SONARGAON UNIVERSITY

Dhaka, Bangladesh

Project on:

DESIGN OF A COST-EFFECTIVE SOLAR STILL FROM BANGLADESH PERSPECTIVE

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Certificate

This is to certify that the thesis entitle "Design of a Cost-Effective Solar Still from Bangladesh Perspective" has been carried out by Md. Arifur Rahman, Roll BME 1803016451, Md. Helalur Rashid, Roll: BME 1603010357, Noyan Ali, Roll: BME 1803016139, Rashadul Islam Sakib, Roll: BME 1803016258, Shahad Shahariar Shuvo, Roll: BME 1803016244 under my supervision in the Department of Mechanical Engineering at Sonargaon University, Bangladesh.

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ABSTRACT

In modern times, several coastal and remote regions face a scarcity of safe drinking water source. The conventional fossil fuels used for boiling the water are also running short day by day, so using renewable energy sources to purify the water is a dire need. In this project a computational model has been developed using appropriate equations and data, in order to optimize solar stills performance. The daily drinking water production rate of a still depends on factors such as solar insolation, ambient temperature, wind velocity, etc. The production rate also depends on still size, shape, inclination angle, wick material properties, insulation system, water depth, heat-storing mediums, etc. The main challenge of this project is the low production rate that depends on the natural conditions and still parameters. Besides, high installation and maintenance cost are also a great concern. So the primary goal of this research is to increase production rate and design the still as a cost-effective one. The study is conducted using meteorological data of specific locations in Bangladesh. At first, a preliminary design of stepped solar still was prepared using Autodesk Fusion360, then its performance was optimized using the computational model. Thus resulting in a final design of the still. The still has polystyrene foam as wick material, copper wire mesh as heat storing medium and external reflectors for enhancing the amount of water production. Maximum distillate water achieved was around 4 liters for Dhaka City and around 4.7 liters for Siddirganj, Naraynganj during the month of March.

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LIST OF ABBREVIATIONS

Ag_2O	Silver Oxide
Al_2O	Aluminium Oxide
ANN	Artificial Neural Network
BDT	Bangladesh Taka
CuO	Copper Oxide
ESMAP	Energy Sector Management Assistance Program
IDCOL	Infrastructure Development Company Limited
INSEL	Integrated Simulation Environment Language kg
	Kilogram
MICS	Minimum Internal Control Standards
mm	millimeter
mg	milligram
m/s	meter per second
NASA	National Aeronautics and Space Administration
NFA	National Food Administration.
PCM	Phase Changing Material
pH	potential of hydrogen
PV	Photo Voltaic
PVC	Polyvinyl Chloride
PVGIS	Photo-voltaic Geographical Information System
RO	Reverse Osmosis
SU	Sonargaon University
TSS	Tubular Solar Still
USD	United States Dollar
USGS	United States Geological Survey
UNICEF	United Nations Children’s Fund
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WHO	World Health Organization
ZLD	Zero Liquid Disch

NOMENCLATURE

P_w Partial pressure of water (P_a)
P_g Partial pressure of gas (P_a)
T_{wi} Initial temperature of water (^{0}C) T_w
Final temperature of water (^{0}C) T_{go}
Initial temperature of glass (^{0}C) T_{gi}
Internal temperature of glass (^{0}C)
$I(t)$ Solar Insolation (W/m^2)
h_{Ewgi} Evaporative heat transfer coefficient from water to glass surface (W/m^{2}K) h_{Cwgi}
Convective heat transfer coefficient from water to glass surface (W/m^{2}K) h_{Rwgi}
Radiative heat transfer coefficient from water to glass surface (W/m^{2}K) Q_{Ewgi}
Evaporative heat transfer rate (W/m^{2}K)
Q_{Cwgi} Convective heat transfer rate (W/m^{2}K)
Q_{Rwgi} Radiative heat transfer rate (W/m^{2}K) V_w
Wind velocity (m/s)
U_{dw} Attenuation factor
A_b Basin horizontal surface area (m^2)
A_{ss} Basin Wall area (m^2)
K_g Thermal conductivity of glass cover(W/mK)
K_w Thermal conductivity of water (W/mK)
L_i Thickness of insulation (m)
L_g Thickness of glass (m)
t Time (s)
R Reflectivity
s_g Emissivity of glass cover
s_w Emissivity of water
α_g Solar absorptivity of glass cover
α_w Solar absorptivity of water
η_d Efficiency of the still

Chapter 1

INTRODUCTION

1.1 Background

Water is the most significant part of the survival of all living forms on Earth. According to the United States Geological Survey USGS (2014) (R-42), water has occupied 71% of our Earth's surface in which the ocean is holding 96.5% of water. But drinkable freshwater is holding up a little fraction of our planet's water which is only 2.5% of our planet's water; among them 0.5% freshwater of total water in the earth is available for human use (USGS(2014) (42).

On average 8.4 million liters are available for each person on earth according to the (Reclamation,2020) (33). People use more than the average available water in their whole life span. So, an alternative idea for fresh drinkable water supply is necessary. So we may have to desalinate seawater for using it as there is scarcity of fresh water. Water may be simply desalinated by burning fossil fuels like gas, oil, coal, etc. But according to in 2018 about 79% of domestic energy production was from fossil fuels and 80% of domestic energy consumption originated from fossil fuels. (33)

Fossil fuels are very limited, so sooner or later we will have to rely on the renewable sources of energy. That is why solar water desalination is an increasing demand nowadays. Solar water desalination is a technique to produce water with a low salt concentration. The drinking water is produced from seawater or from waste water using solar energy to evaporate the water and then condense and collect that vapor. We are using stepped solar still for solar water desalination as it is considered to be more efficient compared to conventional solar stills.

Solar energy is the most abundant form of renewable energy resource. According to Chowdhury (2021) (10), Bangladesh receives around 4.5kWh/m ^{2} solar insolation daily and this can be used to generate energy via solar photovoltaic. Photovoltaic route is increasingly proving itself to be more viable. A geographical distribution of solar energy potential is in figure2.7. It represents long-term average between the years 1999 to 2018. It can be noted that the southeastern part of the country holds higher potential. (10)
Compared to the rest. According to Chowdhury (2021) (10) the southern coastal belt, especially the Meghna estuary region has quite sizeable photovoltaic power and this can be a good location for setting up large scale solar energy based plants. (10)

1.2 Problem Statement

As mentioned earlier, water is the most essential part of our livelihood. Due to the lack of freshwater, people suffer a lot from many waterborne diseases. Solar still is a desalination device that can help people get fresh water. In most of the solar still projects, the researchers have tried to improve the performance and efficiency. There are also some challenges which are-

The lower yield rate of the desalinate device; time-consuming and the device cannot be used without proper availability of sunlight; high foreign equipment investment is needed per unit of water production.

Some factors are related to water production by the solar still which are air velocity, water depth, basin absorption, solar angle, atmospheric pressure and temperature. Count- tries having many seasons, the yield rate differs from one season to another season. The Solar stills fabrication with cost effective materials ensures pure drinkable water at the cheapest rate is possible.

1.3 Objectives

1. To develop solar still device that can help people get fresh water.
2. To analysis the performance of a develop solar still.
3. To design a cost-effective solar still from Bangladesh perspective using the locally available environment-friendly materials.
4. To conduct performance analysis of the solar still in Bangladesh.

1.4 The Main Scopes of the Project

The main purpose of the project is to ensure an improvement in the rural, coastal and slum communities of Bangladesh for having a better source of safe drinking water. The significance may be noted mostly in rural and coastal communities of Bangladesh, as water supply system there is not so established as in the urban areas.

The whole setup can be easily fabricated using the materials that are available in the local market. For getting safe drinking water, solar still desalination is being considered as one of the cheapest methods rather than using conventional water purification methods. So implementation of solar water purification units may result in making more healthy and progressive communities.

There are lot of factors in this project that can be improved thoroughly with the flow of time such as- increasing efficiency of the solar water purifier, having better design parameters, having proper system for the usage of heat energy.

In chapter one, a overview about the thesis project is given including backgrounds, objectives of the project and also the problems which are going to be faced.

In chapter two, about various types of solar stills are discussed. Then the codes, standards and guidelines for water consumption are discussed shortly. Then literature review is done on various existing research projects.

In chapter three, project methodologies are discussed and shown in a flow chart. In chapter four, design specification of the project are discussed with justifications. At last the result of the project is discussed in chapter five.

Chapter 2

LITERATURE REVIEW

2.1 What is Solar Still?

Solar still is a process where it absorbs solar radiation and use that energy of heat to evaporate the supplied water. When water evaporates, it cannot carry the soluble mineral salts and impurities with it. That is how saline and impure water can be detached from the salts and impurities by using solar radiation. After that the evaporated water have to be condensed for later usage. The whole system remains insulated just to prevent heat loss and vapor loss.

2.2 Heat Transfer Process in Solar Still

Performance of solar still is based on productivity, efficiency as well as internal heat and mass transfer coefficient. Internal heat and mass transfer coefficient in the solar still are based on three parameters called convection, radiation and evaporation. hence there are three heat transfer coefficients called convective heat transfer coefficient, radiation heat transfer coefficient and evaporation heat transfer coefficient.

- Convection heat transfer: Action of the buoyancy force due to the density difference of humid air. Temperature difference is the major reason behind the convective heat transfer coefficient in solar still.
- Radiation heat transfer: Solar energy is responsible for the formation of pure water from the solar still. Radiation heat transfer also happens due to the energy from the Sun.
- Evaporation heat transfer: When solar energy is incident inside the solar still, water evaporates and converts into steam.

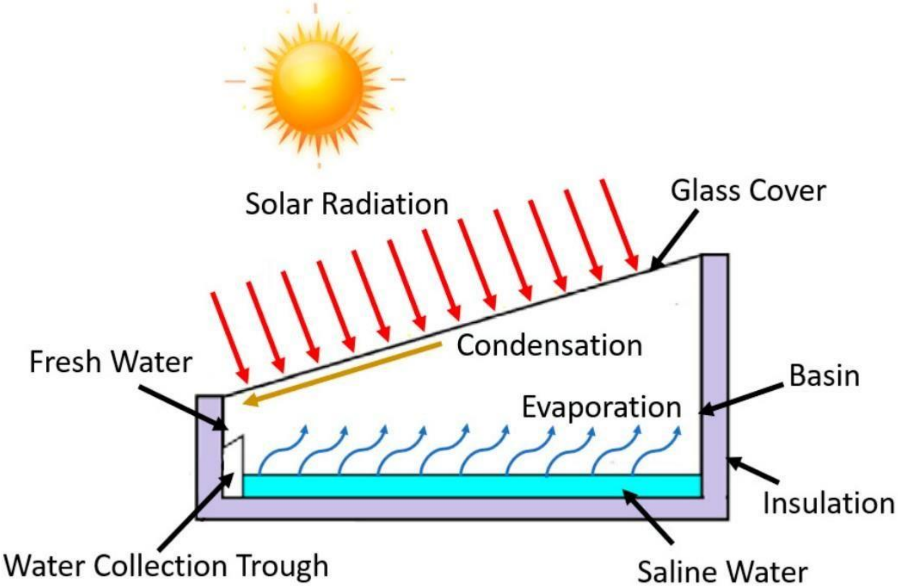


Figure 2.1: Simple Solar Still.
Adopted From:Johnson et al.(2019) Figure 3, p. 5)

2.3 Different Types of Solar Stills

There are different types of solar stills, they are-

- Spherical Solar Still (Arunkumar et al.,2012a)
- Pyramid Solar Still (Arunkumar et al.,2012a)
- Hemispherical Solar Still (Arunkumar et al.,2012a)
- Double-Basin Solar Still (Arunkumar et al.,2012a)
- Tubular Solar Still (Arunkumar et al.,2012a)
- CPC-TSS Solar Still (Arunkumar et al.,2012a)
- CPC-Pyramid Solar Still (Arunkumar et al.,2012a)
- Spherical Basin Solar Still (Arunkumar et al.,2012a)
- Single-Effect Single-Slope Condenser Solar Still (Rubio et al.,2020)
- Single-Effect Double-Slope Condenser Solar Still (Rubio et al.,2020)

2.4 Types of Solar Still Models Available

Many types of solar still are available, among them few of the basic types are discussed below in brief.

2.4.1 Single-effect single slope solar still

Single slope solar still is one of the most basic designs of solar still. This type of solar still consists of a single transparent cover on top of the water basin and the water collector is set in the bottom as water slides down using the internal slope of the top cover. It is very easy to fabricate and gives a specific amount of output depending on various geographical conditions.

