Design and Fabrication of Solar-Thermal Water Purification System

By

Zimaar Fahad Aziz (2015-NUST-SCEE-BE-Env-147492)
Sumaiya Hussain (2014-NUST-SCEE-BE-Env-36075)
Suleman Sikandar (2015-NUST-SCEE-BE-Env-131298)

Submitted in Partial Fulfillment of the Requirement
For the Degree of Bachelors In Environmental Engineering 2019

Institute of Environmental Sciences and Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology
Islamabad, Pakistan

Approval Sheet

It is certified that the contents and form of the FYP Report entitled "**Design and Fabrication of Solar-Thermal Water Purification System**" submitted by Mr. Zimaar Fahad Aziz, Ms. Sumaiya Hussain, and Mr. Suleman Sikandar, have been found satisfactory for the requirement of the degree of Bachelors of Environmental Engineering.

Supervisor: ……………

Dr. Muhammad Zeeshan Ali Khan

Assistant Professor,

IESE, SCEE, NUST

Acknowledgement

First and foremost, we would like to express gratitude to our supervisor Dr. Muhammad Zeeshan Ali Khan for his valued guidance, constant support, encouragement and motivation which brought us in a position to successfully complete our project. It was his incomparable expertise and foresight that helped us achieve our goals productively and in defined time limit.

We thank our families for their relentless support, care and concern.

We would also like to thank Engr Aamir Khan for assisting and guiding us every then and now, and for directing us to relevant resources when needed.

Furthermore, we would like to thank the honourable Staff Members of IESE, who provided us space within their area and time frame that helped us to perform our experimentation in due time.

Abstract

Sustainable Development Goal no. 6 indicates that all should be provided with clean water and sanitation. The enormous growth of population and industry is leading to a worldwide imbalance between supply and demand of fresh water. Though access of urban and rural populations to clean potable water is comparatively better, for people living in remote areas, no technological solution is available for clean drinking water supply at low costs. Solar thermal desalination is the simplest and most attractive technique among the treatment processes. Solar energy in Pakistan has got potential to be harnessed efficiently for solar thermal treatment technologies as it is environmentally sustainable, cheaper than other fuels and abundantly available. The objective of this project is to design and fabricate a prototype of “solar thermal water purification system” for a domestic water supply that ensures improved water quality with no ongoing expense and zero carbon footprint. The system comprises of two units, an evaporator and a condenser. Water from a feed water tank is supplied to the evaporator via perforated pipes and runs down the absorption mat. The solar radiation incident on the evaporator causes a rise in temperature inside the panel resulting in formation of water vapours. The vapours are directed into the condenser through entrance pipes where they condense on a surface of coiled copper pipes. These pipes have water circulating inside them at room temperature, to provide a cooling surface for the vapours to condense. These condensed vapours are then collected from the bottom of the condenser. To ensure that the system can treat feed water with varying initial parameters, 3 types of feed water were used: tap water, saline water and treated waste water effluent. The testing phase involved testing of drinking water parameters of both feed and product water. Based on the results obtained and analysis performed it was determined that the yield obtained in terms of feed water in vs product water out was 83%. Also, a maximum temperature difference of 37.8°C was achieved between inside of the evaporator and condenser facilitating rapid condensation of the incoming vapours. The system gave a maximum yield of 350ml/hour and all the tests conducted confirmed that all drinking water parameters of product water were within the limits of both WHO and NSDWQ proving that the system is capable of treating wide range of feed water.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

It has been approximated that currently more than 7.7 billion people reside in the planet we call Earth and this number is rising at a phenomenally high rate. Already almost 1.2 billion people are situated in areas of extreme water scarcity and another 1.6 billion people live in locations that entail restrictions on water use due to economic water shortages. The Sustainable Development Goal no. 6 indicates that provision and access of clean, affordable, and safe drinking water should be made available for all and the United Nations has set this target for the year 2030. However, the enormous and accelerating growth in human populations and rapid modernization and industrialization of our surroundings is leading to a worldwide imbalance between the supply and demand of fresh water for uses that include drinking, washing, bathing, cooking, cleaning, sanitation, etc. The total amount of global water reserves is about 1.4 billion km3. Seawater constitutes about 97.5% of this amount, and the remaining 2.5% fresh water is present in the atmosphere, surface water, glaciers and ground water. This means that only about 0.014% is directly available to human beings and other organisms and most of this water is being polluted by anthropogenic activities like dumping of wastewater in clean flowing rivers and dumping of wastes eg. plastics into open water bodies. To treat this water and supply it in the form of clean potable water to both urban and rural populations, we have utilized desalination techniques which are one of mankind's earliest forms of water treatment. Even so, most conventional desalination systems are energy intensive and so consume high grade energy through fossil fuel burning leading to a large carbon footprint and ultimately global warming. Some examples of this are reverse osmosis, ion exchange, electrodialysis etc. Due to high energy demands, they are also quite expensive and thus, cannot be properly made use of for people living in remote or poor areas with inadequate electricity supplies.

As a result, these people have to use contaminated waters and so approximately about 4 million people die each year due to water-borne diseases. Contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio. Some 842 000 people are found to die each year from diarrhoea as a result of unsafe drinking-water, sanitation which is preventable and avoidable. Almost 240 million people are also affected by schistosomiasis – an acute and chronic disease caused by parasitic worms contracted through exposure to infested water and numerous others are killed due to diseases like malaria and dengue caused by insects that breed and live in these waters. Almost all of these deaths occur in the remote or low-income areas with no access to improved quality water sources. Pakistan is facing major challenges associated with drinking water. According to a report by Water Aid, Pakistan is one of the top 10 countries with the lowest access to clean water. Most areas of Pakistan are under medium to high water scarcity risk. With a per person annual availability of water at 1,017 cubic meters, Pakistan is fast closing in at 1,000 cubic meters, which indicates the country is water scarce. Industrialization, demands of agriculture, depleted and increasingly saline groundwater and rapid urbanisation are the severe challenges faced by the country.

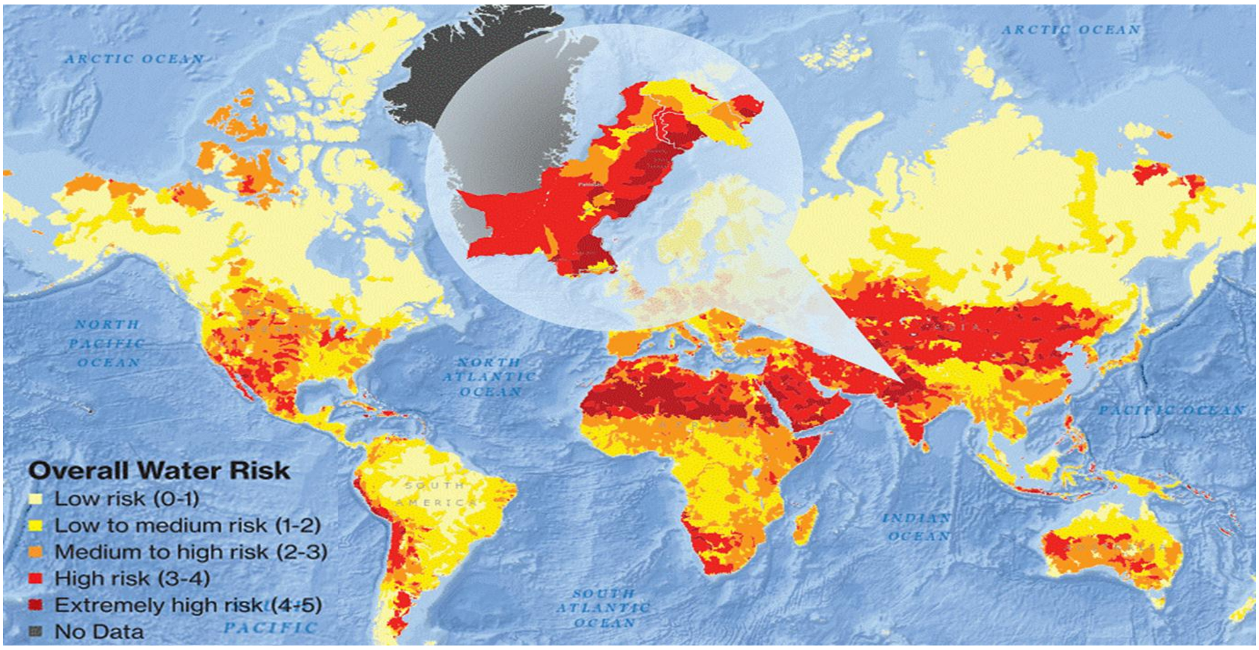


Figure 1.1 Overall Water Risks of the countries of the world.

