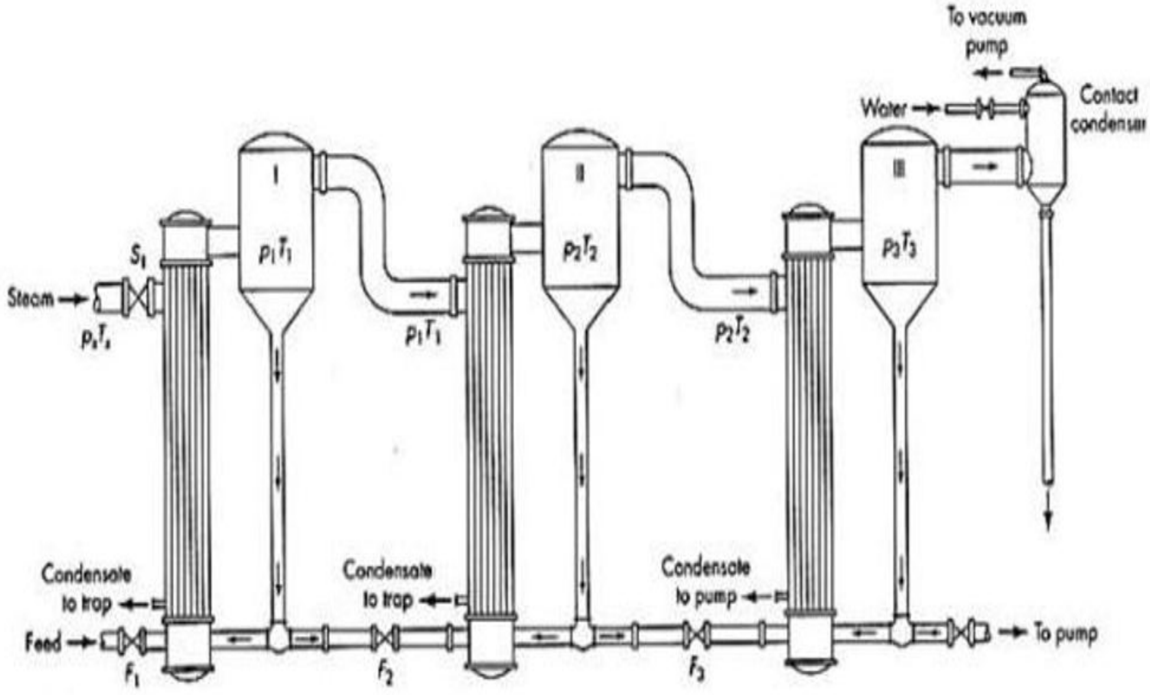

Figure 2.1: Schematic view of industrial Multi-Effect evaporation (McCabe et al., 2001).[10]

The schematic of a horizontal tube Multi-Effect MED unit is presented in Figure 2.2 (IDE schematic view, old Internet publication). The steam enters the plant and is used to evaporate heated seawater. The secondary vapor produced is used to generate tertiary steam at a lower pressure. This operation is repeated along the plant from stage to stage. The primary steam condensate is returned to the boiler of the power station since it is of extremely high quality that is needed for turbine steam production. The MED technique is based on double-film heat transfer. Latent steam heat is transferred at each stage by steam condensation through the heat transfer surfaces to the evaporated falling film of seawater. The process is repeated up to 16 times or more in existing plants between the upper possible temperature and the lower possible cooling water, which depends on seawater temperature used for cooling the water. The product water is the condensate that accumulates from stage to stage. A vacuum pump/compressor is used to maintain the gradual pressure gradient inside the vessel by removing the accumulated noncondensable gases together with the remaining water vapor after the final condensation stage. The pressure gradient along the MED effects is dictated by the saturation pressure of the feed stream and the saturation pressure of the condensing steam exiting the last stage and is condensed by cooling with seawater.[10]

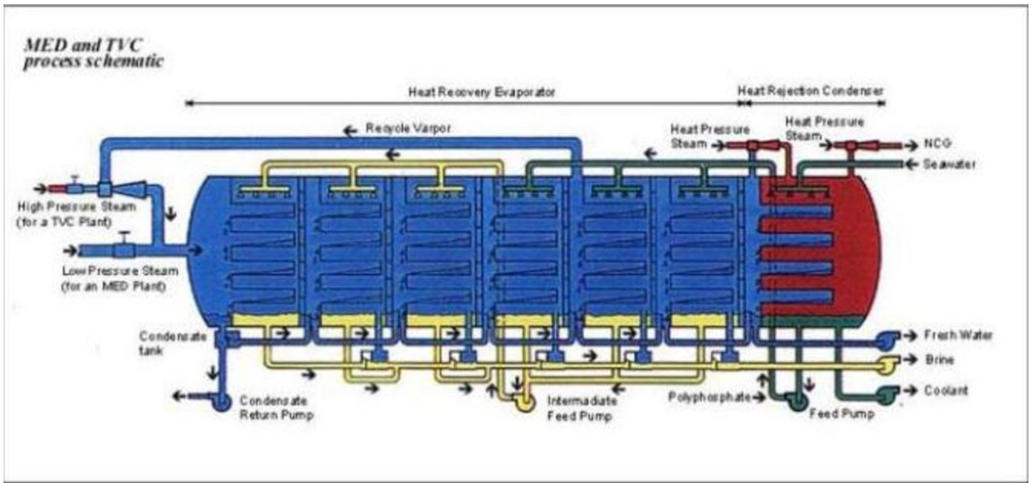

Figure 2.2: Schematic view of a horizontal tube Multi-Effect Distillation plant (IDE Design, Internet publication).[10]

2.2 General of Multi Effect Distillation

Multiple-effect distillation (MED) is a distillation process often used for sea water desalination. It consists of multiple stages or "effects". In each stage the feed water is heated by steam in tubes. Some of the water evaporates, and this steam flows into the tubes of the next stage, heating and evaporating more water. Each stage essentially reuses the energy from the previous stage. The tubes can be submerged in the feed water, but more typically the feed water is sprayed on the top of a bank of horizontal tubes, and then drips from tube to tube until it is collected at the bottom of the stage.[11]

2.2.1 Operating principels

The plant can be seen as a sequence of closed spaces separated by tube walls, with a heat source in one end and a heat sink in the other end. Each space consists of two communicating subspaces, the exterior of the tubes of stage n and the interior of the tubes in stage n+1. Each space has a lower temperature and pressure than the previous space, and the tube walls have intermediate temperatures between the temperatures of the fluids on each side. The pressure in a space cannot be in equilibrium with the temperatures of the walls of both subspaces. It has an intermediate pressure. Then the pressure is too low or the temperature too high in the first subspace, and the water evaporates. In the second subspace, the pressure is too high or the temperature too low, and the vapor condenses. This carries evaporation energy from the warmer first subspace to the colder second subspace. At the second subspace the energy flows by conduction through the tube walls to the colder next space.[11]

2.2.2 Trade-offs

The thinner the metal in the tubes and the thinner the layers of liquid on either side of the tube walls, the more efficient is the energy transport from space to space. Introducing more stages between the heat source and sink reduces the temperature difference between the spaces and greatly reduces the heat transport per unit surface of the tubes. The energy supplied is reused more times to evaporate more water, but the process takes more time. The amount of water distilled per stage is directly proportional to the amount of energy transport. If the transport is slowed down, one can increase the surface area per stage, i.e. the number and length of the tubes, at the expense of increased installation cost.

The salt water collected at the bottom of each stage can be sprayed on the tubes in the next stage, since this water has a suitable temperature and pressure near or slightly above the operating temperature and pressure in the next stage. Some of this water will flash into steam as it is released into the next stage at lower pressure than the stage it came from.

The first and last stages need external heating and cooling respectively. The amount of heat removed from the last stage must nearly equal the amount of heat supplied to the first stage. For sea water desalination, even the first and warmest stage is typically operated at a temperature below 70 °C, to avoid scale formation.

The lowest pressure stages need relatively more surface area to achieve the same energy transport across the tube walls. The expense of installing this surface area limits the usefulness of using very low pressures and temperatures in the later stages. Gases dissolved in the feed water may contribute to reducing the pressure differentials if they are allowed to accumulate in the stages. External feed water must be supplied to the first stage. The tubes of the first stage are heated using an external source of steam or though any other source of heat. Condensate (fresh water) from all the tubes in all the stages must be pumped out from the respective pressures of the stages to the ambient pressure.[11]

2.2.3 Advantages of MED

- Low energy consumption compared to other thermal processes.
- Operates at low temperature (< 70 °C) and at low concentration to avoid corrosion and scaling.
- Does not need pre-treatment of sea water and tolerates variations in sea water conditions.
- Highly reliable and simple to operate.
- Can be adapted to any heat source including hot water, waste heat from power generation industrial processes or solar heating.
- Produce steadily high purity distillate.
- Can be adapted to any heat source including hot water.

- Allow very high thermal efficiencies and savings in fuel costs.
- Low maintenance cost.