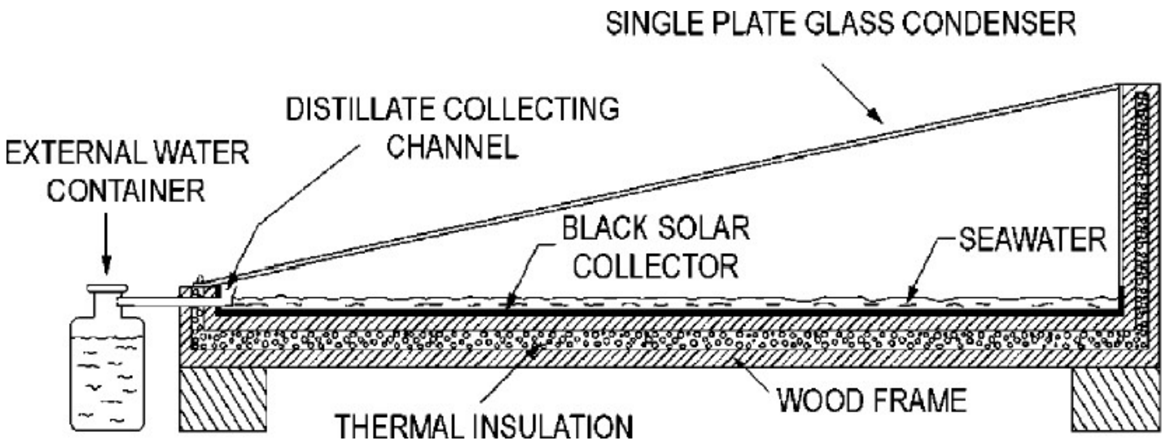


Figure 2.2: Single-Effect Single-Slop Solar Still.

Attribution: Adopted from((Rubio et al. 2020, Figure 1, p. 2) t2020 by the authors. Licensee MDPI, Basel, Switzerland.

2.4.2 Pyramid Solar Still

In a pyramid type solar still, two transparent covers are placed on top of the water basin. Pyramid shaped solar still is considered to be more efficient according to Arunkumar et al. (2012b) (6).

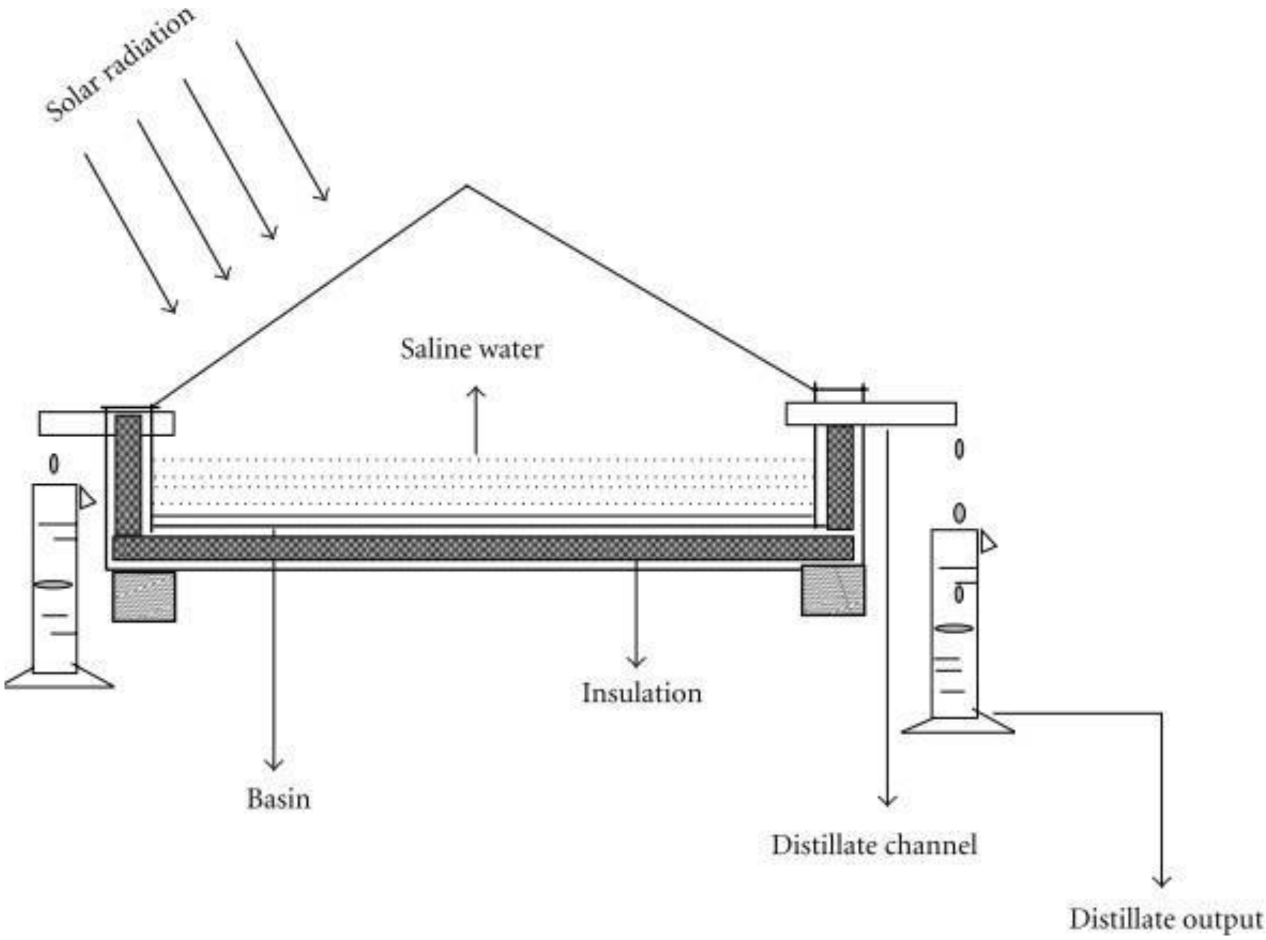


Figure 2.3: Pyramid Type Solar Still.

2.4.3 Spherical Shaped Solar Still

A circular absorption basin is situated in the middle of the device which is coated with black paint just to absorb the maximum solar radiation falling on it. An absorber basin can't be physically connected with the thin layer of transparent polythene cover. According to the experimental result, spherical solar still efficiency is observed 30% more than the conventional solar still.

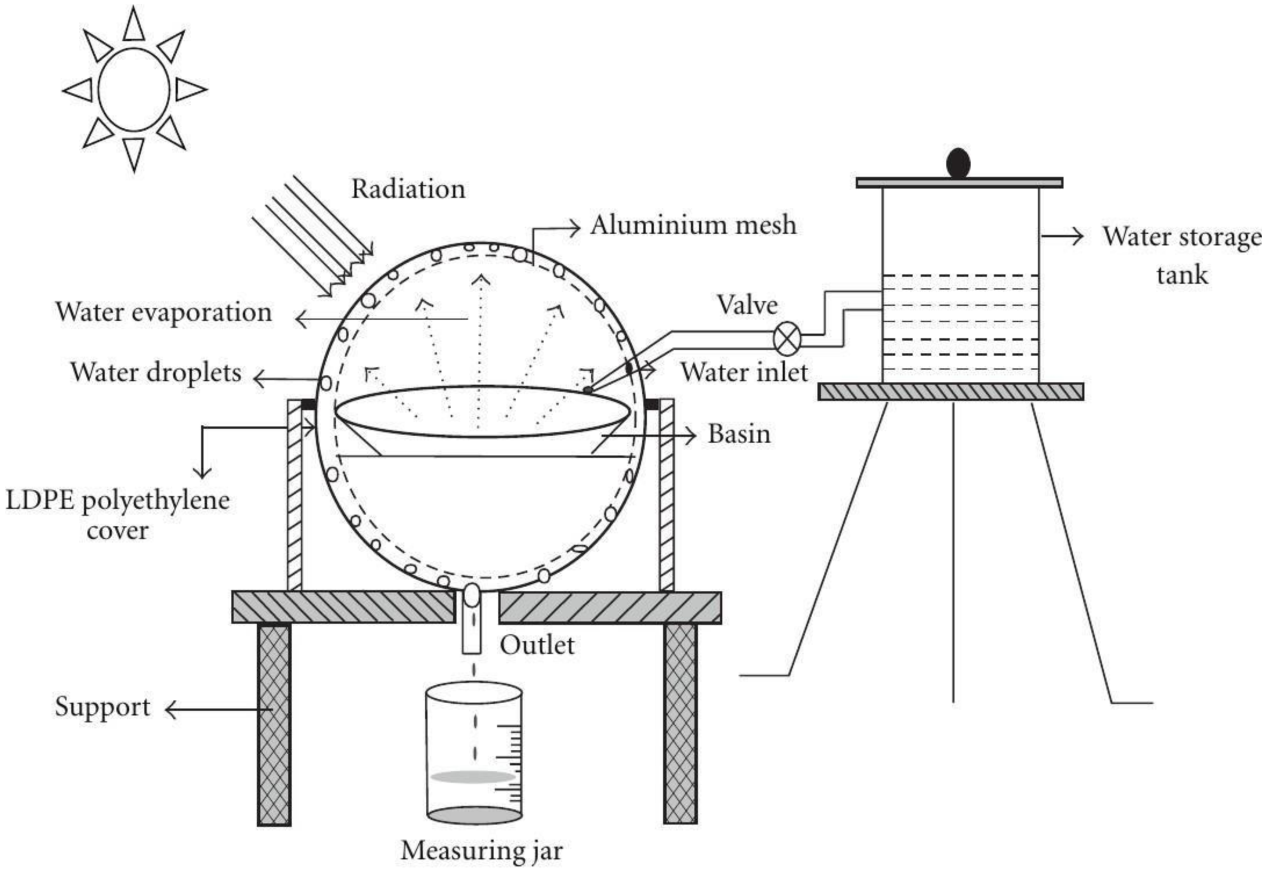


Figure 2.4: Spherical Solar Still
Attribution: Adopted from (Arunkumar et al.(2012b), Figure 2) c 2012 T. Arunkumar et al. Distributed under the Creative Commons Attribution (CC BY) license

2.4.4 Hemispherical Solar Still

According to Arunkumar et al.(2012b) (6), Distilled water production of hemispherical solar still varies from 3580 to 3680$ml/m^2/day$. In the case of this design, the daily average water productivity is increased from 3660 to 4200$ml/m^2/day$ with fixed water supply flow rate of 10 ml/min. Consequently, water productivity increases to about 15% due to the effect of condensation. (6)

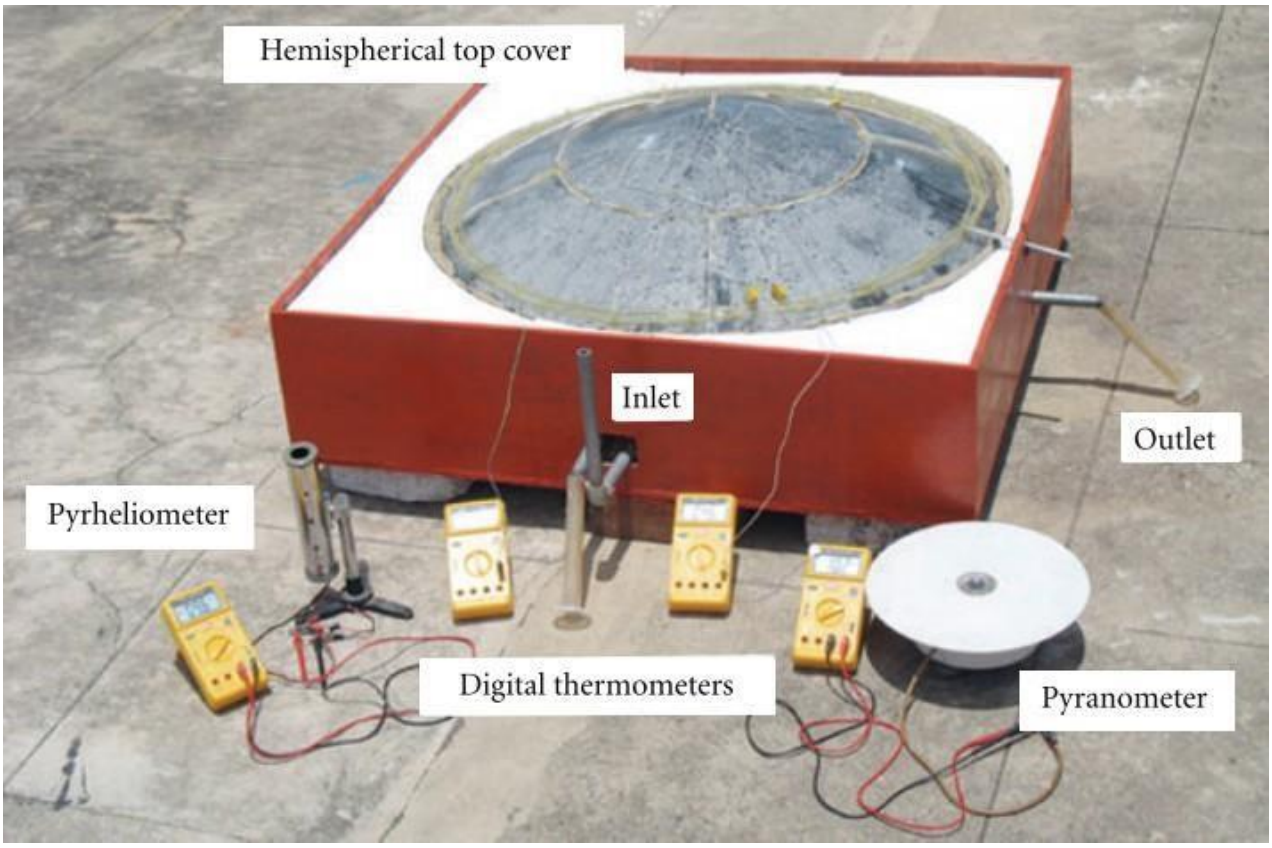


Figure 2.5: Hemispherical Solar Still.