To eliminate the gargantuan number of problems associated with conventional desalination methods, there needs to be an increase in innovation, establishment, and usage of solar thermal desalination techniques. Solar energy, especially in Pakistan, has got potential to be harnessed efficiently for solar thermal technologies to provide for the shortfall of water especially in remote areas of Pakistan because it has 70% of its area classified as arid and semi-arid regions. Due to the geographical location of Pakistan, the huge amounts of solar energy there can be efficiently made use of for solar thermal desalination along with numerous other applications in domestic and industrial sectors. Pakistan is situated in the temperate zone and is just above the tropic of cancer with climates ranging from temperate to tropical, and therefore it receives gigantic numbers of solar energy throughout the year. The average solar radiation incident on Islamabad has an intensity value that can fall anywhere between 4.5 and 5 $kWh/m^2/day$ annually. During winters it is from 4 to 4.5$kWh/m^2/day$. (*NREL, 2007*).

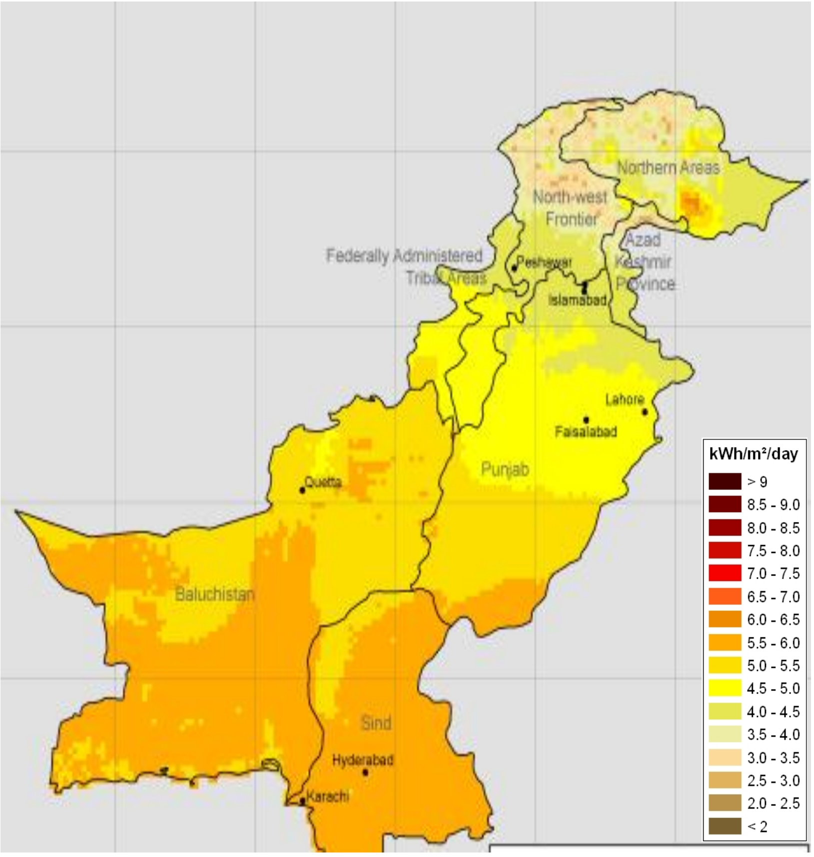


Figure 1.2 Spatial Variation of solar radiation intensity during winters in Pakistan

Therefore, employing solar desalination can reduce the carbon footprint and global warming normally associated with the fossil fuel burning of conventional techniques and also provide an environmentally sustainable, cheaper than other fuels, and abundantly available energy source that can provide clean potable water to the arid and semi-arid remote regions in the world and for our focus, Pakistan.

1.2 Problem Statement

The already vast and ever-growing world population is leading to a sudden rise in freshwater depleting anthropogenic activities, resulting in a severe shortage of clean drinking water all around the world.

1.3 Objectives

To present an effective, renewable, and sustainable solution for present and any future water crisis, the following are the deliberated objectives:

- To design a prototype of **"***solar thermal water purification system***"** on a domestic level.
- To fabricate the prototype and optimize its efficiency through appropriate upgrades.
- To achieve improved water quality with no on-going expense and zero carbon footprint.

1.4 Scope

The project is based on design of a durable and efficient water purification system that is fuelled by solar energy. The scope of the project is to efficiently harness solar thermal energy and convert it to warm up the feed water. Three different types of feed water were intended to be tested to ensure flexibility of the product, which were tap water, synthetic saline water, treated waste water effluent. For successful completion of the project, locally available materials of construction were used. For the purpose of this project hybridization is not being considered. But it can always be hybridized to increase the yield.

2 Literature Review

In literature review we studied different parameters that affected the rate of evaporation and condensation. The yield of the product varies with solar radiation available, ambient temperature, cloud cover and wind speed, and these factors cannot be controlled by humans as they are meteorological parameters. However, some design parameters affecting evaporation and condensation can be optimized to increase the production rate.

The following are the parameters:

2.1 Water Depth

Evaporation rate of water in the panel is inversely proportional to the depth of water. According to the studies made by martin and his co-workers lesser the depth of water higher will be the heat transfer coefficient and hence it gives higher productivity. As is seen in the graph the overall efficiency decreases with increase in depth. (*Ahsan A et al., 2014)*

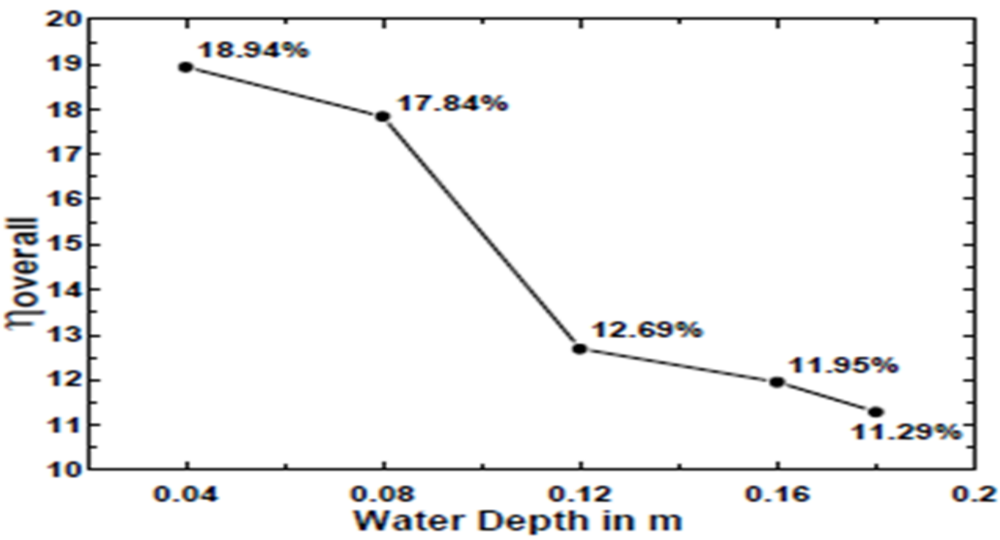


Figure 1.1 Effect of varying water depth on yield

2.2 Temperature Difference between Evaporator and Condenser

The temperature difference between the evaporating and condensing areas affects productivity of the system. Investigations determined that increasing the temperature difference between the two improves the output distillate yield. According to a study conducted by A.E. Kabeel et al, separating the evaporation and condensation units and passing the saturated air from evaporator to the condenser can increase the temperature difference between the two and the yield can nearly double.

2.3 Wind Velocity

The parameter affecting condensation is wind velocity. El Sebaii et al found that wind velocity has a significant effect on cover temperature. At higher wind velocity, due to higher convective heat transfer from the cover to atmosphere the productivity increases. (*El Sebaii AA, 2011)*

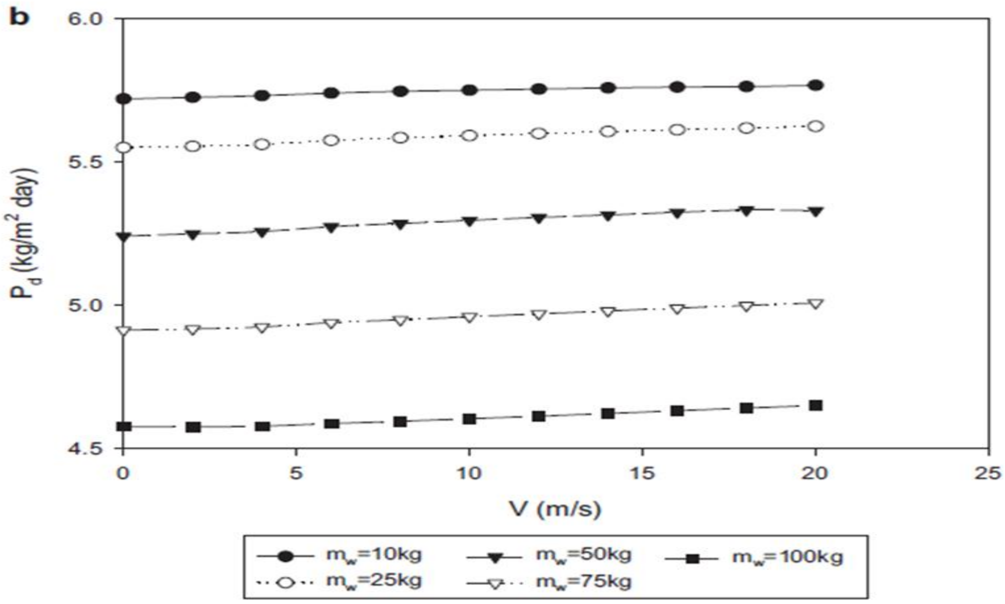


Figure 2.2 Variation in productivity as the wind velocity increases

2.4 Panel Frame Material Selection

To select panel frame material, we decided between PVC and Aluminium. Our criterion was ease of movement and change, weight, locally available, price as stated in table 2.1.

