Design and Fabrication of a Portable Solar Desalination Unit (DeSolE)

By:
Ali Ahmed (2019-NUST-SCEE-BE-Env-315557)
Masooma Zahra (2019-NUST-SCEE-BE-Env-290223)
Shaheer Ahmad (2019-NUST-SCEE-BE-Env-286366)

Supervisor:
Dr. Muhammad Zeeshan Ali Khan

Institute of Environmental Sciences and Engineering (IESE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST)

Islamabad, Pakistan
2023

THE FINAL YEAR DESIGN PROJECT (FYDP) REPORT
SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF

**BACHELOR'S IN ENVIRONMENTAL
ENGINEERING**

APPROVAL SHEET

It is certified that contents and form of FYDP Report entitled “Design and Fabrication of a Portable Desalination Plant” submitted by Ali Ahmed, Masooma Zahra and Shaheer Ahmad have been found satisfactory for the requirement of the degree.

____

Dr. Muhammad Zeeshan Ali Khan

Associate Professor (Project Supervisor)

IESE, SCEE, NUST

____

Head of Department

IESE, SCEE, NUST

____

Dr. Imran Hashmi

Professor (Associate Dean)

IESE, SCEE, NUST

ACKNOWLEDGEMENTS

First and foremost, we would like to thank Almighty Allah. Without him, nothing throughout this project would have been possible. We would also like to thank our Esteemed Advisor Dr Muhammad Zeeshan Ali Khan, whose guidance and knowledge made our project's success possible. We would also give a huge acknowledgement to our co-advisor, Dr. Hassan Anwer, and Ma'am Mominah Ahmad, for their constant assistance throughout the course. We would also like to thank our parents, friends, and teachers for their support. Without the collective efforts and support of everyone, our project would not have taken steps forward towards achievements.

DEDICATION

We dedicate this thesis to all the closest people in our lives. The people who have given us all the support we required throughout the course of the project or otherwise. We dedicate this project to our family, friends and most importantly our teachers. Their support and efforts kept us dedicated to complete our project.

ABSTRACT

Water scarcity is a leading issue globally, due to the exponential increase in the global population. During the past 40 years, the population of the world has doubled due to which the water demand is said to have quadrupled. Currently, the water scarcity, especially the drinking water scarcity is adverse globally, let alone the third world countries.

Due to the existing technologies being either expensive or highly inefficient in producing results, we decided to design a solar desalination prototype that has an optimum efficiency to cater an average family, while being the cheapest option in market. To make it possible, we utilized the design of solar stills, along with the use of enhancing materials to increase efficiency of the output water.

DeSolE's main aim is to provide cheap and efficient water supply to water scarcity areas, especially coastal areas where abundant source of water is available but there is no way to clean it. The project's will not only deal with building the prototype but also its' testing and fabrication. The project initiated with the testing of synthesized water, and then testing it with different parameters, such as TDS, Conductivity, Hardness, Chlorides, and pH. The work was done on design optimization by simulating the solar still and energy flows of the solar still to determine dimensions of the still. After dimensions were determined, the construction of the prototype was performed, and the reflector sheet was added to enhance the reflective properties and increasing the evaporation rate. To assist the use of reflectors, separators were used in between the evaporator and condenser and added a fan as a barrier to circulate the air containing vapors to allow increased vapors to move towards the cool condenser area. The prototype was designed in this way, after which testing were started on it. Different input water quantities, along with the use of surface area enhancing Jute Ropes were observed. The input water was considered as the independent quantity and the optimum level of water input to get the best output was found, considering the solar radiation cannot be changed or controlled in any way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
C	Degree Celsius
%	Percentage
CO2	Carbon Dioxide
DeSolE	Desalination Using Solar Energy
IFY	Input feed water
GW	Gigawatt
HEDR	Heat Exchanger Design & Rating
MW	Megawatt
MWh	Megawatt hour
HV	High Voltage
kV	Kilovolt
kW	Kilowatt
L/W	Length: Width Ratio
O&M	Operation and Maintenance
OCY	Optimum Condensate Yield
PKR	Pakistani Rupees
PV	Photovoltaic
RE	Renewable Energy
SAM	System Advisor Model
SDG	Sustainable Development Goals
SSW	Synthesized Sea Water
USPCAS-E	U.S. Pakistan Center for Advanced Studies in Energy
UN	United Nations
W	Watt
WHO	World Health Organization
WB	World Bank

1 INTRODUCTION

Water Scarcity is globally one of the significant issues, affecting up to quarter of the global population. Around 2 billion people are living in countries where water supply is adequate. 785 million people lack access to clean drinking water. Every day, over 800 children die from dirty water, due to diarrhea caused by poor water, sanitation and hygiene and scarce or unreliable water and sanitation facilities in many communities around the world. Women and children are worst affected - children because they are more vulnerable to diseases of dirty water and women and girls because they often bear the burden of carrying water for their families for an estimated 200 million hours each day. This problem is arising despite of the fact that 70 percent of earth is covered with water, which means there are resources are available, but there is no proper way to clean it.

1.1 Current Availability of water

The Earth is covered with 70 percent of water. Even though the proportion of Water to Human is exceedingly high, water scarcity is still a major issue. This is because majority of the water is either saline, brackish or has been a part of sewers. Only 0.5% of the water on Earth is freshwater, and the supply is being gravely threatened by climate change. Terrestrial water storage, which includes soil moisture, snow, and ice, has decreased by 1 cm year during the previous 20 years, having significant effects on water security. More than one-sixth of the world's population currently lives in regions supplied by melt water from major mountain ranges, but it is predicted that these regions' water supplies stored in glaciers and snow cover will continue to decline over the course of the century. As a result, water availability during warm and dry periods will decrease ***(IPCC)*.** This leaves us with the option of treating the undrinkable water, in which there are several options.

1.2 Current Water Treatment Water

Globally, there have been different technologies developed to treat several types of water with different contaminants. Conventional water treatment plants exist in developing countries, which treats water using physico-chemical and biological processes. The processes involved in these processes are highly advanced and has the capacity to remove contaminants such as fecal sludge and treat grey water. This process of recycling water does sounds like a viable option to cater water needs. But due to its high operational, capital and maintenance, along with publics hesitation to reuse water that has been a part of sewers, it is not recommended in third world countries. Thus, we move towards treating ocean water.

Reverse Osmosis, a treatment method in high use in Middle Eastern countries is used. Water is forced through a semipermeable membrane, which filters out impurities and contaminants. Despite of its impeccable working capability, it is considered as an expensive method. However, RO is expensive when compared to other traditional technologies because of a few variables, including high energy consumption, the need for pre-treatment, the complexity of the system, the need for membrane replacement and maintenance, and water loss. The efficiency of RO in producing high-quality water justifies its usage in many applications despite the greater expense.
Passive Desalination technologies rely on natural or low-energy processes. These approaches can be employed in locations where electricity is not available or where energy expenditures are excessive. Some passive desalination methods are as follows:

- **Solar stills:** This process uses the sun's energy to evaporate water, which condenses on a surface and gathers as fresh water, leaving salt and other pollutants behind. Solar stills are easy to build and can be created with locally accessible materials.
- **Distillation by evaporation:** This method evaporates water using heat from a stove or other source, which is then condensed and collected as fresh water. Heat can be generated by burning wood or coal.

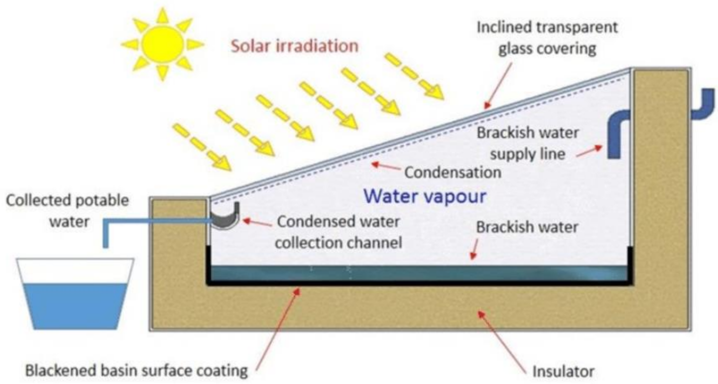

Figure 1.1 Working of a passive solar still (Fawcett, 2020, p.65)

1.3 Compliance with SDGs:

The Sustainable Development Goals (SDGs) are a set of 17 universally agreed upon aspirations adopted by the United Nations in 2015 to end poverty, protect the planet, and ensure peace and prosperity for all people by the year 2030. They are an integrated, interrelated, and indivisible framework of goals, targets, and indicators that form a blueprint for global action to create a more sustainable future for all, by addressing systemic and intergenerational inequalities, promoting inclusive and sustainable economic growth, and fostering peaceful, just, and inclusive societies. Unlike previous development agendas, the SDGs apply to all countries and actors, requiring a collaborative and multi-stakeholder approach to achieve their transformative vision of a sustainable world for present and future generations.

Our project is aligned with SDG 6. SDG 6 is particularly important as it aims to ensure the availability and sustainable management of water and sanitation for all. Water and sanitation are basic human needs and access to clean water and proper sanitation facilities is essential for human health and well-being. Many regions in the world are facing water scarcity due to increasing demand, mismanagement, and climate change. SDG 6 seeks to address these challenges and promote the sustainable use of water resources.

