DESALINATION OF SEA WATER BY USING SOLAR CONCENTRATORS

A project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
CHEMICAL ENGINEERING

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CERTIFICATE

This is to certify that project report entitled **"DESALINATION OF SEA WATER BY USING SOLAR CONCENTRATORS"** has been prepared by Mr. T.V. Anudeep Naidu, Ms. K. Tejaswi, Ms. D. Lavanya, Mr. G. Srujan under the guidance of Dr. Ch. Anil, Associate professor and HOD. This project report is being submitted to the Department of Chemical Engineering, ANITS in partial fulfilment of requirements for the award of degree of Bachelor of Technology in Chemical Engineering.

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Further on, we want to show our greatest appreciation to our friends and other classmates who directly or indirectly helped and supported us morally and economically.

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DECLARATION

We hereby declare that the project entitled "**DESALINATION OF SEA WATER BY USING SOLAR CONCENTRATORS"** is the work done by us and submitted towards partial fulfillment for the award of the degree BACHELOR OF TECHNOLOGY in CHEMICAL ENGINEERING and has not been submitted to any other university for the award of any other degree.

Date: 01-06-2022

Place: Visakhapatnam

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Problem Statement

To produce portable water by desalinating sea water using solar energy and increasing the efficiency by using solar concentrators.

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CHAPTER 1

1. INTRODUCTION

India is one of the most populous countries in the world, which supports about 17.1%(>1.3billion) of world's population and about 500 million livestock that accounts for 20% of world's livestock population. On account of rapid economic and demographic change, the water demands in all the sectors are increasing. According to the projections by National Commission on Integrated Water Resources Development (NCIWRD)their irrigation sector alone is going to need an additional 71bcm by 2025 and 250bcm (billion cubic meters) of water by 2050 compared to the demands of 2010 (Press Information Bureau 2013). A NITI Aayog report in 2018 stated bluntly that 600 million people, or nearly half of India's population, face extreme water stress.

This project report focuses primarily on water desalination based on the use of solar energy. Global water withdrawals amount to around 4,000 billion m^3 per year and in some regions – especially the Middle East and Northern Africa (MENA) – desalination has become the most important source of water for drinking and agriculture. Today's global desalinated water production amounts to about 65.2 million m^3 per day (24 billion m^3 per year), equivalent to 0.6% of global water supply.

Solar desalination is technique used to remove salt from water via a specially designed still that uses solar energy to boil sea water and capture the resulting steam, which is cooled and condensed to fresh water. This is cost effective and have high efficiency.

Recent reports state that the Saline Water Conversion Corporation (SWCC) will likely build three new solar-powered desalination plants in Farasan, Dhuba, Haqel in order to reduce Saudi's oil dependency.

Several prototypes were evaluated by the researchers including a low-cost system that directly uses solar energy and an efficient system that employs solar photovoltaic panels. The low-cost system was found to be capable of producing 4.95 liters of fresh water per day per m^2 of evaporator area and upon installation of a reflector, nearly 7.5 liters of fresh water per day per m^2 could be produced. The second system, on the other hand, was capable of producing

12 liters of water per day per m^2. Therefore, these results ensure a strong potential for desalination processes that make use of renewable energy sources.

In present work, water desalination techniques are studied. Water desalination based on solar energy, different designs are developed and these designs are experimented to know which design is effective, improved their efficiency by solar concentrators and calculations.

CHAPTER 2

2. LITERATURE SURVEY

Freshwater is a renewable resource, but increasing population growth and population density has strained the ability of many local supplies to sustain water quantity requirements at suitable levels of water quality. In response to the United Nations prediction that 2 - 7 billion people will face water scarcity by the middle of the century (Hameeteman, 2013), the water industry has become increasingly reliant upon desalination of ocean and brackish water supplies.

Desalination has become one of the world's most crucial water treatment solutions to meet the increased water demand caused by rapid population growth, economic expansion, and agricultural developments (Ghaffour et al., 2013). According to the International Desalination Association (IDA), in 2018, the total capacity of all operating desalination plants in the world was 92.5 million m^3/d (IDA report 2017). Since July 2018, around 400 desalination projects were contracted worldwide. The capacity of the desalination projects contracted in the first half of 2019 was approximately 4 million m^3/d, which is equivalent to the total of both the years of 2015 and 2016 (IDA report 2019). Four independent projects in the Middle East made up 60% of this capacity which are Taweelah and Umm al Quwain (1.6 million m3/d) in the United Arab Emirates, and Shuqaiq and Rabigh (980,000 m^3/d) in the Saudi Arabia (IDA report 2019). These high desalination capacities are necessary as their fresh water resources are not enough to meet the growing water needs (Nair and Kumar, 2013).

Desalination occurred on earth millions of years ago—the natural process of water evaporating from the surface of the sea and condensing to form rain. The freezing of seawater near the Polar Regions wherein the ice crystals formed are from pure water, as salt is excluded from the crystal growth is another example. The first references to the use of desalination occur from 300 BC to 200 AD. In an account by Alexan- der of Aphrodisias (320 BC), it is mentioned that sailors at sea boiled seawater and suspended sponges from the mouth of a brazen vessel to absorb the vapor. The water condensed was drawn off the sponges and referred to as sweet water. The French explorer, Jean De Lery, reported the successful desalination of seawater during a voyage to Brazil in 1565. In 1627, after the Dark Ages, Sir Francis Bacon suggested the use of sand filters for desalination which paved the way for further advances in this area. The advent of steam power in the mid-eighteenth century and the understanding of the thermodynamics of steam processes were significant in the development of desalination technology. Throughout the early 1900s, evaporation and condensation continued to be the common desalination methods. The Second World War saw an increased demand for potable water for troops stationed in the arid regions. Commercial desalination plants started making their appearance in 1960 and most of these were based on thermal processes (Nair and Kumar, 2012).

Desalination systems can be classified according to the energy source such as; thermal, mechanical, electrical and chemical energy sources. Another classification depends on the desalination process: evaporation-condensation, filtration, and crystallization technique. Some of the desalination technologies are still under development such as; solar chimney, greenhouse, natural vacuum, adsorption desalination, membrane distillation, membrane bioreactor, forward osmosis, and ion exchange resin. The reverse osmosis followed by multistage flashing and multi-effects distillation systems are the most worldwide implemented desalination technologies. The western and developed countries prefer RO systems due to its efficient power consumption, while the Middle East and Gulf countries prefer multi stage flash and multi effect distillation systems due to the abundant source of available oil. The simplest desalination technology is the solar still distillation system, which is suitable to the remote areas with a small water demand due to the low productivity of these systems.

Table 2.1: Energy required to produce 1 m^3 of drinking water from different water sources (Nassrullah et al., 2020)

Water Source	**Energy (kWh/m^3)**
Surface water (lake or river)	0.37
Ground water	0.48
Waste water treatment	0.62 - 0.87
Waste water reuse	1.0 - 2.5
Sea water	2.58 - 8.5

Although desalination has been considered a critical source for fresh water worldwide, one of the main challenges to extend it is its high cost (Schallenberg et al., 2014). According to the Global Water Intelligence (GWI) DesalData, a total of $93,700 million is expected to be spent on desalination projects in the coming four years (GWI DesalData, 2020). Approximately, $51,600 million is dedicated only for operating expenditures. Almost 50% of the operating expenditures will be spent on thermal and electrical energies. This high cost of energy for desalination is not surprising given that in 2014, desalination was classified as the most energy-intensive water treatment process which consumes 75.2 TWh of energy per year (UN water, 2014). The amount of energy required for a desalination process is dependent on the quality of feed water, level of water treatment, treatment technology used by the facility, and plant capacity (Shazad et al., 2017). Table 2.1 shows the various energies needed to obtain 1 m^3 of drinking water when water is treated from different sources. Compared to the other water resources, desalination of seawater is the most energy intensive. Even though energy costs are lower for groundwater and surface water treatment, the supply from this source is not enough to meet the increasing demand for fresh water. Therefore, desalination of sea water seems to be the world's most suitable solution for water scarcity regardless of the energy costs associated with it. Amongst all the different water types, the amount of sea water consumed in new desalination plants has been the highest over the last years. In fact, in 2019, the amount of sea water consumption for newly contracted desalination plants was almost double the amount used by plants built in 2018. This continuous increase in the consumption leads to higher energy demands and rising costs. Research and development on the current desalination technologies could be one way to lower Specific energy consumptions and achieve higher efficiency (Anis et al., 2019).

The list of top 10 countries employing desalination is given in Table 2.2 and top 10 countries employing sea water desalination is given in Table 2.3.

Table 2.2: Top 10 countries employing desalination

S. No	Country	Total Capacity (m^3/day)	Market Share (%)
1	Saudi Arabia	9.9	16.5
2	USA	8.4	14
3	UAE	7.5	12.5
4	Spain	5.3	8.9
5	Kuwait	2.5	4.2
6	China	2.4	`4.0
7	Japan	1.6	2.6
8	Qatar	1.4	2.4
9	Algeria	1.4	2.3
10	Australia	1.2	2.0

Water and energy are inseparable sources which interchangeably affect each other. Producing fresh water by desalination requires energy which is conventionally supplied from fossil fuels. Similarly, water is required in the extraction and refining of fossil fuels. These processes as well as burning fossil fuels to produce energy for desalination have severe harmful impacts on the environment due to the greenhouse gases emissions. By 2050, the worldwide emission from desalination processes is expected to reach 0.4 billion tons of CO_2 equivalents per year. Therefore, the growing demand for clean water will not only cause a depletion of fossil fuels but also significant damage to our environment. Relying on fossil fuels as the main energy source for desalination also affects the process economics due to the rapid changes in the cost of fossil fuels. Thus, using renewable energy sources for desalination is essential to provide a suitable supply of clean water to meet our future needs and reduce the harmful effects on the environment (Nassrullah et al., 2020).