Table 2.1 Characteristics of PVC and aluminium for material selection criteria

Sr. No.	Type of Material	Weight	Upgrade Accessibility	Locally Available	Price	Sturdiness
1	**PVC**	Light	High	Yes	Low	Low
2	**Aluminium**	Heavy	Low	Yes	High	High

So, to allow for room for improvements and changes and because it was cheaper, we decided to utilize PVC pipes for frame but in commercialization aluminium is preferred.

2.5 Absorbing Mat Material Selection

The first parameter is radiation absorption efficiency of the evaporating panel. The absorption rate is increased by using different types of absorbing material along with feed water. Materials like mat or sponge increase the surface area available for absorption due to void spaces. Moreover, using a black coloured mat or sponge can increase the amount of radiation absorbed. According to an investigation conducted by Bassam and his co-workers using a black sponge increased the yield 10 to 15 times. (*Bassam et al., 2003)*

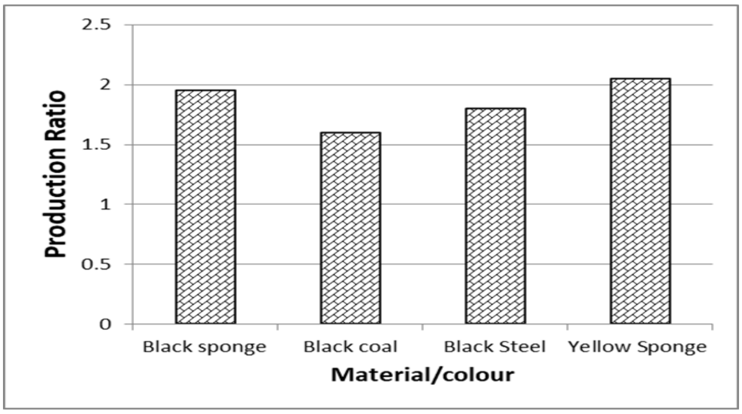


Figure 2.3 Effect of absorption mat colour on production ratio

Due to local unavailability of unlined sponges large enough to cover panel we tested between black nylon and polyester mats to check time taken for 1 litre of water to evaporate from it. We found the nylon mat to have a higher absorption and evaporation rate as calculated in below mentioned table 2.2.

Table 2.2 Rate of evaporation for two different types of mats

	Nylon	**Polyester**
Weight of dry mat (g)	577.74	688.3
Weight of empty bottle (g)	16.431	16.47
Weight of water + bottle (g)	551	550
Weight of water (g)	534.6	534.4
Volume of water (mL)	500	500
Density of Water (g/mL)	1.069	1.069
Weight of mat + water (g)	1112.34	1222.7
Weight of container (g)	397.32	383.67
Weight of container + wet mat (g)	1064.42	1541.29
Weight of water in mat after 25 mins (g)	89.36	469.32
Weight of water evaporated (g)	445.14	65.18
Volume of water evaporated (mL)	416.4	60.97
Rate of evaporation (mL/min)	16.7	2.44
Time taken for 1L water to evaporate (hour)	**1**	**6.81**

2.6 Wire Mesh Material Selection

Some comparison of the iron and aluminium is given in Table 2.3 below.

Table 2.3 Comparison of Iron and Aluminium for material selection

Sr. No	**Material**	**Weight**	**Resistance to Corrosion**	**Cost**	**Local Availability**
1	Iron	Heavier	Low	Low	Yes
2	Aluminium	Lighter	High	High	Yes

Even though Iron is cheaper, we required a material that wouldn't corrode due to persistent water exposure and so we decided to go with Aluminium wire mesh.

2.7 Transparent Cover Material Selection

We compared the 2 materials of soft PVC sheet and Glass as the cover to allow solar energy through in table 2.4.

Table 2.4 Comparison of PVC and glass for material selection

Sr. No.	Material Type	Specific Heat Capacity kJ/(kg.K)	Transmittance (%)	Thermal Conductivity W/(m.K)
1	PVC	1.13	89	0.13
2	Glass	0.792	87	1

We are using soft PVC plastic because it has high transmittance hence allowing maximum light to pass through. It also has low thermal conductivity which is favourable because it keeps the heat trapped inside the panel causing a rise in temperature thus increasing the rate of evaporation. Moreover, PVC does not have a very high specific heat capacity making it easier to rise its temperature to enhance evaporation.

2.8 Angle of Panel

According to Kabeel et al, the yield of water attained will be maximum when the angle of the panel is equal to the latitude of the location it is placed at, which is 34 degrees for Islamabad.

3 Methodology

For ease of understanding, the project methodology is summarized in the following flow diagram.

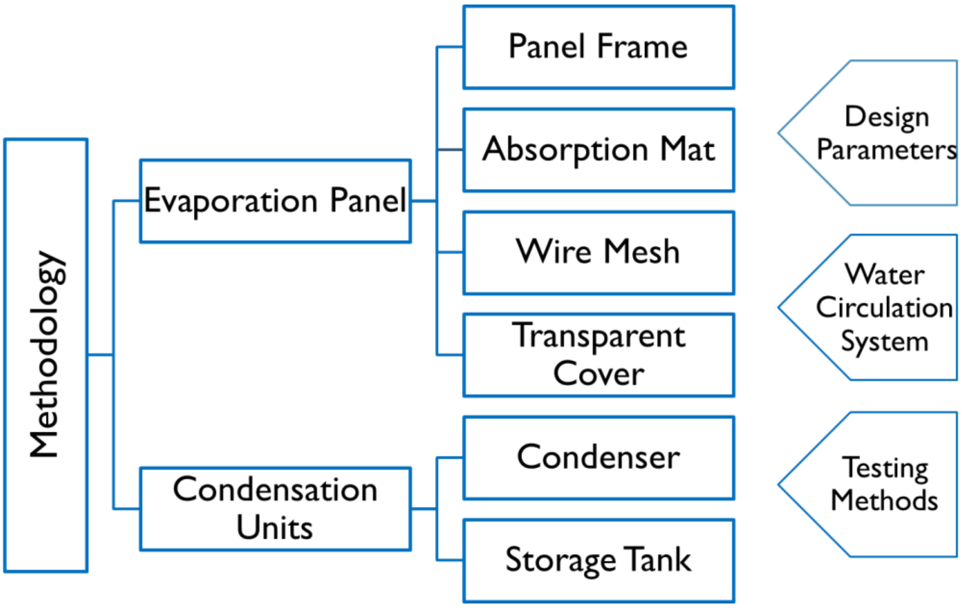


Figure 3.1 Framework of Methodology

The flow chart shows that the methodology has been divided into two most general parts i.e. The evaporator panel and the condensing units. Both the parts are further divided into some basic parts.

3.1 Design parameters

There are some parameters which affect the rate of evaporation and condensation and these parameters were optimized using the most feasible materials available as guided in the literature. The quantity of vapours produced directly depends on the following factors;

- Solar radiation available
- Ambient temperature
- Cloud cover
- Wind speed

These factors are completely natural and cannot be changed however there are some design parameters which can be optimized in order to increase the evaporation and condensation rate to enhance the overall yield and efficiency. Those factors are

- Radiation absorption efficiency
- Depth of water
- Temperature difference between evaporator and condenser

These factors were optimized using the best suitable material available and selection criteria of all materials will be mentioned in each respective unit of product.

3.2 Evaporation Panel

The evaporation panel is the first unit in the whole methodology of the system and it is responsible for evaporating the feed water and conveying the vapours to the condensation unit. The design of the panel was made in such a way that the materials required are easily available in the market and are equally feasible in the terms of cost.