G.N. Tiwari, H. N. Singh, etl present status of distillation in the world today and its future perspective. The review also includes water sources, water demand, availability of potable water and purification methods including the state of art and historical background. The classification of distillation units has been done on the basis of literature survey till today. The basic heat and mass transfer relation responsible for developing, testing procedure for various designs of solar stills have also been discussed. The present status of solar distillation units in India, economics of single and double slope fiber re-in forced plastic on the basis of long-term performance and recommendations for future have been discussed in brief.[2]

Akili D. Khawajia, Ibrahim K. Kutubkhanah, etl represent number of seawater desalination technologies had been developed during the last several decades to augment the supply of water in arid regions of the world. Due to the constraints of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. However, the steady increasing usage of seawater desalination has demonstrated that seawater desalination is a feasible water resource free from the variations in rainfall. A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. The process requires some form of energy to desalinate, and utilizes several different technologies for separation. Two of the most commercially important technologies are based on the multi-stage flash (MSF) distillation and reverse osmosis (RO) processes. Although the desalination technologies are mature enough to be a reliable source for fresh water from the sea, a significant amount of research and development (R&D) has been carried out in order to constantly improve the technologies and reduce the cost of desalination. This paper reviews the current status, practices, and advances that have been made in the realm of seawater desalination technologies. Additionally, this paper provides an overview of R&D activities and outlines future prospects for the state-of-the-art seawater desalination technologies. Overall, the present review is made with special emphasis on the MSF and RO desalination technologies because they are the most successful processes for the commercial production of large quantities of fresh water from seawater.[12]

P. K. Sen, Padma Vasudevan Sen, etl discussed about removal of dissolved salts and toxic chemicals in water, especially at a few parts per million (ppm) levels is one of the most difficult problems. There are several methods used for water purification. The choice of the method depends mainly on the level of feed water salinity, source of energy and type of contaminants present. Distillation is an age old method which can remove all types of dissolved impurities from contaminated water. In multiple effect distillation (MED) latent heat of steam is recycled several times to produce many units of distilled water with one unit of primary steam input. This is already being used in large capacity plants for treating sea water. But the challenge lies in designing a system for small scale operations that can treat a few cubic meters of water per day, especially suitable for rural communities where the available water is brackish. A small scale MED unit with an extendable number of effects has been designed and analyzed for optimum yield in terms of total distillate produced.[13]

Ali M. E1-Nashar and Atef A. A1-Baghdadi, they used the Second Law of Thermodynamics to describe and quantify the exergy losses involved in the different processes taking place in desalination plants is of considerable importance both for the design and operation of these plants. Although the First Law of Thermodynamics is adequate in giving the overall plant performance indices, it does not show the actual irreversibility's in the different parts of the plant. An estimation of the exergy destruction involved in each part of the plant gives a quantitative measure of these irreversibility's which, if reduced during design or operation, can result in a reduction of energy consumption and increase plant performance. Based on actual measured data from a multiple-effect stack seawater desalination plant now in operation in the solar plant near Abu Dhabi, the exergy destruction was calculated for each source of irreversibility. The major exergy destruction was found to be caused by irreversibility's in the different pumps with the vacuum pump representing the main source of destruction. Major exergy losses are associated with the effluent streams of distillate, brine blow-down and seawater. Exergy destruction due to heat transfer and pressure drop in the different effects, in the preheaters and in the final condenser and in the flashing of the brine and distillate between the successive effects represents an important contribution to the total amount of exergy destruction in the evaporator.[14]

Adel M. Abdel Dayem work to demonstrate experimentally and numerically the performance of a simple solar distillation unit that is based on the multiple condensation–evaporation cycle. The pilot plant was designed, fabricated, tested and simulated at the solar energy laboratory, Mattarria Faculty of Engineering, Cairo, Egypt. The distillation chamber consists of a humidifier and a dehumidifier unit. The circulation of air in the two units is maintained by natural convection. The cold salt water is preheated inside the distillation unit before exchanging heat with the solar collector loop. This plant has a flat-plate collector field area of $3.1m^2$, it constitutes a closed loop with its own storage tank. The research is then carried out to evaluate the unit performance of such design and to estimate the fraction factor of the solar system to the load. A numerical simulation was developed for the system being considered. A detailed annual performance of the system is presented. The annual variation of the temperatures and useful heat gain were estimated for the system components. In addition, the optimum collector area by which the system has the maximum lifecycle savings and solar fraction was obtained. The comparison between the numerical and experimental result are accepted. The multiple-effect distillation unit that is considered in the study produces 24l/day of distilled water. The system performance can be accepted according to the previous edited results.[15]

Mahmoud Ben Amara, Imed Houcine, etl research for experimentally investigate the principal operating parameters of a new desalination process working with an air multiple-effect humidification-dehumidification method. A test set-up was designed and constructed to carry out and optimize this technique. The main parts of the present set-up consist of a heat equipment device (heat exchanger), a spray humidifier and a dehumidifier system. This equipment was used to simulate the seawater desalination process experimentally with an eight-stage air solar collector heating-humidifying system. The outlet temperature of the air solar collector was correlated for use in the desalination process as a solar heating device. The operating conditions studied were: ratio of water to dry air mass flow rate through the system, humidifier inlet absolute humidity, dry air mass flow rate through the system and solar irradiation or humidifier inlet air temperature. The experimental results obtained were used to put stress and correlate the influence of the different operating conditions on the behavior of the eight-stage air heating-humidifying desalination process. The ratio of water to dry air mass flow rate was optimized, precisely 45%. The value of dry air mass flow rate through the system can be also varied with solar radiation in order to have a maximum of humidity content at the end of the system and though working in an adiabatic humidification process.[16]

Hassan E.S. Fath had discussed under a passive mode of operation, a transient analysis of a new, simple design, two effects solar distillation unit is presented. The unit consists mainly of a single sloped basin solar still of a shutter fashion type reflector, purging its vapor to a second effect still connected at the shaded side of the first effect still. Based on the energy balance for the different components of the two effects distillation unit, the hourly variation in the unit energies, temperatures, productivity, and efficiency was obtained. The effects of some design, operational, and environmental parameters on the distillation unit productivity are presented. On the basis of the numerical computations, it was observed that the unit first to the second effects volume ratio, the solar intensity, the base and side wall insulation, and the initial temperature of the basin water significantly influence the unit's productivity. The daily productivity increases to as high as 10.7 kg/m^2.d, for the proposed unit under the climatic conditions of the city of Dhahran, Saudi Arabia. The proposed distillation unit is simple, passive and adds no design, operation or maintenance complexities over the conventional single effect basin solar still.[17]

Ali M. E1-Nashar had compared the economics of using solar energy to operate small multiple effect seawater distillation systems in remote areas with the conventional method of using fossil fuels. The particular multiple effect system used is an advanced horizontal tube, falling film system called "multiple effect slack", MES, in which the pumping energy requirement is relatively low compared with the horizontal in-line system. Three system configurations were investigated: (1) conventional system using a steam generator to provide steam for the MES evaporator and a diesel generator to provide pumping power, (2) solar-assisted system which uses solar thermal collectors to provide hot water (instead of steam) for the evaporator and a diesel generator for pumping power, and (3) solar stand-alone system which uses solar thermal collectors for the evaporator heat requirement and a solar PV array to provide electrical energy for pumping. At the present time, solar energy cannot compete favorably with fossil energy particularly under the present international market prices of crude oil. However, in many remote sunny areas of the world where the real cost of fossil energy can be very high, the use of solar energy can be an attractive alternative. Two important cost parameters affect the relative economics of solar energy vis-a-vis conventional (fossil) energy: the collector cost in \$ per square meter and the cost of diesel oil in \$ per Giga Joule. Solar energy becomes more competitive as the local cost of procuring conventional fuel increases and as the collector cost decreases. The water cost from a solar thermal-diesel-MES system can be seen to approach the water cost from a steam generator-diesel-MES system when the collector cost drops to 200 \$/m^2 and diesel oil cost at the remote site reaches 50 \$/GJ. Using a 100% solar system with solar thermal and solar PV collectors being utilized, the economics was seen to improve in favor of the solar system. Even when diesel fuel can be procured at 10 $/GJ at the remote site, the cost of water from the solar system can be seen to approach that from a conventional plant when thermal collectors costing 200 $/m^2$ are used. The cost of water from the solar system was shown to be always less than that fi'om a conventional system which uses diesel oil procured at the high price of 50 $/GJ but always higher than water produced from a conventional system using diesel oil at the low price of 10 $/GJ.[18]

Zhili Chen, Guo Xie, etl had discussed about the mechanism of falling film evaporation condensation, a new four-stage distillation unit with triple-effect regeneration has been designed, constructed and field tested. The seawater desalination system is driven by 80 m^2 all-glass vacuum tube solar collection system with an additional 1 kW wind power system to provide electricity for pumps. The field testing and monitoring of the system had been carried out under the real weather condition for 2 years. The results show that the water production of the system for per unit of solar collector area could reach up to more than 12 kg/m^2/day under the fine weather conditions. Water production of the system was stable in long period and the annual production could reach to 250 tons in northern China. The economic performance of the system is also discussed. The cost of water production is estimated approximately 4.6 Dollar/ton for the 15-year service life.[19]

L. Garcia-Rodriguez and C. Gomez-Camacho had discussed about the thermo economic optimization of a multi effect distillation (MED) desalination system with thermo vapor compressor (TVC) is performed. A model based on the energy and exergy analysis is presented here. An economic model of the system is developed according to the Total Revenue Requirement (TRR) method. The objective functions based on the thermodynamic and thermo economic analysis are developed. The proposed multi effect distillation system including six decision variables is considered for optimization. A stochastic/deterministic optimization approach known as genetic algorithm is utilized as an optimization method. This approach is applied to minimize the cost of the system product (fresh water).[20]

Xiaolin Wang, Alexander Christ, etl had received tremendous attention recently for thier research about low grade heat driven multi-effect distillation technology. The primary reason is that many countries are water short and conventional desalination technology is energy intensive. If the required energy hails from fossil fuel source, then the freshwater production will contribute to carbon dioxide emission and consequently global warming. Low grade heat sources such as geothermal energy and waste heat from process plants generate minimal carbon dioxide. This source of energy is generally abundant at a typical temperature around 65–90°C in many localities, and matches perfectly with the MED technology which is driven with a maximum temperature of about 90°C. In this paper, we propose a MED design to better harness the low grade thermal energy. By means of a calibrated simulation model, validated with experimental data of single effect freshwater generators, we demonstrate that 25–60% improvement to the freshwater yield compared with conventional MED design is possible.[21]