2.5 Potential of Solar Energy in Bangladesh

A solar energy-based project such as solar still has the potential to produce a better cost-effective supply of drinking water for rural and coastal communities in Bangladesh. The maximum radiation is found throughout March and April as estimated a result by "RETScreen expert" version 8.0 the utmost radiation can be noted as 5.76KWh/m^2/d during April as shown below-

	Unit	Climate data location	Facility location	Source
Latitude		23.7	23.8	
Longitude		90.4	90.4	
Climate zone		1A - Very hot - Humid		NASA
Elevation	m	9	17	NASA – Map
Heating design temperature	°C	14.6		NASA
Cooling design temperature	°C	31.6		NASA
Earth temperature amplitude	°C	14.2		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	18.4	51.6%	5.58	4.36	101.4	2.5	18.1	0	260
February	22.2	42.6%	13.16	4.92	101.2	2.5	22.2	0	342
March	27.4	40.0%	31.93	5.59	100.8	2.8	28.0	0	539
April	30.6	51.9%	84.90	5.76	100.6	3.6	31.8	0	618
May	30.6	65.3%	182.28	5.30	100.3	3.8	31.6	0	639
June	29.5	79.4%	233.70	4.53	99.9	4.3	30.0	0	585
July	28.7	85.1%	256.06	4.23	100.0	4.3	29.0	0	580
August	28.5	85.6%	218.86	4.29	100.1	3.7	28.8	0	574
September	27.9	85.3%	197.40	4.02	100.4	3.0	28.1	0	537
October	26.5	77.9%	118.73	4.32	100.8	2.2	26.6	0	512
November	23.1	68.4%	21.30	4.28	101.2	2.1	22.9	0	393
December	19.4	61.8%	8.06	4.21	101.4	2.2	19.0	0	291
Annual	**26.1**	**66.4%**	**1,371.96**	**4.65**	**100.7**	**3.1**	**26.4**	**0**	**5,869**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA

Figure 2.6: Solar Radiation for Dhaka City ("RETScreen expert" version 8.0) Screenshot.

From the above table, it can be noted that for the implementation of solar still plants in Bangladesh, an abundance of solar radiation is of great potential.

According to Global Solar Atlas (GlobalSolarAtlas,2020) (20), Bangladesh is located between 20°and 27°north latitude and 88°and 93°east longitude having a complete land area of 1,48,460 km^2. From the map of Bangladesh in figure2.7it can be seen that solar radiation falls in this area around 300 days per annum. (20)

The south-eastern part of Bangladesh which are near to the equator, receives the most solar insolation from the sun. The central part of Bangladesh where Dhaka is located, receives one of the least amount of insolation. So implementing solar energy based devices in south-eastern regions will give the most output compared to other regions.

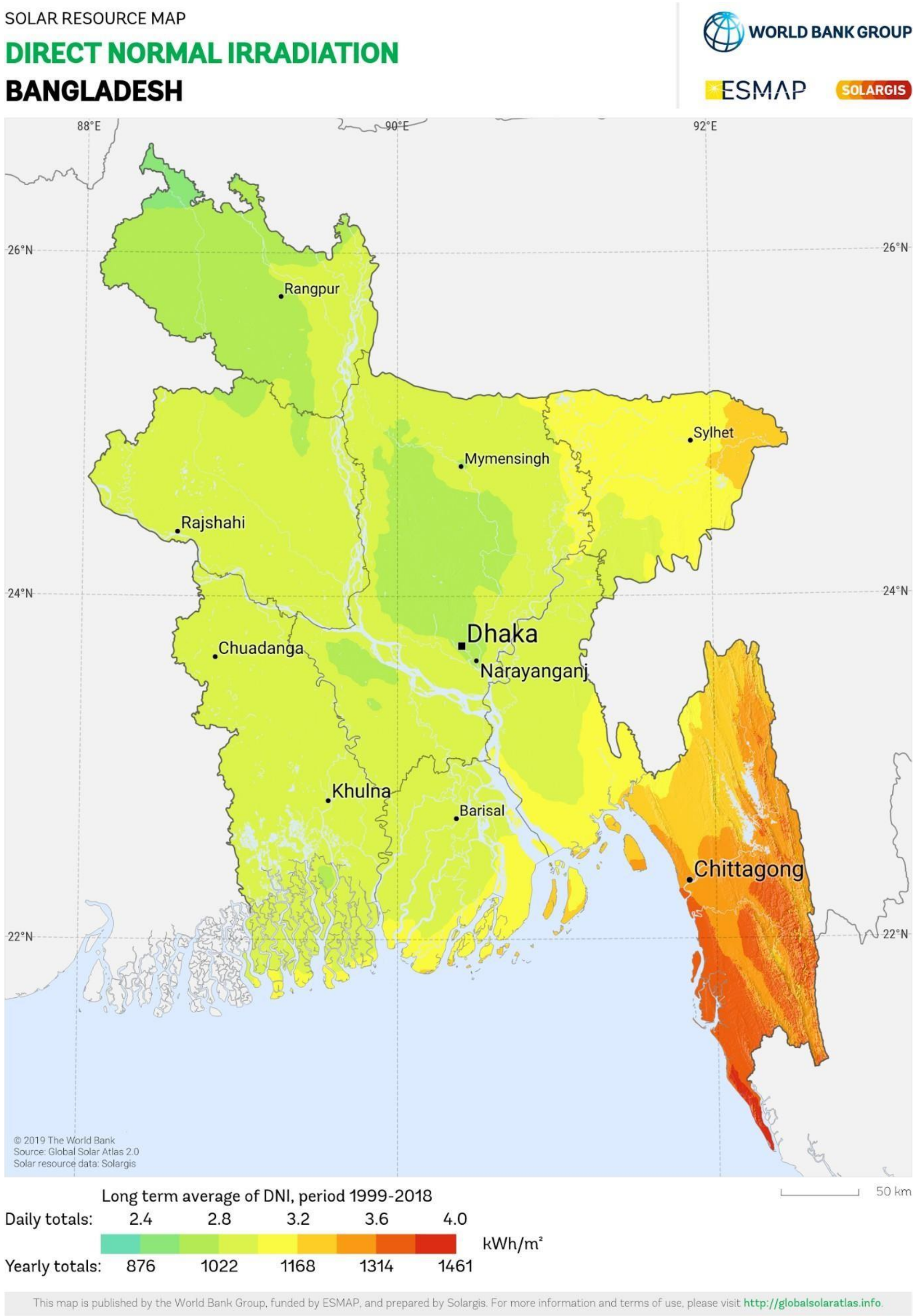


Figure 2.7: Direct Normal Irradiation According to Global Solar Atlas 2020.

2.6 Solar Resource Assessments

2.6.1 Solar Azimuth Angle, φ

According topveducation.org (2021) (31), the azimuth angle is the compass direction from which the sunlight is coming. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown in the illustrations below that were illustrated using MS Paint. (31)

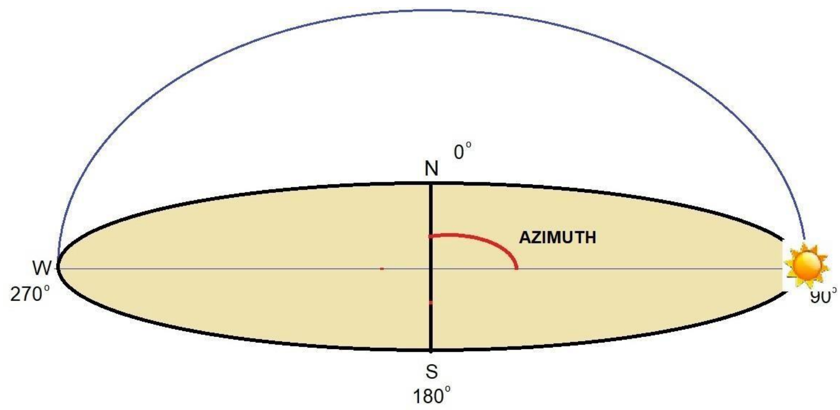


Figure 2.8: At sunrise on the Spring & Fall equinox, the azimuth angle is 90°.

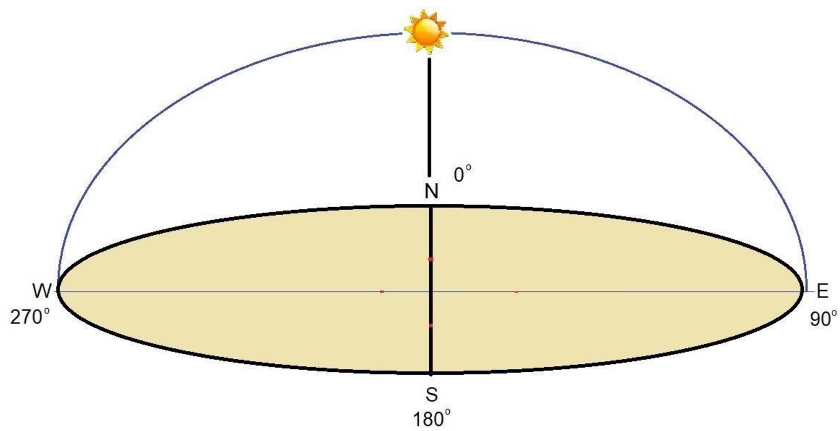


Figure 2.9: At solar noon the azimuth angle is 0°.

At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90°at sunrise and 270°at sunset.

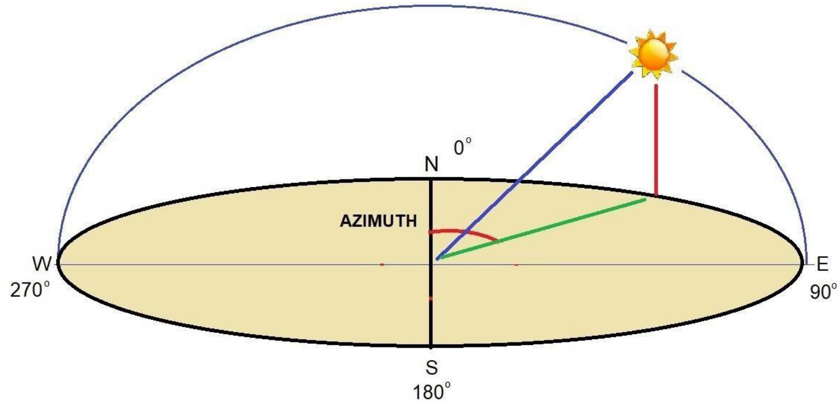


Figure 2.10: The azimuth angle is like a compass direction with North=0°& South=180°.

In general however, the azimuth angle varies with the latitude and time of year. The Azimuth angle calculation formula is given belowpveducation.org (2021) (31).

2.6.2 Elevation Angle, α

According topveducation.org (2021) (31) The elevation angle is the angular height of the sun in the sky measured from the horizontal. Confusingly, both altitude and elevation are also used to describe the height in meters above sea level. The elevation is 0°at sunrise and 90°when the sun is directly overheadpveducation.org (2021) (31). It can varies throughout the day & also depends on the latitude of a particular location and the day of the year pveducation.org (2021) (31).

2.7 Domestic Water Consumption in Bangladesh

As estimated by UNICEF, 97% of our total population has access to improved water sources, but access to safe drinking water is not high which only around 34.6% is. It is an irony that 41% of drinking water available to people is contaminated due to faecal material WHO (2008) (43). It has been estimated by UNICEF that almost one-third of drinking water is polluted with the presence of E.coli bacteria which is the cause of diarrhoea. According to the MICS (UNICEF,2021) (41) survey, microbial contamination is making this worse. In the case of water transportation from the source, 38.3% of our total population in Bangladesh drink water from contaminated sources. Natural calamities like floods, landslides and cyclones are also the reason for water contamination. (41,43)

2.8 Codes/ Guidelines

2.8.1 WHO Recommendations

Recommended levels of iron and manganese in drinking water must be 2 mg/l and 0.5mg/l respectively WHO2008 (43). High levels of manganese also have neurological effects.