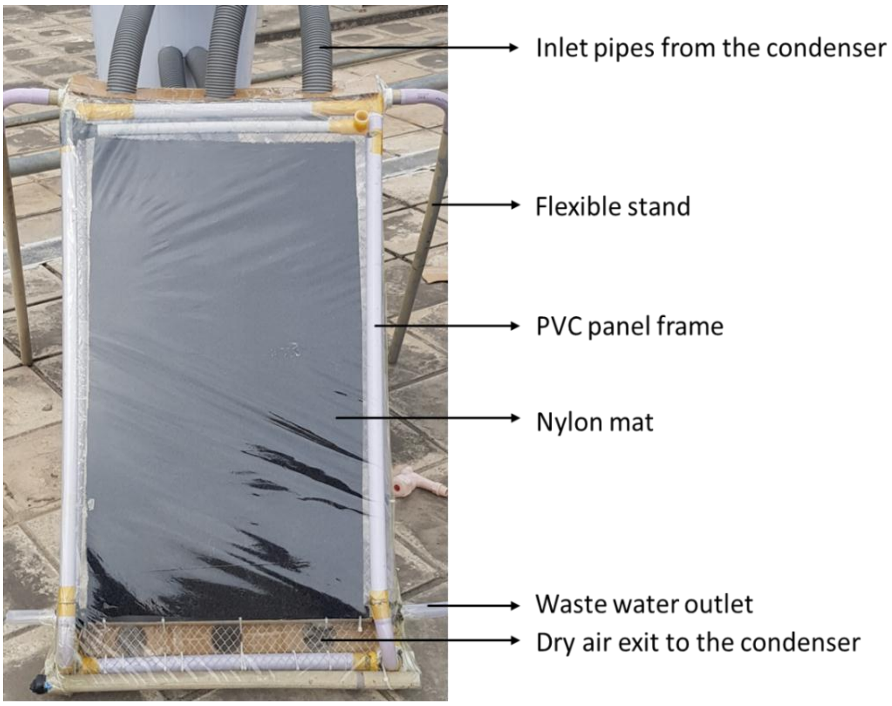


Figure 3.2 Evaporation panel showing its components

It consists of four basic parts which are as follows:

3.2.1 Panel frame

The panel frame was made using PVC pipes. The PVC was used keeping under consideration a number of reasons. PVC pipes were compared in every aspect with the alternative that is Aluminium and was preferred in every aspect. PVC is cheaper than aluminium and is lighter in weight. PVC is available locally and is resistant to corrosion. PVC is highly stable to temperatures up to 250 degrees so the ambient conditions should not vary its properties in any way.

3.2.2 Absorption Mat

The second part of the evaporation panel is the absorption mat and it serves the purpose of absorbing the feed water and increasing its surface area tremendously in order to enhance the rate of evaporation for better yield. The criteria over which the mat was selected was the ease of availability, black colour, abundant void spaces and high evaporation rate. The black colour was selected keeping in mind the fact that black absorbs most solar radiations hence more the energy, more will be the rate of evaporation. The abundant void spaces serve the purpose of providing maximum hollow for water absorption in order to saturate the mat as soon as possible to increase the rate of both evaporation and condensation. Another major characteristic of the absorber mat is to keep the water depth as low as possible distributed well over the length of mat so that solar radiations can penetrate in easily and energize water molecules close to the near surface of the mat.

3.2.2.1 Panel frame design and dimensions

The precise measurements and dimensions of the evaporator panel frame and mat are highlighted in figure 3.3. and table 3.1.

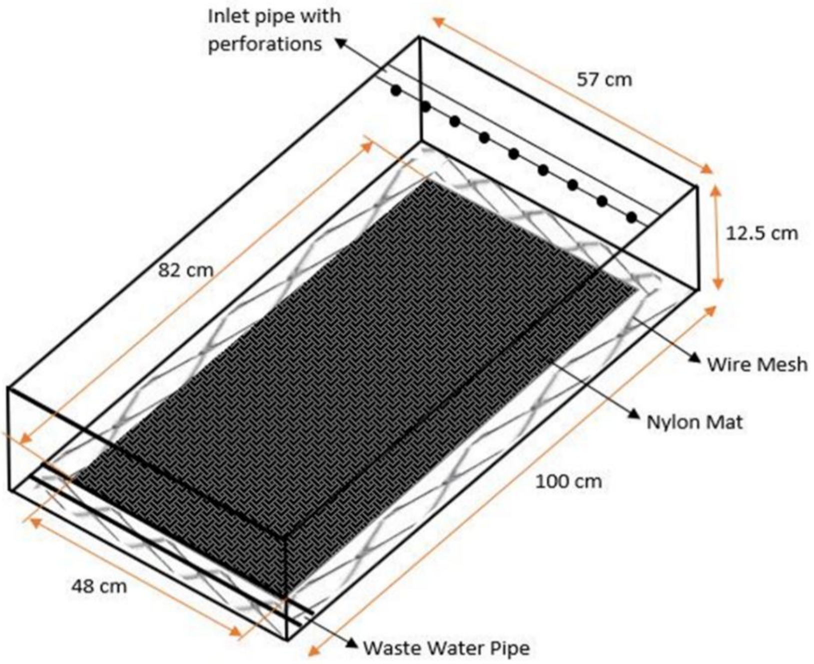


Figure 3.3 Design of Panel showing dimensions

Table 3.1 Dimensions of evaporation panel and absorbing mat

Panel Dimensions	
Length	100 cm
Width	57 cm
Height	12.5 cm
Mat Dimensions	
Length	82
Width	48
Height	0.8

3.2.3 Wire mesh

Wire mesh is the third component of the evaporator panel and its job is to support the weight of the absorber mat so that it doesn't get any fold in it in order to keep the absorbed water concentrations spread equally over the mat. The criteria over which the wire mesh was selected was the weight and resistance to corrosion and the most suitable option was aluminium mesh.

3.2.4 Transparent cover

The transparent cover was wrapped over the frame in order to create a greenhouse inside and trapping maximum heat inside and preventing it from escaping. The plastic wrap that was used was made of PVC. It was, among others, a very suitable option considering its transmittance which is 89% and more than glass which was the other available option. The thermal conductivity is 0.13 W/m.K which is low and is highly desirable because lower the thermal conductivity, lesser heat will be the heat conducted across the material. The PVC also has low specific heat of 1.13 kJ/(kg.K).

3.3 Panel angle variation

Panel placement angle is another very crucial parameter which impacts the rate of radiation absorbed and hence directly affects the rate of evaporation. According to the literature review the angle of solar heating technologies is always kept equal to the latitude of the place. The latitude of Islamabad is 34 degrees so that is the angle at which the evaporator panel was placed in figure 3.4.

Figure 3.4 Panel placed at 34° with adjustable stand

3.4 Condensation Unit

The second unit of the solar thermal water purification system methodology is the condensation unit which receives the high energy vapours from the evaporation panel and condense them to make clean drinking water. The vapours from the evaporator panel are directed towards the condensation unit via the inlet pipes which leave the evaporator from the top side. There are three pipes leaving the evaporator so that maximum possible passage could be provided to the vapours to be transported to the condenser. The length of these pipes is kept as less as possible to make sure that the condensation rate within the pipes is negligible. The arrangement is shown in figure 3.5.

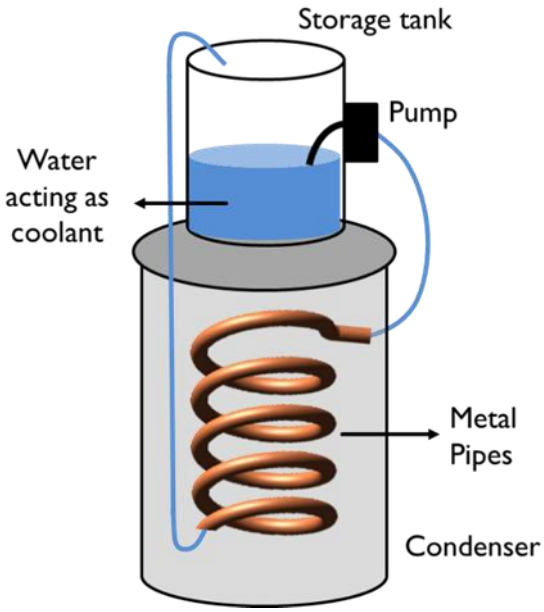


Figure 3.5. Arrangement of Condensation Unit

The condensation unit consists of two parts, the condenser and the cooling water storage.

3.4.1 The condenser

The condenser is made using a large size bucket so that maximum area could be provided to the incoming vapours so that they can lose their heat and condense easily. Inside the bucket is an arrangement of copper pipes which are in some sort of spirals and both its opening ends leave the bucket from the top side. The water is circulated in these pipes at all times the unit is running. The purpose of this assembly is to ensure rapid heat exchange which leads to fast condensation of the incoming vapours. The copper pipes arrangement is shown in figure 3.6

Figure 3.6 Arrangement of copper pipes inside container

The dimensions of the condenser are shown in the schematic below

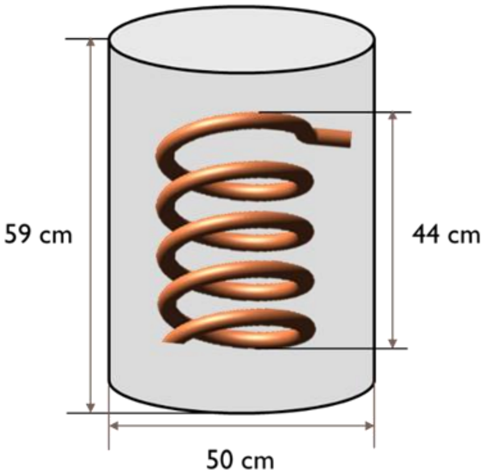


Figure 3.7 Dimensions of the condenser

The condenser is placed in the shade so that its temperature could be kept lower than that of evaporator panel. This is done to ensure that the temperature difference between two units is high so that maximum condensation rate can be achieved under normal conditions. It was studied from literature that greater the temperature difference between the evaporator and condenser, higher will be the rate of condensation and hence more yields could be achieved.