Table 2.3: Top 10 countries employing sea water desalination

S. No	Country	Total Capacity (m^3/day)	Market Share (%)
1	Saudi Arabia	7.4	20.6
2	UAE	7.3	20.3
3	Spain	3.4	9.4
4	Kuwait	2.1	5.8
5	Qatar	1.4	3.9
6	Algeria	1.1	3.1
7	China	1.1	2.9
8	Libya	0.8	2.3
9	USA	0.8	2.2
10	Oman	0.8	2.2

Compare to other techniques, solar energy for desalination uses free energy, it is inexpensive and low maintenance costs which make them less attractive. Recently, more interest is directed towards solar concentrators as it has potentially lower specific energy cost and there are continuous research developments in this technology.

Saffa Riffat et.al, performs the experiment on the v-trough solar concentrator for water desalination application. It is introduced as new type of collector. By experimentation they found that the water is heated up to 100 0C, and the efficiency is maximum reached up to the 38%. The new VTC is more economical in terms of cost and land requirement than the FPC and other type of collectors.

The conventional desalination systems are energy intensive process. Solar energy could be used for desalination of water as solar energy is available in abundant, and as its technical feasibility is more. In conventional water treatment process the fuel consumption is more, so for avoid this solar powered desalination gain more attention, as sources of fuel are limited. The production rate of water by using solar powered desalination is more as compared to the conventional water desalination process. With the proper solar radiation data collection and modeling after few years the solar powered desalination is the best option for convention desalination system.

There are various alternative renewable sources for the desalination. Among all those solar energies has the potential which gives future energy demand. Due to increase in population of developing countries need for the potable water is also increased. These countries cannot afford to use conventional desalination systems. So, these countries can use solar powered desalination systems. These countries are having higher solar radiation also. For example, the India the average daily solar radiation in India is 4–7 kWh/m^2 compared with the global average of 2.5 kWh/m^2. Therefore, solar energy driven/assisted desalination is becoming more viable despite its high capital cost.

The main parameters for technology selection for policy/decision makers are the total investment and produced water costs, the type of the project contract, and other parameters such as local incentives or subsidies. In fact, the cost of desalination with different processes is site-specific and depends on many parameters such as feed water salinity and other water quality parameters, plant capacity, energy and labor costs, type of the contract, political and environmental restrictions, and many other factors which are discussed in this paper. Selection of appropriate technology for any specific location thus requires an accurate methodology for each technology (Ghaffour et al., 2013).

Based on these facts, this project is intended to study the various available desalination technologies, their advantages and disadvantages. As energy and water are interrelated and are in scarcity due to population growth, deforestation and climatic conditions, the study is mainly focused on renewable energy powered desalination technologies that are suitable for India.

CHAPTER 3
3. DESALINATION TECHNIQUES

Desalination technologies can be classified according to the energy source such as; thermal, mechanical, electrical and chemical energy sources. Another classification depends on the desalination process: evaporation-condensation, filtration, and crystallization technique. Some of the desalination techniques are still under development such as; solar chimney, greenhouse, natural vacuum, adsorption desalination, membrane distillation (MD), membrane bioreactor (MBR), forward osmosis (FO), and ion exchange resin (IXR). The reverse osmosis (RO) followed by multistage flashing (MSF) and multi-effects distillation (MED) systems are the most worldwide implemented desalination technologies. illustrates the main desalination techniques around the world.

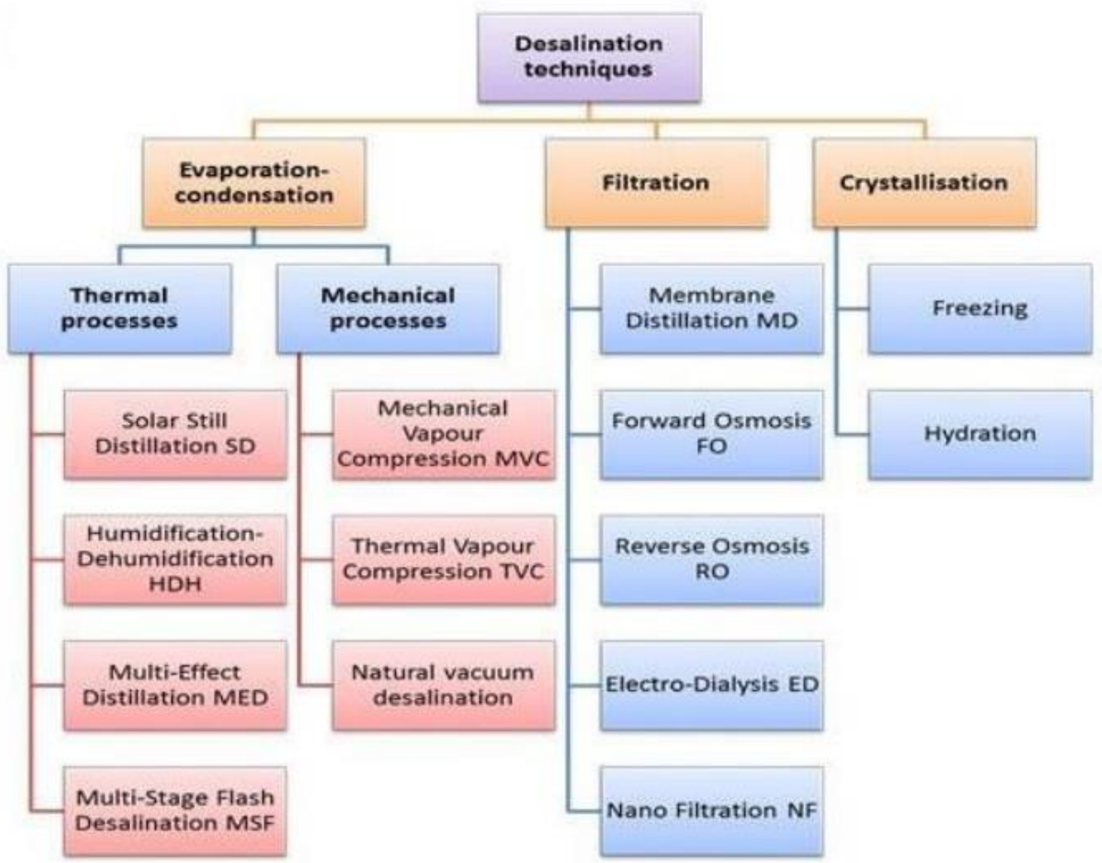


Figure 3.1: Main desalination techniques

3.1 Multi stage flash distillation

Multi-stage flash distillation (MSF) is a water desalination process that distils sea water by flashing a portion of the water into steam in multiple stages of what are essentially counter current heat exchangers. Current MSF facilities may have as many as 30 stages. Multi-stage flash distillation plants produce about 26% of all desalinated water in the world, but almost all of new desalination plants currently use reverse osmosis due to much lower energy consumption.

The plant has a series of spaces called stages, each containing a heat exchanger and a condensate collector. The sequence has a cold end and a hot end while intermediate stages have intermediate temperatures. The stages have different pressures corresponding to the boiling points of water at the stage temperatures. After the hot end there is a container called the brine heater.

Such plants can operate at 23–27 kWh/m^3 (appr. 90 MJ/m^3) of distilled water. Because the colder salt water entering the process counterflows with the saline waste water/distilled water, relatively little heat energy leaves in the outflow—most of the heat is picked up by the colder saline water flowing toward the heater and the energy is recycled.

In addition, MSF distillation plants, especially large ones, are often paired with power plants in a cogeneration configuration. Waste heat from the power plant is used to heat the seawater, providing cooling for the power plant at the same time. This reduces the energy needed by half to two-thirds, which drastically alters the economics of the plant, since energy is by far the largest operating cost of MSF plants. Reverse osmosis, MSF distillation's main competitor, requires more pre-treatment of the seawater and more maintenance, as well as energy in the form of work (electricity, mechanical power) as opposed to cheaper low-grade waste heat.

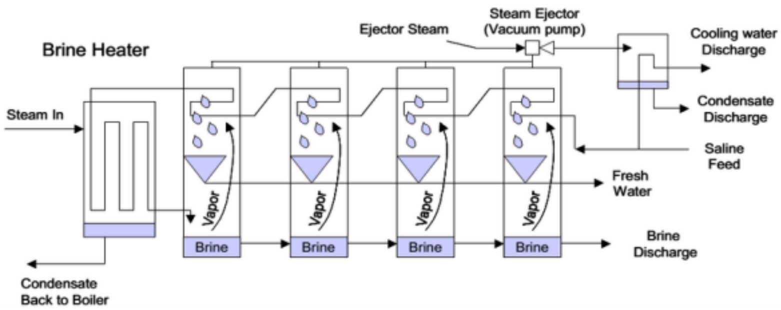


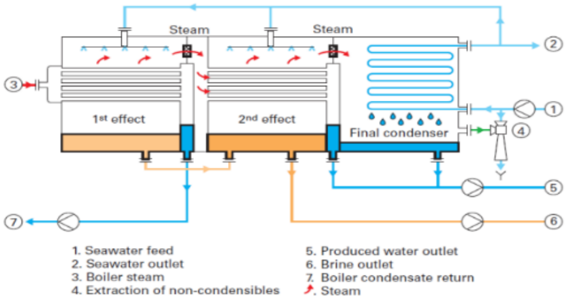
Figure 3.2: Multistage flash distillation

3.2 Multi-effect distillation

Multi-effect distillation employs the same principals as the multi-stage flash distillation process except that instead of using multiple chambers of a single vessel, MED uses successive vessels.

The main difference between these arrangements is in the flow direction of brine and vapors. In the forward feed scheme, all the feed is heated in the first effect and vapor from the first effect is used to heat the following effects. In this case, the feed and vapor flow in the same direction. On the other hand, in the backward feed scheme, feed and vapor flow in opposite directions. Saline feed water enters from the low temperature end and the vapor flows from the high temperature end. This way, high salinity water is exposed to the high temperature end. Because the brine flows from high pressure to low pressure, this arrangement requires additional pumping between the stages. Also, the system is susceptible to severe scaling.