Toxicity studies on laboratory animals given manganese in drinking water shows that 0.5 mg/liter is sufficient for the protection of public health WHO (2008) (43). The guideline value is calculated for 0.06 mg manganese per kg body weight for a person with a body mass of 60 kg and 20 % of daily intake of manganese through water (2 L/day). (43)

2.8.1 Water Purification

According to National Food Administration Sweden NFA (2020) (27), chemical usage should be prevented for the work environment and economic reasons. Water treatment must strive as simply as possible. (27)

2.8.2 Oxidation

“Oxidation is the method of adding oxygen into the water, which is done for the following reasons: disinfection, precipitation of iron and manganese, removal of smell and taste and removal of other organic substances” (Ahmad,2012) (13).

Common methods of oxidation are aeration and chemical oxidation, but electro-chemical oxidation has been proven to be more effective, although the method is not used on a larger scale. Oxidant requirements and reaction times can be seen in the table below (Ahmad, 2012) (13).

Table 2.1: Oxidant Requirements and Reaction Times.

	Iron		Manganese	
O_2	0.14 mg	< 1 min- hrs, pH-dependent	0.29 mg	80 min-days,pH-dependent
O_2	0.43 mg	<2 min	0.67 mg	< 5 min
ClO_2	1.2 mg	<5min	2.4 mg	<5 min
$KMnO_2$	0.94 mg	<5min	1.92 mg	<7 min

2.9 Commercial Products in Bangladesh

- **F-Cube Limited:** F-cube limited, Australia is a global brand that has comer- chilly launched the solar still system in 20 countries around the world. F-Cubed was created to develop solar-thermal desalination, a zero liquid discharge (ZLD), and solar water treatment systems. The system meets the critical need for clean drinking water, producing clean water from saline or contaminated sources.

  This is less expensive than conventional systems (reverse osmosis technology) and, above all, a zero liquid discharge (ZLD). It ensures secure, high-quality drinking water from any source, including seawater, freshwater, and polluted or contaminated water, from any source. It also incorporates ZLD (Zero liquid discharge) technology when the plates are in a series, converting the remaining brine into drinking water and precious fractionated salts (F-cubed,2020) **(17).**

2.10 Previous Research Activities

- **A solar powered desalination system for remote region in Bangladesh**

  A desalination process using reverse osmosis was suggested in this research article. Initially, they designed this desalination system for 10 families and each family has 5 people. Each person needs 2 litres of water per day. The cost of separating water per litre is 0.024 BDT which is more efficient than the existing mineral water system in Bangladesh. For this research, they select the Swandwip region of Bangladesh.

- **Effect of top cover material on the productivity of solar distillation unit**

  This study primarily considers the feasibility of using a transparent PVC cover that stretches instead of the transparent glass sheets traditionally used in solar-powered devices.

- **Design, Construction and Performance Test of a Solar Still for Water Desalination in Bangladesh Perspective**

  Basin type solar still was used for the project. The solar still was designed to purify clean water. The maximum temperature of basin water and glass was 57^0C and 45.5^0C, respectively. The maximum output per hour was 150 mph with a maximum efficiency of 26.32%.

- **Solar desalination using low-cost tubular solar still (TSS)**

  This research relates to tabular solar stills. Tabular solar is still very simple and construction costs are very low. Analysis shows that the solar still production rate mainly depends on the intensity of solar radiation and the rate of production in the summer is high. The average daily production rates of the tube solar system were still 2.074L/m^2 a day.

  The production cost of distilled water is 0.453 taka/liter. Tubular solar still systems can be built from locally available materials to produce salt-water from remote, coastal, and arid regions to meet freshwater needs of all sizes.

2.11 Design Parameters

2.11.1 Number of Steps in the Still Basin

Stepped type solar still performs better compared to conventional single basin solar still. Velmurugan et al.(2008) (42) have done several experiments on stepped solar still with output raised by 98% over conventional still. (42)

In a stepped type solar still the large basin surface is divided into a number of small steps resulting in better performance over conventional still where only a single basin is used with no steps.

2.11.2 Water Depth

According to an experiment conducted by Kabeel et al. (2012) (24), the maximum yield of 53.7% can be obtained by using a 5 mm water depth and 120 mm width of the tray. (24)

2.11.3 Top Cover Related Parameters

A top transparent cover mostly made of glass is used in the solar still. Solar radiation passes through the cover and heats up the basin water. Various parameters of top cover are maintained in order to get the best performance.

- **Inclination Angle of the Top Cover**

  The amount of freshwater production is heavily dependent on the inclination of the top cover, El-Samadony et al.(2016) (15) . The proper cover inclination increases productivity by 22.3%. The inclination of the cover to the ground must be equal to the latitude of that place and facing south, in order to achieve the maximum performance ElSamadony et al.(2016). (15)

- **Material of the Top Cover**

  When it comes to material, glass gives the best performance, according to the study conducted by Begum et al (2018) (7) the solar still temperature rises much higher if glass cover is used instead of PVC. The productivity was 53% more when glass was used instead of PVC. (7)

- **Thickness of the Top Cover**

Glass cover of 3mm thickness increases productivity by 16.5% more Ghoneyem and Ileri (1997) (19) . 3 mm thick glass can be easily found in local markets of Bangladesh. (19)

- **Distance between the Top Cover and Water Surface**

According to a study conducted inGhoneyem and Ileri(1997) (19), the vertical distance between cover and water must be within 8 cm, as a result, the performance may increase by 11%. (19)

2.11.4 Wick Material Related Parameters

Several experiments performed by Hansen et al.(2015) (22), using different wick materials and wire mesh. The maximum distillation was 4.28 litres/day by using water coral fleece fabric with wire mesh-stepped absorber plate. (22)

Water coral fleece with stepped wire mesh absorber can increase the output productivity of the still by 71.2% and 58% when polystyrene sponge with stepped wire mesh is used.

Further, it can be estimated that in the context of Bangladesh to fabricate a cost- effective solar still desalination, water coral fleece can be used to give the best performance. But it is the common property of coral fleece fabric to degrade performance if exposed to water for a long time, so as an alternative polystyrene sponge can be used as an absorber material. According to the study Hansen et al.(2015) (22), productivity can be reached up to 3.9l /day and it is also commercially available. (22)

2.11.5 Heat Storing Medium Related Parameters

According to Patel and Kumar (2016) (29) , productivity increases by 11.24% when energy absorbing medium is implemented in the still. Charcoal, black gravel, etc can increase the absorbed solar radiation in water.(29)

In the context of Bangladesh, charcoal is easily available and cheap, so using charcoal may bring a cost-effective benefit. The productivity increases by using aluminum filling as an energy storage system beneath the absorber plate Abdullah (2013) (1).

The tray of solar still can be made with copper sheet, having thermal conductivity around 380 W/mK to 401 W/mK depending on the material grade and various other factors Cengel and 1Boles(2015) (9).Copper can be used, due to the reason of having a high thermal conductivity at a low cost, thus enhancing the overall output of the still. (9).

- **Absorber Plate Shape**

Convex and concave shaped absorber plates increase the efficiency of Solar still. They increase the production by 56.60% and 29.24% higher respectively Gawande and Bhuyar (2013) (18).

2.11.6 Insulation Related Parameters

If insulated, we can prevent unwanted heat loss from the solar still. As mentioned in the study Ghoneyem and Ileri(1997) (19). So important parameters regarding insulation are noted below. (19).

• **Insulation Material and Thickness**

26% heat loss can be avoided by using sawdust as an insulator (25 mm thick) and distillate productivity can be increased by 7%. Rubber is also a very good insulating material.

2.11.7 Reflectors Related Parameters

Reflectors play a a important role in enhancing the output of solar stills. Various experi- ments with internal and external reflectors are conducted in Tanaka (2011) (40) and Omara et al.(2014). (28)

- **Internal and External reflector**

  According to Tanaka (2011) (40), the performance can be increased by 48% by using an internal reflector. It has been further stated. That the performance can be increased by 25%-
  65% using a flat external bottom reflector Tanaka (2011. (40)

- **Inclination Angle of Reflectors**

The productivity of a solar still can be increased by 125% over conventional stills, by using internal and external reflectors. Omara et al.(2014) (28)

The reflector's angles needed for various seasons are provided below Tanaka(2010), Tanaka(2011) (40)

Table 2.2: Reflector Angle During Various Seasons.

Reflector angle	Spring	Summer	Autumn	Winter	Reference
Top Y^0	7_0	15_0	8_0	15_0	Tanaka(2010)
Bottom X^0	30_0	50_0	30_0	20_0	Tanaka(2011)

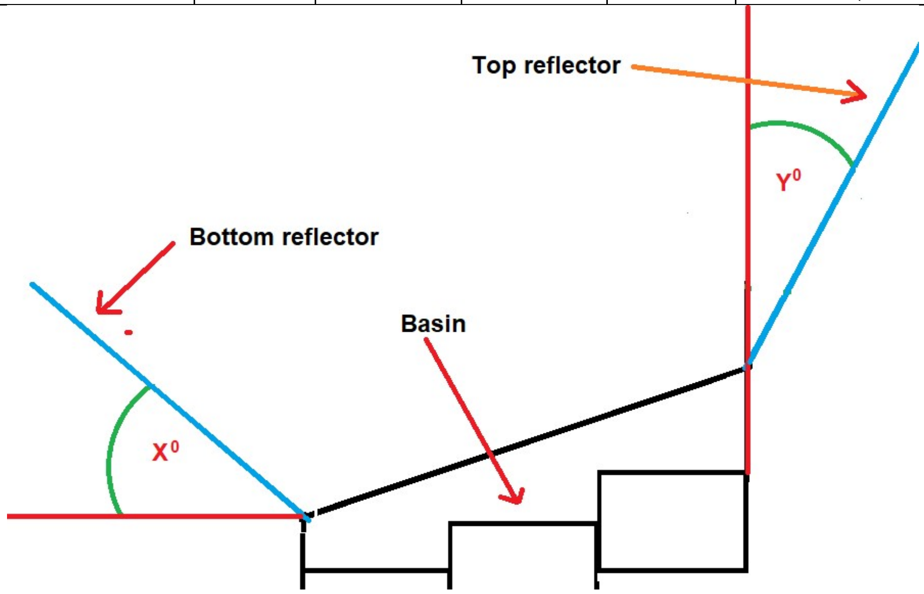


Figure 2.12: Reflector Angle

2.11.8 Additives Related Parameters

Various additives such as PCM and nanoparticles play significant role in enhancing the output of a solar still.

- **Phase Changing Material (PCM)**

  Phase changing material plays a great role as an enhancement parameter. A study conducted in El-Sebaii et al.(2009) (16) shows that the daily productivity can be increased by 85.3% by using PCM (16).

  Using Stearic acid underneath the basin can improve productivity by 80%El-Sebaii et al.(2009). “Fatty acids like cupric acid (655 mol%) + lauric acid (35 mol%) is an organic PCM” Dimaano and Watanabe (2002) (16).

  “Among inorganic PCMs there are salt hydrates, manganese nitrate healthy- (64.0 wt%) + stearic acid (36.0 wt%)”Nagano et al.(2004) (26) . Lauric acid gives 22% higher productivity. (26)

- **Nanoparticles**

  Water productivity can be increased by 30% using CuO nanoparticle as an additive Gupta et al.(2016) (21). Water productivity can also be increased by 50% by using graphite nanoparticlesSharshir et al.(2017b). (21, 37).

2.12 Calculation Formulas

In order to calculate the overall performance of a solar still, various equations are used and among those, few are given below. The employed equations were developed by Agrawal et al.(2017) (2), Dunkle (1961) (13), Sharshir et al.(2017a) (36) and the analysis was done using Microsoft Excel spreadsheets.(2,13,36)

2.12.1 Heat Transfer Related Formulas

The formulas used for internal and external heat transfer are given below Dunkle (1961) (13):

2.12.2 Important Assumptions for the Computational Model

Some important assumptions were made in the computational model in order to optimize it for best output. The assumptions are given below (Johnson et al.,2019) (23):

1. The solar still has no vapor leakage.
2. Various properties were kept constant even with temperature variation.
3. The physical water properties remain constant even with different temperatures.
4. Water quality is not brought into consideration.
5. Compared to the heat capacity of the basin water, the heat capacity of insulating materials used in the solar still is negligible.

Chapter 3

METHODOLOGY

Methodology is the specific procedures or techniques for completing a certain formal work. Those certain steps of continuous progress need to be followed to make a successful work. So, here the continuous steps of progress that have been followed are illustrated below.

Figure 3.1: Research Methodology for the Final Year Project.

Chapter 4

DESIGN SPECIFICATIONS

4.1 Preliminary Design Specifications

The Solar still has been designed using Autodesk Fusion 360 with a minimum expected output around 4.5 litres of fresh water per day. The feed water capacity will be around 8 litres per day.