3.4.2 The cooling water storage

The coolant water that is circulated in the copper pipes is stored in the container which is placed above the condenser bucket for the ease of control. The coolant is kept at ambient temperature and can be any kind water either clean or polluted because its only job is to carry the heat from the vapours and lose it in the atmosphere. Figure 3.8 shows tank.

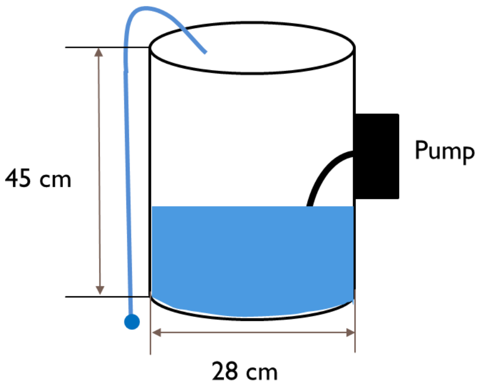


Figure 3.8 cooling water storage tank

As shown in figure 3.5, the storage container is placed right over the condenser. The exit mouth of the pipe which returns the water back to the container is kept at a certain height over the container so that the heat in water can be lost in the atmosphere via aeration. By doing this the temperature of the water in the storage can be kept in ambient range.

It must be made sure that the water used as the coolant must most have coarse suspended particles or there is chance that the pump or the copper pipes can be clogged and the whole system can malfunction.

Figure 3.9 Condenser

Figure 3.10 Cooling water storage tank with pump

3.5 Water Circulation Systems

3.5.1 Pump

A small centrifugal pump of 8 W and 12 V is used to circulate the coolant in the copper pipes. The pump must be running at all times in order to keep the proper and efficient hear exchange running.

Figure 3.11 DC pump used to circulate water

3.5.2 Feed water circulation system

The water that is to be treated is fed at the top of the evaporator panel and via perforated pipes spread across the width of the absorption mat. The feed water is stored in a container at some height from the top level of the evaporator panel so that the water is fed using the available head difference. The flow of water is maintained by valve installed in the container. The flow of water has to be optimized given the ambient conditions of the area. The flow rate for our system was kept as low as 7ml/min to ensure maximum evaporation rate and minimum drainage losses from the mat. The flow rate can be increased or decreased further in case of temperature anomalies.

It is preferred to keep the feed water tank outside the shade so that the temperature of water is already high and the evaporation rate can be enhanced further and the efficiency can be increased

Figure 3.12 Feed water tank with tap to control flow

After fabrication the system was installed at the IESE roof top and experiments were conducted there for the month of March and April 2019. Figure 3.13 on the next page shows the arrangement of the unit. To ensure maximum rate of production of water, the condenser was kept in shade and rest of the unit was kept under sunlight.

Figure 3.13 Installation of prototype on IESE roof top

3.6 Testing methods and equipment

The final part of the project methodology is to test the produced water by selecting the necessary parameters and the required equipment for the experimentations. Since the water produced has to be suitable for drinking purposes, the parameters which are to be checked are selected on the basis of drinking water parameters by WHO and NEQS.

The test that are performed on the feed water are:

1. Conductivity test
2. pH test
3. Hardness test
4. Turbidity test

For the given tests, certain equipment is used i.e. Conductivity is tested using conductivity meter, pH is calculated using pH meter, hardness is calculated by performing titration and turbidity by turbidity meter. The temperatures of the evaporator and condenser were measured using digital thermometer.

Figure 3.14 Conductivity meter

Figure 3.15 pH meter

Figure 3.16 Turbidity meter

Figure 3.17 Digital thermometer

4 Results and Analysis

Testing methodology involved testing of five different parameters for three feed waters: Tap water, synthetic saline water, and treated waste water effluent. Later the same tests were conducted on the product water and the values were compared with the feed water to analyse the percentage decrease in the parameter after treatment. The values of product water were also compared with the WHO guidelines and NSDWQ limits to ensure that they were within limits.

4.1 Temperature variation of Evaporator and Condenser

Testing was conducted in the month of March and April 2019 and temperature variations inside the evaporator and condenser were recorded over the day, from 9:00 am to 6:00 pm. These values were then averaged out and are represented below

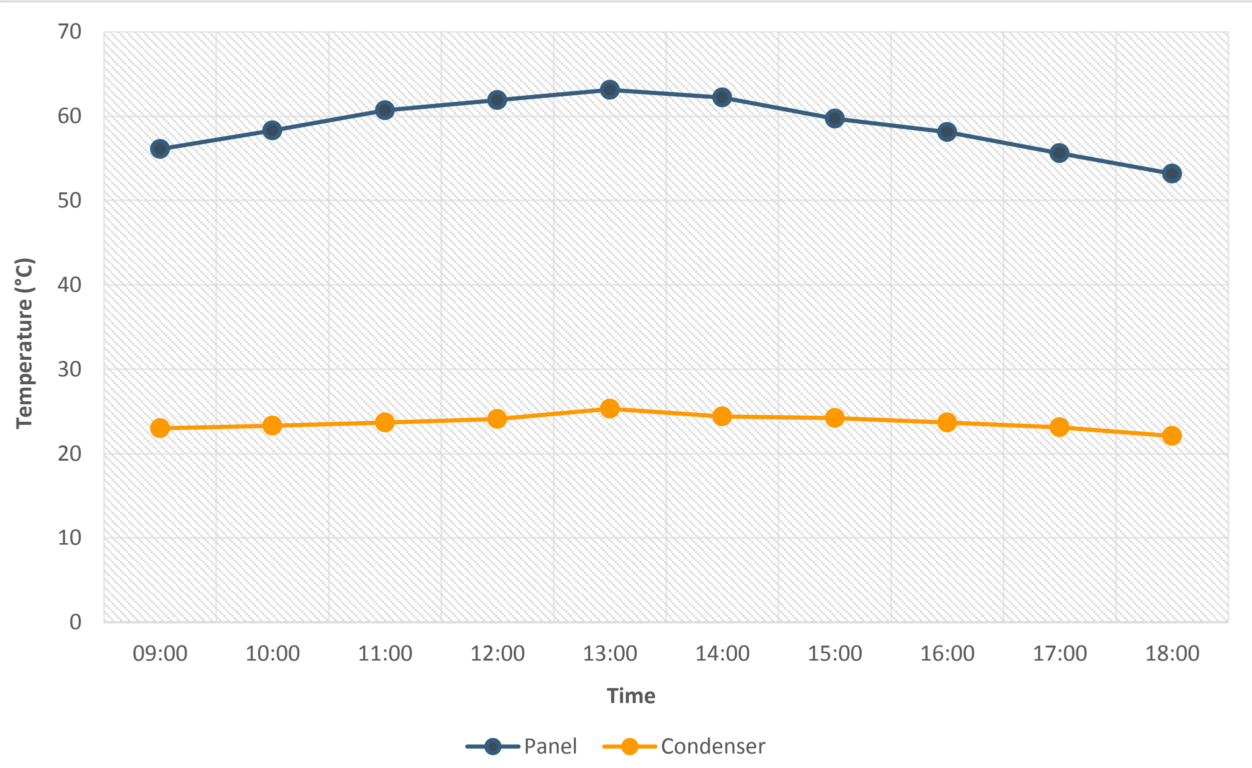
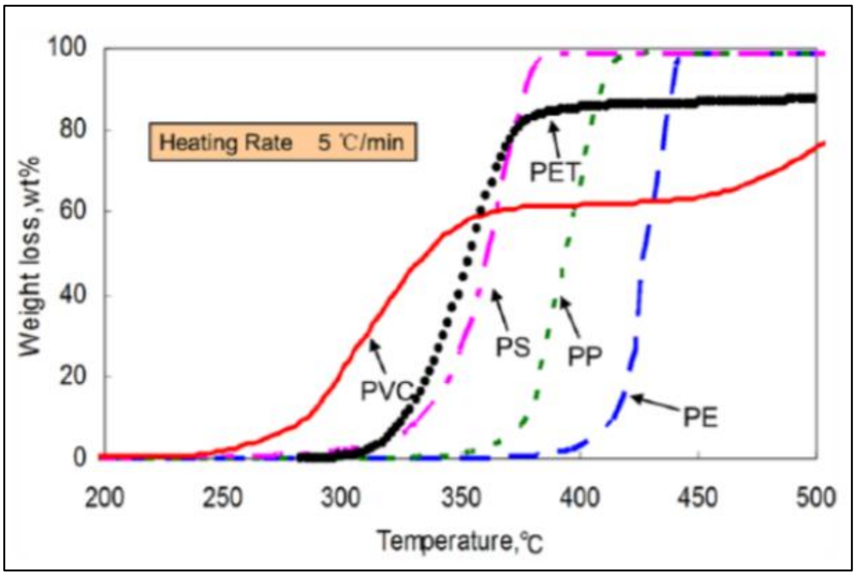


Figure 4.1 Mean temperature values recorded inside the evaporator and the condenser at hourly intervals for the months of March and April 2019

From the graph it can be inferred that temperature difference between the evaporator and the condenser is large enough to facilitate condensation of the evaporated vapours. As discussed earlier, greater the temperature difference between the evaporating and condensing surfaces, greater the rate of condensation, thus yielding more water. The maximum temperature difference obtained between both areas was 37. 8°C and the minimum temperature difference obtained was 31.1°C. The mean temperature difference was 35.2°C. The temperature inside the evaporator reached 63.1.