Mohammad Ameri, Saeed Seif Mohammadi, etl had presented effect of various parameters on multi effect distillation and specification. Potable water supply has a significant role in today's developing world. It is very important to determine the specifications of desalination systems in order to achieve cheaper water prices and better operational conditions. Multi-effect desalination (MED) with thermal vapor compressor (TVC) is a progressing, low cost and easy operating system to produce drinking and pure water for both social and industrial applications. In this paper, the effects of different design parameters such as number of evaporation effects, inlet steam pressure, temperature difference of the effects, and feed water temperature on MED system specifications, i.e. performance ratio, required heat transfer area and cooling sea water, are studied. The results show that there is an optimum value for the number of effects for a system with constant production capacity. This optimum value is a function of seawater salinity, effects temperature difference and feed water temperature. The results also show that the increase of inlet steam pressure increases the performance ratio and the required heat transfer surface area of the system and decreases the cooling seawater mass flow rate.[22]

Diego C. Alarcón-Padilla, Lourdes García-Rodríguez, etl had dealed with the design of a solar thermal desalination system based on a multi-effect distillation (MED) plant connected to a double-effect absorption heat pump (DEAHP). To date, the only two demonstration projects employing this technology worldwide have been implemented at the PSA (Almería, Spain). Two different prototypes of a DEAHP (LiBr–H2O), manufactured by the French company ENTROPIE, were connected to an existing multi-effect distillation unit (nominal PR 10.5) in 1991 and 2005, respectively. This paper presents the first experimentally validated design proposal for a solar desalination system based on MED-DEAHP technology. The overall performance ratio, experimentally measured at the Plataforma Solar de Almería test facilities was 20, which results in a 50% of reduction of the required solar field area compared to a solar MED system.[23]

Eyad S. Hrayshat and Aiman E. Al-Rawajfeh had discussed about the potential of desalination as a viable alternate water source for Jordan using a multiple effect distiller (MED), evolved to operate using solar energy under Jordanian conditions is discussed. A computer code in C++ was generated in order to simulate the MED process, and to predict the water production at 10 different Jordanian sites, based on available solar radiation data and salinity of the feed water. With a TDS of 7000 mg/L, the annual water production for these sites was 12,342, 10,950, 10,367, 10,262, and 10,063 m^3 respectively. Furthermore, in all of these sites about 63% of the daily amount of water produced during a 1-year cycle occurs during the summer months (April to September), when the water consumption is the highest, and water desalination is a necessity.[24]

Mounir M. Helal, Abdalla S. Hanafi, etl had analyzed the MED unit and divided into two sections: heat recovery section and heat rejection section. The heat recovery section consists of a series of effects, while the heat rejection section consists of one effect only (condenser). The MED system contains the evaporators, feed water preheaters and the flashing tanks (boxes). The physical model of effect number ith of MED unit is considered. The physical model can be divided into five compartments such as brine pool, vapor space, condensate tube bundle, feed water preheaters and flash tank. The mass, salt and energy balance equations for each previous compartment have been solved dynamically taking into consideration the effect of each one on the other. Dynamic equations in each of the last five compartments mentioned are formulated mathematically for the whole MED system. All effects have identical dynamic equations, except the first evaporator (effect), last evaporator (condenser), and the first flashing tank are formulated mathematically standalone. To obtain a proper dynamic model solution, without simplification and complicated approaches, some assumptions have been considered and will be mentioned in the final manuscript. A disturbance technique for the choice parameters has been done to perform the dynamic model program and study the reaction of that disturbance on the behavior of the remaining parameters studied.[25]

Lourdes Garcla-Rodnguez, Ana I. Palmero-Marrero, etl had represented the application of the direct steam generation into a solar parabolic trough collector to multi effect distillation was proposed and economically evaluated. The thermal fluid of the solar field is pure water, which boils as circulating along the solar collectors. The steam generated drives a multi effect distillation unit. This solar distillation system is compared with multi effect plants connected to a conventional parabolic trough collector field, and with fossil fuel powered distillation plants. Different parameters are analyzed, the plant capacity and performance ratio, the cost of conventional thermal energy, the cost of the solar collectors, and the annual average of the fresh water obtained per$m^2$of solar collector. Results obtained are useful in finding the most suitable conditions in which solar energy could compete with conventional energies in solar desalination.[26]

Lourdes Garcia-Rodriguez, Ana I. Palmero-Marrero, etl had dealed with a global analysis of the use of solar energy in seawater distillation under Spanish climatic conditions. Static solar technologies as well as one-axis sun tracking were compared. Different temperature ranges of the thermal energy supply required for a desalination process were considered. At each temperature range, suitable solar collectors were compared in some aspects as: (1) fresh water production from a given desalination plant; (2) attainable fresh water production if a heat pump is coupled to the solar desalination system; (3) area of solar collector required for equivalent energy production. Results showed that direct steam generation (DSG) parabolic troughs are a promising technology for solar-assisted seawater desalination.[27]

2.3 Common Conclusion of Literature Review

A number of seawater desalination technologies have been introduced successfully during the last several decades to augment the water supplies in arid regions of the world. Due to the constraint of high desalination costs, many countries are unable to afford these technologies as a fresh water resource. The desalination technologies are mature enough to be a reliable source of fresh water from the sea. Rainfall in many countries is variable so now a days people don't have to dependent on it. Still many peoples and institutes are working on desalination technology for environment asspects like improvements in the desalination processes for reducing and/or disposing of effluents. At the present time, solar energy cannot compete favorably with fossil energy particularly under the present international market prices of crude oil. However, in many remote sunny areas of the world where the real cost of fossil energy can be very high, the use of solar energy can be an attractive alternative. Solar energy becomes more competitive as the local cost of producing conventional fuel increases and as the collector cost decreases.

2.4 Objective of Project

By utilizing solar energy into Solar multi-effect distillation and provide fresh water to such a remote areas where good sunny lights is available but shortage of drinking water.

Chapter 3

Design & Fabrication

3.1 Line Focusing Collector: Parabolic trough Reflector

The principle of the parabolic trough collector, which is often used in concentration collectors. Solar radiation coming from the particular direction is collected over the area of the reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross-section, the solar radiation is focused alone a line. Mostly cylindrical parabolic concentrator are used, in which absorber is placed along focused axis. The collector pipe, preferably with a selective absorber coating, is used as an absorber. The dimension of parabolic trough or parabolic cylindrical collector can vary over a wide range the length of a reflector unit may be roughly 3 to 5 m, and the width about 1.5 to 2.4m, such units are often connected end to end in a row, several rows may also be connected in parallel. Parabolic trough reflector have been made of highly polished aluminum, of silvered glass or of a thin film of aluminized plastic on a firm base. Instead of having a continuous form, the reflector may be constructed from a number of long flat strips on a parabolic base.

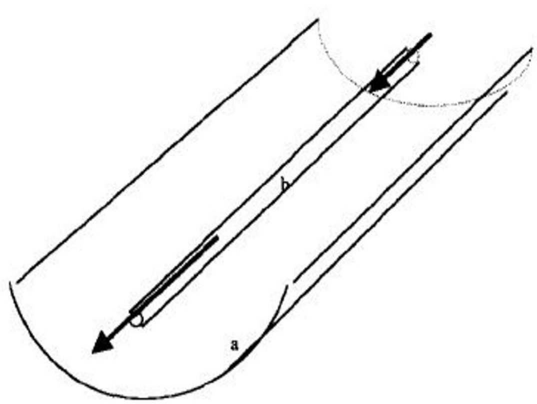

Figure 3.1: parabolic trough collector

For the solar radiation to be brought to a focus by parabolic trough reflector, the sun must be in such a direction that it lies on the plane passing through the focal line and the vertex of the parabola. Since the elevation of the sun is always changing, either the reflector trough or the collector pipe must be turn continuously about its long axis to maintain the required orientation. Both schemes are used in different practical-designs. Either the cylindrical reflector the pipe is turned by partial rotation around a single axis to the trough length. Trough type collectors are generally oriented in the east-west or north-south direction. For the north-south orientation, however, the north end of the trough is raised so that the collectors are sloped facing south-just like flat-plate collectors. Ideally, the slope angle should be changed periodically; it is simpler, but less efficient, however to use a fixed angle design.

The north-south orientation permits more solar energy to be collected than the east-west arrangement, expect around the winter equinox. On the other hand, construction costs are higher for the north-south type. Moreover, a system of such collectors requires a larger land area to allow for the shadowing effect of the sloping troughs. The increased separation distance between rows of collectors also results in increased pipe line cost and greater pumping and thermal losses. Finally the sun-set position of an east-west reflector is essentially the same as the sunrise position, and little and no ever night adjustment is required. For, the north-south orientation, however, the trough must be turned through a large angle from sunset to sunrise. The choice of orientation in any particular instance depends on the foregoing and other considerations.