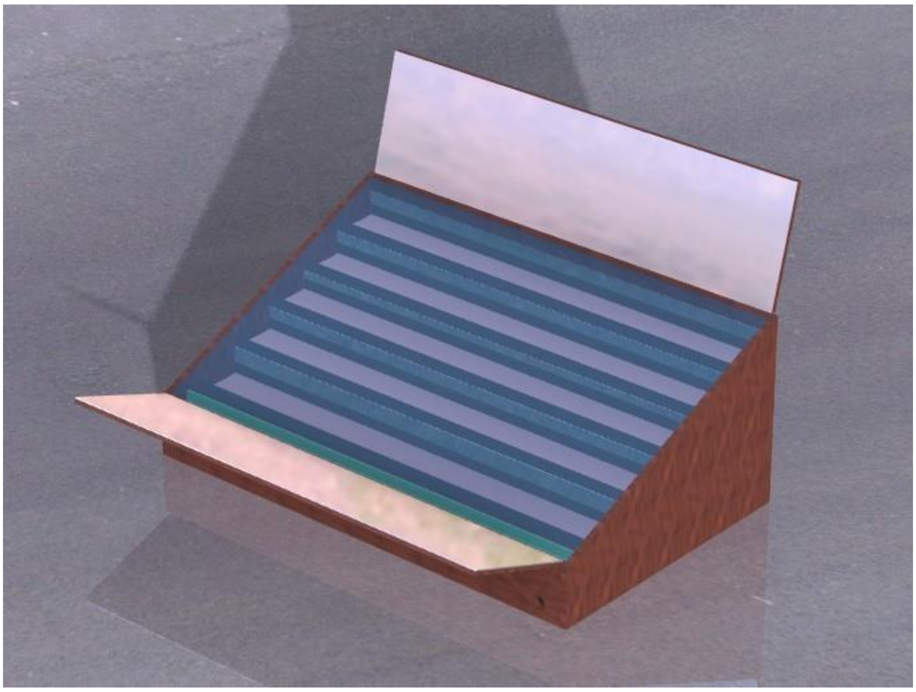


Figure 4.1: Designed Solar Still.

By using the given formulas shown in section 2.10 of chapter 2, the rate of internal heat transfer, external heat transfer, water production etc were calculated. The detailed dimensions and properties of various components used in the still are given below.

4.1.1 Basin and Tray Related Parameters

The basin is divided into 5 steps and each step will have 1 tray made of copper so in total 5 trays are used in the still. Basin is made up of wood which is available commercially and having solar absorptivity α_b = 0.59 Cengel (2013) (8)

Table 4.1: Basin and Tray Dimensions (mm).

Parameter	Dimension (mm)
Basin Length	1000
Basin Width	600
Surface Area	$0.6m^2$
Basin wall thickness	20
Tray Length	1000
Tray Width	120
Tray Height	50
Tray Thickness	2

The basin will be painted with black spray paint having solar absorptivity of α_p= 0.97 Cengel and Boles (2015) (9). Wood is selected for the basin frame because it acts as a very good insulating medium. The side view of the still in millimeter scale is given below. (9).

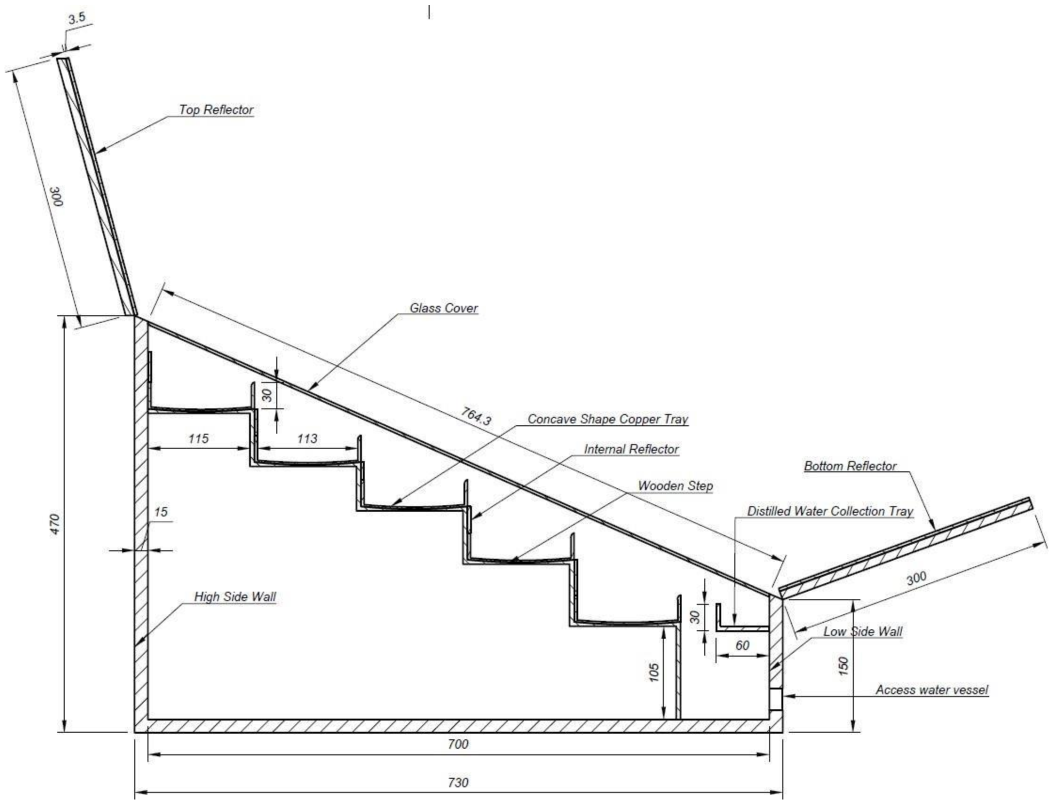


Figure 4.2: Side View of Solar Still (Unit is Millimeter).

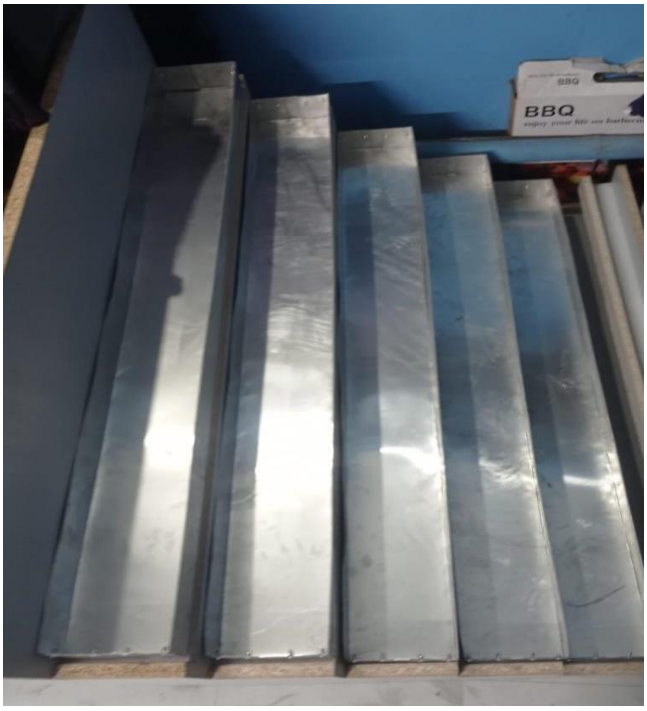


Figure : Illustration of Copper Tray (From Practical).

The number of trays is 5 due to the reason that the total surface area covered is 0.6 m^2. By using 5 trays the expected output is around 3.5-4.5 liters/day. The parameters are taken as experimental values and will be optimized according to the simulation output.

4.1.2 Wick Material and Heat Storing Medium Related Parameters

In the table4.2detailed properties of wick materials have been shown. Polystyrene sponge does not degrade the same as water coral fleece. So it will be a better choice to use polystyrene sponge over water coral fleece in order to minimize the cost of maintenance of the still.

Table 4.2: The Properties of Wick Materials.

Wick	Porosity	Absorbency	Capillary rise(mm/h)	Reference
Polystyrene sponge	52.06%	300	0	Hansen et al.(2015) (22)
Water coral fleece	69.67%	2	10	Hansen et al.(2015) (22)

Water coral fleece can gain peak temperatures around 75^0 C but the main problem is with the degradation that will cause problems with water purification Hansen et al.(2015) (22). The wick will be wrapped around a copper plate or a wire mesh with a goal to enhance the productivity.

The cross section area and diameter of the copper mesh is not yet justified but for experimental validations the parameters will be selected according to El-Said et al.(2020) (14).

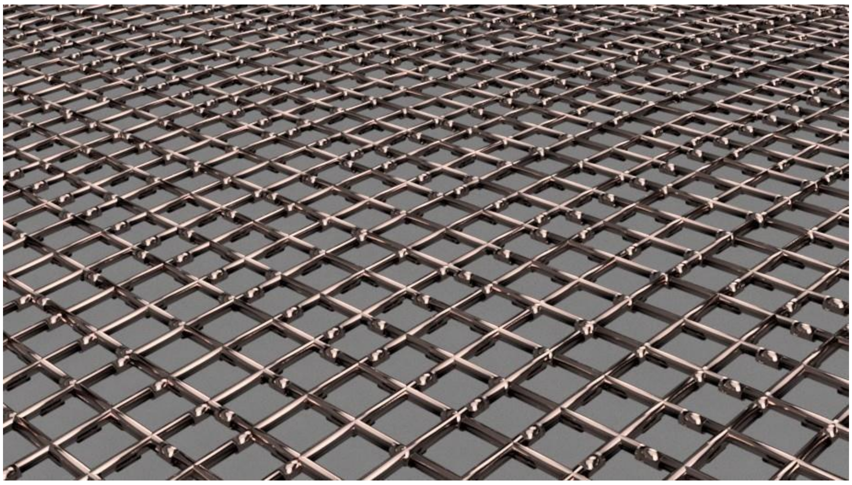


Figure 4.4: Copper Wire Mesh.

Figure 4.5: Copper Plate/Mesh Wrapped in Wick.

- **Additives**

CuO nanoparticles will be used to enhance the output capacity of the solar still. Ac- cording to the analysis performed byGupta et al.(2016), CuO (copper oxide) acts as a very effective heat-storing nanoparticle.

It increases productivity by 30 % over normal stills. But in this project the quantity of nano particles to be used is not yet justified and will be done if required output is not obtained from the existing system.

4.1.3 Top Cover Related Parameters

Glass is installed acting as the cover of the solar still. Refraction takes place as the sun rays pass through the glass and reach the water surface below as a result heating up the water.

For preliminary analysis, thickness of the glass is 3 mm and the surface area of the glass is around 0.67 m^2. Distance between the water surface and glass cover is less than 60 mm to get the maximum yield rate.

Table 4.3: Glass Cover Parameters.

Inclination angle	23.7°
Glass Cover thickness	3 mm
Cover Surface area	0.67 m^2
vertical distance between cover to water surface	60 mm

The latitude for the Dhaka city is 23.7^0 and inclination of the cover to the ground must be equal to the latitude of the place to achieve the maximum performance (El-Samadony et al.(2016) (15). Hence, the inclination of the glass cover is $23.77\ ^0$ with a target of maximum yield rate. (15).

4.1.4 Insulation and Water Flow Related Parameters

- **Insulation**

  The basin frame is made up of wood which is one of the best insulating materials after rubber. Rubber will be also used as an enhanced insulating medium being placed under and sides of each tray. As mentioned earlier, the wooden basin walls and support structure together form up a closed thermodynamic system to minimize heat loss.

- **Water Inlet and Outlet**

  To fill up the basin with feed water, the upper portion of the basin has a hole through which a pipe will be inserted.

  When the whole basin is filled up with required water, the excess wastewater will flow out of the system via a small hole being cut in the bottom of the still.

- **Collection Tray**

  There is a collection tray installed in the lower portion of the still. Having a length of 980 mm and Width of 50 mm. There is a small hole and a pipe being connected through which the yield output water will flow and finally be stored in a container.

4.1.5 Reflectors Related Parameters

Reflectors will be installed in the solar still with a target to increase the productivity. According to Omara et al.(2014) (28), the production of a solar still will increase by 125% by using external top and bottom reflectors. (28)

- **External Reflector**

The dimensions of the reflectors are not yet justified. A illustration of the still made using Fusion360 with reflectors is shown below.