4.1.1 Thermal decomposition of polymers

A problem associated with use of PVC plastics at high temperatures is the release of polymers due to thermal decomposition hence we reviewed some literature to study the release of polymers. Figure 4.2 shows the percentage weight loss of various types of polymers against the increasing temperature. PVC plastic does not lose any weight unless it is heated above 250 degrees Celsius which justifies that plasticizers cannot be released under the temperatures reached inside the evaporator. *(Bhaskar et al., 2006)*



PET: polyethylene terephthalate;
PVC: polyvinylchloride;
PS: polystyrene;
PP: polypropylene;
PE: polyethylene

Figure 4.2 Thermal decomposition of some important polymers (Bhaskar et al., 2006)

4.2 Testing of feed and product water for drinking water quality parameters

The five water quality parameters tested were: pH, total dissolved solids (TDS), hardness, turbidity and conductivity. Feed water for each run was tested for these five parameters and the values were averaged out. The product water for each corresponding run was also collected and tested for the five parameters. The values were averaged out and recorded. These values were then compared to the WHO guidelines for drinking water and NSDWQ.

4.2.1 pH of feed and product water

Figure 4.3 shows the pH of three types of feed waters and the corresponding product water. The feed waters had their pH within the limits of WHO and NEQS drinking water parameters except for the saline water whose pH was 5.35 which is well below the lower acceptable limit. It was noted that the pH values of the tap feed and product water did not fluctuate much. On the other hand, the pH for the saline water increased from 5.35 to 7.43. In the case of waste water the pH decreased from 7.84 to 7.54

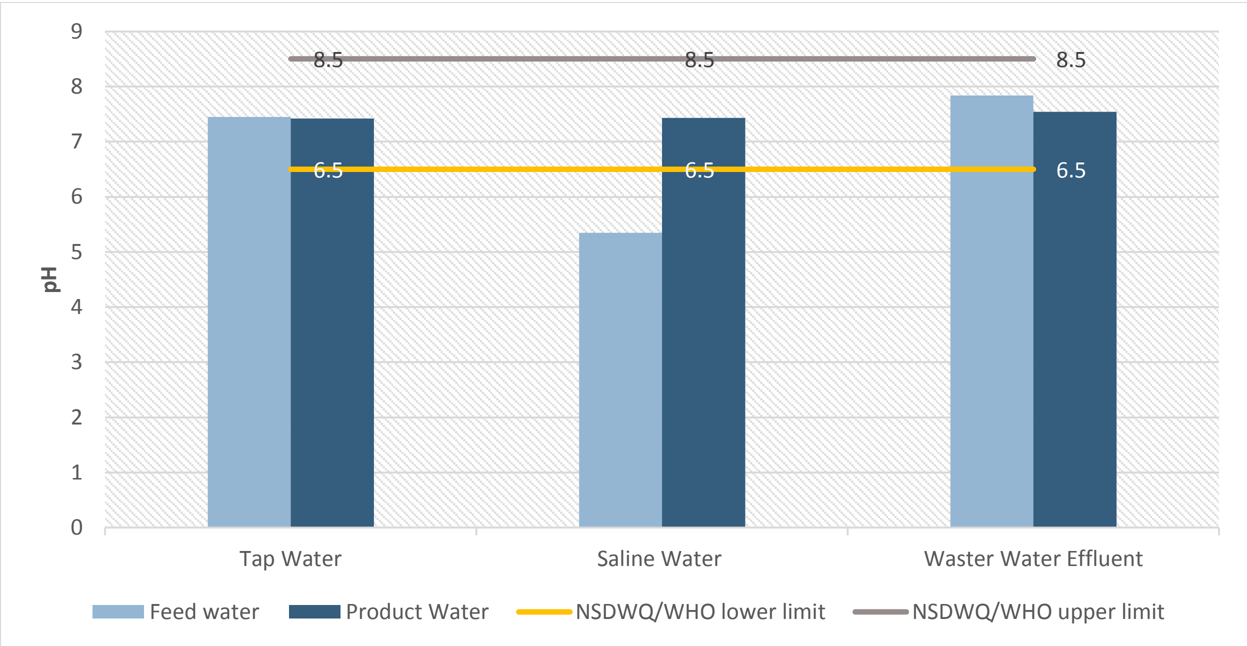


Figure 4.3 pH of feed and product water

4.2.2 TDS of feed and product water

Figure 4.4 shows the results for the total dissolved solids. The feed water TDS were within the limits except for the saline water whose value was noted to be 30900 mg/L which was way above the acceptable limit of 1000 mg/L. TDS of tap water reduced from 433 mg/L to

309 mg/L and that of wastewater reduced from 764 mg/L to 312 mg/L. TDS of saline water showed a decrease of 99.1% after treatment and came out to be well below limit.

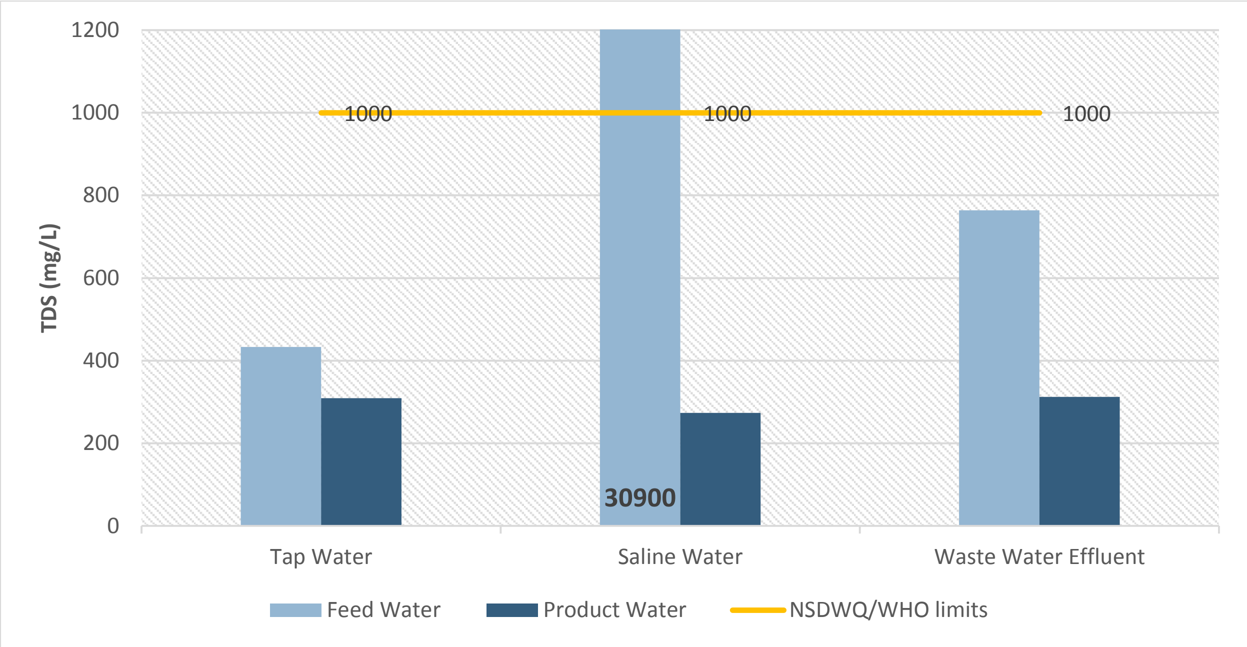


Figure 4.4 TDS of feed and product water

4.2.3 Hardness of feed and product water

Figure 4.5 shows the results for Hardness. The hardness of saline water was noted to be 6630 mg/L as calcium carbonate, which was significantly above the limit of 1000 mg/L, reduced to 325 after treatment. The hardness of tap water decreased from 444mg/L to 308mg/L and that of treated waste water effluent decreased from 504mg/L to 317mg/L. All product waters were within the NSDWQ limit of 500 mg/L and were slightly above the WHO limit of 300mg/L.