3.2 Performance evaluation of parabolic trough collectors

Absorber tube ID $(D_i) = 22$ mm

Absorber tube OD $(D_o) = 26$ mm

Glass cover ID $(D_{ci}) = 36$ mm

Glass cover ID $(D_{co}) = 40$ mm

Emissivity of absorber tube surface $(\epsilon_p) = 0.66$

Emissivity of glass $(\epsilon_c) = 0.88$

Mean temprature of absorber tube $(T_{pm}) = 95$°C

Wind Speed $(V_\propto) = 3$ m/sec

Ambient temperature $(T_a) = 25$°C

Length of tube (L) = 30 m

Width of collector (W) = 1.16 m

3.2.1 Calculate the overall loss coefficient, U_l

now,

$$\frac{q_l}{L} = h_{p-c}(T_{pm} - T_c)\Pi D_o + \frac{\sigma \Pi D_o(T_{pm}^4 - T_c^4)}{\{\frac{1}{\epsilon_p} + \frac{D_o}{D_{ci}}(\frac{1}{\epsilon_c} - 1)\}}$$

$$\frac{q_l}{L} = h_{p-c}(368 - T_c)\Pi \times 0.026 + \frac{5.67 \times 10^{-8} \times \Pi \times 0.026(368^4 - T_c^4)}{\{\frac{1}{0.66} + \frac{0.026}{0.036}(\frac{1}{0.88} - 1)\}}$$

$$\frac{q_l}{L} = 0.0816(368 - T_c)h_{p-c} + 0.2875 \times 10^{-8}(183.39 \times 10^{-8} - T_c^4) \qquad (1)$$

$$\frac{q_l}{L} = h_w(T_c - T_a)\Pi D_{co} + \sigma \Pi D_{co}\epsilon_c(T_c^4 - T_{sky}^4)$$

$$\frac{q_l}{L} = h_w(T_c - 298)\Pi \times 0.4 + 5.67 \times 10^{-8} \times \Pi \times 0.04 \times 0.88 \times (T_c^4 - 292.2^4)$$

$$\frac{q_l}{L} = 0.1256 \times h_w(T_c - 298) + 0.62 \times 10^{-8}(T_c^4 - 72.9 \times 10^8) \qquad (2)$$

3.2.1.1 Calculation of convective heat transfer coefficient between the absorber tube and the glass cover, h_{p-c}

Mean temp. of air between tube and cover

$$= \frac{368 + 310}{2}$$

$$= 339k$$

$$= 66^{\circ}C$$

At this temp.

$k = 0.02935 W/m - k$

$\nu = 19.495 \times 10^{-6} m^2/s$

$Pr = 0.695$

Radial gap$(b) = (D_{ci} - D_o)/2 = 0.005m$

Rayleigh Number (Ra) :

$$Ra = 9.81 \times \frac{1}{339} \times \frac{(368-310) \times 0.005^3}{19.495^2 \times 10^{-12}} \times 0.695$$

$$Ra = 383.65$$

now,

$$\frac{k_{eff}}{k} = 0.317(Ra^\star)^{1/4}$$

where,

$$(Ra^\star)^{1/4} = \frac{ln(D_{ci}/D_o)}{b^{3/4}(\frac{1}{D_o^{3/5}} + \frac{1}{D_{ci}^{3/5}})} \times Ra^{1/4}$$

So,

$$\frac{k_{eff}}{k} = 0.317 \times \frac{ln(D_{ci}/D_o)}{b^{3/4}(\frac{1}{D_o^{3/5}} + \frac{1}{D_{ci}^{3/5}})} \times Ra^{1/4}$$

$$\frac{k_{eff}}{k} = 0.317 \times \frac{ln(0.036/0.026)}{(0.005)^{3/4}(\frac{1}{(0.026)^{3/5}} + \frac{1}{(0.036)^{3/5}})} \times (383.65)^{1/4}$$

$$\frac{k_{eff}}{k} = 0.6375$$

Now,

$$h_{p-c} = \frac{2k_{eff}}{D_o ln(D_{ci}/D_o)}$$

$$h_{p-c} = \frac{2 \times 0.02935 \times 0.6357}{0.026 \times ln(0.036/0.026)}$$

$$h_{p-c} = 4.41 W/m^2 - k$$

3.2.1.2 Calculation of wind heat transfer coefficient, h_w

Mean temp. of air between the cover and ambient

$$= \frac{310 + 298}{2}$$

$$= 304k$$

$$= 31^{\text{o}}C$$

At this temp.
$k = 0.0268 W/m - k$
$\nu = 16.09 \times 10^{-6} m^2/s$
Now,

$$Re = \frac{3 \times 0.04}{16.09 \times 10^{-6}}$$

$$Re = 7458$$

for 40<Re<4000, c_1=0.615, n=0.466

for 4000<Re<40000, c_1=0.0.174, n=0.618

for 40000<Re<400000, c_1=0.0293, n=0.805

Now,

Nusselt number

$$Nu = c_1 Re^n$$

$$Nu = 0.174(7458)^{0.618}$$

$$Nu = 43.03$$

Table 3.1: values of $T_c$and q_l/L by trail and error

T_c	(q_l/L)	from
	eq^n(1)	eq^n(2)
310	47.04	55.51
305	50.51	33.80
306	49.83	38.13
307	49.13	42.46
308	48.44	46.80
308.5	48.05	48.98
309	47.74	51.15

$$h_w = 43.03 \times \frac{0.0268}{0.04}$$

$$h_w = 28.83 W/m^2 - k$$

Substituting the values of h_{p-c} and h_w in equation (1) & (2), we obtain the values of T_c and (q_u/L) by trial and error.

So, around 308.5 k temp. values of both h_{p-c} & h_w are nearer to each other.

So, 308.5 is acceptable

hence,

$$U_l = \frac{48.535}{\Pi \times 0.026 \times (95 - 25)}$$

$$U_l = 8.49 W/m^2 - k$$

3.2.2 Convective heat transfer coefficient, h_f

properties of sea water:

$\rho = 1042.5 kg/m^3$

$\nu = 90845 \times 10^{-7} m^2/s$

$C_p = 3.8 KJ/kg - k$

$k = 0.607 W/m - k$

Average velocity

$$V = \frac{\dot{m}}{\frac{\Pi}{4} D_i^2 \rho}$$

$$V = \frac{0.00166}{\frac{\Pi}{4} \times (0.022)^2 \times 1042.5}$$

$$V = 0.00419 m/sec$$

Reynold's number

$$Re = \frac{V D_i}{\nu}$$

$$Re = \frac{0.00419 \times 0.022}{9.845 \times 10^{-7}}$$

$$Re = 93.63$$

Prandtl number

$$Pr = \frac{C_p \nu \rho}{k}$$

$$Pr = \frac{3.8 \times 9.845 \times 10^{-7} \times 1042.5 \times 1000}{0.607}$$

$$Pr = 6.4$$

Nusselt number

$$Nu = 5.172[1 + 0.005484\{6.4(\frac{93.63}{4})^{1.78}\}^{0.7}]^{0.5}$$

$$Nu = 7.35$$

therefore,

$$h_f = 7.35 \times \frac{0.607}{0.022}$$

3.2.3 Collector heat-removal factor, F'

$$F' = \frac{1}{U_l(\frac{1}{U_l} + \frac{D_o}{D_i h_f})}$$

$$F' = \frac{1}{8.49 \times (\frac{1}{8.49} + \frac{0.026}{0.022 \times 202.79})}$$

$$F' = 0.9528$$

3.2.4 Concentration ratio of the collector, C

$$C = \frac{(W - D_o) \times L}{\Pi D_o L}$$

$$C = \frac{(1.16 - 0.026)}{\Pi \times 0.026}$$

$$C = 13.89$$

3.2.5 Absorbed flux, S

$$S = I_b r_b (\rho\gamma)(T\alpha)_b + I_b r_b (T\alpha)_b (\frac{D_o}{W - D_o})$$

$$S = 594.51 \left[0.85 \times 0.95 \times 0.85 \times 0.95 + \frac{0.85 \times 0.95 \times 0.026}{1.16 - 0.026} \right]$$

$$S = 398.66 W/m^2$$

3.2.6 Useful heat gain, q_u

$$q_u = F_R(W - D_o)L\left[S - \frac{U_l}{C}(T_{fi} - T_a)\right]$$

$$q_u = 0.2901 \times (1.16 - 0.026) \times 30 \times \left[398.66 - \frac{8.49}{13.89}(27 - 25)\right]$$