A parametric study on the different arrangements of MED using mathematical models. They studied the effect of different parameters on the performance of MED. The results showed that as the number of effects increases, the specific heat transfer area increases. The same trend was observed in all schemes. This is because at a constant total 15 temperature range in the process, increasing the number of effects reduces the temperature drop per effect. Thus, more area is required to maintain the water production at a specific level. Due to the drop in temperature difference across the effects and increase in specific heat transfer area, specific heat consumption decreases and the gain output ratio (GOR) increases. One major drawback in MED process design is the need for large specific heat transfer areas compared to MSF. MED needs about double the heat transfer area required in MSF. Also, MED plants which operate at higher TBT require less heat transfer area. This is because the low TBT gives a small heat transfer coefficient which increases the needed heat transfer area. So far, the most abundant thermal technology in the world is MSF, even though it requires more energy and has higher brine temperature and capital cost than MED. MED is gaining more attention not only due to its recent technological developments but also because life of most MSF plants in the Middle East is ending.



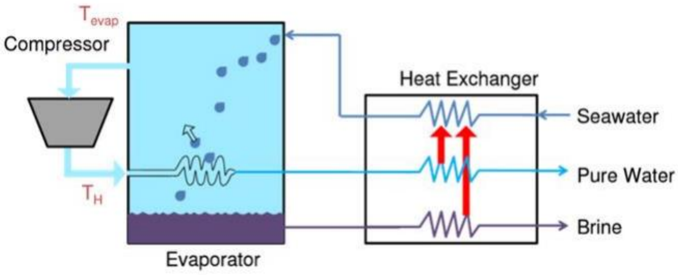


Figure 3.4: Vapor compression

Figure 3.3: Multi-effect distillation

3.3 Vapor Compression

It refers to a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapor. Since compression of the vapor increases both the pressure and temperature of the vapor, it is possible to use the latent heat rejected during condensation to generate additional vapor. The effect of compressing water vapor can be done by two methods.

The first method utilizes an ejector system motivated by steam at manometric pressure from an external source in order to recycle vapor from the desalination process. The form is designated eject compression or thermocompression.

Using the second method, water vapor is compressed by means of a mechanical device, electrically driven in most cases. This form is designated mechanical vapor compression (MVC). The MVC process comprises two different versions: vapor compression (VC) and vacuum vapor compression (VVC).

The VVC process is the more efficient distillation process available in the market today in terms of energy consumption and water recovery ratio. As the system is electrically driven, it is considered a "clean" process, it is highly reliable and simple to operate and maintain.

Vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a metering device or thermal expansion valve (also called a throttle valve), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor_and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes.

The superheated vapor then passes through the condenser. This is where heat is transferred from the circulating refrigerant to an external medium, allowing the gaseous refrigerant to cool and condense into a liquid. The rejected heat is carried away by either the water or the air, depending on the type of condenser.

3.4 Electro dialysis

Electrodialysis is a process by which electrically charged membranes. are used to separate ions from an aqueous solution Sy the driving force. of an electrical potential difference. Electrodialysis is used today mainly. for desalination of sea and brackish water.

Electro Dialysis (ED) is used to transport salt ions from one solution through ion exchange membranes to another solution under the influence of an applied electric potential difference. This is done in a configuration called an electro Dialysis cell as shown in Fig. 3.5. The cell consists of a feed (dilute) compartment and a concentrate (brine) compartment formed by an anion exchange membrane and a cation exchange membrane placed between two electrodes. In almost all practical electro dialysis processes, multiple electro dialysis cells are arranged into a configuration called an electro dialysis stack, with alternating anion and cation-exchange membranes forming the multiple electro dialysis cells. Electro dialysis processes are different from distillation techniques and other membrane-based processes (such as reverse osmosis (RO)) in that dissolved species are moved away from the feed stream rather than the reverse. Because the quantity of dissolved species in the feed stream is far less than that of the fluid, electro dialysis offers the practical advantage of much higher feed recovery in many applications.

In an electro dialysis stack, the dilute (D) feed stream, brine or concentrate (C) stream, and electrode (E) stream are allowed to flow through the appropriate cell compartments formed by the ion-exchange membranes. Under the influence of an electrical potential difference, the negatively charged ions (e.g., chloride) in the dilute stream migrate toward the positively charged anode. These ions pass through the positively charged anion-exchange membrane, but are prevented from further migration toward the anode by the negatively charged cation exchange membrane and therefore stay in the C stream, which becomes concentrated with the anions. The positively charged species (e.g., sodium) in the D stream migrate toward the negatively charged cathode and pass through the negatively charged cation-exchange membrane. These cations also stay in the C stream, prevented from further migration toward the cathode by the positively charged anion-exchange membrane. As a result of the anion and cation migration, electric current flows between the cathode and anode. The overall result of the electro dialysis process is an ion concentration increase in the concentrate stream with a depletion of ions in the dilute solution feed stream.

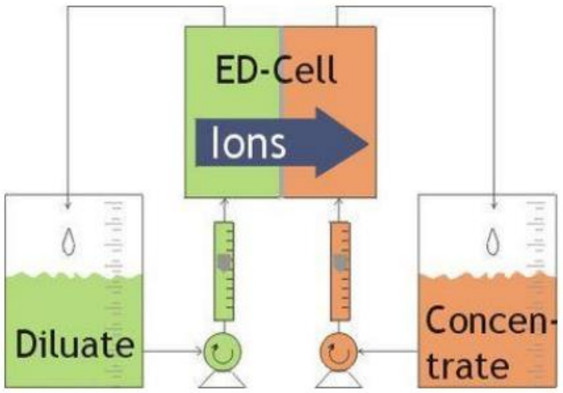


Figure 3.5: Electro dialysis

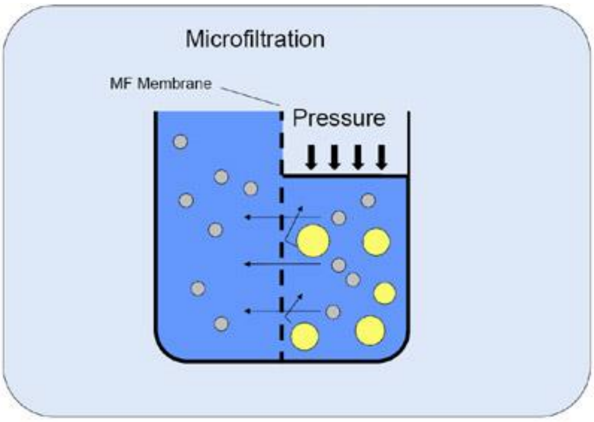


Figure 3.6: Microfiltration

3.5 Microfiltration

Microfiltration (MF) is loosely defined as a membrane separation process to remove the particles having average molecular weight > 400kDa using membranes with a pore size varying between the 0.05 and 10µm under an operating pressure of less than 2 bar.

Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. The typical particle size used for microfiltration ranges from about 0.1 to 10 µm. In terms of approximate molecular weight these membranes can separate macromolecules of molecular weights generally less than 100,000 g/mol. The filters used in the microfiltration process are specially designed to prevent particles such as, sediment, algae, protozoa or large bacteria from passing through a specially designed filter. More microscopic, atomic or ionic materials such as water

(H_2O), monovalent species such as Sodium (Na^+) or Chloride (Cl^-) ions, dissolved or natural organic matter, and small colloids and viruses will still be able to pass through the filter.

The suspended liquid is passed through at a relatively high velocity of around 1–3 m/s and at low to moderate pressures (around 100-400 kPa) parallel or tangential to the semi-permeable membrane in a sheet or tubular form. A pump is commonly fitted onto the processing equipment to allow the liquid to pass through the membrane filter. There are also two pump configurations, either pressure driven or vacuum. A differential or regular pressure gauge is commonly attached to measure the pressure drop between the outlet and inlet streams. The most abundant use of microfiltration membranes are in the water, beverage and bio-processing industries. The exit process stream after treatment using a micro-filter has a recovery rate which generally ranges to about 90-98 %.

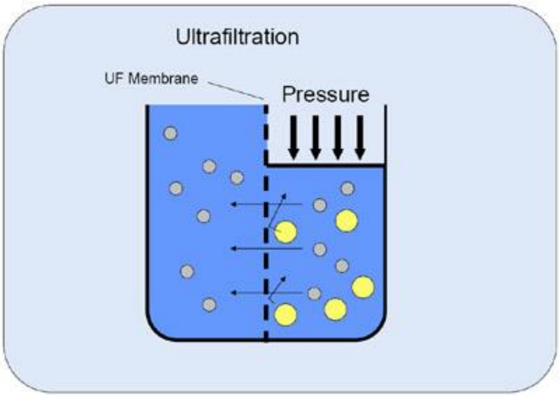
3.6 Ultrafiltration

Ultrafiltration (UF) is a pressure-driven barrier to suspended solids, bacteria, viruses, endotoxins and other pathogens to produce water with very high purity and low silt density. Ultrafiltration (UF) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane.

As in nonbiological examples of ultrafiltration, pressure (in this case blood pressure) and concentration gradients lead to a separation through a semipermeable membrane (provided by the podocytes). The Bowman's capsule contains a dense capillary network called the glomerulus. Blood flows into these capillaries through the afferent arterioles and leaves through the efferent arterioles.

The high hydrostatic pressure forces small molecules in the tubular fluid such as water, glucose, amino acids, sodium chloride and urea through the filter, from the blood in the glomerular capsule across the basement membrane of the Bowman's capsule and into the renal tubules. This process is called ultrafiltration; the resulting fluid, virtually free of large proteins and blood cells, is referred to as glomerular filtrate, or ultrafiltrate. Further modification of ultrafiltrate, by reabsorption and secretion, transforms it into urine.

In haemodialysis centres, ultrafiltration takes place in a haemofilter on the haemodialysis machines, when the blood pressure is greater than the dialysate pressure (difference = transmembrane pressure (TMP)). This removes fluid from the blood while keeping its blood cells intact.