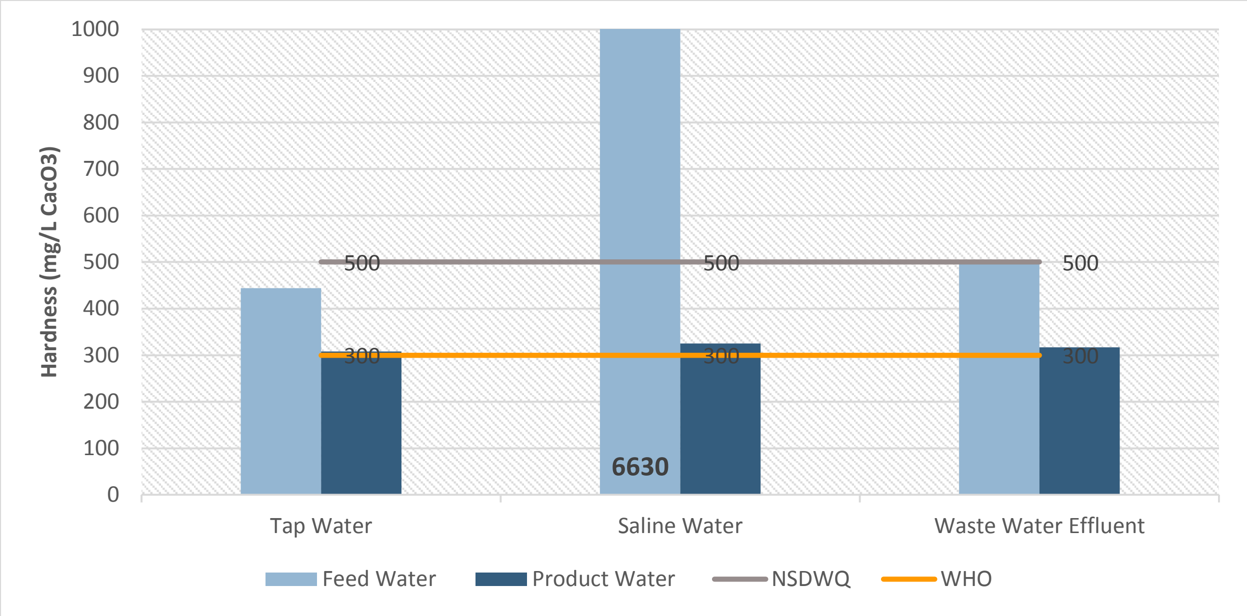


Figure 4.5 Hardness of feed and product water

4.2.4 Turbidity of feed and product water

Figure 4.6 shows the turbidity values of the feed and product water and it was measured that the turbidity of waste water effluent was 8.96 NTU which exceeds the limit of 5 NTU. It was reduced to 0.91 NTU after treatment. The turbidity values for tap and saline water were already under the limit and were further reduced to 0.84 NTU and 0.87 NTU respectively.

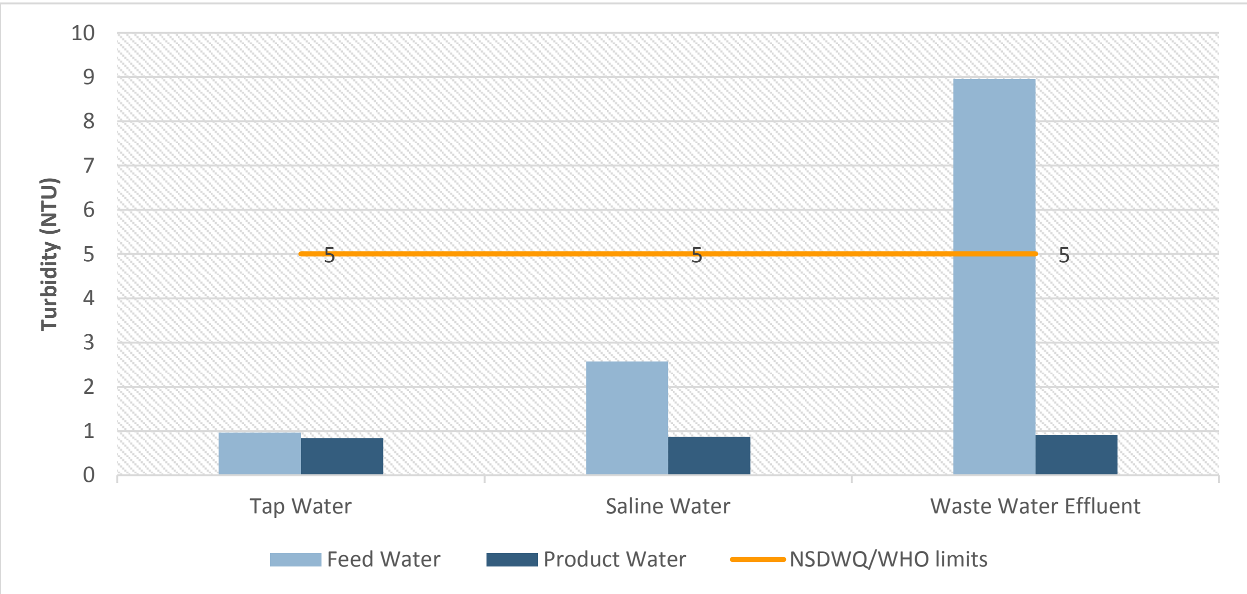


Figure 4.6 Turbidity of feed and product water

4.2.5 Conductivity of feed water and product water

Figure 4.7 shows the conductivity values of the feed and product water. The conductivity of saline feed water was 61.8 milli siemens and was reduced to 547 micro siemens. The conductivity of tap water reduced from 866 micro siemens to 560 micro siemens. The conductivity of waste water reduced from 1528 micro siemens to 566 micro siemens.

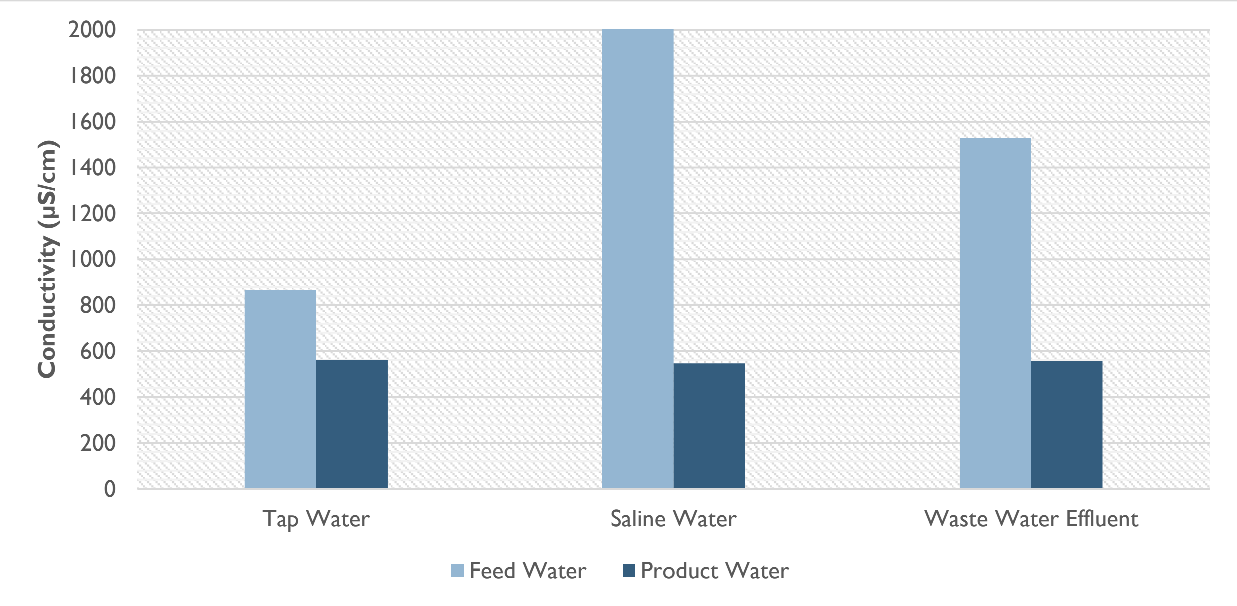


Figure 4.7 Conductivity of feed and product water

4.3 Average yield and productivity

The average yield of product water obtained with the mentioned dimensions of the evaporator and condenser was 350mL/hour for the months in which experiments were conducted (March and April 2019). Productivity of our system in terms of the feed water supplied to the system versus the product water produced out was 83%

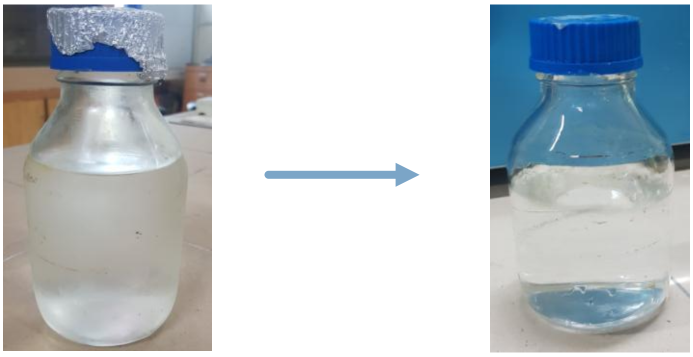


Figure 4.8 Saline feed water vs product water

4.4 Analysis

To analyse the effectiveness of the system, percentage decrease in each of the parameter, for the three types of feed water, was determined and graphed out. Figure 4.9 shows that saline water shows the most decrease in its parameters after treatment (except turbidity) as the initial values of the parameters for saline water varied a lot from the WHO and NSDWQ limits. Of the three feed waters, waste water effluent showed the most decrease in turbidity. This analysis shows that the system is capable of treating feed waters that varies widely from the limits.