Our project caters to address SDG 6 as it provides an opportunity to utilize available water and clean it for drinking purposes, which is essential for a healthy environment. Our project also makes sure that the water input is from an abundant source i.e., the ocean, which has never-ending supply of water is used efficiently.

1.4 Objectives

The main objective of the project was to design and fabricate a portable solar desalination unit. The aim was to find the optimum solution to desalination problems by designing a prototype that provides inexpensive drinking water at a medium to high efficiency. The project further planned to utilize locally available materials, to keep the cost as inexpensive as possible. With the high price of drinking water and the lack of availability of water resources in the country, it was imperative to design such a prototype that can ease the pockets of lower to middle class families of the country. The prototype ought to boost the use of solar energy as the essential energy hotspot for the desalination cycle. Solar energy is abundant, and harmless to the ecosystem, so using it lessens dependence on petroleum products and decline ozone depleting substance discharges. Furthermore, the prototype was made to accomplish high energy proficiency by improving the change of solar energy into mechanical or nuclear power expected for the desalination cycle. This includes choosing proper sunlight-based assortment innovations (like solar panel or solar collector) and incorporating them with effective desalination frameworks. The plant ought to be intended to guarantee dependable activity over a drawn-out period. It ought to endure cruel ecological circumstances, require negligible upkeep, and have hearty parts and frameworks to expand its life expectancy.

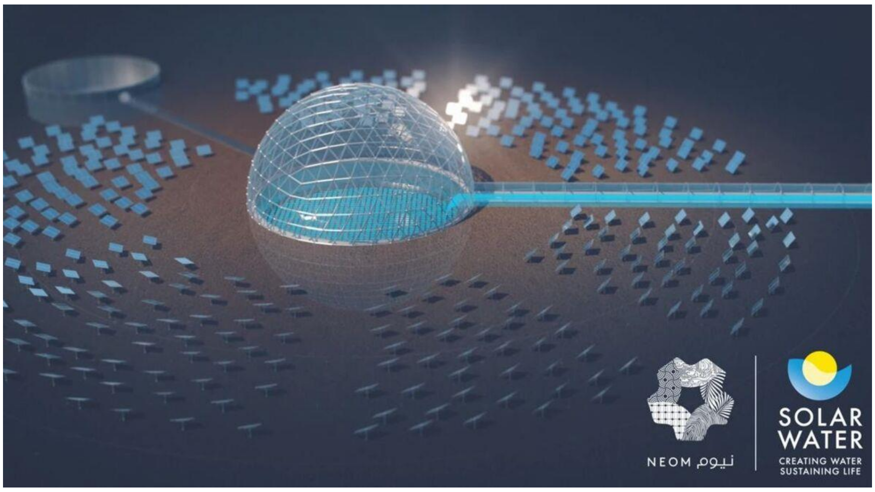

Figure 1.2 Neom City Desalination Plant, the inspiration to our project.

1.5 Scope

The project will focus on the design optimization of evaporator and condenser. Furthermore, the project prioritized the use of green energy, and a ridiculously small amount of electrical energy was utilized, to run a small fan installed in the prototype. To make things as inexpensive as possible, locally available materials were used. Their purchase, construction and fabrication were done in the vicinity and availability of the materials were considered seriously prior to the construction of the project. DeSolE utilized the abundant resource of Ocean Water. This was done to accommodate the Metropolitan City of Karachi. The nation's financial hub is home to about 30 million people and growing. With the increased poverty and water demand, it is key to provide a safe, yet an inexpensive water.

2 LITERATURE REVIEW

The different literature reviews carried ranged from the papers defining different types of passive and active solar stills, their working efficiency, and the integration of enhancing materials. Furthermore, extensive study was conducted to find the best dimensions of the solar still, typically using modeling software.

2.1 A review of solar still performance with reflectors

The conventional solar still has restricted efficiency, driving analysts to look for elective plans. Reflectors, either inward or outer, are a change that has been displayed to expand the solar illumination coordinated towards the water and further develop the distillate productivity of the still. The paper orders reflectors utilized in solar stills into three sorts: inner reflectors, outer reflectors (top and base), and a mix of inward and outside reflectors. The utilization of reflectors has been viewed as a practical method for expanding the solar light episode on the bowl liner. The inside reflectors altogether affect the result of refined water as they concentrate and divert the solar radiation onto the water, decreasing the waste intensity energy from the still. Studies have been directed to show the viability of interior reflectors. Tamimi concentrated on a solitary incline bowl solar still with mirrors introduced as an afterthought wall and found that utilizing mirrors expanded the bowl effectiveness over the course of the day. El-Swify and Metias utilized numerical demonstrating and tests to find the impact of inside reflectors on the back side walls of a solitary slant, reasoning that the distillate increments of 82.6% and 22% can be gotten in winter and summer, separately. One more concentrate by Minasian et al. utilized a metallic round and hollow illustrative reflector to focus occurrence solar radiation on the dark external surface of a bowl liner. The paper likewise examines the utilization of outside reflectors, which are favored when daylight is frail, or the neighborhood temperature is low. The outside reflectors can redirect the solar pillars to work on the adaptability of the safeguard plate design. The outer reflectors utilized can be made of various materials, including aluminum, copper, and glass, among others. At last, the paper presumes that the utilization of reflectors in solar stills is a compelling and effective method for expanding the efficiency and yield of refined water. A straightforward examination of various solar stills with reflectors is given, considering their area, everyday yield, efficiency improvement, proficiency, and perceptions from tests. (Omara et al, 2017)

2.2 An Optimal Sizing of Stand-Alone Hybrid PV-Fuel Cell-Battery to Desalinate Seawater at Saudi NEOM City

This paper centers around giving a possibility and techno-financial assessment of utilizing a half breed sustainable power framework to drive a seawater desalination plant in NEOM City, Saudi Arabia. This city is being arranged as the world's most ecofriendly city controlled by sustainable power sources as a component of Saudi Arabia's Vision 2030. The desalination plant is being intended to give 150 m3 of freshwater each day to 1000 individuals in NEOM City.

Three situations are considered for the half and half sustainable power framework, each with an alternate mix of parts. The main situation comprises of a half breed of solar photovoltaic (PV) boards, power modules (FC) with a hydrogen stockpiling framework, and batteries. The subsequent situation includes a half and half of PV boards and batteries, while the third situation includes a mixture of PV boards and FC with a hydrogen stockpiling framework. The HOMER® programming was utilized to decide the ideal design in view of the aftereffects of the techno-financial examination of every part of the half breed sustainable power framework. The ideal design was viewed as a mixture of PV boards, FC, and batteries, with an ideal size of 235 kW PV cluster, 30 kW FC, 144 batteries, 30 kW converter, 130 kW electrolyzer, and 25 kg hydrogen tank. The expense of the framework was assessed to be $438,657, with an expense of energy of $0.117/kWh. The creators presume that this framework is one of the most harmless to the ecosystem for controlling a seawater desalination plant and that it can assist with decreasing ozone depleting substance emanations and the impacts of an Earth-wide temperature boost.

The exploration paper features the significance of utilizing sustainable power sources in the seawater desalination process and gives an illustration of a practical and financially suitable answer for meet the electrical energy needs of the desalination plant in NEOM City. (Rezk et al, 2020)

2.3 Performance enhancements of conventional solar still using reflective aluminum foil sheet and reflective glass mirrors: energy and exergy analysis

In this paper, reflective mirrors and reflective aluminum foil sheet were fixed on internal surfaces of the single-slope solar distiller, prompting more water creation. The presence of mirrors and aluminum foil sheet on inward surfaces of the solar distillate allows the impression of solar radiation falling inside the bowl. Tests were completed on three stills: the main distiller is customary solar still with dark painted walls (CSS-BPW); the subsequent distiller is traditional solar still with intelligent aluminum foil sheet walls (CSS-RAFW); and the third distiller is ordinary solar still with intelligent glass reflect walls (CSS-RGMW). The optimum complete drinking water creations from the CSS, CSS-RAFW and the CSS-RGMW are 3.41, 5.1 and 5.54 kg/m2, separately. In contrast to the CSS-BPW, the creation of drinking water was expanded by 68.57% while utilizing the intelligent glass mirrors and 48.57% while utilizing the intelligent aluminum foil sheet. (Chandrika et al, 2021)

2.4 A solar energy desalination analysis tool, SEDAT, with data and models for selecting technologies and regions

This exploration paper examines the improvement of an easy-to-use programming device called "SEDAT" for empowering a near assessment of solar passive desalination innovation choices and recognizing locales of high potential for solar warm desalination. SEDAT is an open-source, Python-based device that incorporates different layers of information depicting solar and saline water assets, water and energy foundation, guidelines, costs, and serious costs. It utilizes geospatial examination in blend with an energy and desalination innovation displaying structure to portray current and arising desalination processes on modern scales. The product permits the client to enter information and parametric contributions on geospatial, financial, and specialized factors, and gives a guide-based information investigation interact with the capacity to pick an area, solar innovation model, and cost model to create a report and outlines of framework data sources and results for assessment and correlation of various choices for innovation and site determination. SEDAT likewise gives a web connection point to speedy representation of geospatial information and performing straightforward techno-monetary computations without programming establishment, and a work area application for more definite geospatial and techno-financial examinations. The work area application incorporates extensive techno-financial models of desalination innovations that work with the best utilization of solar nuclear power. The paper sums up the different periods of the apparatus' turn of events, presents model outcomes showing the capability of solar desalination in pieces of the southwestern US, and talks about technique subtleties that would be helpful for future model turn of events. (Fthenakis, 2022)