$$q_u = 3922.39W$$

3.2.7 Efficiency, η

$$\eta = \frac{q_u}{I_b r_b W L}$$

$$\eta = \frac{3922.39}{594.51 \times 1.16 \times 30}$$

$$\eta = 18.95\%$$

3.3 Construction of Vertical Tube Evaporator

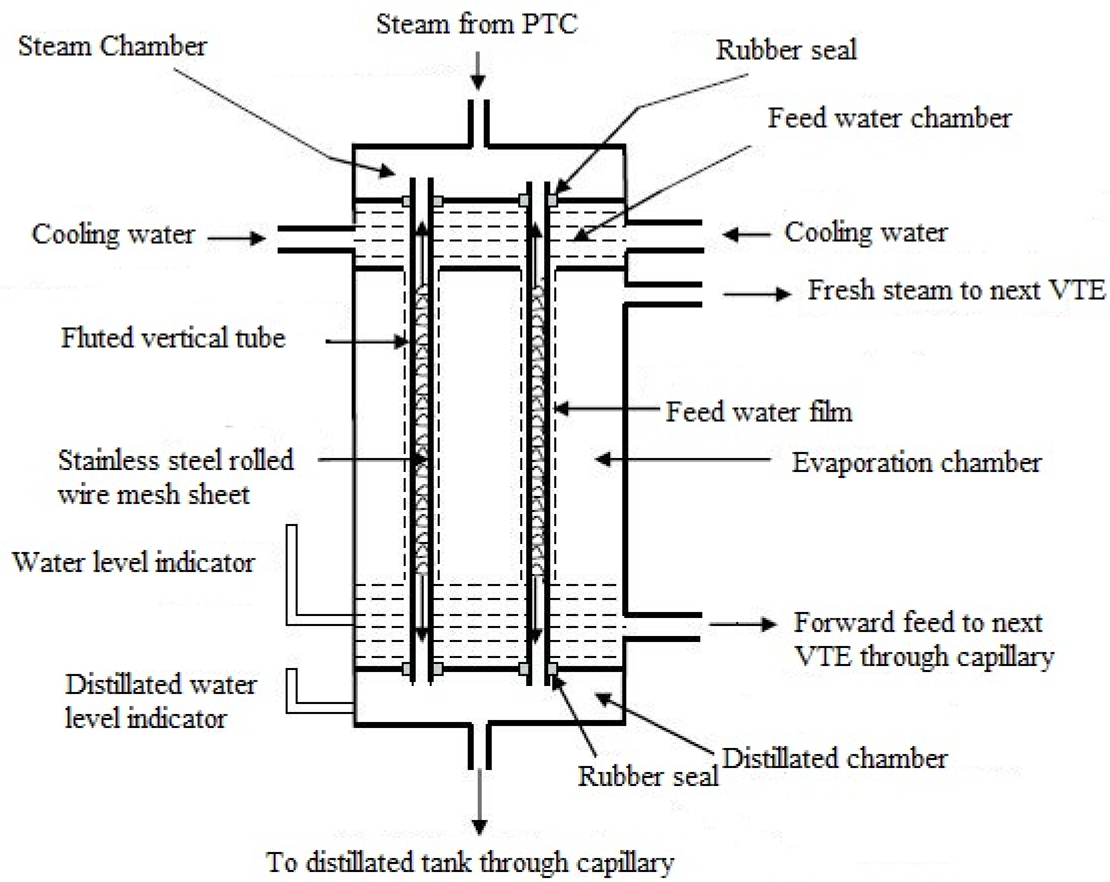

Figure 3.2: Construction of VTE

The complete VTE unit, inclusive of steam chamber, feed water chamber, evaporator chamber, and distillate chamber is made of mild steel (MS) seamless pipe. The evaporator tubes pass through the evaporator section and feed water chamber. Thus, one end of the tubes projects inside the input steam chamber on top, while the other end projects inside the distillate collector at the bottom. Total length of the VTE unit is 1 m and total lenght of the aluminium tube is 0.7 m. There are 6 aluminium fluted tubes in each VTE, which is sealed with a high temperature rubber bush that is shown in the above fig. Here, well machined hollow aluminium bushes were push fitted at both the ends of the tubes to have smooth finished surface. These tube ends were tightly inserted in the rubber bush which can withstand temperatures above 200 °C. These rings were inserted in the holes drilled in the tube plates, with the smooth flat face of the rubber ring facing inward where tube end is inserted. This arrangement prevents leakage of fluid in between the chambers and properly isolates the chambers. One important reason for making this choice is because turbulence generating inserts are easier to put inside the tubes. Stainless steel wire mesh inserts were provided inside the tubes to increase turbulence inside the tubes and for breaking the condensate film and keep the condensing film for longer distances, for improved heat transfer.[29]

The feed water flow rate should be such that it keeps the tubes wet throughout their periphery and total length. During evaporation, the feed water flowrate should be such that it meets the requirement of the rate of evaporation of feed water, as well as the additional amount required to maintain the surface film. This helps in avoiding hot spots, and in minimizing scaling of the tubes. Illustrates water film flow over full length of the tubes. Each VTE unit has three inlets and three outlets. These are respectively, the steam inlet, the two feed water inlets; the distillate outlet on the tube side, and, the brine outlet, and the fresh steam outlet on the shell side. For monitoring respectively the distillate level in the tube side and the brine level in the shell side, each VTE is fitted with two glass tube water level indicators. The heat transfer area and other construction details are kept identical for all the VTEs for ease of fabrication and possibility of interchange during maintenance of the unit. Capillaries are used for feed water input, distillate withdrawal and inter-effect brine transfer.[30]

3.4 Calculation of Vertical tube evaporator

$$Q = \dot{m}(i_m - i_l)$$

$$Q = \frac{4.6}{3600}(2259 - 419)$$

$$Q = 2.35kw$$

cooling water mass flow rate

$$\dot{m}_c = \frac{Q}{(T_{co} - T_{ci}) \times C_{pc}}$$

$$\dot{m}_c = \frac{2.35}{(60 - 30) \times 3.985}$$

$$\dot{m}_c = 0.0196kg/sec$$

Now,

$$\dot{m} = \rho A u N_T$$

$$0.0196 = 1.03 \times 10^3 \times \frac{\Pi}{4} \times (0.022)^2 \times u \times 6$$

$$u = 0.008m/sec$$

Reynold's number

$$Re = \frac{\rho u d}{\mu}$$

$$Re = \frac{1.03 \times 10^3 \times 0.008 \times 0.022}{0.000291}$$

$$Re = 622.95$$

Reynold's number is less than 4000 so, it is laminar flow.

Prandtl number

$$Pr = \frac{C_p \mu}{k}$$

$$Pr = \frac{0.000291 \times 3.985 \times 10^3}{0.607}$$

$$Pr = 1.91$$

$$\mu_w = 1.42 \times 10^{-5} pa \cdot s \text{ (at 150ºC)}$$

$$\mu_b = 1.20 \times 10^{-5} pa \cdot s \text{ (at 100ºC)}$$

$$Nu_T = 1.86(Re_b Pr_b \frac{d}{L})^{1/3} (\frac{\mu_b}{\mu_w})^{0.14}$$

$$Nu_T = 1.86(\frac{1.03 \times 10^3 \times 8 \times 10^{-3} \times 0.022}{1.20 \times 10^{-5}} \times 1.91 \times \frac{0.022}{0.7})^{1/3} (\frac{1.20 \times 10^{-5}}{1.42 \times 10^{-5}})^{0.14}$$

$$Nu_T = 17.58$$

now we get h_i

$$h_i = \frac{17.58 \times 0.607}{0.022}$$

$$h_i = 485W/m^2k$$

Now, Shell side calculation

$D_s = 0.114m$

$$P_T = 1.25d_o$$

$$P_T = 1.25(0.024)$$

$$P_T = 0.03125$$

Now, equivallent diameter

$$D_e = \frac{4(P_T^2 - \Pi d_o^2/4)}{\Pi d_o}$$

$$D_e = \frac{4(0.03125^2 - \Pi \times 0.024^2/4)}{\Pi \times 0.024}$$

$$D_e = 0.0278m$$

Shell side mass velocity

$$C = P_T - d_o$$

$$C = 0.03125 - 0.024$$

$$C = 0.00725m$$

$$A_s = \frac{D_s C B}{P_T}$$

$$A_s = \frac{0.114 \times 0.00725 \times 0.7}{0.03125}$$

$$A_s = 0.0185m^2$$

$$G_S = \frac{\dot{m}}{A_s}$$

$$G_S = \frac{0.0196}{0.0185}$$

$$G_S = 1.059kg/s \cdot m^2$$

Reynold's number

$$Re = \frac{G_S D_e}{\mu}$$

$$Re = \frac{1.059 \times 0.0278}{0.291 \times 10^{-3}}$$

$$Re = 101.16$$

Here, Reynold's number is less than 4000. So, flow is laminar.

$$Pr = \frac{\mu C_p}{k}$$

$$Pr = \frac{0.291 \times 10^{-3} \times 3.985 \times 10^3}{0.607}$$

$$Pr = 1.91$$

$$Nu_b = 1.4[Re_b Pr_b d/L](\mu_b/\mu_w)^n$$

$$\frac{h_o D_e}{k} = 1.4[\frac{1.455 \times 0.0278}{1.20 \times 10^{-5}} \times \frac{1.20 \times 10^{-5} \times 3.985 \times 10^3}{0.607} \times \frac{0.0278}{0.7}] \times (\frac{1.20 \times 10^{-5}}{1.42 \times 10^{-5}})^{0.05}$$

$$\frac{h_o D_e}{k} = 14.64$$

$$h_o = \frac{14.64 \times 0.607}{0.0278}$$

$$h_o = 319.67 W/m^2 - k$$

Overall heat transfer co-efficient

$$\frac{1}{U_c} = \frac{1}{h_o} + \frac{r_o}{r_i}\frac{1}{h_i} + \frac{r_o}{k} ln(\frac{r_o}{r_i})$$

$$\frac{1}{U_c} = \frac{1}{319.67} + \frac{0.012}{0.011}\frac{1}{485} + \frac{0.012}{255} ln(\frac{0.012}{0.011})$$

$$\frac{1}{U_c} = 3.12 \times 10^{-3} + 2.24 \times 10^{-3} + 4.094 \times 10^{-6}$$

$$\frac{1}{U_c} = 5.36 \times 10^{-3}$$

$$U_c = 186.56 W/m^2 - k$$

Now,

$$Q = U_c A_o \triangle T_m$$

$$A_o = \frac{Q}{U_c \triangle T_m}$$

$$A_o = \frac{2.35 \times 10^3}{186.56 \times (150 - 100)}$$

$$A_o = 0.2519 m^2$$

Now, find the lenght of the tube on the basis of overall heat transfer co-efficient and the area find above.[31]

$$N_T \Pi d_o L = 0.2159 m^2$$

$$L = \frac{0.2159}{6 \times \Pi \times 0.022}$$

$$L = 0.62 m$$

Length of the tube is coming 0.62 m and we have assume the length 0.7 m. We can conclued that our assumption is nearer to the right answer.

Chapter 4

Experimental Setup

There are main two part in the setup one is Parabola trough collector unit and the second is Multi-effect distillation unit.

4.1 PTC Setup

Figure 4.1: parabolic trough collector

Fig. 4.1 shows the setup of parabolic trough collector, total lenght(L) of the parabola trough collector is 30 m and width(W) is 1.16 m. Here absorber tube is placed on the stand of parabola such that the focus is coming on the absorber tube. Material of the absorber tube is S.S. Absorber tube is painted with the black nickel paint with the purpose of getting higher temperature. That absorber tube is covered with the glass cover. The purpose of covering the absorber tube with glass cover is heated up the absorber tube. Glass cover get heated quikly compare to the other materials. That heat is transfered to the absorber tube because of the temperature gradient so, the absorber tube getting heated earlier. In that absorber tube we have to flow the water such as at the end of PTC we get only dry steam. By using pump water is pumped into the absorber tube.