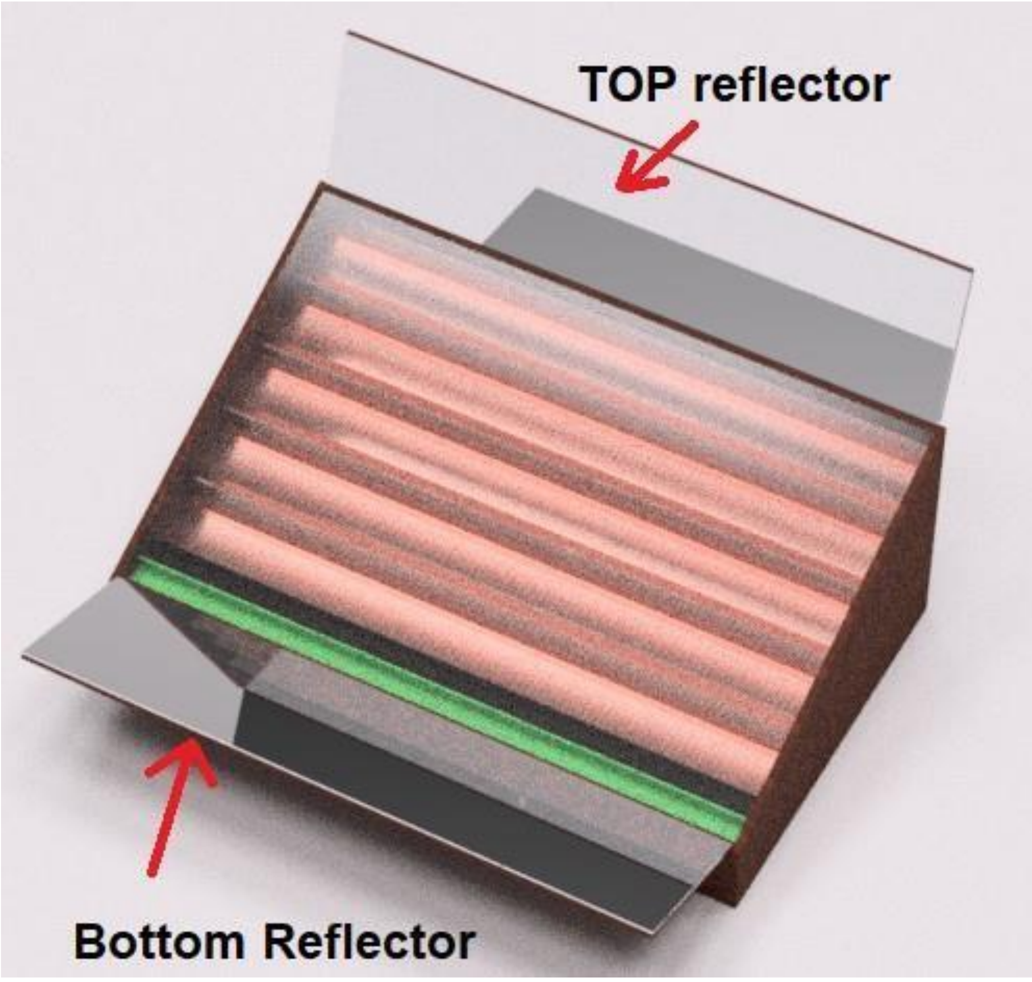


Figure 4.6: Stepped Solar Still With External Reflectors.

- **Reflector Angle**

The reflector angles needed for various seasons are given in the below figure4.7which was illustrated using Microsoft Paint and table4.4.

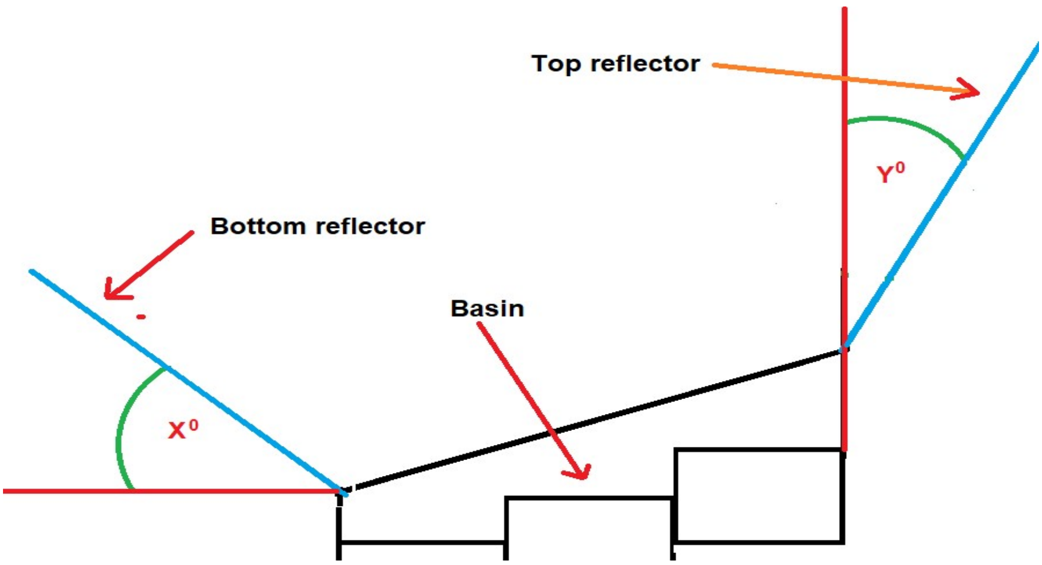


Figure 4.7: Reflector Angle (Illustrated Using Microsoft Paint).

Table 4.4: Reflector Angle During Various Seasons.

Reflector angle	Spring	Summer	Autumn	Winter	Reference
Top Y^0	7_0	15_0	8_0	15_0	Tanaka (2010) (40)
Bottom X^0	30_0	50_0	30_0	20_0	Tanaka (2011) (40)

The above mentioned parameters were set for the preliminary design specifications. Using the developed computational model, the performance were optimized and resulted in final design specifications as mentioned in the next sections.

4.2 Final Design Specifications

Final design of the solar still was done using Autodesk Fusion360. According to the simulation result, various design parameters were optimized. So there are various changes that have been made from the preliminary design and details are shown in figures below.

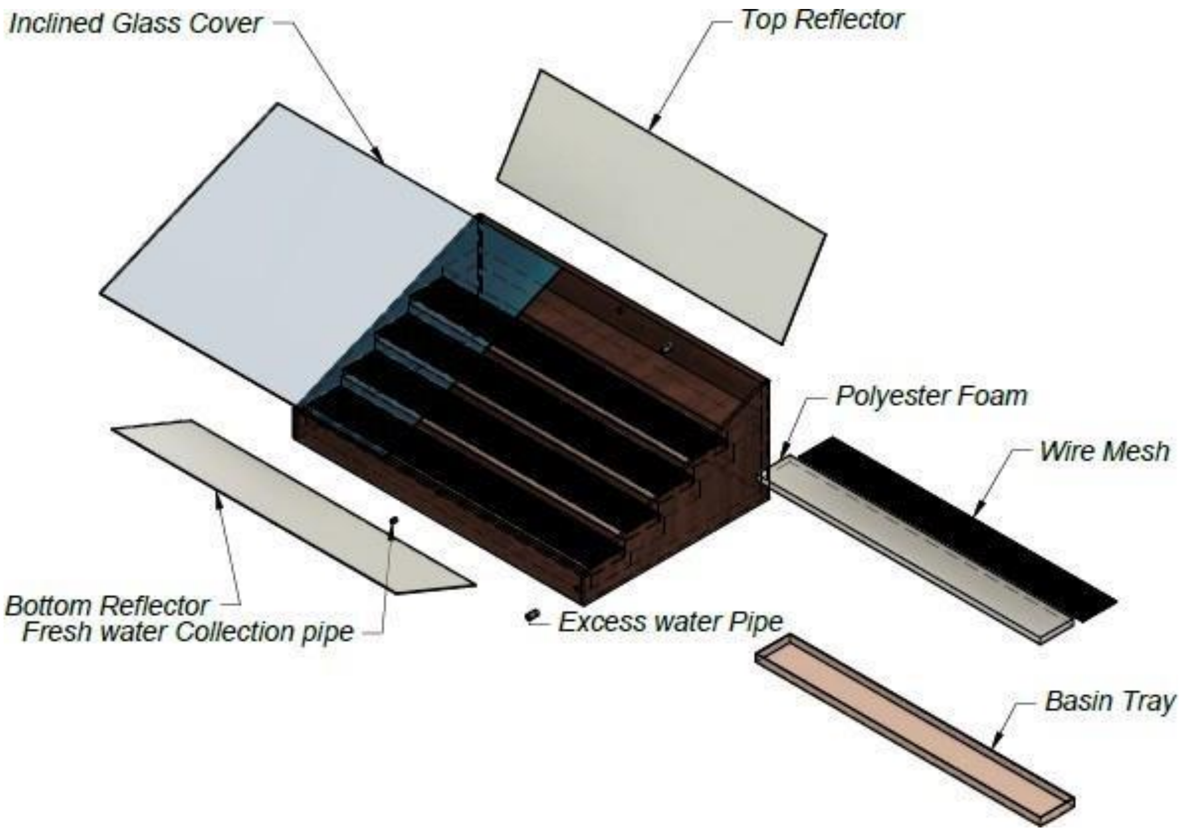


Figure 4.8: Exploded View of the Designed Solar Still.

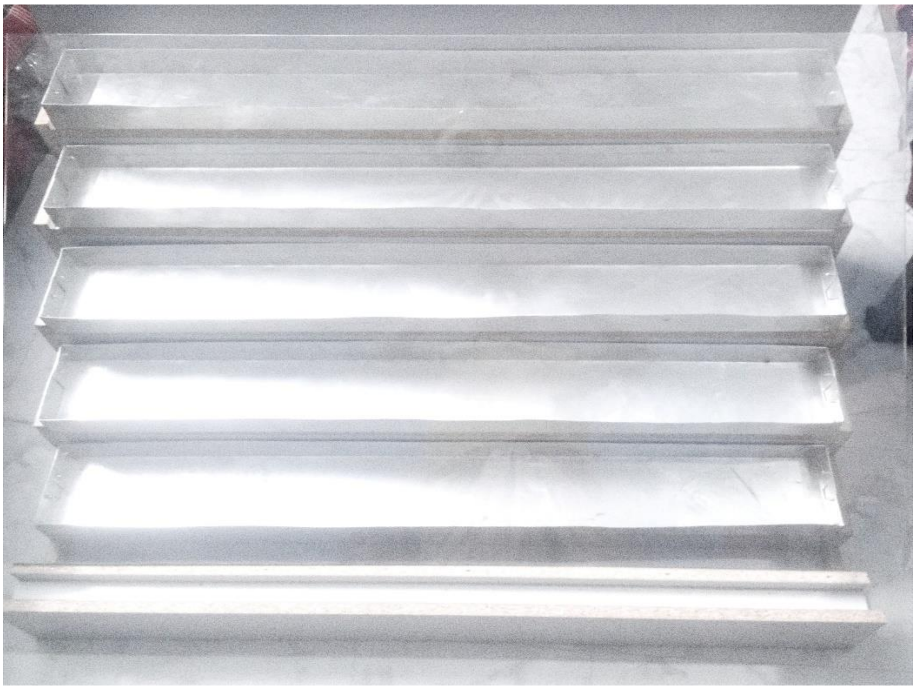


Figure: Final Designed of Solar Still by Practically

The various components used in the design along with the quantity and materials are given in the table below.

Table 4.5: Stepped Solar Still Components.

Component	Quantity	Material
Box	1	Wood
Basin Tray	5	Galvanized Steel Sheet
Polyester Foam	5	Polyester
Wire Mesh	5	Copper
Reflector	2	Aluminum
Pipe	3	PVC
Inclined Glass Cover	1	Glass

The side view of the designed solar still designed in Autodesk Fusion360 with detailed labels is shown below. All the units are in millimeter.

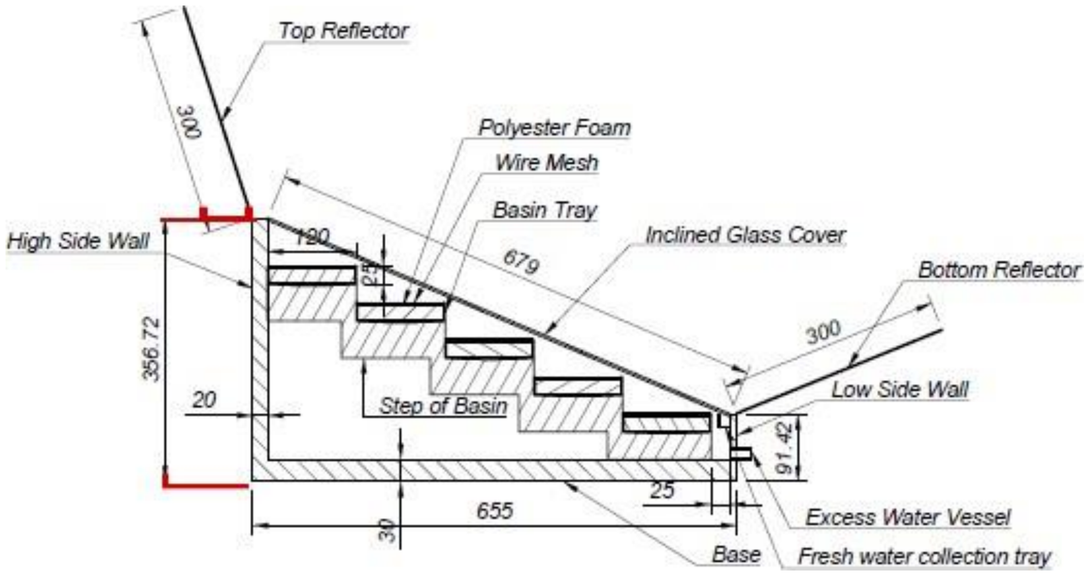


Figure 4.9: Side View of Stepped Solar Still (Unit is Millimeter).