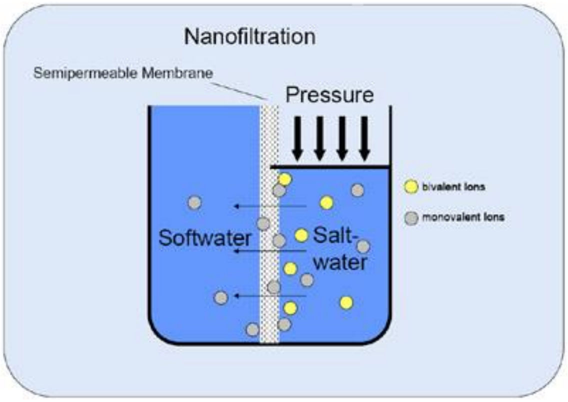


Figure 3.7: Ultra filtration **Figure 3.8: Nano filtration**

3.7 Nanofiltration

Nanofiltration is a pressure-driven membrane process that lies between ultrafiltration and reverse osmosis in terms of its ability to reject molecular or ionic species. Nanofiltration membranes, organic membranes, or ceramic membranes can be either dense or porous.

Nanofiltration is a membrane filtration-based method that uses nanometre sized through-pores that pass through the membrane. Nanofiltration membranes have pore sizes from 1-10 nanometres, smaller than that used in microfiltration and ultrafiltration, but just larger than that in reverse osmosis. Membranes used are predominantly created from polymer thin film. Materials that are commonly used include polyethylene terephthalate or metals such as aluminium. Pore dimensions are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2. Membranes made from polyethylene terephthalate and other similar materials, are referred to as "track-etch" membranes, named after the way the pores on the membranes are made. "Tracking" involves bombarding the polymer thin film with high energy particles. This results in making tracks that are chemically developed into the membrane, or "etched" into the membrane, which are the pores. Membranes created from metal such as alumina membranes, are made by electrochemically growing a thin layer of aluminium oxide from aluminium metal in an acidic medium.

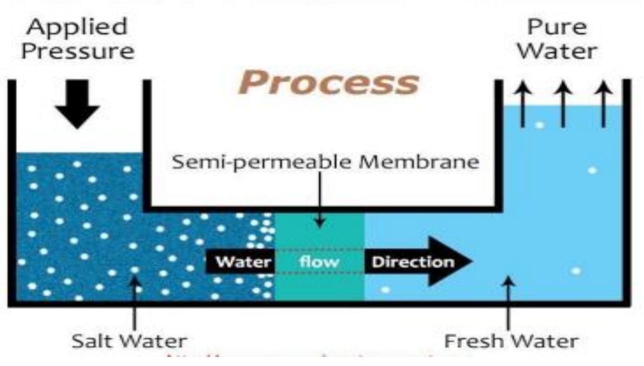
3.8 Reverse osmosis

Reverse osmosis is a water purification process that uses a semi-permeable membrane (synthetic lining) to filter out unwanted molecules and large particles such as contaminants and sediments like chlorine, salt, and dirt from drinking water.

In reverse osmosis, an applied pressure is used to overcome osmotic pressure, a colligative property that is driven by chemical potential differences of the solvent, a thermodynamic parameter. Reverse osmosis can remove many types of dissolved and suspended chemical species as well as biological ones (principally bacteria) from water, and is used in both industrial processes and the production of potable water. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. To be "selective", this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as solvent molecules, e.g., water, H_2O) to pass freely.

Reverse osmosis differs from filtration in that the mechanism of fluid flow is by osmosis across a membrane. The predominant removal mechanism in membrane filtration is straining, or size exclusion, where the pores are 0.01 micrometres or larger, so the process can theoretically achieve perfect efficiency regardless of parameters such as the solution's pressure and concentration. Reverse osmosis instead involves solvent diffusion across a membrane that is either nonporous or uses nanofiltration with pores 0.001 micrometres in size. The predominant removal mechanism is from differences in solubility or diffusivity, and the process is dependent on pressure, solute concentration, and other conditions.

Reverse osmosis is most commonly known for its use in drinking water purification from seawater, removing the salt and other effluent materials from the water molecules.



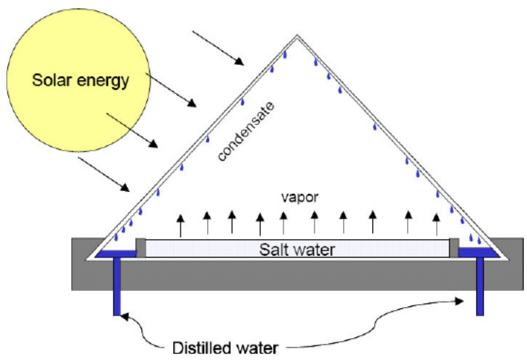


Figure 3.9: Reverse osmosis desalination **Figure 3.10: Solar distillation**

3.9 Solar distillation

Solar distillation is a process in which the energy of the sun is directly used to evaporate freshwater from sea or brackish water. The process has been used for many years, usually for small-scale applications.

Still types include large scale concentrated solar stills and condensation traps**.** In a solar still, impure water is contained outside the collector, where it is evaporated by sunlight shining through a transparent collector. The pure water vapour condenses on the cool inside surface and drips into a tank.

Distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, its vapour rises, condensing into water again as it cools. This process leaves behind impurities, such as salts and heavy metals, and eliminates microbiological organisms. The end result is pure (potable) water.

3.9.1 Advantages of solar distillation

- Free of sun charge energy (during sunlight it eliminates 500-watt electric consumption per one hour of sunlight).
- **T**here are no moving parts, therefore it is almost reliable and maintenance free.
- Water taste is claimed to be better since the device acts as a solar water vaporizer and it doesn't boil the water.
- Neutral pH is claimed (rainwater).

3.9.2 Disadvantages of solar distillation

- Solar distillers don't kill bacteria and they don't breakdown harmful chemicals because they don't boil the water.
- The large area tilted glass cover might be attraction to bugs and insects.
- Low production capacity, not enough for the drinking water needs of the average family.

CHAPTER 4

4. SOLAR DESALINATION AND COMPONENTS OF A SOLAR DESALINATION PLANT

Solar desalination is primarily a zero-carbon emission process and the advancements in solar technology enables overcoming previously existing problems like dust and high temperatures, which affected the efficiency of previously used solar panels. In 2011, the Environment Agency-Abu Dhabi (EAD) tested cutting-edge solar technologies for desalinating water in the desert. The trial conducted at 30 sites in the Emirate of Abu Dhabi was said to be the largest across the globe. Each unit set at the solar desalination facilities in Sweihan and Hameem could generate 35 kW/h of energy on average and thus produce 1050 kW/h of energy on the whole. This shows that the negative impact of desalination process on the environment as well as the cost of producing water can be reduced using the solar desalination technology.

The key benefits of solar desalination include usage of free solar energy for desalination, low maintenance costs, environmentally friendly. The plants could be set up easily either onshore or offshore, they are inexpensive, light in weight and easy to transport.

4.1 Solar Desalination Plant

Desalination is the lifeblood of cities in the Gulf region, where fresh water is scarce but demand is high. As established cities grow in population, and as gleaming new cities emerge in the desert, the requirement for desalinated seawater will only grow. Traditional desalination is extremely energy intensive, expanding carbon footprint and greenhouse gas emissions, and negatively impacting the marine environment as the salty brine residue is returned to the ocean following desalination.

Solar Water Plc has developed the world’s first completely carbon neutral hydro-infrastructure project, designed to produce and make available a massive ongoing amount of pure, clean water for municipal, industrial, farming and bio-tech consumption. The technology involves a dome – a hydrological sphere – constructed from glass and super conductive steel into which sea water flows. Large parabolic mirrors surround the dome, capturing the sun’s energy which is reflected onto the dome. This energy heats the continuous inflow of seawater to high temperatures at which the sea water evaporates, condenses, and precipitates as fresh water, thereby creating a constant water cycle within the dome. Fresh water is collected and channeled into reservoirs, and the remaining brine gathers at the bottom of the dome's basin. Salt is extracted from the brine as a by-product and sold commercially, ensuring that neither salt nor brine is returned to the ocean. The quantity of water generated will depend on the size of the dome, which comes in diameters between 20m and 120m. Other variables such as geography, latitude, and availability of continuous sunlight will also play a part.

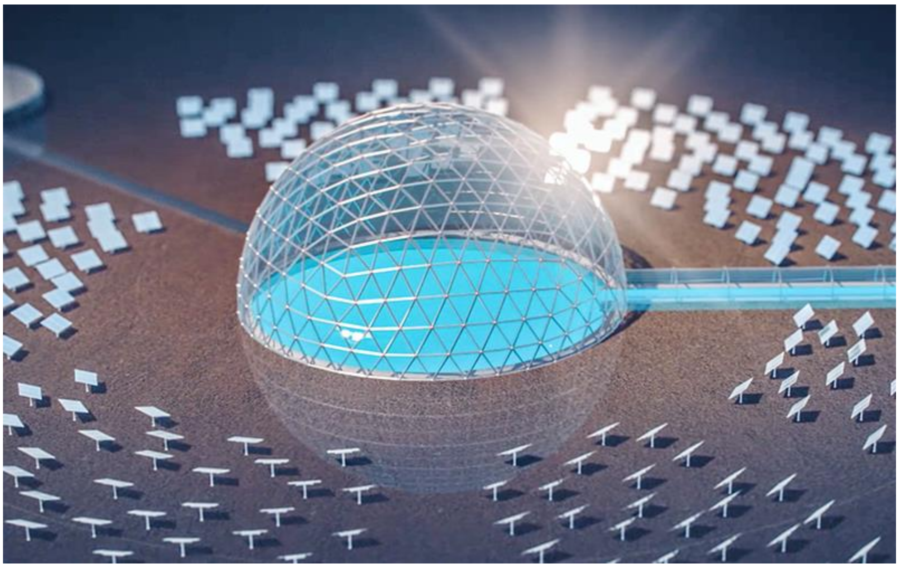


Figure 4.1: Solar Water Plc, desalination plant

4.2 Solar Concentrators

Solar concentrators utilize optical devices which absorb a large area of sunlight. They function on the idea of focusing a bundle of sunlight on a small area with the assistance of a mirror or optical equipment. In order to ensure that the solar concentrator works efficiently, they have to be placed in such a manner that it directly faces the sun.