2.5 Energy and exergy analyses of a solar desalination plant for Karachi, Pakistan.

This paper examines the energy and exergy of three unique plans of a latent vacuum solar streak desalination plant in Karachi, Pakistan. The review uses ongoing information of solar transition in the district of Karachi and normal hourly information of solar irradiance for the long stretches of April, June, September, and December to survey the presentation of each plan in various weather patterns. The outcomes showed that plan 1 has a higher warm and exergy effectiveness than plan 2 yet plan 2 has a more extended life for the solar gatherers. Plan 3, which uses an economizer heat exchanger, had the most noteworthy energy and exergy productivity. The review presumes that the proposed plan 3 has the most elevated creation rate. It's quite important that while this study gives a few helpful experiences into the presentation of various plans of an uninvolved vacuum solar streak desalination plant in a particular district, the outcomes may not be relevant to different locales with various climatic circumstances and solar irradiance designs. Further examinations in different districts might be expected to decide the generalizability of the discoveries. Moreover, the concentrate just thinks about energy and exergy efficiencies, and distinct factors like expense, support prerequisites, and natural effect ought to likewise be thought about while settling on the most suitable desalination innovation to utilize. Plan 1 is one of the three distinct plans examined in a review zeroed in on the energy and exergy examination of an uninvolved vacuum solar streak desalination plant for Karachi, Pakistan. It has higher warm and exergy productivity than plan 2, however its lifetime of the solar gatherers may not be as lengthy. Further subtleties on the specific details and activities of plan 1 are not determined in that frame of mind of the article. (Malik et al, 2020)

3 METHODOLOGY AND MATERIALS

To understand the working of DeSolE project, understanding of its process methodology is necessary. The DeSolE prototype works on the simple principle of evaporation and condensation. However, it’s in depth has much more complexity. Other than the methodology of the prototypes working, the different materials of the prototype were chosen, construction was performed and testing were carried out to formulate results

3.1 Process Methodology

Saline Water is stored inside black aluminum pan, where enhanced evaporation takes place due to the shiny and dark black evaporation pan, along with the presence of internal reflector sheets. The water evaporates and is either suspended in the atmosphere or sticks to the acrylic case. Below the evaporation pan, there is thermocol sheet in which a fan is installed, under which a condenser tray lies. The condenser tray is suspended in a coolant bath, allowing the tray to remain cold and provide as much condensation possible. The cold acrylic case along with the air circulation provided allows the vapors to move towards the titled condenser tray. When the vapor reaches the cool titled condenser tray, it cools down while encountering the surface of water. The water is collected onto the opposite side of the fan on the downslope of the condenser tray, there 5 joints of pipes are used.

Water is evaporated from the evaporation pan and the jute wicks. The jute wicks increase the surface area of the water surface due to the capillary action provided. However, use of Jute is just an extension to our project, and results without the use of jute products have also been exceptional.

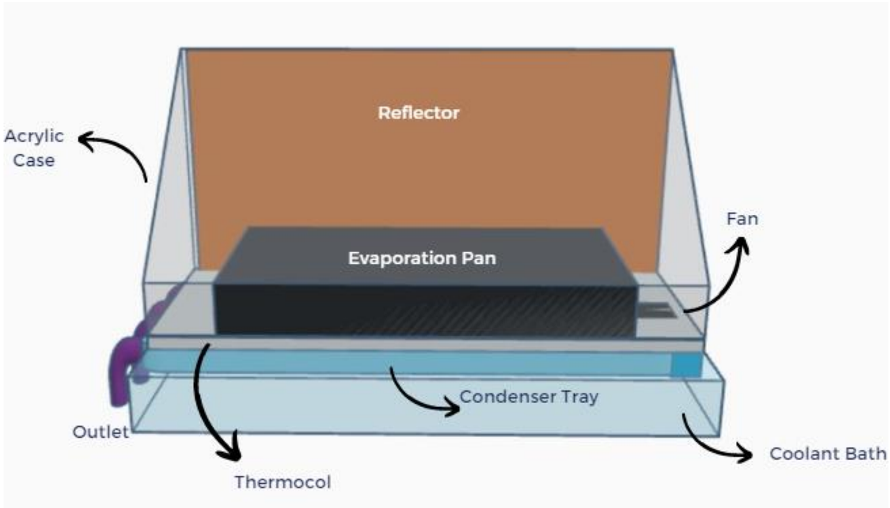

Figure 3.1 Front view of the fully assembled DeSolE prototype

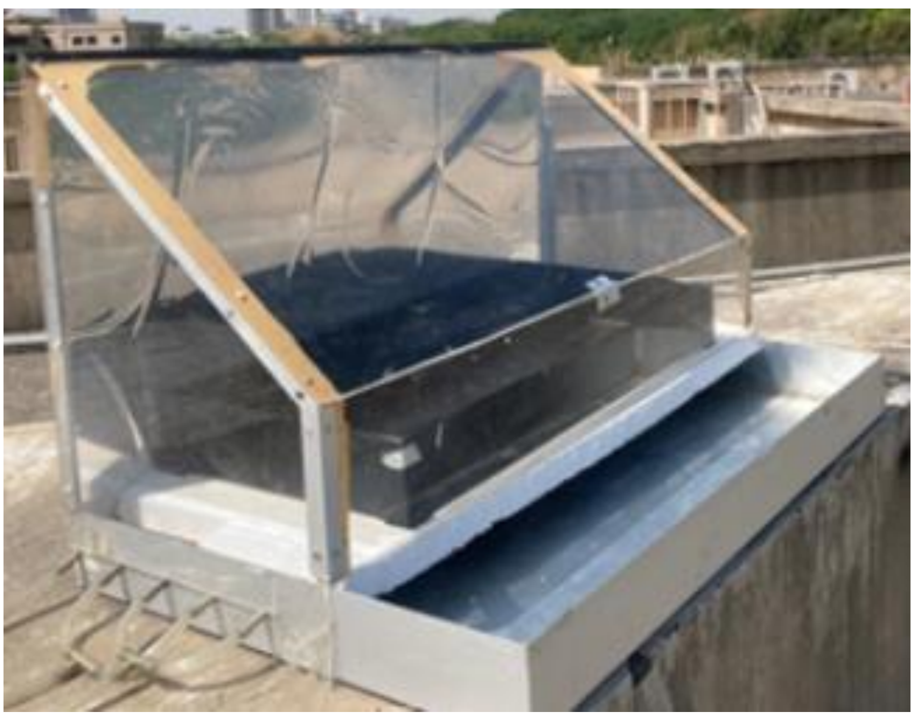

Figure 3.2 Fully assembled DeSolE prototype.

The two pictorial representation shows the graphical representation of the prototype and its' components, along with the actual prototype. Notice that the acrylic case in **Fig 3.2** is only placed over the evaporation pan and is not covering the coolant basin. This is to keep the coolant basin's water cool by discouraging the acrylic case's property to retain heat. This came up with the added advantage of increased portability and robustness of the acrylic case, which was the only assumed fragile component of the prototype.

Figure 3.3 shows the energy and mass flow diagram of the prototype. In this process flow diagram, not only the mass involved in the process is discussed, but the energy flows have also been briefly described. Sea Water, along with the Solar Irradiance are taken as inputs of the prototype. The Sea Water then absorbs the Solar Irradiance in the form of heat energy, causing the enhanced evaporation. The condensation then takes place in which the heat energy is lost in the coolant water, which then dissipates the energy to the surroundings from the aluminum base, while the condensed water is collected. The collected water is mineralized (Which can be an optional process) after which the water can be safely used, specifically for drinking purposes.

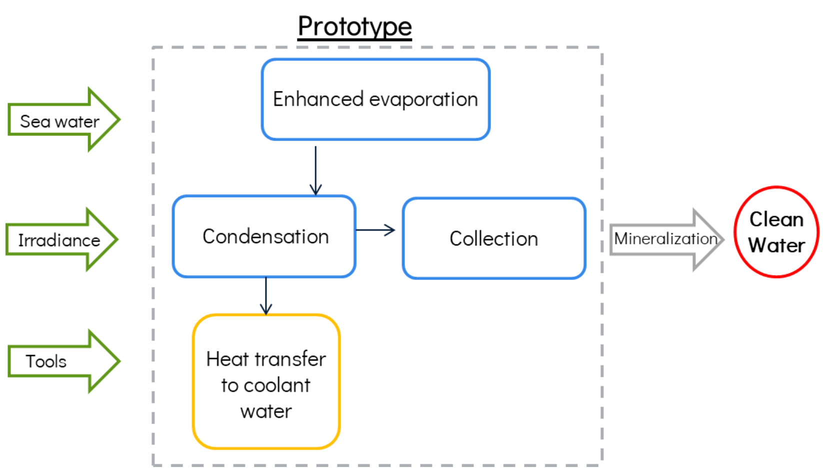

Figure 3.3 Energy & Mass Flow Diagram of DeSolE Prototype.