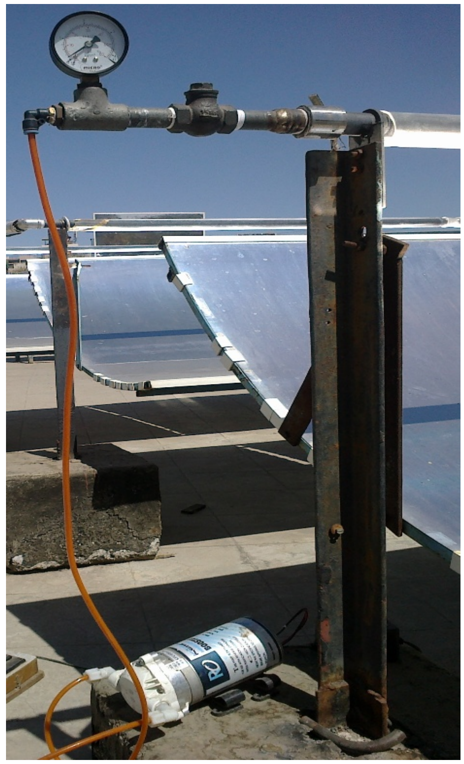

Figure 4.2: water inlet to PTC using pump

Fig. 4.2 shows the solar pump using for pumped the water in PTC. That pump is working on the solar panel. Thae capacity of the Pump is 1.8 ltr/min. We have to take care of the flowrate of pump, if the flowrate is low than there may be chance of back pressure. That back pressure can damage to the pump because the operating temperature of the pump is upto 60 degree and back pressure is created because of the steam generation which have temperature above 100 degree. And if the flowrate is high than the water doesn't get enough time to evaporate, so at the end we get mixture of the water and steam which has higher TDS and it is not good for the final water product. To maintain the pressure there is pressure gauge at the inlet pipe as shown in fig.4.2 and there is another pressure gauge at the end of the parabolic trough collector, so pressure can be maintain such as the pressure at the inlet temp doesn't exceed the pressure at the end and the water flow remains constant in the inlet pipe.

The pump is 48 volt dc pump, nominal flowrate of the pump is 1.8 LPM, maximum outlet pressure is 110 psi and maximum inlet pressure is 60 psi.

Figure 4.3: steam separator

Fig. 4.3 shows the complete figure of the separator. Steam which is coming from the parabolic trough collector is stored in that seperator. The seperator consists of one pressure indicator and temperature indicator which shows the pressure of the steam and the temperature created inside the separator. There are two valves one is on the upper side of the separator and the another one is at the end. Upper valve is situated on the steam line which is going into the MED unit, that valve open after getting the sufficient pressure (nearly 20 PSI). After getting sufficient pressure the valve of the MED unit have to open the half of it, so some of the steam remains stored and the unit can continously running. Bottom valve is for drainage, there may be some mixup of water and steam so, the drainage valve should be drained after regular intervals.

4.2 Construction of MED

The main components of the MED system designed and fabricated are the following: vertical tube evaporators (VTE), condenser, mist eliminators or feed entrainment separators, distillate withdrawal capillaries, mixed (parallel and forward) feed and brine transferring capillaries, and other peripherals.

In that case there are main four part: on the upper side (i) steam chamber, (ii) cooling(feed) water chamber, (iii) vertical tube evaporator(VTE) and (iv) distillated chamber.

Figure 4.4: front side of the MED unit

Fig. 4.4 shows the front side of the MED unit. Steam which is coming from the parabolic trogh collector that all goes direct to the steam chamber of the first evaporaotr/condensor, below the steam chamber there is feed water chamber. In the feed water chamber water cooling water is pumped by the pump which is driven by solar panel. Cooling water is pumped such a way that the water flows on the tubes in very thin layer so cooling water gets proper time for evaporated. Steam chamber and feed water chanber is closed with the stainless steel end plate, and there is rubber bushes which doesn't allow the leakage. Water is flowing outside the tube and inside the tube steam is flowing which is rejecting heat to the cooling water to evaporate. The steam which is condensated inside the tubes is collected in the distillted chamber. After some time when the sufficient amount of steam is generated inside the evaporation chamber than the valve on the line from VTE to mist-elliminator is opened. In the mist-elliminator stainless steel wire net putted for more turbulance and the heat transfer. Some of the steam which is saturated is condensate there and the remainng dry steam goes to the steam chamber of the next evaporator/condensor and the same process is repeated. Water level indicator gauge is provided on the VTE, distillated chamber, and mist-elliminator.

Figure 4.5: back side of the MED unit

Fig. 4.5 shows the back side of the unit. Steam coming from the parabolic trough collector is goes to the steam chamber of the first evaporator/condensor, for cooling that steam feed water is provided by the pump is shown in above fig.4.5. One pressure gauge is also provided on the line of cooling water to manitain the pressure. Pressure of that valve shouldn't exist the pressure of the steam which inside the separator. If that pressure increses than there would be chance of the leakage. There is one capillary provided from the end of the first VTE to the feed water chamber of the next evaporator/condensor, that will incresing the efficiency of the unit. To maintain the flow rate there is one bypass valve, and pressure gauge is provided on each feed water chamber that pressure shouldn't exceed the pressure of the steam chamber, otherwise it causes back pressure.

4.2.1 Different components used in unit and measuring instruments

4.2.1.1 Vertical tube evaporator

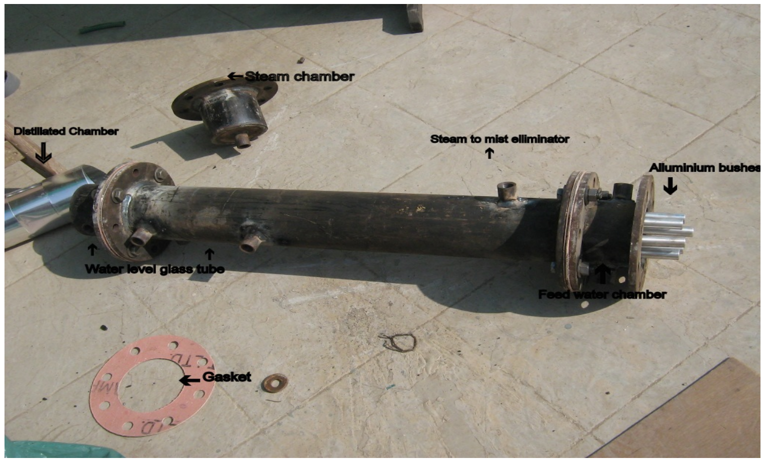

Figure 4.6: Vertical tube evaporator

Fig. 4.6 shows the vertical tube evaporator, steam chamber, distilletd chamber, gasket, alluminium bushes and water level glass tube. There are four holes on the VTE, two holes are provided for fitting the water level glass tube, third is for steam line from VTE to mist-elliminator and the last is provided for the drainage of the water from the VTE. Mild steel is used to fabricated the all component because of long life with the water. Total lenght of the evaporator/condensor is 1 m, steam chamber and distillated chamber 90 mm, feed water chamber 78 mm, VTE 0.7 m long.

4.2.1.2 Mist-elliminator

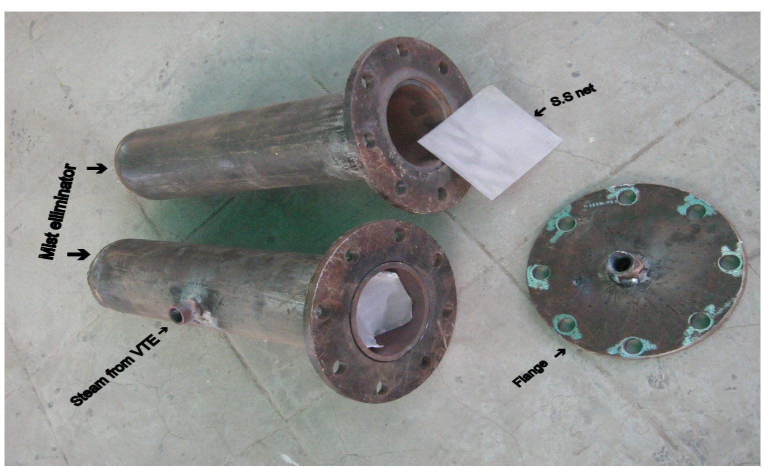

Figure 4.7: Mist-elliminator

Fig. 4.7 shows the mist-elliminator, length of the mist-elliminator 0.42 m made from mild steel. There are three holes on the mist-elliminator, one hole is provided for steam line from the VTE and rest of two are for water level glass gauge. Stainless steel wire net is put inside the mist-elliminator for more turbulance and heat transfer.

4.2.1.3 Alluminium tubes and alluminium bushes

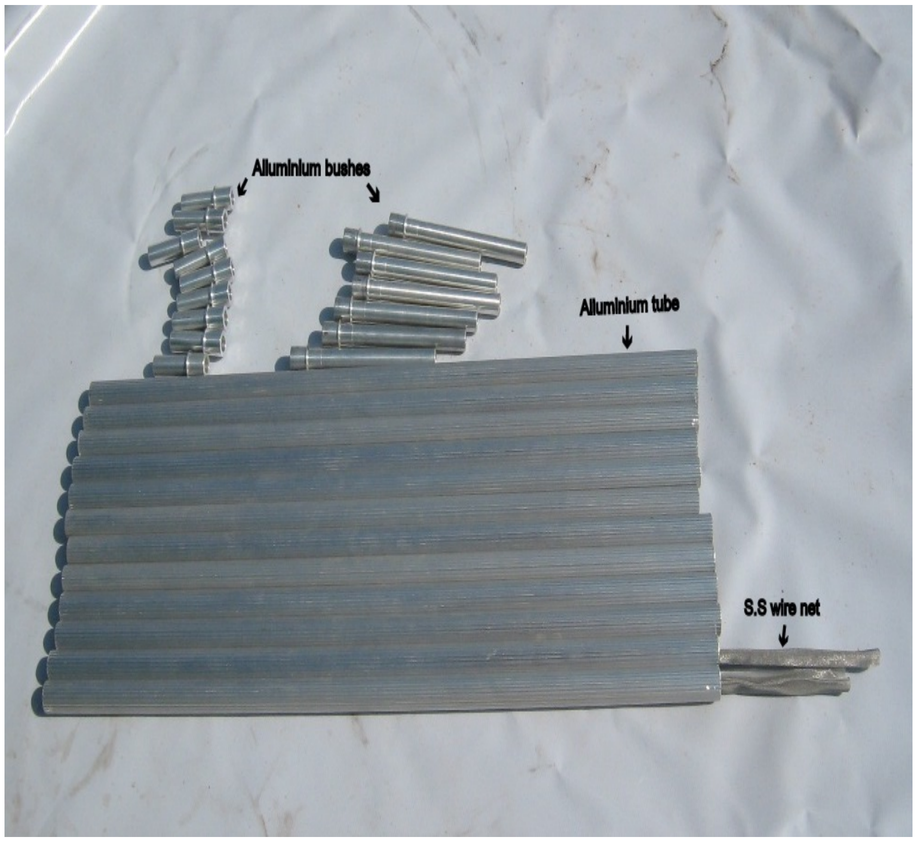

Figure 4.8: Alliminium tube and bushes

Fig. 4.8 shows the alluminium tubes and alluminium bushes. All alluminium tubes have 24 flute on each tube (ID 22mm and OD 24mm, lenght 0.7m). Alluminium bushes are made from the alluminium solid rod by turning and drilling processes. Alluminium bushes are made in a such way that they can be fitted in the tubes and other end can be fitted in the rubber bushes in the end plate.