To ensure that the solar concentrators can absorb maximum radiance during the day's sunshine hours, there is a need for the concentrators to follow the sun. This can be achieved efficiently with the help of a tracker. Tracking can be of single axis which is from East to West and can also be from North to South so that the altering path of the sun can be tracked.

4.2.1 Types of Solar concentrators

Flat plate concentrators with plane reflectors and adjustable mirrors, in this type of solar concentrators, the mirrors are used to reflect radiation to the absorber plate. It is quite simple in design and has a good concentration ratio. It is important to note that with a single collector, it is always possible to use four reflectors simultaneously.

Cylindrical parabolic collector, it is also known as the linear parabolic collector. In this type of collector, the primary emphasis is on the focal axis of the reflecting material. The absorber is usually made of copper or stainless steel and has a diameter of 3cm to 5cm.

Solar ray collector with a circular concentrator, it is a type of collector which has a moving receiver. In this type of concentrator, there are mirror strips that produce a narrow image which follows a circular path, the receiver moves along the circular way so that it can track the sun.

Parabolic Dish Collector, in this type of collector, the concentrator tracks the sun with the help of rotation along the two axes. The sun's rays are brought to the primary focus. There exists a fluid which flows through the receiver, and this heat is used to drive a mover. The parabolic dish collectors can generate power in kilowatts.

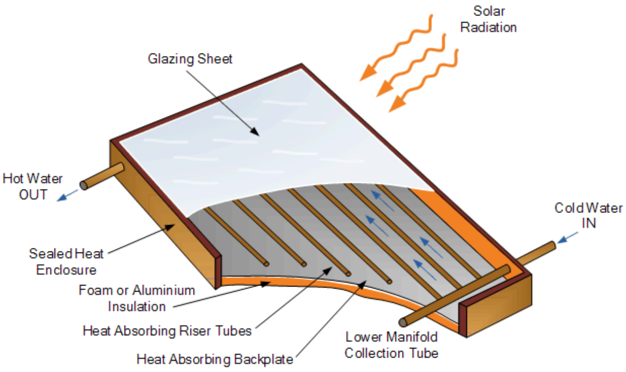


Figure 4.2: Flat-plate solar concentrator

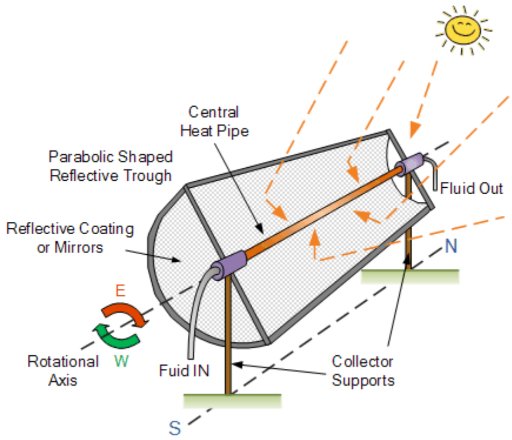


Figure 4.3: Cylindrical parabolic concentrator

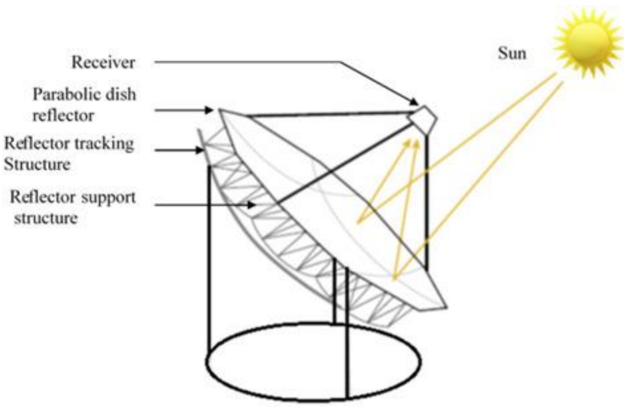


Figure 4.4: Parabolic dish collector

4.2.2 Advantages of Solar concentrators

It comes with the ability to increase the intensity of solar energy by concentrating the available energy over a large area on a smaller surface, it assists in reducing the cost in a solar power generation system as it replaces an extensive and costly receiver with a less expensive reflecting area.

The heat loss is drastically reduced. The temperature on the receiving area is quite high, a thermodynamic match can be achieved which augurs well for the overall efficiency of the solar power system. Solar concentrators have potential applications in both photovoltaic and thermal utilization.

4.3 Heliostat

A heliostat is a device that includes a mirror, usually a plane mirror, which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky. The target may be a physical object, distant from the heliostat, or a direction in space. To do this, the reflective surface of the mirror is kept perpendicular to the bisector of the angle between the directions of the sun and the target as seen from the mirror. In almost every case, the target is stationary relative to the heliostat, so the light is reflected in a fixed direction. Heliostats should be distinguished from solar trackers or sun-trackers, which always point directly at the sun in the sky. However, some types of heliostats incorporate sun-trackers, together with additional components to bisect the sun-mirror-target angle.

4.3.1 Types of Heliostats

Manually operated heliostats, the earliest known heliostats were also the simplest. They were used for daylighting in ancient Egypt, more than 4000 years ago. The interiors of Egyptian buildings were elaborately decorated, and would have been damaged by smoke from flaming torches. Instead, polished metal mirrors were used to reflect sunlight indoors. Mirrors are moved manually to keep reflecting sunlight in the right directions as the sun moved across the sky.

Clockwork heliostats, A simple type of semi-automatic heliostat uses a mirror mounted so it can be rotated by a clockwork mechanism about an axis that is parallel with the earth's axis of rotation. The clockwork turns the mirror once every 24 hours in the direction opposite to the earth's rotation. The mirror is oriented so it reflects sunlight along the same polar axis as its axis of rotation. At an equinox, this means that the mirror is inclined at 45 degrees to the axis. At other times of the year, this inclination angle must be changed as the sun moves north and south. Pivots are provided to allow this adjustment to be done by hand every few days. Also, the setting of the clock has to be varied occasionally to take account of the Equation of Time, a small east-west seasonal movement of the sun. This is also done manually. The beam of light that is reflected along the polar axis by the rotating mirror is intercepted by a second, stationary mirror, which reflects the light in any desired direction. This type of machine can run automatically for a few days, but requires manual readjustment fairly frequently to follow the sun's seasonal movements. Also, of course, the clockwork has to be wound up and the mirrors cleaned periodically.

Heliostats controlled by light-sensors, if electricity is available, heliostats that use light-sensors to locate the sun in the sky are practicable. A simple design uses a principal axis of rotation that is aligned to point at the target toward which light is to be reflected. The secondary axis is perpendicular to the first. Sensors send signals to motors that turn around both axes so that a small arm, carrying the sensors, points toward the sun. (thus this design incorporates a sun-tracker.) A gear mechanism bisects the angle between the sun-pointing arm and the principal rotation axis. This gives the direction in which the perpendicular to the mirror must be pointed.

Computer-controlled heliostats, most heliostats are controlled by computers. The software they use calculates, from astronomical theory, where the sun is in the sky. Sensors are not needed, and the calculation takes account of both the daily and seasonal movements of the sun. The information that has to be available is simply the position of the heliostat on the earth's surface, as latitude and longitude, and the time and date. When the position of the sun has been calculated, it is combined with the direction in which light is to be reflected, which also has to be provided, to calculate the direction of the required angle-bisector. The computer then sends control signals to motors that rotate the mirror to the correct orientation. This whole process is repeated every few seconds, so the mirror is kept correctly aligned.

For daylighting purposes, individual mirrors controlled by their own computers are often sufficient. However, for solar-thermal power generation, "fields" of heliostat mirrors, often hundreds of them, are used to reflect large amounts of sunlight onto a boiler or other heat collector. The heat is used to make steam, which drives turbines to generate electricity. Usually, just a single computer controls all the mirrors.

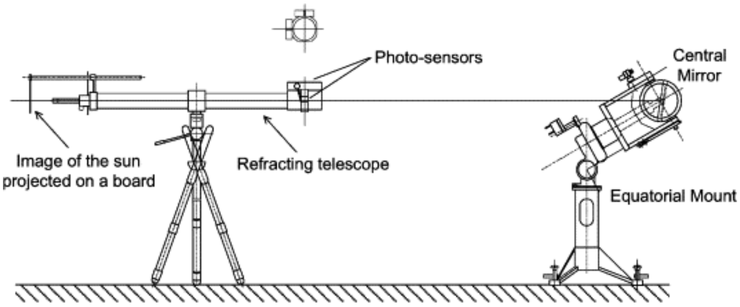


Figure 4.6: Heliostat controlled by light-sensor

Figure 4.5: Clockwork heliostat

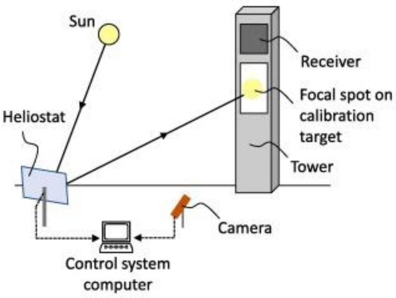


Figure 4.7: Computer controlled heliostat

4.3.2 Advantages of Heliostat

Solar energy, in the solar thermal plants of the heliostat, it is used to concentrate the sun's rays at a specific point or area where the solar collectors are located.

Astronomy, in astronomy this mechanism is used to observe the Sun without having to vary the orientation of the observation apparatus.

Geodesy, in the field of geodesy, the heliostat is used to transmit long-distance light signals.

In case of ***solar thermal energy***, the temperature can be increased considerably. In this way it is easier to obtain steam to be able to drive a steam turbine and generate electricity. In the case of ***photovoltaic solar energy***, it allows more solar radiation to be concentrated in the same photovoltaic module. In this way it is possible to increase the solar yield.

4.4 Solar reflectors

Reflectors are used in the solar technology to concentrate the sunlight onto the solar panels. They employ glass as a base material with a silver coating and a protective layer over it. They elevate the energy input of solar panels as the whole solar spectrum is reflected on them. Materials with more reflective properties are needed to be used to increase the reflectivity and efficiency of solar reflectors. If solar reflectors are used with the solar panels, then their efficiency as well as production from the solar panels will be maximized.