3.2 Design & Optimization Tools

To optimize and design the prototype and test the results to the real life, certain assistance was taken from tools mentioned below:

3.2.1 Thermodynamic Equations

For the mathematical derivation of the dimensions for the solar still, the following equation has been driven from thermodynamic equations.

$$m = q'' \times l$$

Where

m = mass of water,

l = latent heat of vaporization,

q” = total energy utilized

The factor of q” depends upon the heat absorbed by the input water, the loss of heat energy from the acrylic lid and sides along with the losses from the aluminum base of the prototype. The losses depend upon the properties of materials as well.

The assumptions during the derivation were taken that the heat that is being projected on the water is not raising the temperature directly being utilized for phase change i.e., the latent heat of evaporation is being considered and specific heat is neglected.

3.2.2 Simulation

For the rectification of the errors and finalization of design, the energy values were input to some software to come up with the most practical and desired output. Main software used were ASPEN HYSYS and HEDR. Aspen Chemical processes, from single activities to entire chemical plants and refineries, can be mathematically modelled using the HYSYS (or just HYSYS) chemical process simulator being developed by AspenTech. Numerous essential calculations in chemical engineering, such as those involving mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop, can be carried out using HYSYS. For process design, performance modelling, and optimization, as well as steady-state and dynamic simulation, HYSYS is widely used in both industry and academia.

A heat exchanger was simulated for evaporated and condenser separately. The evaporator surface area for optimum evaporation of 9 liters of water came to be 450 square inches. For the condensation process, the heat exchange of almost 9.81kj/kg.h was required between the condensation chamber and external environment or in our case the Aluminum pan.

After careful consideration with literature and Simulations, the selection of single unit layout was opted for this prototype. The optimum length to width ratio for maximum solar still evaporation came out to be 2:1 (Bahar et.al). So, the overall dimensions for the evaporator pan were made to be 30” by 15” by 4” in order to maximize evaporation. For the condenser, to maximize the heat transfer, the Aluminum base was made with dimensions of 45” x 30” x 4”. This ensured maximum condensation efficiency as well as elevated levels of portability.

3.2.3 Literature

Along with the energy optimization using Aspen HYSES, many research papers were consulted to find the most optimum prototype dimensions. One of the best works we found related to the solar desalination was thoroughly consulted, assisting us in finalizing the dimensions of our evaporator. The elements of the solar stills utilized in the paper were resolved in view of the trial plan and the ideal perspective proportions. The aspects and viewpoint proportions were decided to research the impacts of various arrangements on the efficiency of the solar stills. In the review, two distinct models were developed: Model A and Model B. Model A had a length/width (L/W) proportion of 1.0, while Model B had a L/W proportion of 2.0. These proportions were chosen to contrast the presentation of solar stills and various extents. For Model A, a pan size of 500 × 500 × 100 mm was utilized. This implies that the length and width of the bowl were both 500 mm, and the height (or profundity) of the bowl was 100 mm. The aspects were decided to make a square-formed bowl with equivalent sides. For Model B, a more extensive opening was expected to oblige various Fresnel focal points. The bowl size for Model B was 700 × 350 × 100 mm. This implies that the length of the bowl was 700 mm, the width was 350 mm, and the level continued as before at 100 mm. These aspects took into consideration a more extensive bowl while keeping up with a similar profundity as Model A. The aspects were resolved considering the exploratory plan and the objectives of the review. The picked aspects and viewpoint proportions were planned to research the impact of these elements on the efficiency and execution of the solar stills with regards to freshwater creation and desalination proficiency.

3.3 DNI Analysis

One of the most important considerations while evaluating and maximizing the technological idea for a CSP plant is the Direct Normal Irradiance (DNI). A lot of attention should be put on accurately determining the relevant DNI for a certain project and its location. Every decrease in solar resource uncertainty will immediately improve the predictability of a certain concept's ability to produce energy (which may be estimated through performance modelling). The amount of solar radiation received by a surface that is constantly held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky is known as Direct Normal Irradiance (DNI). A surface can often get the most irradiance per year by maintaining a normal angle to incoming radiation. Both concentrated solar thermal plants and installations that track the location of the sun are particularly interested in this amount.

For the specification of input energy, DNI data was taken from the weather station which is under supervision of U.S. Pakistan Center for Advanced Studies in Energy (USPCAS-E), NUST. The location of the weather station is NUST, H-12, Islamabad.

3.4 Sea Water Synthesis & Analysis

Initially, the sea water was expected to be collected from Karachi coastline to replicate the real testing scenario and get accurate testing results. However, there were several reasons why the collection was not done from Karachi. Primarily, collection of water from the coast would not be the most feasible solution due to the pollution on the coastline caused due to human activity and effluent discharge. If we had to go for the composite sampling of sea water from the middle of the sea, it would have been an expensive job. Furthermore, the testing was done in Islamabad, going from Islamabad to Karachi just for collection of water would have costed a significant amount of money.

Thus, to avoid all of this, it was decided that the sea water would first be synthesized according to the ocean like conditions, and then analysis would be carried out to compare the parameters of synthesized and natural sea water. First literature review was done to know the process of replicating aquarium like conditions in the sea. According to (Hover et al, 2018) a 35% salinity in sea water is the most optimum concentration of salt present in the water, to best replicate the water with the ocean. The method of sea water synthesis was mentioned in (Yong Hoo et al, 2020), which mentioned the use of Aquarium Sea Salt to synthesize water. The aquarium sea salt is a type of sea salt which allows fishes in aquarium to get ocean like conditions, enabling their growth and longer lifetime. The Aquarium Sea Salt is essentially made out of sodium chloride (NaCl), which makes up most of its composition. Nonetheless, it additionally contains different minerals and minor components that are available in seawater. A few other minerals found in ocean salt incorporate magnesium, potassium, calcium, and follow measures of iodine. These extra minerals add to the distinct flavor and attributes of sea salt contrasted with table salt, which is ordinarily more refined and contains less pollutants. After consideration and buying of sea salt, the synthesis was performed in the following steps:

- 1 L of distilled water was taken, 35g of sea salt was added into it with light mixing of the water.
- The water sample was heavily mixed using aquarium pump for about 15 minutes, the time when all the sea salt is dissolved in water.
- The water sample is taken out and then testing is done onto it, mainly chlorine test, hardness test, conductivity, and pH

After the synthesis was completed, analysis of the sea water was completed. The first test performed was the pH test, followed by the conductivity test. The testing was then followed by the Hardness and Chlorine test, which determined the Chlorine content and the magnesium and calcium content in water.

After analysis and result calculation, the water was compared with the sea water composition of different seas, given in (Hover et al, 2018) The results are given in **Table 5-1**. The table shows that the synthesized water had replicating conditions with the sea water from different seas, the Arabian Gulf Coast, which has its' close geographical proximity with the Pakistan's southern coastline. However, due to lab scale experiment and ideal conditions provided to the water, the hardness and was a comparatively higher in the synthesized sea water. However, the rest of the conditions lied in optimum zone.

Table 3.1 Comparison of Synthesized Sea Water with different Sea Water

Sample Name	pH	Salinity	Conductivity (µS/cm)	Chlorides (g/L)	Total Hardness (g/L)
Arabian Gulf	8.06	35 %	73,000	23	2.265
Red Sea	8.2	40 %	55,000	22.2	0.967
Mediterranean Sea	8.03–8.53	37.51-39.71	50,000	21.2	1.826
Overall Ocean Water	8.1	33-39	50,000	19.162	1.6876
Synthesized Sea Water	**7.8**	**35.7**	**61,000**	**19.76**	**3.5732**

3.5 Prototype Design and Configurations

The saline water in a solar still's central trough is heated by sun radiation that passes through the glass cover and evaporates some of it. This condenses on the glass's underside, dissipating heat into the environment.

Thermal distillation uses a heat source that can be fueled by a variety of energy sources to change the physical state of water. In essence, this process involves heating seawater, brackish water, or any other impure water to the boiling point and producing steam, which is then condensed to freshwater in a condenser. In typical passive solar stills, heat from the sun is first used to warm the water and supply the energy needed to transition from the liquid to the vapor phase.

Saline water is still desalinated using solar technology using direct solar energy from the Sun. It operates on the evaporation and condensation process theory. The still, which consists of a basin into which salt water is poured, is completely insulated on all sides, and covered with transparent glass to let in solar energy. The saline water in the basin evaporates because of the radiation penetrating the glass cover, producing water vapor that rises.

Efficiency, output, internal heat and mass transfer coefficients, as well as other performance factors for solar stills, are crucial. The ratio of the latent thermal energy of the condensed water to the total quantity of solar energy incident on the still can be used to measure their efficiency. While productivity is measured as the amount of water produced daily per square foot of the solar still. The basin's water temperature and the inner surface of the glass cover determine the still's productivity rate. Therefore, it mostly depends on the rate at which water from the basin evaporates and the rate at which vapor condenses on the lower surface of the glass cover. The classification of solar stills can be divided into two primary categories: active stills and passive stills. In order to increase the evaporation rate and therefore productivity in active solar stills, more thermal energy is given to the basin by an external mode (such as collector/concentrator pane or waste thermal energy from chemical plants). Additionally, this type increases the temperature difference between the areas of evaporation and condensation. If this external mode is minimal, the solar is still referred to be passive.