4.2.1 Basin and Tray Related Parameters

The basin is divided into 5 steps and each step will have 1 tray made of galvanized steel sheet. Total 5 trays are used in the still. Basin is made up of wood which is available commercially and having solar absorptivity $\alpha_b = 0.5$

Table 4.6: Basin and Tray Dimensions.

Parameter	Dimension
Basin Internal Length	1000 mm
Basin Internal Width	600 mm
Internal Surface Area of Basin	$0.6m^2$
Basin wall thickness(side)	50 mm
Tray Length	1000 mm
Tray Width	120 mm
Tray Height	25 mm
Tray Thickness	1 mm

4.2.2 Wick Material Related Parameters

Polystyrene foam is used as the wick material. From the computational model it can be found that polystyrene foam performs as a better wick material compared to coral fleece. The wick will be placed on the basin trays.

Table 4.7: Property of Wick Material.

Wick	Porosity	Absorbency	Capillary rise(mm/h)	Reference
Polystyrene sponge	52.06%	300	0	Hansen et al.(2015) (22)

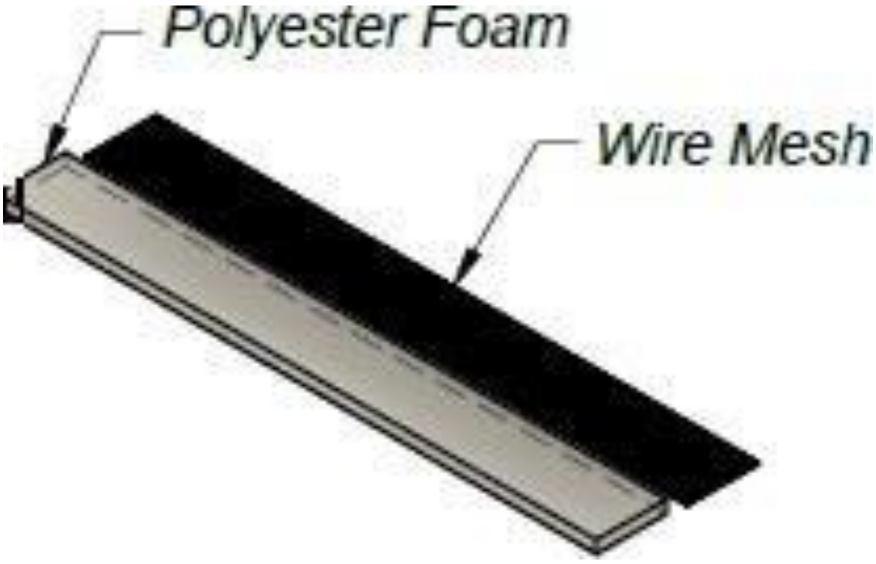


Figure 4.10: Polystyrene Foam.

4.2.3 Heat Storing Medium Related Parameters

Copper wire mesh will be placed on top of polystyrene foams in order to receive direct solar insolation from the sun. Copper acts as the heat storing medium for the system thus increasing the water production. The designed copper mesh has been shown below.

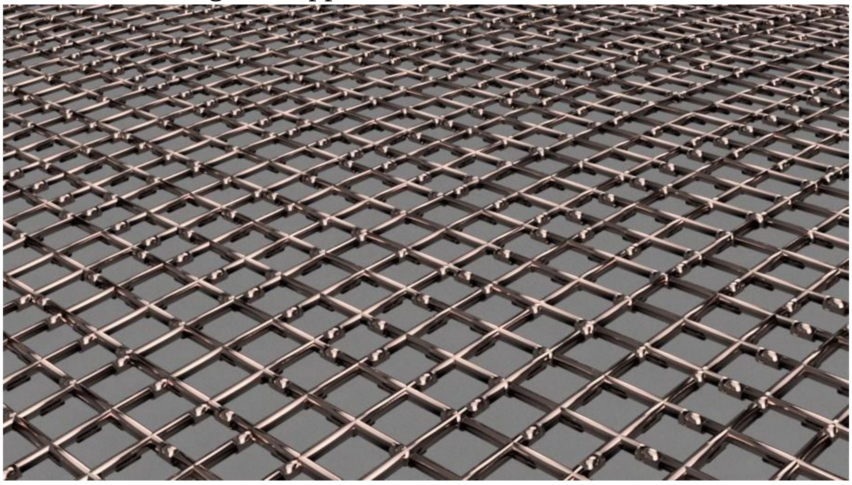


Figure 4.11: Copper Wire Mesh.

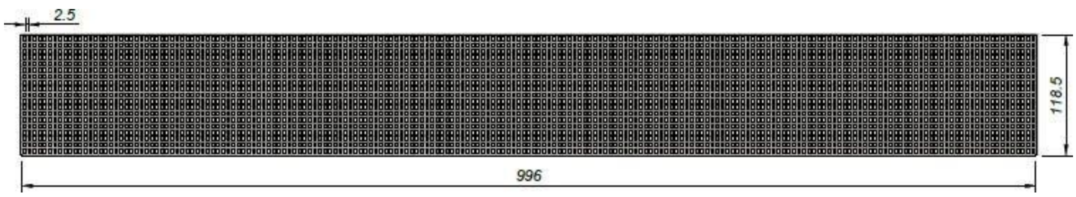


Figure 4.12: Copper Wire Mesh With Dimensions.

The cross section area and diameter of the copper mesh have been justified and details have been shown in the table below (El-Said et al.(2020) (14).

Table 4.8: Copper Wire Mesh Parameters.

Parameter	Value
Material	Copper
Wire Diameter, mm	0.56
Wire to Wire Gap, mm	2.5
Length X Width,mm	996 x 118.5

4.2.4 Top Cover Related Parameters

Thickness of the glass is 3 mm and the surface area of the glass is 0.67 m^2. Distance between the water surface and glass cover is less than 60 mm to get the maximum yield rate. The latitude for the Dhaka city is 23.7^0 and inclination of the cover to the ground must be equal to the latitude of the place to achieve the maximum performance El-Samadony et al.(2016) (15). Hence, The inclination of the glass cover is $23.77\ ^0$ with a target of maximum yield rate. (15)

Table 4.9: Glass Cover Parameters.

Inclination angle	23.77°
Glass Cover thickness	3 mm
Cover Surface area	0.52 m^2
vertical distance between cover to water surface	60 mm

4.2.5 Insulation and Water Flow Related Parameters

1. **Insulation**

   The basin frame is made up of wood. As mentioned earlier, the wooden basin walls and support structure together form up a closed thermodynamic system to minimize heat loss.

2. **Water Inlet and Outlet**

   The upper portion of the basin has a hole through which a PVC pipe is inserted. When the basin overflows, the excess wastewater will flow out of the system via a small hole being cut in the bottom of the still.

3. **Collection Tray**

   There is a collection tray in the lower portion of the still. Having a length of 980 mm and Width of 50 mm. There is a small hole and a pipe being connected through which the yield output water will flow and finally be stored in a container.

4.2.6 External Reflectors Related Parameters

External reflectors are installed in the still with a target to increase the productivity. The detailed representation of the reflector system used in the still is shown below.

- **External Reflector**

The reflectors are made of aluminum sheet having reflectivity R=0.85. Thickness of the mirror has negligible effect on the performance of still so this parameter was not considered in the computational model and final design.

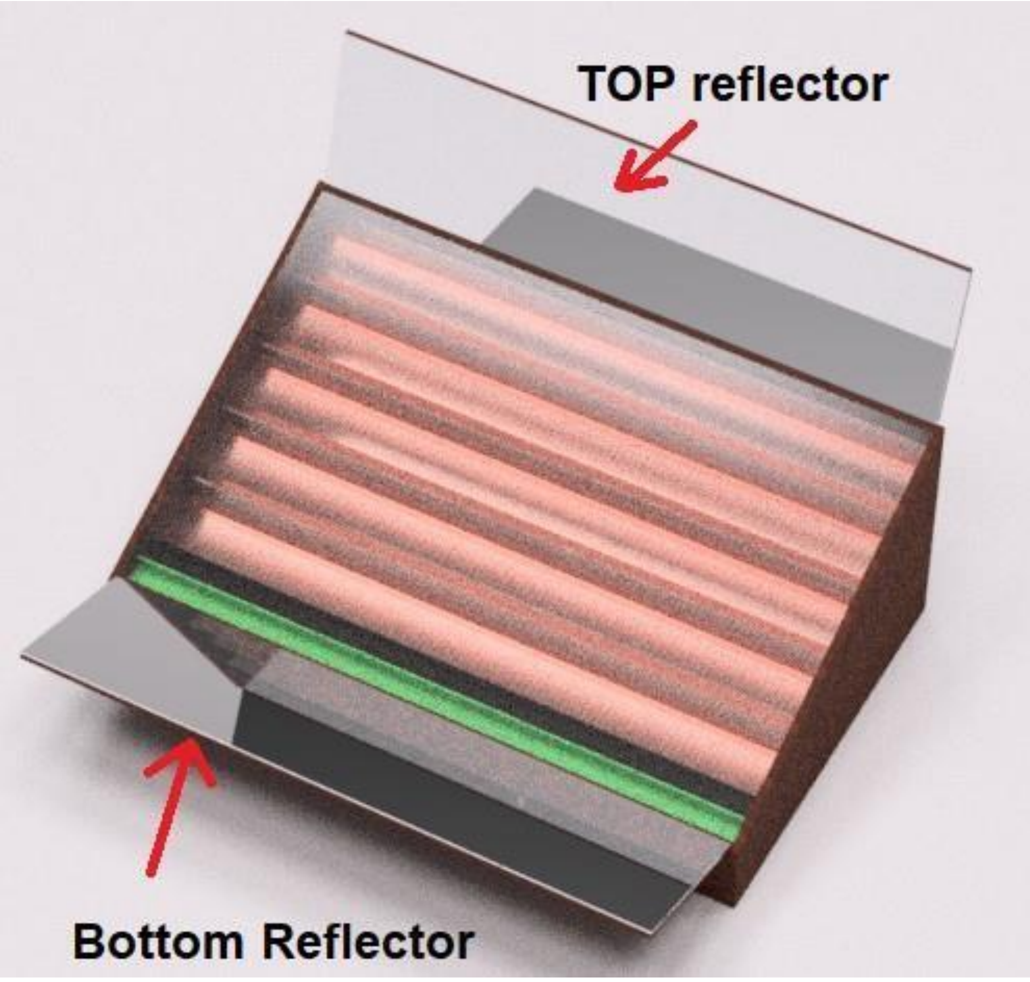


Figure 4.13: Stepped Solar Still With External Reflectors.

- **Reflector Angle**

The solar still's reflector angles need to be varied according to seasons, in order to get the maximum output. Required inclination for various seasons are given below table4.10. The values were obtained from the reference Tanaka (2010) and Tanaka (2011) **(**39).

Table 4.10: Reflector Angle During Various Seasons.

Reflector angle	Spring	Summer	Autumn	Winter	Reference
Top Y^0	7_0	15_0	8_0	15_0	Tanaka (2010) (39)
Bottom X^0	30_0	50_0	30_0	20_0	Tanaka (2011) (39)

A detailed representation of the angles are given in the figure4.14. X^0 represents the bottom reflector angle and Y^0 represents the top reflector angle.