For enhanced efficiency, solar reflectors are used on the sideways of solar panels to concentrate the sunlight on them. Solar reflectors are used to increase the efficiency and gain of the solar collectors as well. Solar reflectors concentrate the incident solar radiation onto the receiver.

The energy is spread out so it does not rapidly heat things. But by concentrating the sun's energy using solar reflectors can produce dramatic results. The most durable material for solar reflectors known to present is the silver/glass thick mirror whose reflectivity values reaches close to 94%. A highly reflective thin film was reported by Xu et al., which possesses the self-cleaning properties. This thin film consisting of TiO_2–SiO_2–Ag was efficaciously prepared by magnetron sputtering for the solar front reflectors. This layer retains high reflectivity of 0.9578 after a 1200 h aging test.

However, silver polymer solar reflectors are used mostly in dish concentrator applications. This increases the storage of solar energy and causes low solar losses.

4.4.1 Types of reflectors

Parabolic trough, the construction of parabolic trough includes a parabolic reflector that reflects and concentrates light onto a receiver positioned at the reflector's focal line. The receiver maybe a receiving tower or a tube filled with a working fluid. This reflector follows the sun by tracking along a single axis and reflects more sunshine, in result acting as an amplified source for power generation.

Fresnel reflectors, they comprise many thin, flat mirror strips, which concentrate the sunlight onto the tubes filled with working fluid. Fresnel reflectors have flat mirrors, providing more reflective surface in the same amount of space as of a parabolic trough, thus capturing more of the accessible sunlight.

Dish Stirling, the construction of a Dish Stirling system has a standalone parabolic reflector that concentrates light onto the receiver positioned at the reflector's focal point. Dish Stirling reflector tracks the Sun along two axes.

Solar power tower, A solar power tower consists of an array of dual-axis tracking reflectors (heliostats) that concentrate sunlight on a central receiver at the top of the tower. That concentrated light is then used for the power generation using a working fluid inside the solar power tower system.

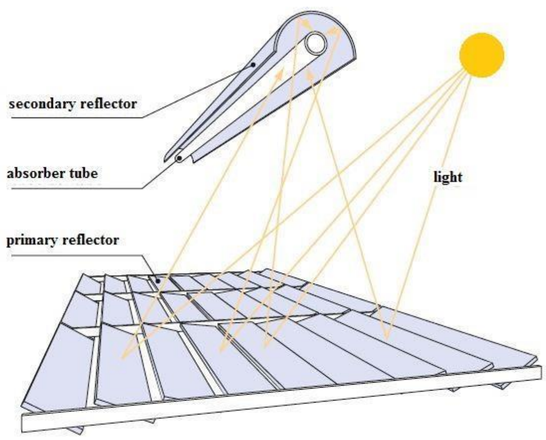


Figure 4.8: Linear Fresnel reflector

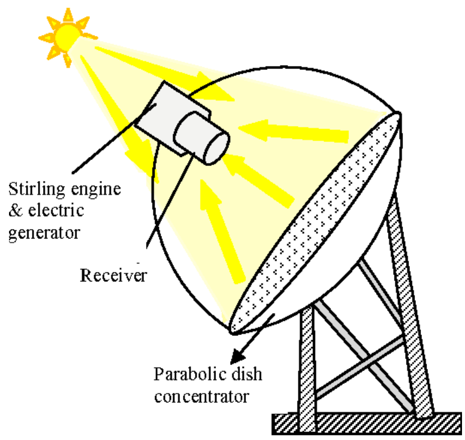


Figure 4.9: Dish Stirling reflector

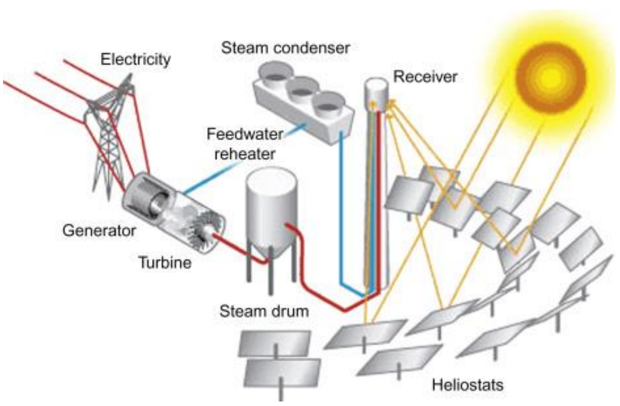


Figure 4.10: Solar power tower

4.4.2 Comparison of reflective values of different materials on solar cells

An experiment was carried out to find out which material produces most energy output on solar cells (Table 4.1). The solar panel was placed such that it faces away from sun. Different materials were placed a foot from solar panel at 45º and their reflective properties were measured by using an amp-meter. It was repeated three times and the values were averaged. The silver photo reflector possesses the most reflective value. Silver-based reflector56 can be used as an efficient solar reflector material.

Table 4.1: Material wise reflectivity values

S.no	Materials	Average reflective values (milli ampere)
1.	Mirror	135.3
2.	Aluminum	46.3
3.	Silver photo reflector	140.3
4.	White plastic	41.3
5.	White ceramic tile	38.5
6.	White foam board	65
7.	Plywood	43.3
8.	Cardboard	33.3
9.	Black fabric	13

4.4.3 Applications of reflectors

Harnessing more energy using reflectors in rural and urban areas, the solar power generation plants are feasible for the rural as well as urban areas. As far as the most rural areas are concerned, electricity is still found to be nowhere. Some small villages got electricity lines but with no electricity or for a few hours. This problem can be elucidated by using the solar panels with embedded solar reflectors in order to fulfil the needs of the particular area population. Solar reflectors facilitate the panels to get more intense sunshine, hence more energy harnessing in less time.

Solar energy is not only used for electricity generation but also for various energy applications like solar water heating or solar geysers, solar food cooking, food preservation/ drying, etc. These reflectors-facilitated solar panels can be equally useful for the urban areas owing to their intensifying properties. Their usage will double the power generation and allowing more energy generation in small time.

CHAPTER 5

5. DESIGNING OF EQUIPMENT AND CALCULATIONS

Equipment design can be of any shape and of different size such as rectangle, sphere, inclined, square, etc., The shape opted for designing is sphere by taking spherical tank which is similar to sphere shape and decided to work on two different sizes 10 inch and 8 inch for observing evaporation rate.

Equipment is designed on the basis of evaporation of water rate and collection of condensate in a suitable manner, the model which is being designed is portable model which is solely used for domestic purposes and can be carried, placed in any place with respective to needs. Water used in experimental process for selecting of the model is sea water.

Figure 5.1: 10-inches bowl

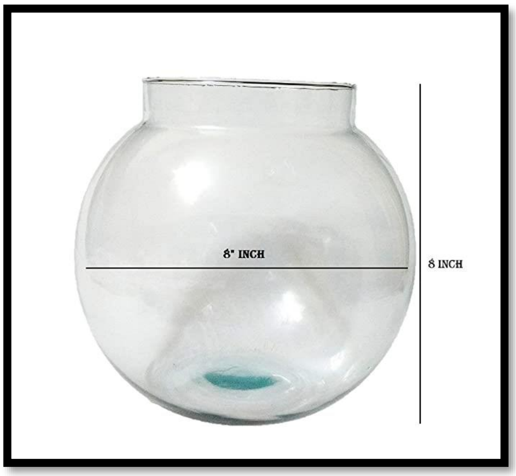


Figure 5.2: 8-inches bowl

By consider 2 glass domes of different sizes, which are of 8 inches in size and 10 inches in size respectively. Conducted the evaporation test in a similar setup.

Figure 5.3: Spherical dome

By comparing the evaporation rate from both the spherical domes. We concluded that rate of evaporation increases with increase in surface area.

5.1 Working Designs

5.1.1 Design 1: Non-Removable cover

- The design-1 was prepared by using a plastic cover, which acts as a lid & a structure made from cardboard which supports the plastic cover.
- The lid was placed in a slanting way so the water which gets evaporated has been collected by condensation at the top on the surface of the plastic cover.
- The collected water has been sent down into a paper cup which eventually gives us pure evaporated water
- Experiment by the design-1 was done from 10.00 am in the morning till 2.30 pm in the afternoon.
- The readings are noted after a fixed time interval, without interfering in the evaporation, which is like the batch process of collection of data.
- The collection of condensate in about 50%.

This design had provided a good evaporation rate because it is acting as a closed vessel. But, this design-1 failed in the aspect of collecting the water in to the paper cup. As it is non-removable lid model, the water after four and half hours collected was very less.

The main important factor affecting here is temperature, evaporation is based mainly on temperature so weather is important factor here. Though the water was lost from the initial measurement to final measurement from the spherical bowl, but the collection of the evaporation made a drawback in this model.

Table 5.1: Data table of design 1

	Temperature	**Time**	**Volume in bowl**
Initial readings	31ºC	10.00 am	300 ml
Final readings	33ºC	2.30 pm	256 ml

Figure 5.4: Non-removable cover

5.1.2 Design 2: Removable cover

- The design-2 was prepared with the same material which was been used in the design-1.
- The design-2 adjustments and the method of orientation also similar to the design-1, but the main difference is we made the lid to be removable and not be fixed.

- So, the data is collected for certain time intervals. Which is similar to continuous model of collection of data.
- Experiment by the design-2 was done from 11.30 am in the morning till 2.50 pm in the afternoon.
- Even in this design the collection in only about 40 to 45%.

This design had provided less evaporation compared to the design-1 as we continuously removed the lid for collection of data. The design-2 failed in the aspect of collecting the water in to the paper cup similar to the design-1, but it even failed in a deeper way because of continuous removal of lid.

When conducting the experiment, the weather is cloudy which is a important factor in evaporation and it made collection of condensate difficult compared to previous model.