3.6 Components of the Prototype

Solar stills consist of the following components:

- Evaporation Pan,
- Condenser Tray,
- Acrylic Case,
- Coolant Base,
- Reflector,
- Wicks,
- Thermocol Sheet.

Maximizing the distillate output is the main goal of solar stills. Distillate production is influenced by a variety of variables, including design parameters (such as the orientation of the still and tilt angle of the cover) and operating parameters (such as water depth in the basin and water salinity), as well as climate parameters (such as solar intensity, ambient air temperature, wind velocity, the humidity of the atmosphere, water-glass temperature difference, and atmospheric conditions).

3.6.1 Evaporation Pan

The evaporation pan has the main purpose of evaporation of the water. It was optimized in a way that the surface area of the water can be maximized. The evaporator was designed in a 13.7" x 27.5" or almost a 1:2 ratio of length: width, with a 4" height. The evaporator was painted black with black matte acrylic paint to allow maximum radiation to be absorbed by the water. The orientation was done in such a way that DNI can directly or indirectly be absorbed on the evaporator.

The passive solar desalination prototype works ceaselessly for however long there is daylight accessible. The evaporator keeps on retaining solar energy, advancing the evaporation of water, while the buildup and assortment processes guarantee a constant stock of freshwater.

Solar desalination prototype, with the assistance of vanishing dish, offer a manageable and energy-productive strategy to get freshwater from saline or seawater sources, especially in parched or radiant districts. They give a harmless to the ecosystem way to deal with tending to water shortage and can be utilized for different purposes, including agribusiness, drinking water, and modern applications. The evaporation pan is accessible to clean and remove salts easily. For aesthetic purposes, it is recommended to coat the evaporation pan with a thick layer of acrylic black paint for not only high absorption but also to avoid scaling of salts onto the basin.

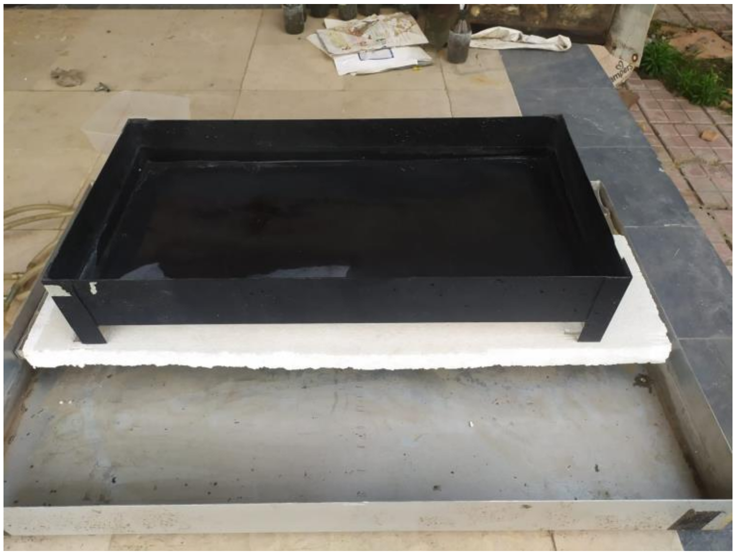

Figure 3.4 Evaporation Pan

3.6.2 Condenser Tray

A condenser plate plays an important role in causing the formation of vapors in a passive solar powered desalination prototype. It gives a cooler surface to the water vapors to experience, which forms vapor in the tray, which is further removed using the outlets pipes.

The condenser plate is commonly positioned over the evaporation pan, with the Length x Width of 13.7" x 39.3”, The width of the evaporator to allow all the vapors to be taken in. The separation between the evaporator and given using a thermocol sheet and a fan, which causes air to be sucked in towards the condenser to disallow vapor accumulation in the top part of the prototype. Condenser Sheet is provided insulation with the thermocol, which is intended to have a lower temperature contrasted with the evaporation pan. There are a couple of systems by which the condenser plate works with the buildup cycle.

Primarily, the condenser plate is kept cooler than the water vapor ascending from the evaporator. The mechanism works on simple heat equilibrium. The evaporator and the zone above the thermocol is hot, allowing formation of vapors. The air circulation carries the vapor into the condensation zone, where the cool temperature is maintained using the condenser tray dipped slightly in cold water. The heat from the water is removed.

The use of aluminum is guaranteed to allow maximum heat transfer between the condensers. The top of the tray is covered with the thermocol sheet to avoid the exposure to direct sunlight and provide insulation as well. The base of the tray is slightly touching a water bath placed beneath it. The water bath is ⅓ exposed to the open atmosphere.

Figure 3.5 Condenser Tray

3.6.3 Acrylic Case

The acrylic case is used for multiple purposes due to multiple reasons. The acrylic has is transparent, which allows maximum radiations to take place. Furthermore, high insulation capacity allows the heat to stay inside the evaporation zone, allowing more and more heat to be absorbed. The acrylic case covers the whole evaporation zone and is slanted from the top to allow radiations from all sides to hit the evaporation pan. Furthermore, the sides are also covered in acrylic to increase the absorption of water.

The back of the acrylic case is covered with internal reflector. This is mainly done because the orientation of the prototype with the sun allows the slanted side to be completely exposed with the sun, while the back being completely useless. However, the addition of acrylic allows the reflection of the solar radiation to the water.

The slant angle of the acrylic case was about 36 Degrees. The angle was chosen to align with Pakistan's solar angle, which is the same as the slant angle of the acrylic case. The slant angle allows maximum radiation throughout the year. The slanted point guarantees that a bigger surface region of the case is presented to daylight, expanding heat, and advancing productive dissipation. Besides, the gathered freshwater streams descending, diminishing the gamble of reintroduction of pollution by the leftover salt and debasements. This component improves on the extraction interaction, empowering simple assortment and capacity of the isolated freshwater. Furthermore, the utilization of acrylic as the material for the case gives solidness and protection from the destructive impacts of saltwater, guaranteeing the life span of the prototype. The slanted acrylic case addresses a useful and maintainable answer for desalination, outfitting the force of solar energy to address water shortage and elevate admittance to clean freshwater assets.

Figure 3.6 The acrylic case assembled over the prototype

3.6.4 Coolant Base

The coolant base is an aluminum base made with the dimensions of 27.5” x 39.3” of Length x

Width. Initially, the purpose of the coolant base was to allow the condensation to occur in the basin, while it is dipped in a much bigger coolant basin or inside the soil. However, due to portability issues, the functionality of the aluminum base was modified, and it was used as a coolant base. The coolant base has a volume capacity of about 140 liters and will be filled up to the limit of condenser tray, to allow the contact of coolant water with the condenser tray. The material selection criteria for the coolant base were the same. Due to the high heat absorption and emission of aluminum, the material was selected to allow maximum absorption of the heat from the condenser tray. The coolant water will then emit the heat to the surroundings. The coolant bath is uncovered with the acrylic case and 1/3rd of the coolant base is under the thermocol. This creates a major heat temperature changes.

3.6.5 Reflectors

Modern architecture was influenced by aluminum's gleaming appearance, but nowadays, light-reflecting properties matter far more than just aesthetics. This is so that buildings can be cooled in an eco-friendly manner, which is a key component of the sustainable architecture movement.

Aluminum reflects light more effectively than most other metals without the use of expensive coatings and is also highly recyclable and reusable. Up to 95% of sunlight can be reflected by aluminum roofs, which improves a building's efficiency. Structures made of aluminum will endure longer with fewer maintenance tasks than those made of other materials due to its inherent resistance to corrosion. Aluminum has played a significant role in the advancement of solar technology more recently. Thermal and photovoltaic (PV) concentrating solar energy systems are the two main categories. In both situations, the technique is more effective the lighter you can reflect. One of the most basic solar energy systems includes concentrating sunlight through reflectors to heat a space or body of water. These solar reflectors, which are quite common in underdeveloped countries, don't require any additional power, making them quite helpful in locations where electricity may be scarce or expensive. Concentrating solar power is a more recent innovation that uses reflectors to focus sunlight onto a receiver, which will subsequently transform it into heat. The heat is then utilized to heat water, which produces steam that powers a turbine that in turn powers an industrial operation or produces electricity.

The latest research indicates that some researchers employed reflecting glass to boost productivity. The usage of aluminum foil sheet to increase productivity is not considered in the thorough review.

Therefore, the current study intends to increase sun distillation productivity by combining reflective glass mirrors and reflective aluminum foil sheet on interior surfaces of the solar distillate. Due to the sun's rays being focused within the basin by the reflective mirrors and reflective aluminum foil sheet present on the inside sides of the solar distillate, the water temperature rises. The sheet of aluminum foil has a thickness of 0.2 mm. There are matte and shiny sides to aluminum foil. The outside surface is bright, which improves reflectivity, while the internal surface is dull, which reduces radiation emission and absorption. Mirror reflectivity is 99%, whereas aluminum foil has a reflection of 88%. Glass reflectors and aluminum foil sheets are mounted to the solar distillery's interior walls during trials.