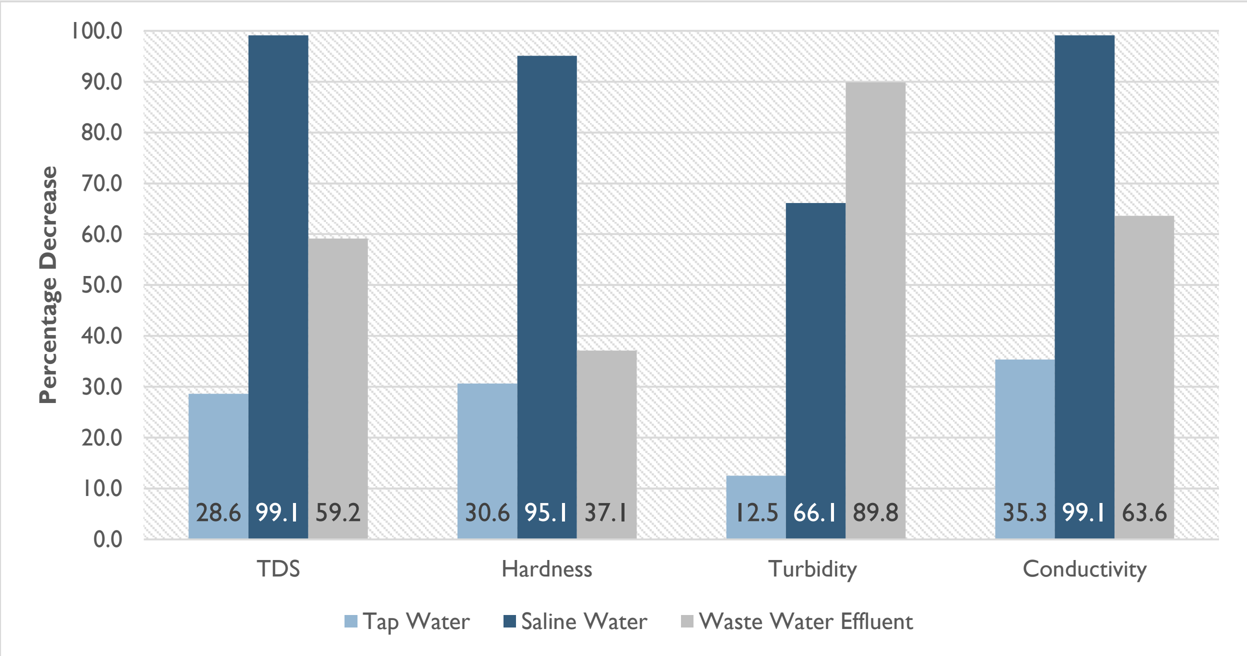


Figure 4.9 Percentage decrease in initial parameters of feed water

5 Cost Analysis

5.1 Cost of evaporation panel and condenser constructed

Table 5.1 summarizes the costs of different materials used to construct the evaporator. The total cost for constructing the evaporator came out to be PKR 3850.

Table 5.1 Cost of materials used for construction of evaporator

Sr. No	Component	Area Used (m^2)	Cost (PKR)	Cost/square meter (PKR/m^2)
1	Mat	0.4	700	1800
2	PVC Pipes	7 (meters)	1000	150
3	Plastic Cover	2	250	130
4	Wire Mesh	0.6	350	600
5	Tap	-	150	-
6	Feed Water Pipe	-	100	-
7	Tools	-	800	-
8	Feed Water Can	-	500	-
9	**Total**	-	**3850**	-

Table 5.2 summarizes the costs of different materials used to construct the condenser. The total cost for constructing the condenser came out to be PKR 8500.

Table 5.2 Cost of materials used for construction of condenser

Sr. No	Component	Length (m)	Cost (PKR)	Cost/square meter (PKR/m^2)
1	Condenser Bucket	-	1000	-
2	Storage Tank	-	500	-
3	Plastic Pipes	10	1000	100
4	Copper Pipes	16	3000	190
5	Manufacturing	-	4000	-
6	**Total**	-	**8500**	-

The total final cost of the product came out to be PKR 12500.

5.2 Cost of evaporator and condenser in case of commercialization

For the purpose of conducting experiments and for ease in modifications, evaporator was constructed using PVC plastics and pipes, which cost lesser than the intended materials of construction i.e.: glass or acrylic and aluminium. Hence, we estimated the cost of the unit if it were commercialized on a large scale. Table 5.3 summarizes the cost of evaporator panel in case of commercialization. The cost of the panel would increase to approximately PKR 14000 as PVC pipes and plastic sheet will be replaced by Aluminium sheet and acrylic respectively.

Table 5.3 Cost of materials used for construction of evaporator in case of commercialization

Sr. No	Component	Cost/square meter (PKR/m^2)	Area Required (m^2)	Cost (PKR)
1	Mat	1800	0.4	700
2	**Aluminum Frame**	**6000**	**0.4**	**2400**
3	**Acrylic**	**2400**	**2**	**4800**
4	Wire Mesh	600	0.6	350
5	Tap	-	-	150
6	Feed Water Pipe	-	-	100
7	Tools	-	-	800
8	Feed Water Can	-	-	500
9	Manufacturing	-	-	4000
10	**Total**			**13800 ≈ 14000**

The cost of condenser would however remain the same. The total cost of the product will increase to PKR 22500. Although due to large scale production of the product the cost would decrease by approximately 20% giving the total cost of the product to be PKR 18000.

6 Conclusion

Based on project objectives of designing an energy efficient, low emissions solar thermal water purification system and cost optimization by making optimal use of energy and use of local materials for system fabrication, the results of the design and research on the product have led to conclude the project as:

- Sufficient availability of solar energy throughout the year ensures yearlong production of purified water to cater the increasing water demand, especially in rural areas where there is no provision of electricity to supply water by other means.
- Productivity of the product in terms of the feed water supplied versus product water produced came out to be 83%, ensuring that very less amount of water is discarded as waste water
- The maximum temperature difference achieved between inside of the evaporation panel and inside of the condenser for the month of March and April 2019 came out to be 37.8°C
- A maximum yield of 350mL per hour was obtained on average for the months of March and April 2019
- All of the drinking water quality parameters of product water are within limit of NSDWQ and the more stringent WHO guidelines.
- This ensures that the unit is capable of treating feed waters that varies widely from the limits.

7 Recommendations

Considering the extent of the project and through comprehensive observations during the course of the project, here are some of the recommendations that we think must prove advantageous in further improving overall system efficiency.

- Since the pump is DC-operated, if we install a small Photovoltaic module in our system to run the pump, during solar energy availability, the system would be completely independent of on-grid electricity in day time. It may be noted that energy utilization of the pump still is very low.
- For the purpose of conducting experiments and for ease in modifications, the panel frame was constructed using PVC pipes, which do not possess enough strength. To ensure durability of the product, PVC pipes should be replaced by Aluminium for panel frame
- In order to easily modify the design, PVC plastic was used as the transparent cover of the panel as it does not cost much. It should be replaced with acrylic for transparent cover

References

- A. E. Kabeel, Z. M. Omara, F. A. Essa, A. S. Abdullah. “Solar still with condenser – A detailed review” *Renewable and Sustainable Energy Reviews (2016); 59:839–857.*
- A. Muthu Manokar, K. Kalidasa Murugavel, G. Esakkimuthu. “Different parameters affecting the rate of evaporation and condensation on passive solar still.” *Renewable and Sustainable Energy Reviews 38 (2014) 309–322*
- Ahsan A, Imteaz M, Thomas UA, Azmi M, Rahman A, Nik Daud NN. “Parameters affecting the performance of a low cost solar still.” *Appl Energy 2014; 114:924–30.*
- Bassam Abu-Hijleh AK, baba’h Hamzeh M. “Experimental study of a solar still with sponge cubes in basin.” *Energy Convers Manag 2003; 44:1411–8.*
- Bhaskar T, Negoro R, Muto A, et al. (2006) “Prevention of chlorinated hydrocarbons formation during pyrolysis of PVC or PVDC mixed plastics.” *Green Chemistry 8:697-700.*
- El Sebaii AA. “Effect of wind speed on active and passive solar stills.” *Energy Convers Manag 2004; 45:1187–204.*
- I.V. Pollet, J.G. Pieters. “PAR transmittances of dry and condensate covered glass and plastic greenhouse cladding.” *Agricultural and Forest Meteorology 2002; 110:285–298.*
- Kalidasa Murugavel K, Chockalingam KnKSK, Srithar K. “Progresses in improving the effectiveness of the single basin passive solar still”. *Desalination 2008; 220:677–86.*
- Lyman J. and Fleming R.H. (1940) “Composition of sea water”. *Journal of marine Research, 3, 134-146.*
- Martin CL, Goswami DY. “Solar energy pocket reference”. *Freiburg: International Solar Energy Society; 2005.*
- National Standards for Drinking Water Quality (2008)
- Phoebe Sleet, “Water Resources in Pakistan: Scarce, Polluted and Poorly Governed.” *Future directions International; 2019.*
- *The Solar Electricity Handbook, 2017*
- World resource institute aqueduct 2014 water risk atlas
- Xiuping Yin, Yuhao Zhang, Jun Zhang. “Transparent plasticised PVC film with ultraviolet and high-energy visible light shielding performance.” *Plastics, Rubber and Composites 2017; 46:9, 375-380.*