Table 5.2: Data table of design 2

	Temperature	**Time**	**Volume in bowl**
Initial readings	31ºC	11.30 am	300 ml
Final readings	31ºC	2.50 pm	261 ml

Figure 5.5: Removable cover

5.1.3 Design 3: Hanging cup covered with transparent cover

- The design-3 was prepared by using a plastic cover, which acts as a lid & a stone which was been placed on the plastic cover and a paper cup for collection for evaporated water.
- The design had made a simple idea of making a loosely attested plastic cover as the top surface.
- By keeping a paper cup by hanging it with thread beneath the cover, and as placed the stone on the top it made a inverted conical structure which helps in collecting the evaporated water to be condensed at the top on the cover and been collected into the paper cup.
- This whole mechanism is clearly portrayed below. The collection rate is good compared to first two designs about 60%.
- By, this method has collected a good amount of water in the paper cup. Nearly about 8 ml has been collected into the paper cup.
- Experiment by the design-3 was done from 9.05 am in the morning till 2.45 pm in the afternoon.
- This experiment was also done in the closed atmosphere, i.e., without disturbing the apparatus and collecting the data only after a defined time.

This design has shown a clear dominance over the past 2 designs in terms of collection of the evaporated pure water.

The drawback of this design which was overcome was in collecting the final volume of water in the paper cup and also the collected amount of water was good on comparison with the previous designs but not in terms of the volume we required.

Table 5.3: Data table of design 3

	Temperature	**Time**	**Volume in bowl**
Initial readings	29ºC	9.05 am	300 ml
Final readings	34ºC	2.45 pm	256 ml

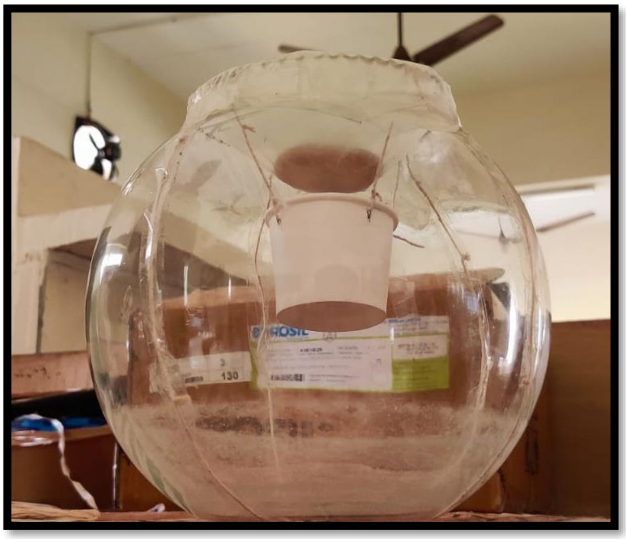


Figure 5.6: Hanging cup model

5.1.4 Design 4: Hanging cup covered with opaque plastic cover

- The design-4 was prepared with the same material which was been used in the design-3. But a opaque cover which completely blocks the light from the top.
- This design was investigated because of the material that we took to cover the top was an opaque material (to be precise, a gift-wrapping cover) which has a smooth surface compared to polythene plastic cover which has a rough surface though it is a transparent one.
- The preliminary idea was due to the smoothness as the condensed droplets at the top would
- easily be collected into the paper cup.
- The experiment had done from 10.40 am to 2.40 pm and below is the experimental reading which is collected.
- There was no water collected in the paper cup.
- The collection is not up to mark when compared to other remaining designs.

The water wasn't been collected in the cup after experiment being done from 10.40 am to 2.40 pm, but there was a difference in the volume of the water in the bowl.

To the conclusion of this design-4, it was failure when compared to design-3, since the opaque cover has stopped the evaporation process, by obstructing the sun to fall from the top of the bowl.

Table 5.4: Data table of design 4

	Temperature	Time	Volume in bowl
Initial readings	31ºC	10.40 am	300 ml
Final readings	34ºC	2.40 pm	280 ml

Figure 5.7: Hanging cup covered with opaque plastic cover

5.1.5 Design 5: Straw collection method

- The design-5 was prepared by using a simple plastic straw for collection.
- The plastic straws were attached inside the inverted spherical dome which acts for collecting the evaporated water.
- From the inverted dome, the water which was collected at the top has been condensed and then slide through the walls of the dome.
- The falling water droplets been collected inside the straws and due to the inclined down setup of the design 5, the water been collected at the bottom into a collecting vessel at the bottom.

- Here, in this model there is no presence of condensate or collecting of water droplets in the plastic straws.
- But only the presence a few moist droplets is observed in the plastic straw surface.
- The evaporation rate for this model is high but collection is difficult due to small size in design, this model can have good results if we scale-up.

This model has high evaporation rate but collecting condensate became difficult.

Evaporation rate is high because the water is covered with glass surface unlike other models which are covered with plastic cover as glass material has high absorption rate than plastic. Collecting water is failure as the collecting pipes we used are not perfectly fitted as they are made of less stiff material (straws).

Table 5.5: Data table of design 5

	Temperature	**Time**	**Volume in bowl**
Initial readings	31ºC	10.00 am	300 ml
Final readings	32ºC	2.55 pm	245 ml

Figure 5.8: Straw collection method

5.2 Calculations of working designs

The calculations for the design had been done by experimental and theoretical approaches. The calculation involves the rate of evaporation happening per day. It involves analyzing different parameters like temperature, time of evaporation, weather conditions like humidity, wind velocity, etc. Also, the height of conduct of experiment also has a certain influence on the rate of evaporation.

Potential Evaporation E_o (mm/day) defined as the quantity of water evaporated per unit area, per unit time from an idealized extensive free water surface under existing atmospheric conditions. Potential Evaporation of a given area varies daily, and is following the variations of the weather.

5.2.1 Theoretical calculation

The theoretical calculations involve the calculation by penman equation for rate of evaporation and the energy balance method for rate of evaporation. There are also certain other methods for calculating the rate of evaporation.

5.2.1.1 Penman equation

The Penman equation describes evaporation (E) from an open water surface, and was developed by Howard Penman in 1948. Penman's equation requires daily mean temperature, wind speed, air pressure, and solar radiation to predict E. Simpler Hydrometeorological equations continue to be used where obtaining such data is impractical, to give comparable results within specific contexts, e.g., humid vs arid climates.

Numerous variations of the Penman equation are used to estimate evaporation from water, and land. Specifically, the Penman–Monteith equation refines weather based potential evapotranspiration (PET) estimates of vegetated land areas. It is widely regarded as one of the most accurate models, in terms of estimates. The original equation was developed by Howard Penman at the Rothamsted Experimental Station, Harpenden, UK.

The equation for evaporation given by Penman is:

$$\boldsymbol{E_o = \frac{700\frac{T_m}{100-A} + 15(T - T_d)}{(80 - T)} \quad mm/day}$$

where $T_m = T + 0.006h$, h is the elevation (meters), T is the mean temperature, A is the latitude (degrees) and T_d is the mean dew-point. The formula applies over a wide range of climates.

5.2.1.2 Energy balance method

This method is widely used for estimating the amount of evaporation from a large body of water such as lakes, reservoirs etc.

Consider an evaporation pan of a circular tank containing water, in which the rate of evaporation is measured by the rate of fall of the water surface (E_r = -dh/dt). Based on the continuity and energy equation, one can derive the energy balance equation for evaporation as

$$E_r = \frac{1}{l_v \rho_w}(R_n - H_s - G)$$

If the sensible heat flux Hs (sensible heat loss to surroundings atmosphere to raise the temperature) and the ground heat flux G are both zero, then an evaporation rate Er can be calculated as the rate at which all the incoming net radiation is

$$E_v = \frac{R_n}{L_v \rho_w}$$

were,

R_n = Net radiation (W/m^2)

L_v = Latent heat of vaporization (J/Kg)

ρ_w = Water density (Kg/m^3)

E_v = Rate of evaporation (m/s)

5.2.2 Theoretical calculations for design models

We have performed the final conclusive calculations, the evaporation rates for the designs by theoretically using *penman equation & Energy balance method*, and experimentally from the obtained data.

5.2.2.1 Design 1

Table 5.1: Data table of working design 1

	Temperature	**Time**	**Volume in bowl**
Initial readings	31ºC	10.00 am	300 ml
Final readings	33ºC	2.30 pm	256 ml

Calculation by Penman Equation:

$$\boldsymbol{E_o = \frac{700\frac{T_m}{100-A} + 15(T - T_d)}{(80 - T)}\ \ mm/day}$$

A=latitude(degrees) = 17.922 degrees north (sangivalasa)

H= 12m (height of the building)

T = Mean Temperature = $\frac{31+33}{2}$ = 32°C

T_d = Mean dew point @ T = 32°C & Relative Humidity = 60% is 24.6°C

T_m = 32+(0.006*12) = 32.072 centigrade (by substituting the values and calculated)

$$E_o = \frac{((700 * \frac{32.072}{100-17.922} + 15 * (32 - 24.6))}{(80 - 32)} = 8.011\,\frac{mm}{day}$$

$$E_o = 8.011 * 50670 \frac{mm^3}{day} = 405.917 \frac{mm^3}{day} = 405 \frac{ml}{day}$$

Calculation by Energy Balance method

$$E_v = \frac{R_n}{L_v \rho_w}$$

L (KJ/Kg) = 2500 - (2.36 * T°C)

T = 32°C

L_v = 2500-(2.36*32°c) = 2424.5 KJ/Kg

R_n is obtained from the net radiation v/s time data graph

At 32°C,

R_n = 190 W/m^2

Density is 997 Kg/m^3

E_v = 190/ (2424.5*997) = 7.86*10^{-8} m/s

= 47.86*10^{-8}*86400*1000 mm/day (Conversion of m/s into mm/day)

= 6.79 mm/day

$$\boldsymbol{E_o} = 6.79 * 50670 \frac{mm^3}{day} = 344.11 \frac{ml}{day}$$

5.2.3 Experimental calculations

The experimental calculations are calculated from basic understandings of balances, i.e., by knowing the volume of water evaporated from the bowl, and how much time required to evaporate that known quantity of water. And now calculating how much water would be available to evaporate for 24 hours.

5.2.4 Experimental calculation for design models

5.2.4.1 Design 1

From our experiment, we conclude that:

The experiment is done for 326 mins (i.e., from 9.20 am to 2.46 pm).