Figure 3.7 Reflector sheets used in DeSolE prototype

3.6.6 Wicks

Solar energy that strikes the glass cover transmits through it and is absorbed by the wick surface. Due to capillary action, some of the energy is used to heat the water that is passing through the wick. The still retains a significant amount of heat, and energy is transferred from the wick surface to the glass cover and the surrounding air. The exterior and internal modes of the distillation system control heat transfers. Convection and radiation, which happen outside the still and are independent of one another, are responsible for the external heat transfer mode. internal heat transfer, which happens because of radiation, convection, and evaporation, is referred to as the mode of heat transfer within the solar distillation unit. The mass transfer is combined with radiative and convective heat transfer in the internal heat transfer mode. The wick surface heats up the water running through it, causing it to vaporize. After dissipating the latent heat of evaporation, the saturated water vapor condenses in the lower surface of the glass cover. Due to gravity, the condensed water droplets flow down and accumulate in the drainage channel.

The jute wick material in the basin absorbs water, and because of capillary action, its upper surface is constantly moist during the hottest parts of the day. The water vapor condenses on the condensing surface, which is made of pure distilled water, after the water has evaporated. As the jute wick floats in the water of the basin, the still's thermal capacity decreases.

3.6.7 Thermocol sheet

The procedure that helps to lessen the flow of heat from the outside to the inside is known as thermal insulation. By keeping the space cooler in the summer and warmer in the winter from the outside, thermocol insulation allows for constancy in room temperature. It saves energy since there is less heat movement from inside to exterior and vice versa. We offer packing materials with Thermocol Heat Cold Insulation.

Speaking of Thermocol production, it is a thermoplastic substance chemically known as polystyrene. Styrene and phenylethane are polymerized to produce polystyrene. The material, sometimes referred to as Expanded Polystyrene (EPS), is completely recyclable and produces a plastic compound. Thermocol material has a wide range of uses in real life because of its eco-friendly attributes.

3.7 Construction of the Prototype

After the selection of the materials, the initial construction of prototype was performed. A local vendor was chosen, and the instructions were provided. The construction started off with the construction of the aluminum base. Aluminum brackets were cut into different pieces and joined using rivets and glued with silicone to provide water insulation. The evaporation pan was constructed using the same way. However, it was painted black to allow maximum evaporation of the water.

The condenser tray was constructed later, followed by the acrylic casing. Initially the acrylic casing was covering the whole prototype. But later, the modifications allowed the acrylic case to be more portable and focused all the radiations onto the evaporation pan only.

Figure 3.8 Final Assembled Prototype

3.8 Testing Methodology

For testing, a three-phase strategy was improvised. This meant three tests of three different sample quantities would be conducted. The input radiation data was collected from USPCAS-E for the past 10 years and 18 days with similar DNI value were selected to keep control.

There were three samples of water, one was de-ionized water, one was tap water and one was our lab synthesized salt water. Each water sample had quantities of 3, 6 and 9 liters with each test taking one of the pre-selected dates. The following data was observed during the testing period.

- **Time:** The general time was kept constant during our testing, starting at 11 AM every day till 4PM in the evening.
- **DNI data during testing:** Although the DNI data was predicted already, the actual data for the day was monitored for any fluctuations
- **Initial temperature of water:** the initial temperature of water defined the baseline of our testing and was kept constant at 25-degree Celsius.

- **Hourly temperature:** the hourly temperature data was taken and the output against the data was observed to infer the time when maximum evaporation occurred.
- **Ambient temperature:** ambient temperature during most of the testing were similar with fluctuations varying from 1-2 degree Celsius.

3.9 Preliminary testing

The preliminary testing of the prototype was done to analyze the working of the evaporator and condenser. To conduct the testing, the ambient conditions were first analyzed. After doing so, the testing was conducted out for three different days. The testing time period was taken of about the same time as the daylight hours of 10:00 HRS to 17:30 HRS. The initial water temperature was noted, and the prototype was kept on testing. Constant water temperature testing was conducted out at intervals, mainly at the afternoon time and at the time of removal of the prototype. The testing showed high increase in the water temperature due to increase efficiency caused due to the reflector sheets and the black paint. However, the condenser output was neglible, mainly due to lack of temperature difference created between the evaporator and condenser, enabling us to perform modifications.

3.10 Modifications

The initial testing, it was discovered that the condenser was not working as simulations suggested and needed modifications. With all the data collected from Preliminary testing observed, it was concluded that the condenser required to be shortened and the temperature difference must be increased. Moreover, the acrylic casing needed to be made smaller to saturate the air inside the casing with water vapors as quickly as possible. Moreover, instead of a **large condenser**, a water-cooled smaller condenser was opted to increase the condensation efficiency. A separate condensation with baffled walls was designed that would be a barrier between the coolant water and the vapors. This enabled the use of previously large condensation tub to be used as a coolant bath where water could be used to cool down the condensation tray.

4 RESULTS & DISCUSSIONS

4.1 Initial Conditions and Independent Variables

To get appropriate results and control parameters, we considered 3 independent parameters: **Evaporation Pan Surface Area, Input Water and Solar Radiation.**

The evaporation pan surface area was kept constant due to the design and construction restrictions. There were two independent quantities causing the change in output. The **Solar irradiation** is an uncontrolled variable due to its constant changing with seasons, weather conditions and time of the day, thus we would not consider that as an independent variable. To cater this, we considered our **Input Feed Water (IFW)** as the independent variable and made the main goal to find the best Input Feed Water (IFW) value; the volume at which the output is maximum. We catered two different input variables by assuming one quantity constant, finding the other independent quantities optimum value, and then keeping that value constant to cater the first independent value. Furthermore, we took three different input values of water and did all our testing based on it. Our **Synthesized Sea Water (SSW)** was the main input feed water that we used throughout all our testing; however, tests run was done on tap water and deionized water to compare the output efficiencies of the three types of water. The tests were performed with two distinctive designs of the prototype: With and Without Wicks. We considered Wicks as an efficiency enhancing product and utilized its capillary action and surface absorption capacity to increase the contact surface area of the prototype.

The classifications of testing can be done as follows:

- Input Feed Water (IFW) – 3L, 6L, 9L
- Type of Water – Deionized Water (DI), Tap Water (TW), Synthesized Sea Water (SSW)
- Use of Wicks (With or Without Wicks)

After considering all the different input water, input rate and orientation types, we finalized that we would have 18 test runs on our prototype. The 18 test results were noted and used in drawing the graphical representation of the tests and to compare the different test results. After deciding the number of tests, the timings and date of testing were chosen. To follow the timeline, the Month of March and April 2023 were chosen as the testing months, mainly because of the good solar irradiation during the months. Prior to the testing, the ambient conditions were noted, including the ambient temperature, relative humidity, and the wind speed. After the conditions were noted, the prototype was setup during the morning hours of 10:00 -11:00 Hrs. The testing continued and the temperature of the water was checked during the morning, afternoon, and evening period. At about 16:00 – 17:00 hrs, the prototype was disassembled, and the final temperature of water was noted. The same practice was done for 18 tests. During the testing, the temperature of water was noted during the afternoon period to collect the data of maximum temperature of water during the testing.

4.2 Testing Results

4.2.1 Mean Water Temperature

Figure 4.1 shows the temperature output of the water during the three intervals on which the temperature was noted. The temperature output in the case is the average values of the temperatures of three types of water during multiple testing days. This was done to optimize and consider the use of all the testing days in our result formulation and consider different weather conditions as well. The temperatures for all three types of water were noted and compared with Fresnel Lens Solar Still (Bahar et al., 2020)

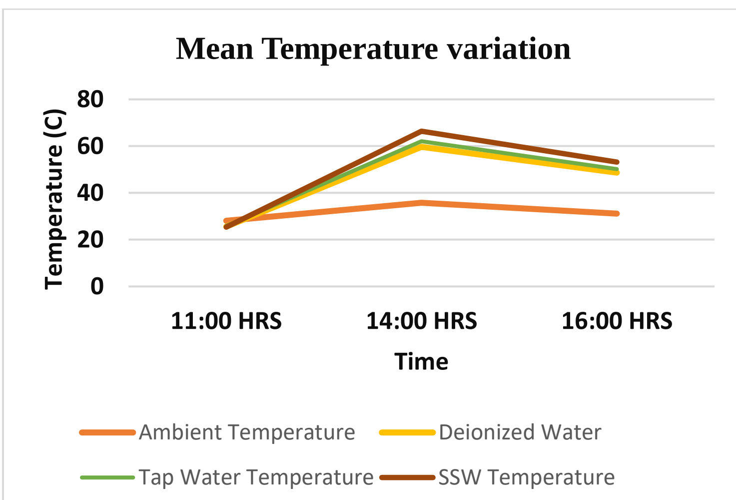

Figure 4.1 Temperature Variation of Water during testing period

The synthesized sea water was noted to have the highest amount of temperature increase as compared to the tap water and deionized water temperature. It was concluded that due to the saline nature of the SSW, the specific heat capacity of the SSW showed a decline, allowing water to rapidly change temperatures with the change in ambient temperatures. Comparing it with the research paper, it was compared and concluded that the SSW temperature, which was the main input water of our testing had the similar temperature increase as the Model B-F of the research paper, indicating that the most suitable comparison between our prototype was with the Model B-F of the research paper which we reviewed.