4.2.1.4 Capillary

Figure 4.9: Capillary

Fig. 4.9 shows the capillary which is used for Feed water input, distillate withdrawal and inter-effect brine transfer are done using capillaries. Material of the capillary is copper and OD is 3 mm. Distillated water which is coming out from the capillary has a temperature around 90 degree, water level glass tube is also provided on the distillated chamber so, flow can be maintained. There is pressure gauge for maintaining the pressure that pressure should be lower than the pressure in the steam chamber otherwise it causes back pressure inside the tubes. There are two valves at the end one is stainless steel needle valve to maintain the flow of output and the other one is for flushing.

4.2.1.5 Solar pyranometer

Figure 4.10: Solar pyranometer

Fig. 4.10 ahows Solar pyranometer. Solar intensity was measured using pyranometer at regular interval of time where as temperature was accurately measured using digital thermometer(HTC-DT305) which has a range of -50$^{\circ}C$ to 1300$^{\circ}C$.

Chapter 5

Result and Discussion

The solar driven distillation system was designed and constructed with 30meter long parabolic trough collectors which efficiently concentrats the solar hear to produce the product in form of distilled water. The loss of heat needs to be accounted for such solar distillation system. The overall loss coefficient was calculated to be 8.49W/m^2K.

Initially, at a regular interval of time, steam temperature and steam pressure were recorded with respect to inpur feed water. The experiments were performed form 10:00 hours to 15:00 hours and the product was obtained from 11:00 hours onward. Steam temperature and steam pressure for a particular days are tabulated in table-5.1.

Such experiments were carried out for couple of days to verify the upper limit of temperature and pressure achieved. All the detailed results for such experimental runs are tabulated in Appendix A for easirer interpretation.

Time	Input Feed Water (ml/min)	Temprature(°C))	Pressure(psi)
10:00	150	-	-
10:15	100	-	-
10:30	100	-	-
10:45	100	-	-
11:00	100	-	-
11:15	10	-	-
11:30	100	-	-
11:45	100	130	22
12:00	120	135	25
12:15	120	135	23
12:30	120	135	25
12:45	120	140	25
13:00	100	135	22
13:15	100	135	20
13:30	100	140	23
13:45	100	130	15
14:00	50	135	23
14:15	50	135	15
14:30	50	130	15

Table 5.1: Recorded data for steam temperature and steam pressure

The feed water was fed at a rate of 6 litrs per hours form the stainless steel absorber tube with glass cover. The distilled product was obtained for the stages of multi effect distillation unit. The maximum product obtained from stage-1 was 12600ml per day and for second stage, it was 5600ml/day. Stage three rarely showed the fair amount of product quantity. The main reason for such results in stage three was the loss of heat from glass cover of absorber tube and consequently, it was not possible to achieve the higher required temperature.

The detailed result showing solar radiation intensity, wind speed, temperature of steam, steam pressure and product mass with its pressure for all the stages is tabulated in table-5.2. The distilled product has almost negligible dissolved solids of about 20ppm. Such experiments were repeated and the detailed results are tabulated in Appendix B.

Time	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	806.4	903.2	967.7	1021.5	1021.5	1075.2	1043.0	1021.5	967.7	860.2
Ambient (°C)	25	26	27	27	27	28	29	29	29	29
Wind speed (m/s)	1.6	1.8	1.4	2.6	1.9	1.2	1.6	1.5	2.1	1.1
Temperature (°C)	120	140	130	125	125	125	120	125	115	110
Pressure (psi)	15	25	5	5	5	1	1	1	1	1
Stage 1 (ml)	0	0	1100	900	1200	1200	1000	1400	1400	1200
Stage 2 (ml)	0	0	0	100	900	700	700	600	500	400
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0
pre-1 (psi)	0	0	7	7	5	2	2	2	1	1
pre-2 (psi)	0	0	0	1	2	2	1	1	1	1
pre-3 (psi)	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	5000	0	2000	0	3000	3000	3000	2000	3000	0
Efficiency (%)	11.69	10.53	9.75	9.22	9.22	8.74	8.96	9.20	9.63	10.81

Table 5.2: Output data of the unit

To calculate the efficiency of the unit we need to consider solar radiation on the parabola as a input of the unit, and in the output of the unit we need to consider the enthalpy of the steam at the end of the parabola at the temperature and pressure noted and substract the enthapy of the feed water which it carries.

calculation of efficiency at 12:00 hour:

Solar radiation = 1021.50 (W/m^2)

Total area of the parabola = 34.8 m^2

Feed water flowrate = 6 kg/hr

Steam flowrate = 4.6 kg/hr

Total input = Solar radiation × Area of the parabola

Total input = 127974.1935 KJ/hr

Total output = (Steam flowrate×Enthalpy of steam) - (Feed water flowrate×Enthalpy of the feed water)

Total output = (4.6×2712.95)-(6×113.1) = 11800.97 KJ/hr

Efficiency = 11800.97/127974.1935

Efficiency = 9.22%

In the similar way effficiency were calculated for every hour for each days, futher detail results are shown in appendix B.

Chapter 6

Conclusion

Since direct steam generation parabolic troughs are not currently commercial. The establishment such of technology is difficult. Initially the setup for solar distillation was designed and fabricated. Solar parabolic trough collector were specially designed with the length of 30mtr. for an efficient concentration of solar radiation. The parabolic trough collectors were attache to multi effect distillation unit to collect the distilled product. The overall heat transfer coefficient was found to be 8.49 W/m^2K. and the efficieny of the fabricated parabolic trough collector was observed as 19%.

Once the setup was prepared, an experiments were performed to attain the higher steam temperature and steam pressure which was found to be 140°C and 25psi respectively. Based on the achieved steam temperature and steam pressure, MED was designed having three stages. Also based on it, the duration of experiment through out the days was established.

With a complete setup, fresh feed of water having TDS of 750ppm was circulated at a rate of almost 6ltrs per hour. Regular experiments were performed at a same rate from 10:00 hours to 15:00 hours during which the intensity of solar radiation was found maximum. The distilled water was obtained at a rate of almost 20ltr per day having TDS of 20ppm.

The maximum product obtained for stage 1 was recorded to be 12.6 ltr per day and for stage 2, it was 5.6 ltr per day. The product was rarely obtained form the third stage. The maximum output form third stage was noted to be 0.5 ltr per day. The main reason for not achieving higher yield from third stage was the lower temperatue in the outer shell of stage two. The product obtained from all the stage had a temperatue of around 90°C.

It can be concluded that their is a higher enhancement in quality of product. Though the main drawback of the system was the consumption of large area, it can be used in the rural areas where solar radiation intensity is higher and it can be used for the purpose of desalination utilizing the solar driven multi effect distillation efficiant using parabolic trough collectos.

Future Scope of Work

The future scope of work includes the achievement of higher temperature by using different material of construction of the absorber tube. Aluminium tube might be used as an alternative for the stainless steel which would conduct higher heat resulting in higher temperature and quantity of product.

The feed water enter the system at 26-28°C and the final product was obtained at 90°C. A process integration can be done by exchanging the heat of final product to feed water by using a heat exchanger which would increase the temperature of feed water. Consequently, there would be an enhancement in the quality and quantity of distilled product.

Heat losses have to be accounted for such solar distillation system. An alternative of a glass cover like evacuated tube might prevent the losses of heat resulting in higher yield of distilled water. A work can also be extended on the different designs of trough collectors for efficiently concentrating solar radiations for enhancement in solar driven multi-effect distillation.