The water evaporated from a hemispherical bowl of evaporation area of circle 62.21 cm^2 is 35 ml (200ml – 165 ml, i.e., at 9.20 am – 2.46 pm)

Now, calculating the amount of water evaporated at this rate per day, is done by considering:

$$44 \text{ ml} \longrightarrow 240 \text{ minutes}$$

$$X \text{ ml} \longrightarrow 1440 \text{ minutes}$$

$$X = (1440*44)/240 = 264 \text{ ml/day}$$

Similarly, the both experimental and theoretical calculations are proceeded with all the design models and they are plotted in the table.

Table 5.6: Calculated table for working design models

Properties		Design 1	Design 2	Design 3	Design 4	Design 5
Temperature	Initial Reading	31ºC	31ºC	29ºC	31ºC	31ºC
	Final Reading	33ºC	31ºC	34ºC	34ºC	32ºC
Size		10 inches	10 inches	8 inches	8 inches	10 inches
Time	Initial Reading	10.00 am	11.30 am	9.05 am	10.40 am	10.00 am
	Final Reading	2.30 pm	2.50 pm	2.45 pm	2.40 pm	2.55 pm
Volume in bowl	Initial Reading	300 ml	300 ml	300 ml	300 ml	300 ml
	Final Reading	265 ml	261 ml	256 ml	280 ml	245 ml
Theoretical calculations	Penman equation	405 ml/day	392 ml/day	254 ml/day	266 ml/day	397 ml/day
	Energy balance method	344 ml/day	344 ml/day	220 ml/day	220 ml/day	344 ml/day
Experimental calculations		264 ml/day	281 ml/day	186 ml/day	120 ml/day	269 ml/day
Theoretical-experimental	Penman-experimental	141 ml/day	112 ml/day	68 ml/day	146 ml/day	128 ml/day
	Energy-experimental	80 ml/day	63 ml/day	34 ml/day	100 ml/day	75 ml/day
Error%	(Penman-exp.)/ exp.	53.41%	39.86%	36.56%	121.67%	47.58%
	(Energy-exp.)/ exp.	30.30%	22.42%	18.28%	83.33%	27.88%

5.3 Final selection model

In the above 5 models design 3 (hanging cup model) is selected because it efficient as evaporation is high so collection is also more in this model.

5.3.1 Design A: Without using Concentrators

By taking 2 glass domes of different sizes, which are of 8 inch in size and 10 inch in size respectively and comparing the evaporation rate from both the spherical domes. Now start the experiment by taken 200ml of sea water on both bowls (small, large).

5.3.1.1 Experimentation by small bowl (8 inches)

Taking small bowl (8 inches) and filled the bowl to 200 ml of sea water and the temperature of the experiment day was 33ºC to 34ºC. Time of start of the experimentation was 10.00 am to 2.30 pm, which is of a duration of 270 minutes.

And the water evaporated on the experiment day was 25ml and remaining water in bowl was 175ml.The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 278ml/day and the error was 91.72%.

Second method is energy balance method, by using this method the theoretical calculation is 220.53ml/day and the error was 60%.

The experimental calculation for small bowl (8 inches) is 145ml/day.

Figure 5.9: Small bowl (8 inches) without solar concentrators

5.3.1.2 Experimentation by large bowl (10 inches)

Large bowl (10 inches) and filled the bowl to 200 ml of sea water and the temperature of the experiment day was 33ºC to 34ºC. Time of start of the experimentation was 10.00 am to 2.30 pm, which is of a duration of 270 minutes.

And the water evaporated on the experiment day was 50ml and remaining water in bowl was 150ml. The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 425ml/day and the error was 91.72%.

Second method is energy balance method, by using this method the theoretical calculation is 220.53ml/day and the error was 60%.

The experimental calculation for large bowl (10 inches) is 277ml/day.

Figure 5.10: Big bowl (10 inches) without solar concentrators

5.3.2 Design B: With Aluminium solar concentrators

5.3.2.1 Experimentation by small bowl (8 inches)

Taking small bowl (8 inches) and eventually filled the bowl to half of the level, which is about 1.5 liters and the temperature of the experiment day was 32^{o}C to 33^{o}C and a cloudy weather was there. Time of start of the experimentation was 10.00 am to 2.30 pm, which is of a duration of 270 minutes

And the water evaporated on the experiment day was 35ml and remaining water in bowl was 1465ml. The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 266ml/day and the error was 36.72%.

Second method is energy balance method, by using this method the theoretical calculation is 220ml/day and the error was 32.53%.

The experimental calculation for large bowl (10 inches) is 166ml/day.

Figure 5.11: Small bowl (8 inches) with Aluminum concentrators

5.3.2.2 Experimentation by large bowl (10 inches)

Large bowl (10 inches) and eventually filled the bowl to half of the level, which is about 3500litres and the temperature of the experiment day was 32ºC to 33ºC and a cloudy weather was there. Time of start of the experimentation was 10.05 am to 2.35 pm, which is of a duration of 270 minutes

And the water evaporated on the experiment day was 50ml and remaining water in bowl was 3450 ml. The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 416ml/day and the error was 74.79%.

Second method is energy balance method, by using this method the theoretical calculation is 344ml/day and the error was 44.54%.

The experimental calculation for large bowl (10 inches) is 238ml/day.

Figure 5.12: Large bowl (10 inches) with Aluminium concentrators

5.3.3 Design C: By placing reflecting mirrors

Taken both the bowls and eventually filled the bowl to half of the level, which is about 1.5 liters and 3.5 liters respectively.

Both the bowls are placed side by side in center of the mirrors which were placed in a circular manner.

5.3.3.1 Experimentation by small bowl (8 inches)

Small bowl (8 inches) is eventually filled the bowl to half of the level, which is about 1500 liters and the temperature of the experiment day was 33ºC to 34ºC and a good sunny weather was there.

Time of start of the experimentation was 9:50 am to 2.40 pm, which is of a duration of 290 minutes.

And the water evaporated on the experiment day was 42ml and remaining water in bowl was 1458ml.The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 278ml/day and the error was 33.67%.

Second method is energy balance method, by using this method the theoretical calculation is 221ml/day and the error was 6.25%.

The experimental calculation for large bowl (10 inches) is 208ml/day.

Figure 5.13: Small bowl (8 inches) with reflecting mirrors

5.3.3.2 Experimentation by large bowl (10 inches)

Taken large bowl (10 inches) and eventually filled the bowl to half of the level, which is about 3500 liters and the temperature of the experiment day was $33^{o}C$ to $34^{o}C$ and a good sunny weather was there. Time of start of the experimentation was 9:50 am to 2.40 pm, which is of a duration of 290 minutes.

And the water evaporated on the experiment day was 65ml and remaining water in bowl was 3435ml.The calculation is done by using 2 methods.

The first method is penman equation, by using this method the theoretical calculation was 434ml/day and the error was 34.36%.

Second method is energy balance method, by using this method the theoretical calculation is 344ml/day and the error was 6.50%.

The experimental calculation for large bowl (10 inches) is 323ml/day.

Figure 5.14: Large bowl (10 inches) with reflecting mirrors

5.4 Calculations of final designs

As done by the calculations for working designs, similar calculations were done for the final designs which involve both theoretical calculations (penman equation, Energy balance equation) and experimental calculations. The calculations for the final 3 designs are tabulated in the table 5.7.

Table 5.7: Calculated table for final design models

Properties		**Design A**		**Design B**		**Design C**	
Temperature	Initial Reading	33ºC	32ºC	32ºC	32ºC	33ºC	33ºC
	Final Reading	34ºC	34ºC	33ºC	33ºC	34ºC	34ºC
Size of bowl		8 inches	10 inches	8 inches	10 inches	8 inches	10 inches
Time	Initial Reading	10.00 am	9.52 am	10.00 am	10.05 am	9.50 am	9.55 am
	Final Reading	2.30 pm	2.00 pm	2.30 pm	2.35 pm	2.40 pm	2.45 pm
Volume in bowl	Initial Reading	200 ml	200 ml	1500 ml	3500 ml	1500 ml	3500 ml
	Final Reading	175 ml	150 ml	1465 ml	3450 ml	1458 ml	3435 ml
Theoretical calculations	Penman equation	278 ml/day	425 ml/day	266 ml/day	416 ml/day	278 ml/day	434 ml/day
	Energy balance method	221 ml/day	344 ml/day	220 ml/day	344 ml/day	221 ml/day	344 ml/day

Experimental calculations		145 ml/day	277 ml/day	166 ml/day	238 ml/day	208 ml/day	323 ml/day
Theoretical-experimental	Penman-experimental	133 ml/day	148 ml/day	60 ml/day	178 ml/day	70 ml/day	111 ml/day
	Energy-experimental	87 ml/day	67 ml/day	54 ml/day	106 ml/day	13 ml/day ml/day	21 ml/day
Error%	(Penman-exp.)/ exp.	91.72%	53.43%	36.14%	74.79%	33.65%	34.36%
	(Energy-exp.)/ exp.	60%	24.19%	32.53%	44.54%	6.25%	6.50%

In the above 3 final selection designs, design C (hanging cup model) is selected because it efficient as evaporation is high so collection is also more in this model.

CHAPTER 6
6. CONCLUSION

The increasing demand for fresh water calls for innovative solutions to enhance the energy efficiency of desalination.

A very significant potential also exists in rural and remote areas, as well as islands where availability of water to generate energy may not be available at affordable costs.
India also has high potential markets for desalination due to population and economic growth along with water shortages. Indian government is putting lot of efforts to install desalination plants across the country as India is suffering from shortage of drinking water.

To conclude, we want to desalinate sea water by using solar energy and for that we designed many models and each model has its advantages and disadvantages. From observing these models some are inefficient because of small set-up but we opted based on this small set-up. Current goal is that our model is useful in domestic purpose and small set-up is quite sufficient. We want to further scale up this design for industrial use.

From our readings and calculations this model (hanging cup model with reflecting mirrors as solar concentrators) is useful indeed for domestic purposes as people can place this model each on their respective houses and use it. Furthermore, it can be useful in rural and urban areas just based on solar energy without relying on other sources which are cost effective.

CHAPTER 7

7. REFERENCES

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