4.2.2 Condensate Yield

Fig 4.2 and ***Fig 4.3*** shows two graphs of the output of water considering several types of water, fresh design optimizations and three different input levels of water. In Fig ***4.2***, the results of testing done with wicks is shown. ***Fig 4.3*** shows results of testing done without wicks. The ***Table 4.1*** outlines the same comparison in the tabular form. The table shows tabular data of both the graphs formulated. The output is the percentage of output received as composed to the input level of water added to the water, also termed as the condensate yield. The best condensate yield was noted out of the two graphs and the input feed water corresponding to the optimum condensate yield (OCY) was considered as the optimum input feed water (IFW).

Table 4.1 Comparison of OCY with IFY

Feed (L)	**% Yield Condensate (No Wick)**			**% Yield Condensate (With Wick)**		
	DI	TW	SSW	DI	TW	SSW
3	24.7	9.67	14	25.33	23.3	26.3
6	32.8	31.5	35.8	36.83	35.8	40.3
9	28.2	26.8	29.5	25.8	25.5	29.7

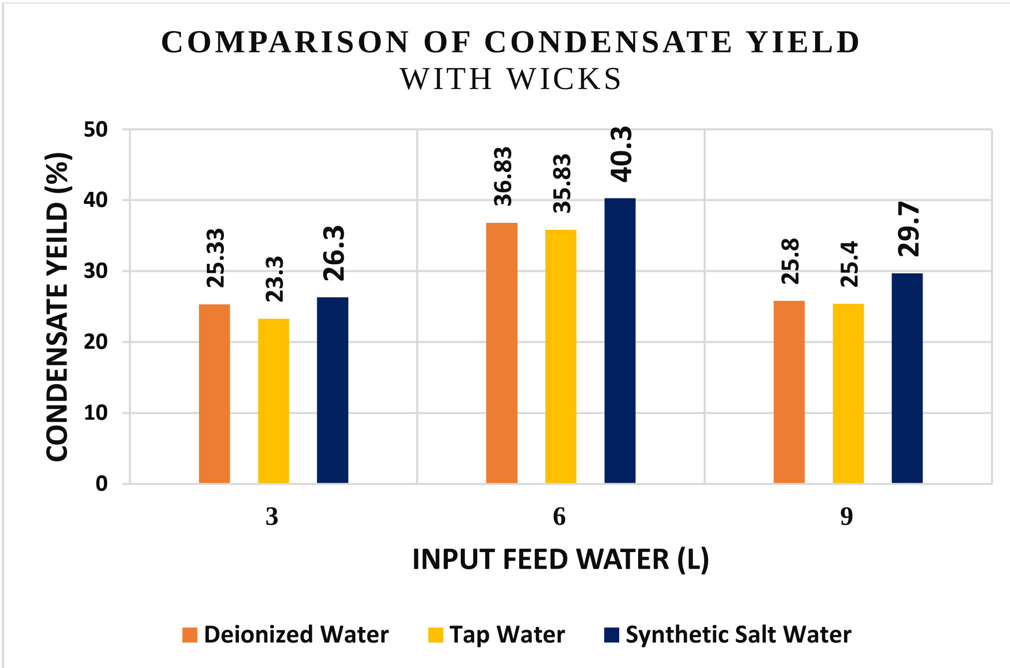

Figure 4.2 Comparison of Condensate Yield – with Wicks

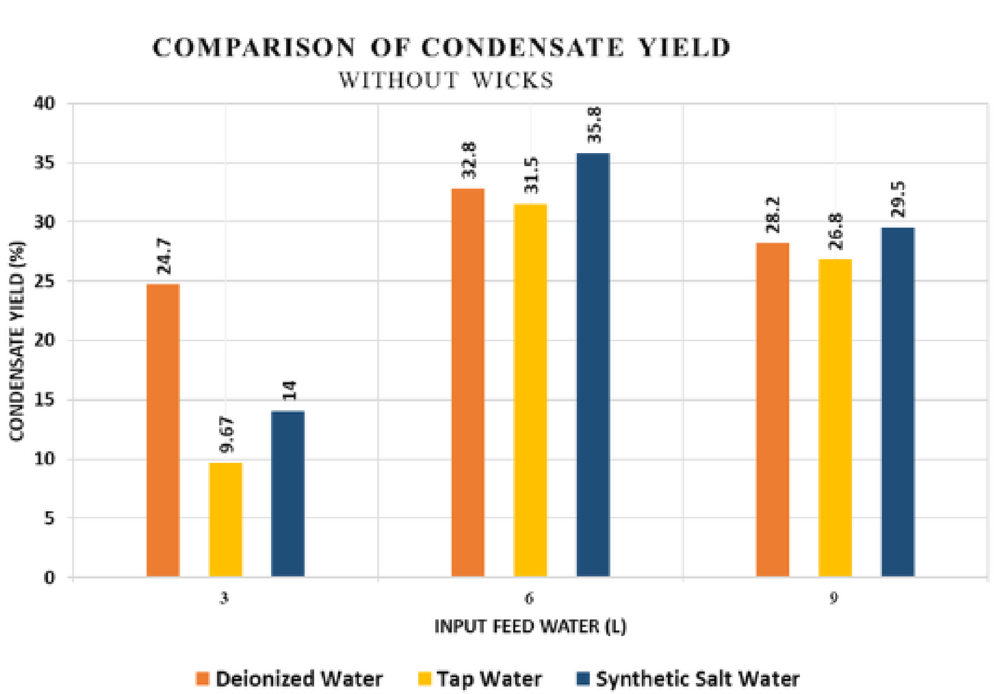

Figure 4.3 Comparison of Condensate Yield – without Wicks

For SSW, the best optimum condensate yield (OCY) was 40.3% at the input feed water of 6L, while using wicks, as shown in fig b. Without wicks, similar but slightly lesser OCY of 35.8% was achieved. Due to highest OCY being achieved at input feed water (IFW) of 6L for both the conditions, we concluded that for our design considerations, 6L was the most optimum IFW out of the three different IFW values. We also considered that during our testing, we would face overcast conditions or rainfall, due to which testing will be affected (The same case is observed in testing of TW and SSW of 3L input, as shown in fig). Thus, we concluded that as the solar irradiations are an un controlling factor for us, to derive its relationship with the results, we will first find the optimum IFW and then keep it at fixed value to find the relationship between solar irradiations and output of water.

4.2.3 Solar Radiation

After selecting the 6L IFW as the optimum test results. we conducted five different tests to determine the relationship between to determine the relationship the solar radiation and output of water. The five tests were the conducted side by side by keeping our first independent quantity (IFW) constant and derive the relationship between the other independent quantity and OFY.

Fig 7.4 graphs the relationship of the solar radiation and OFY.

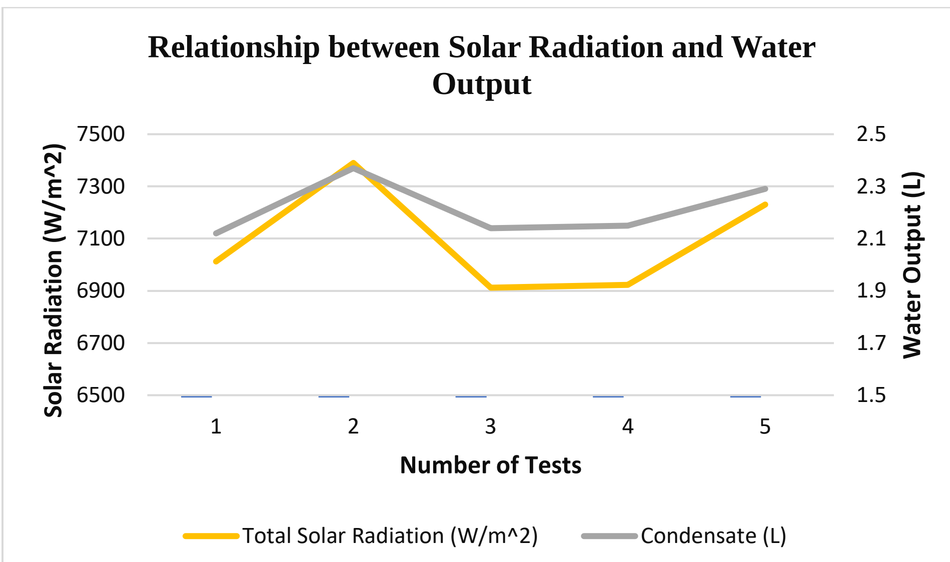

Figure 4.4 Relationship between Solar Radiation and Water Output

The relationship between solar radiation and the output of water in a solar-powered desalination system is significant. Solar radiation is the primary source of energy that drives the desalination process, specifically the evaporation of water and subsequent condensation.

Solar radiation provides the necessary heat energy to convert liquid water into vapor during the evaporation stage. The intensity and duration of solar radiation directly impact the amount of heat transferred to the water, thus influencing the rate of evaporation. Higher solar radiation levels, such as those experienced in regions with abundant sunlight, lead to increased evaporation rates and subsequently higher water output.