APPENDIX A

Steam Pressure and Steam Temperature

Table A.1

Time	Input Feed Water (ml/min)	Temprature (°C)	Pressure (psi)
10:00	100	-	-
10:15	100	-	-
10:30	100	-	-
10:45	100	-	-
11:00	100	-	-
11:15	100	-	-
11:30	100	135	23
11:45	120	135	23
12:00	120	130	20
12:15	120	130	20
12:30	120	130	22
12:45	140	135	23
13:00	140	140	23
13:15	140	140	23
13:30	60	135	22
13:45	60	135	22
14:00	60	130	20
14:15	60	130	15
14:30	60	125	15

Table A.2

Time	Input Feed Water (ml/min)	Temprature (°C)	Pressure (psi)
10:00	150	-	-
10:15	150	-	-
10:30	100	-	-
10:45	100	-	-
11:00	100	-	-
11:15	100	-	-
11:30	100	-	-
11:45	100	-	-
12:00	80	130	20
12:15	80	135	25
12:30	80	135	25
12:45	100	140	25
13:00	100	140	25
13:15	100	130	22
13:30	100	130	23
13:45	100	135	20
14:00	60	135	20
14:15	60	130	15
14:30	60	130	15

APPENDIX B

Data Collection Sheet

Table B.1(21-2-13)

Time	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00	3:30
Intensity (W/m^2)	709.6	860.2	903.2	924.7	967.7	989.2	978.4	956.9	881.7	806.4	752.6
Ambient (°C)	27	29	31	31.5	31	31	31	32.5	33	33.5	34
Wind speed (m/s)	1.9	1.7	0.4	2.7	0.5	0.7	1	0.4	0.6	0.4	1.2
Tempera-ture (°C)	110	130	125	120	120	125	125	115	120	115	110
Pressure (psi)	5	20	10	2	1	2	2	1	1	1	1
Stage 1 (ml)	0	0	800	800	1000	1000	900	800	700	600	400
Stage 2 (ml)	0	0	0	400	600	500	500	500	300	200	200
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0	0
Pressure 1 (psi)	0	0	7	5	5	5	2	2	2	1	1
Pressure 2 (psi)	0	0	0	1	1	2	2	2	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	5000	0	1000	0	2000	2000	2000	2000	500	1000	0
Efficiency (%)	13.16	10.93	10.36	10.06	9.62	9.44	9.54	9.67	10.51	11.46	12.22

Table B.2(25-2-13)

Time	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00	3:30
Intensity (W/m^2)	741.9	881.7	913.9	967.7	989.2	1010.7	1000	946.2	913.9	784.9	741.9
Ambient (°C)	24	27	27	28	28	29	29	29	29	30	31
Wind speed (m/l)	1.4	1.2	0.5	0.6	1.6	1.2	0.9	1.1	0.4	0.9	1.2
Temperature (°C)	110	140	120	115	120	115	120	120	115	110	110
Pressure (psi)	15	25	2	1	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	1000	1100	1000	1200	1000	1400	1200	600	400
Stage 2 (ml)	0	0	0	400	500	700	700	900	800	300	100
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	500	0
Pressure 1 (psi)	0	0	10	7	7	7	5	5	2	1	1
Pressure 2 (psi)	0	0	0	1	1	2	2	2	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	1	0
Input Water (ml)	5000	0	0	3000	3000	0	3000	3000	1000	2000	0
Efficiency (%)	12.66	10.76	10.27	9.65	9.47	9.22	9.35	9.88	10.2	11.82	12.48

Table B.3(27-2-13)

Time	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	806.4	903.2	967.7	1021.5	1021.5	1075.2	1043.0	1021.5	967.7	860.2
Ambient (°C)	25	26	27	27	27	28	29	29	29	29
Wind speed (m/s)	1.6	1.8	1.4	2.6	1.9	1.2	1.6	1.5	2.1	1.1
Temperature (°C)	120	140	130	125	125	125	120	125	115	110
Pressure (psi)	15	25	5	5	5	1	1	1	1	1
Stage 1 (ml)	0	0	1100	900	1200	1200	1000	1400	1400	1200
Stage 2 (ml)	0	0	0	100	900	700	700	600	500	400
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0
Pressure 1 (psi)	0	0	7	7	5	2	2	2	1	1
Pressure 2 (psi)	0	0	0	1	2	2	1	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	5000	0	2000	0	3000	3000	3000	2000	3000	0
Efficiency (%)	11.69	10.53	9.75	9.22	9.22	8.74	8.96	9.20	9.63	10.81

Table B.4(19-3-13)

Time	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	763.4	870.9	913.9	946.2	1000	1053.7	1064.5	1053.7	924.7	913.9	870.9
Ambient (°C)	30	31	32	32	33	33	33	34	34	34	35
Wind speed (m/s)	0.2	0.8	1.2	0.6	0.3	0.2	0.1	0.3	1.2	0.6	0.9
Temperature (°C)	100	125	130	125	125	125	120	115	115	125	115
Pressure (psi)	5	15	10	10	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	500	3600	1200	1100	1300	1400	1400	1000	1100
Stage 2 (ml)	0	0	0	100	800	400	1000	1000	900	500	900
Stage 3 (ml)	0	0	0	0	0	0	0	200	0	0	0
Pressure 1 (psi)	0	0	2	5	5	5	5	2	2	2	1
Pressure 2 (psi)	0	0	1	1	1	2	2	2	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	1	0	0	0
Input Water (ml)	6000	0	6000	0	4000	0	3000	3000	3000	3000	2000
Efficiency (%)	12.08	10.72	10.22	9.84	9.29	8.82	8.71	8.75	9.97	10.15	10.57

Table B.5(21-3-13)

Time	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	784.9	870.9	935.4	1021.5	1043	1086	1107.5	1064.5	1010.7	956.9	903.2
Ambient (°C)	30	32	31	30	31	31	32	32	33	33	33
Wind speed (m/s)	1.2	0.9	0.4	0.6	0.1	1.2	1.1	1.4	0.6	0.2	1
Temperature(°C)	140	115	110	110	115	115	120	115	110	110	110
Pressure (psi)	20	5	1	1	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	1100	1200	1300	1100	1200	1300	1000	900	800
Stage 2 (ml)	0	0	0	0	100	500	400	500	200	0	0
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0	0
Pressure 1 (psi)	0	0	2	2	2	2	2	2	1	1	1
Pressure 2 (psi)	0	0	0	0	1	1	1	1	1	0	0
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	6000	0	3000	0	3000	0	3000	0	2000	3000	0
Efficiency (%)	12.01	10.63	9.89	9.08	8.90	8.55	8.39	8.70	9.12	9.63	10.20

Table B.6(6-4-13)

Time	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	860.2	892.4	956.9	1000	1043.0	1075.2	1086.0	1043.0	1000	903.2	849.4
Ambient (°C)	34	35	38	43	44	43	44	45	45	45	45
Wind speed (m/s)	1	1.1	0.8	0.4	1.1	0.3	0.4	0.3	1.1	1.2	1.4
Tempera-ture(°C)	90	105	120	125	120	115	115	110	115	115	110
Pressure (psi)	5	5	20	1	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	0	1200	1300	1700	1100	1200	1000	900	700
Stage 2 (ml)	0	0	0	100	500	600	400	500	400	200	100
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0	0
Pressure 1 (psi)	0	0	0	8	8	5	5	5	2	1	1
Pressure 2 (psi)	0	0	0	1	1	2	2	1	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	5000	0	5000	0	0	3000	0	3000	0	2000	0
Efficiency (%)	10.56	10.25	9.58	9.12	8.68	8.41	8.31	8.60	9.0	9.97	10.57

Table B.7(9-4-13)

Time	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	784.9	903.2	946.2	1043.0	1064.5	1096.7	1000	1000	1000	903.2	849.4
Ambient (°C)	33.5	35	35.4	38	39.4	40.1	10.1	41.5	41.5	42	42
Wind speed (m/s)	1.1	1.4	1	0.2	0.3	0.8	0.6	0.2	0.7	0.9	1.4
Tempera-ture(°C)	105	125	120	115	120	125	125	110	115	115	115
Pressure (psi)	1	15	2	1	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	1800	1200	1100	1000	1900	1000	1400	1400	1100
Stage 2 (ml)	0	0	0	200	1000	800	700	600	700	700	400
Stage 3 (ml)	0	0	0	0	0	0	0	0	100	200	0
Pressure 1 (psi)	0	0	0	2	2	5	4	4	1	1	1
Pressure 2 (psi)	0	0	0	1	1	2	2	1	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	1	1	0
Input Water (ml)	5000	0	2000	0	3000	3000	0	3000	3000	0	0
Efficiency (%)	11.70	10.27	9.75	8.76	8.59	8.37	9.18	9.04	9.07	10.03	10.67

Table B.8(17-4-13)

Time	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00
Intensity (W/m^2)	774.1	870.9	956.9	1010.7	1021.5	1021.5	1032.2	989.2	967.7	935.4	698.9
Ambient (°C)	28	31	32	32	32	35	36	36	36	36	35
Wind speed (m/s)	1	0.6	0.2	1.4	0.9	1.3	0.4	1.6	1.3	1.4	1.8
Temperature (°C)	105	115	140	110	110	115	115	120	115	110	105
Pressure (psi)	0	1	15	1	1	1	1	1	1	1	1
Stage 1 (ml)	0	0	700	1800	1900	1900	1800	1900	1900	1100	1000
Stage 2 (ml)	0	0	0	0	900	1000	1100	1000	1000	700	500
Stage 3 (ml)	0	0	0	0	0	0	0	0	0	0	0
Pressure1 (psi)	0	0	5	2	1	1	2	2	2	1	1
Pressure 2 (psi)	0	0	0	0	1	1	1	1	1	1	1
Pressure 3 (psi)	0	0	0	0	0	0	0	0	0	0	0
Input Water (ml)	6000	3000	3000	0	3000	3000	3000	0	3000	2000	0
Efficiency (%)	12.0	10.66	9.81	9.14	9.04	9.01	8.89	9.31	9.49	10.47	13.09

Table B.9(Summary of all experimental data)

Date of experiments	Average Solar intensity (W/m^2)	Total Water output (ltr)	TDS input	TDS output
21-2-2013	884.65 (10:30 hours to 15:30 hours)	10.2	750	20
25-2-2013	899.31 (10:30 hours to 15:30 hours)	13.8	750	15
27-2-2013	968.81 (10:30 hours to 15:00 hours)	13.3	750	20
19-3-2013	943.30 (10:00 hours to 15:00 hours)	18.4	750	20
21-3-2013	980.44 (10:00 hours to 15:00 hours)	11.6	750	20
6-4-2013	973.60 (10:00 hours to 15:00 hours)	11.9	750	20
9-4-2013	962.85 (10:00 hours to 15:00 hours)	17.3	750	15
17-4-2013	934.50 (10:00 hours to 15:00 hours)	20.5	750	20

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