Moreover, solar radiation also affects the condensation phase of the desalination process. The condensation of water vapor into liquid form relies on temperature differentials and the availability of a cooler surface for the vapor to condense upon. Solar radiation indirectly influences condensation by heating the air, which can increase its capacity to hold moisture. This can impact the efficiency of condensation by requiring a larger temperature difference between the vapor and the condensation surface for effective water droplet formation.

In summary, solar radiation directly influences the rate of evaporation in a solar-powered desalination system and indirectly affects the condensation process. Higher solar radiation levels contribute to increased evaporation rates and, in combination with appropriate condensation conditions, can lead to higher water output from the system.

4.3 Cost Benefit Analysis

The direct cost of the project consisted of the total cost of the prototype, which included the materials, the labor and the transportation cost. We estimated the bulk cost by predicting the decreased market rates in Karachi, Pakistan and found the bulk costs as well. The direct cost of the project is given below.

4.3.1 Cost of DeSolE

Table 4.2 Direct cost of DeSolE

Prototype	Cost (PKR)
Individual Cost	17,500
Bulk Cost	10,500

4.3.2 Indirect Costs of the Project

The indirect costs of the project consist of monthly, bimonthly, or yearly cost of maintenance encountered due to the wear and tear of prototype. The costs include an insignificant electricity cost to run a 12 V fan, changing of the reflector sheets every six months and the cleaning cost. The table of indirect costs is given below:

Table 4.3 Indirect cost of DeSolE

Indirect Costs	Cost (PKR)/ Month
Electricity	23.50
Reflector Changing	150
Cleaning	150

4.3.3 Cost of Drinking Water without DeSolE

The Table 8-3 represents the costs of drinking water without DeSolE. This cost is necessary to determine the cost benefit analysis as a comparison with other the cost of DeSolE.

Table 4.4 Drinking Water Cost without DeSolE

Costs Type	Cost (PKR)/ Month
Mineral Water	1875
Bottle cost	500

4.3.4 CBA calculation and analysis

We have considered that the lifetime of our prototype is 5 years (A worst case scenario) Considering this, we have calculated the CBA. We approached the CBA using a monthly cost method, in which we calculated the monthly cost of both the DeSolE project and the traditional drinking water and compared it with each other. We also calculated the pay-back period of the prototype and found how much time would it take for an individual and bulk prototype to return its investment. Table 8-4 shows the following:

Table 4.5 Monthly Cost saved and payback period

Investment Type	Monthly Cost Saved (PKR)	Payback period (years)
Individual Investment	946	1.54
Bulk Investment	1178	0.74

Both the individual and the bulk model gave us a staggering result, proving that the DeSolE prototype is perfect for the installation due to its' quick payback period and low-income cost. The best part about it is that the water produced is the same quality as the mineral water purchased from the market, but the prize remains equally low, proving that the one time investment of the DeSolE prototype is best for the low to middle income homes. Furthermore, the expansion of the project can utilize pre-existing pipeline carrying saline water in different areas of Karachi (Our baseline city), and even if expansion is done, we would not require much changes in the infrastructures.

5 CONCLUSION

5.1 Recommendations

The water output achieved was an optimum value, able to achieve output that can cater domestic water uses. However, there are certain enhancements that can be done to achieve higher evaporation and in turn, higher yield of water. The recommended components were avoided during the course of the project to retain the status of an inexpensive yet efficient prototype. However, if the budget of the project can be increased by injecting investments from interested investors, the following recommendations can be suggested:

5.1.1 Vacuum Pump

A vacuum pump lowers the boiling point of water. The amount of pressure applied to a liquid affects its boiling point. A vacuum pump, on the other hand, has the ability to subtly lower the boiling point of water by lowering the pressure above the water's surface. Water boils at 100 degrees Celsius (212 degrees Fahrenheit) under normal atmospheric pressure (1 atmosphere, or 760 mmHg). This is so that the liquid can change into vapor bubbles throughout the liquid at this pressure, where the vapor pressure of water matches the atmospheric pressure. You can lower the pressure in a closed system or container by using a vacuum pump to remove air and other gases. The vapor pressure necessary for water to boil also reduces as the pressure does. Water begins to boil when the pressure falls below the temperature at which water vaporizes. This successfully lowers the boiling point of water below 100 degrees Celsius. For instance, by using a vacuum pump, you can lower the pressure to 50 mmHg and lower the boiling point of water to about 80 °C (176 °F). In some operations, like distillation, where lower temperatures are preferred, this lower boiling point can be advantageous.

5.1.2 Heating Rods

the heading rods are electrically powered devices that has the main purpose of heating liquids. The heating rods has the capability to heat water to boiling temperatures. If the heating rods can be solar powered, the boiling of water can be achieved. The use of heating rods can allow water to efficiency boil and form vapors at an extremely hot temperature. The use of heating rods can increase the evaporation rate of the soar still and can be integrated easily with the whole project to formulate much better results. This can specifically be achieved when scaling up the project.

5.1.3 Scaling up the project

One of the most important things that is a significant need of this project is to scale up the project to a community/ metropolitan level. The increased demand of water endangers the population of water scares coastal cities and empowers the use of DeSolE technology on not only project level but also on community level. The increased dimensions can allow maximum evaporation due to increase in surface area. Along with the integration of mechanical heating and enhanced condensation, the improvement in efficiencies can be achieved to supply water to larger communities, societies or even a whole metropolitan city. The most vital phase in increasing a desalination model is to break down and assess the exhibition of the current model cautiously. This incorporates surveying the proficiency of the desalination cycle, the energy prerequisites, and the general framework plan. In light of this assessment, changes and upgrades might be important to guarantee adaptability. This could include improving the limit of key parts, for example, the dissipation dish or buildup surfaces, advancing the solar collection, and redesigning the capacity and dissemination foundation. Moreover, contemplations should be given to the monetary possibility and natural effect of the increased framework, guaranteeing that it remains savvy and manageable.

5.1.4 Mineralization

The mineralization was one of the most important steps of our project but was left due to it being out of the scope of the project. This was because our primary objective was to design a prototype and analyze its' working efficiency and its' output production capability. But the mineralization component must be added in order to make the water healthy enough to drink after desalination is done. The best method of mineralization is using mineral tablets or mineral drops. The concentrated tablets or drops have the capability to mineralize abundant amount of water using a single drop or tablet.

One more method of mineralization is by using a trace number of salts removed from the water. The sea salts can be added at a very small amount to allow minerals to be mixed in water. Do not mix this with adding all the salts with water, as it will just make the same saline water as before. Our goal is to just let a small amount of sea salts back into the OFY because the sea salts contain healthy minerals, essential from water drinking, including Calcium, Magnesium and Sodium.

5.2 Final Conclusion

The testing of the results showed us that our main parameter was the IFW whose changes gave us different OFY. An optimum value to IFW was achieved at about 6 L. However, with the increase in the surface area, or by adding recommended components, the increase in the IFW can be achieved.

DeSolE is a cost-effective unit to provide clean water. It uses free solar energy due to which the overall cost is relatively low. The unit is relatively inexpensive to build and simple to move, making it possible to transport it to locations that need it the most. This helps to reduce expenses. Solar desalination facilities are inexpensive to maintain and can be built on land or offshore. The beneficial part of this prototype is that it is not only inexpensive to buy, install and maintain, but also has a highly efficient output. With different modifications to the dimensions of the DeSolE, the increase in output can be achieved, allowing it to be used in various areas with drinking water scarcity.

6 REFERENCES

- Safdarian, Farnaz & Nazari, Mohammad Esmaeil. Optimal Sizing of a Solar-Thermal Collector for Residential Applications Using Gravitational Search Algorithm. (2015).
- Kaladharan, P. "Artificial seawater for seaweed culture." Indian Journal of Fisheries 47.3 (2000)
- W. A. Khan and A. Alakram, "Surface Area Optimization of a Domestic Solar Still Design," (2022).
- Hove, Tawanda. "A thermo-economic model for aiding solar collector choice and optimal sizing for a solar water heating system." Africa-EU Renewable Energy Research and Innovation Symposium. Springer, Cham, (2018).
- Mahboob, Ahmed, Khan, Virik. Al-Mulhm, A.A. Baabbad, Assessment of heavy metals pollution in seawater and sediments in the Arabian Gulf, near Dammam, Saudi Arabia, Journal of King Saud University – Science, (2022).
- Ahmed M. Abdel-Halim, Mohamed A. Aly-Eldeen, Characteristics of Mediterranean Sea water in vicinity of Sidikerir Region, west of Alexandria, Egypt, The Egyptian Journal of Aquatic Research (2016).
- Omer, Waleed Ocean Acidification in the Arabian Sea and the Red Sea (2010)
- Kumar, Arshad, Shaheen, Nadeem, Islam, Water sanitation in Karachi and its impact on health (2022)
- Chandrika, V. S., Attia, M., Manokar, A. M., Márquez, F. P. G., Driss, Z., & Sathyamurthy, R. (2021). Performance enhancements of conventional solar still using reflective aluminium foil sheet and reflective glass mirrors: energy and exergy analysis.
- Joseph Fraiman a, a, b, c, d, e, f, g, & 2020, A. (2022, August 31). Serious adverse events of special interest following mrna COVID-19 vaccination in randomized trials in adults.
- Jamali, H. (2019, January 29). Investigation and review of mirrors reflectance in parabolic trough solar collectors (ptscs).