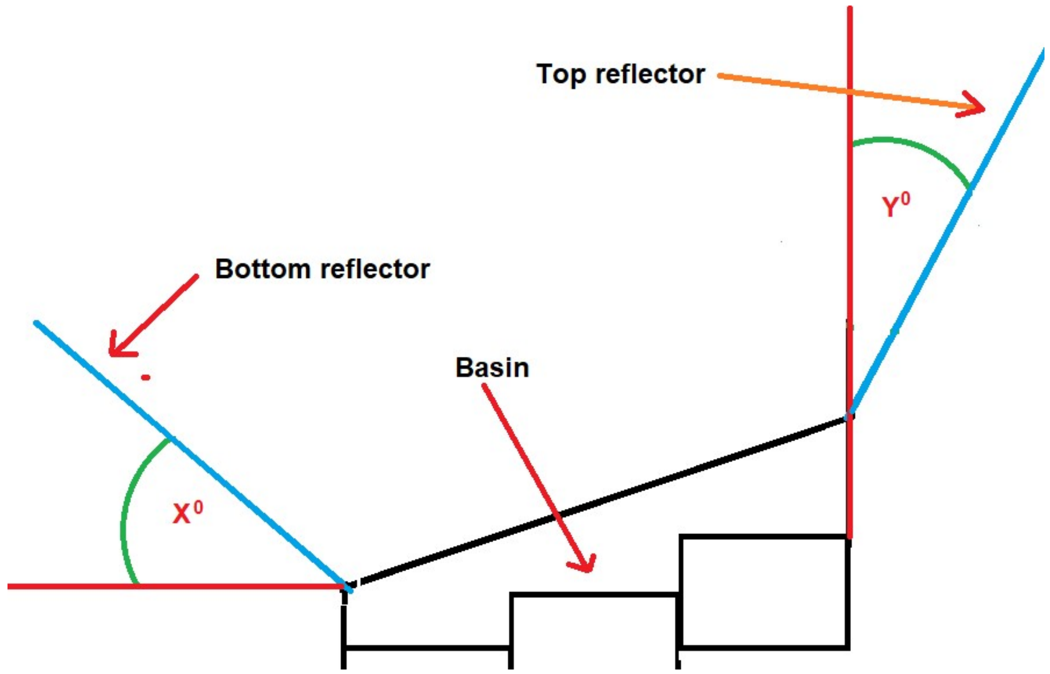


Figure 4.14: Reflector Angles of the Solar Still.

The design was optimized using the computational model. Maximum fresh water yield was around 4 liters during March in Dhaka city and it has been further explained in chapter 5.

4.2.7 Cost Estimation of the Solar Still

According to the final design, the estimated cost of a single solar still unit is shown on the table below.

Table 4.11: Cost Estimation of the Solar Still.

Material List	Local Market Value BDT
Top glass cover (Transparent, 3mm thickness)	630
Wooden Structure (Gamer wood)	4780
Basin (1mm thickness galvanized sheet, 5 unit)	2100
Inlet and outlet pipe (PVC drinking standard pipe)	140
Feed water container (plastic, 10 liter capacity)	320
Wick material (20mm thick black polystyrene foam)	1320
Reflector (Mirror finished Aluminum sheet, 2 mm thickness)	1680
Total	10970 taka

NB: The price was estimated according to the present materials value in the local market of Bangladesh. It may slightly change according to the market price from time to time.

Chapter 5

RESULTS AND DISCUSSION

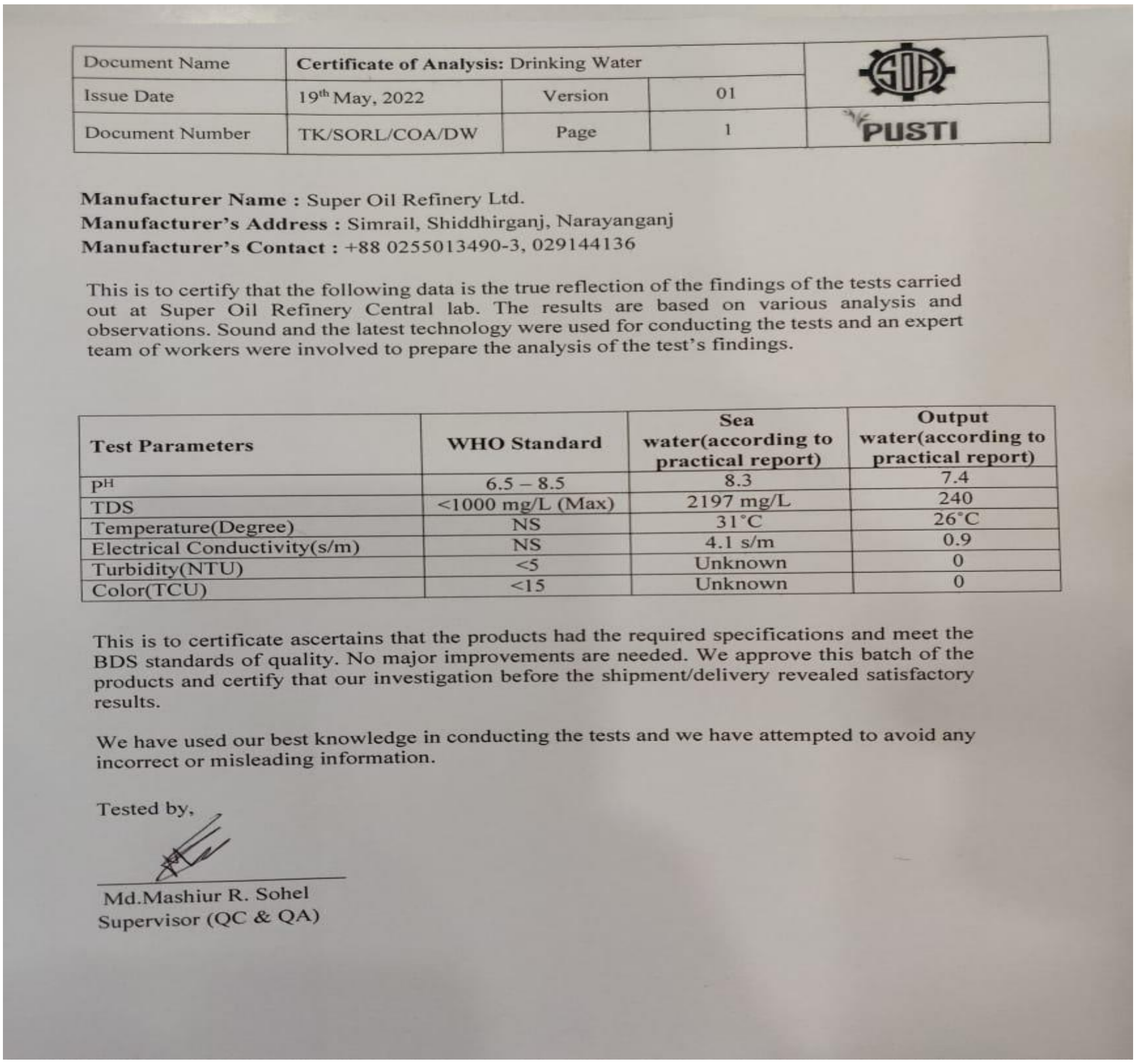
5.1 The Parameter of Solar Still Model

At first our report given by practical in sea water PH-8.3, after our operation output water PH7.4. Then, our report given by practical in sea water temperature 31 degree Celsius, after our operation output water temperature 26 degree Celsius .

Sl.no	**Parameter**	**WHO standards**	**Sea water(according to practical report)**	**Output water (according to practical report)**
1	PH	6.5-8.5	8.3	7.4
2	Temperature(Degree)	NS	31 degree	26 degree
3	Electrical Conductivity(s/m)	NS	4.1 s/m	0.9
4	TDS(mg/l)	<1000	2197	240
5	Turbidity(NTU)	<5	Unknown	0
6	Color(TCU)	<15	Unknown	0

Table 5.1: Parameter of the Solar Still.

Then, our report given by practical in sea water TDS-2197(mg/l), after our operation output water 240(mg/l).



Document Name	Certificate of Analysis: Drinking Water			
Issue Date	19th May, 2022	Version	01	
Document Number	TK/SORL/COA/DW	Page	1	PUSTI

Manufacturer Name : Super Oil Refinery Ltd.
Manufacturer's Address : Simrail, Shiddhirganj, Narayanganj
Manufacturer's Contact : +88 0255013490-3, 029144136

This is to certify that the following data is the true reflection of the findings of the tests carried out at Super Oil Refinery Central lab. The results are based on various analysis and observations. Sound and the latest technology were used for conducting the tests and an expert team of workers were involved to prepare the analysis of the test's findings.

Test Parameters	WHO Standard	Sea water(according to practical report)	Output water(according to practical report)
pH	6.5 – 8.5	8.3	7.4
TDS	<1000 mg/L (Max)	2197 mg/L	240
Temperature(Degree)	NS	31°C	26°C
Electrical Conductivity(s/m)	NS	4.1 s/m	0.9
Turbidity(NTU)	<5	Unknown	0
Color(TCU)	<15	Unknown	0

This is to certificate ascertains that the products had the required specifications and meet the BDS standards of quality. No major improvements are needed. We approve this batch of the products and certify that our investigation before the shipment/delivery revealed satisfactory results.

We have used our best knowledge in conducting the tests and we have attempted to avoid any incorrect or misleading information.

Tested by,

Md.Mashiur R. Sohel
Supervisor (QC & QA)

Figure: Parameter Collection from QC department of Solar Still by Practically

Table 5.2: The Fixed Parameters of the Computational Model.

Parameter	Value	Reference
Wind velocity , V_w	2.2 m/s	Johnson et al.(2019) (23)
Reflectivity of water, R_w	0.05	Johnson et al.(2019) (23)
Reflectivity of glass, R_g	0.05	Johnson et al.(2019) (23)
Reflectivity of aluminum sheet, R_a	0.85	Pavlovich and Kostić(2015) (30)
Effective emissivity of glass covers	0.94	Johnson et al.(2019) (23)
Effective emissivity of water, s_w	0.95	Johnson et al.(2019) (23)

Table 5.3: The Fixed Parameters of the Computational Model.

Parameter	Value	Reference
Absorptivity of glass , α_g	0.0475	Akram et al.(2019) (4)
Absorptivity of Water, α_w	0.05	Akram et al.(2019) (4)
Absorptivity of Basin , α_b	0.9	Johnson et al.(2019) (23)
Attenuation factor, U_{dw} for 5 mm depth	0.6125	Johnson et al.(2019) (23)
Wall surface area, A_{ss}	0.543 m^2	Standard value
Basin area, A_b	0.6 m^2	Standard value
Glass thermal conductivity, K_g	1.03 W/mK	Johnson et al.(2019) (23)
Glass thickness , L_g	0.003m	Ghoneyem and Ileri (1997) (19)
Latent heat of vaporization of water, L_{ev}	2260 KJ/Kg	Akram et al.(2019) (4)
Time ,t	3600 sec	Johnson et al.(2019) (23)

Output Water:

When we are physically went to production then, we get 1st day amount of water 3.3 liter. 2nd day we get amount of water 3.7 liter. 3rd day we get amount of water 4.1 liter

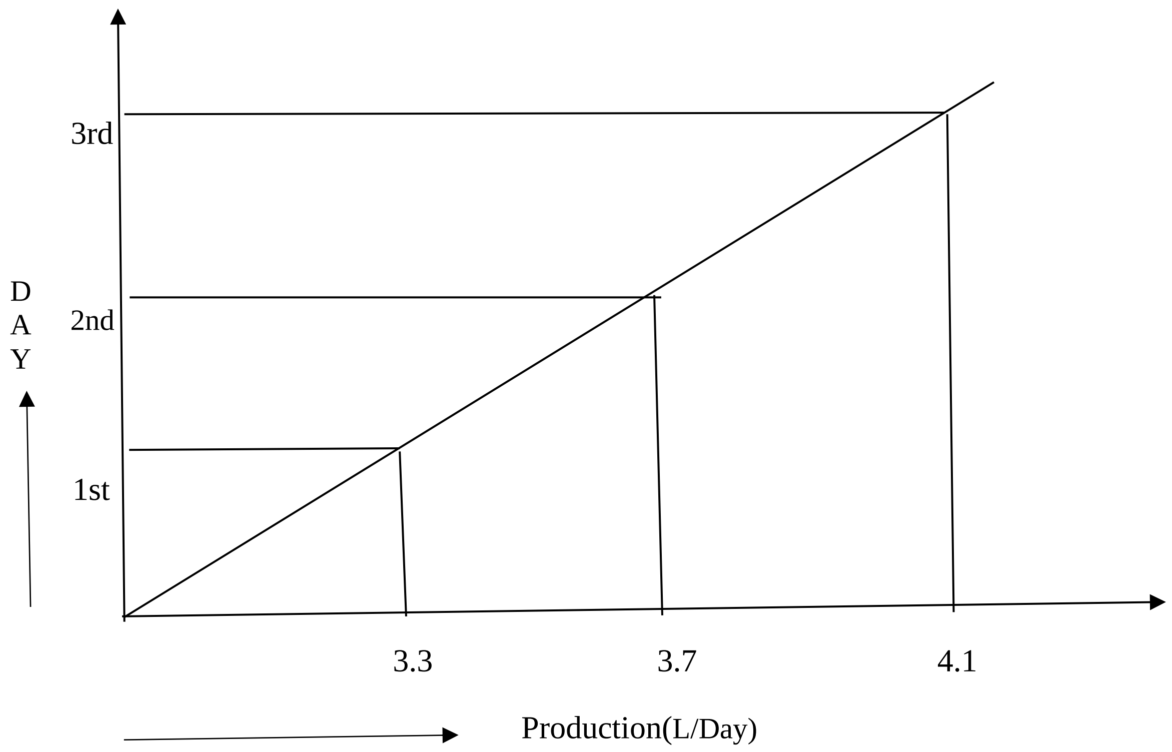
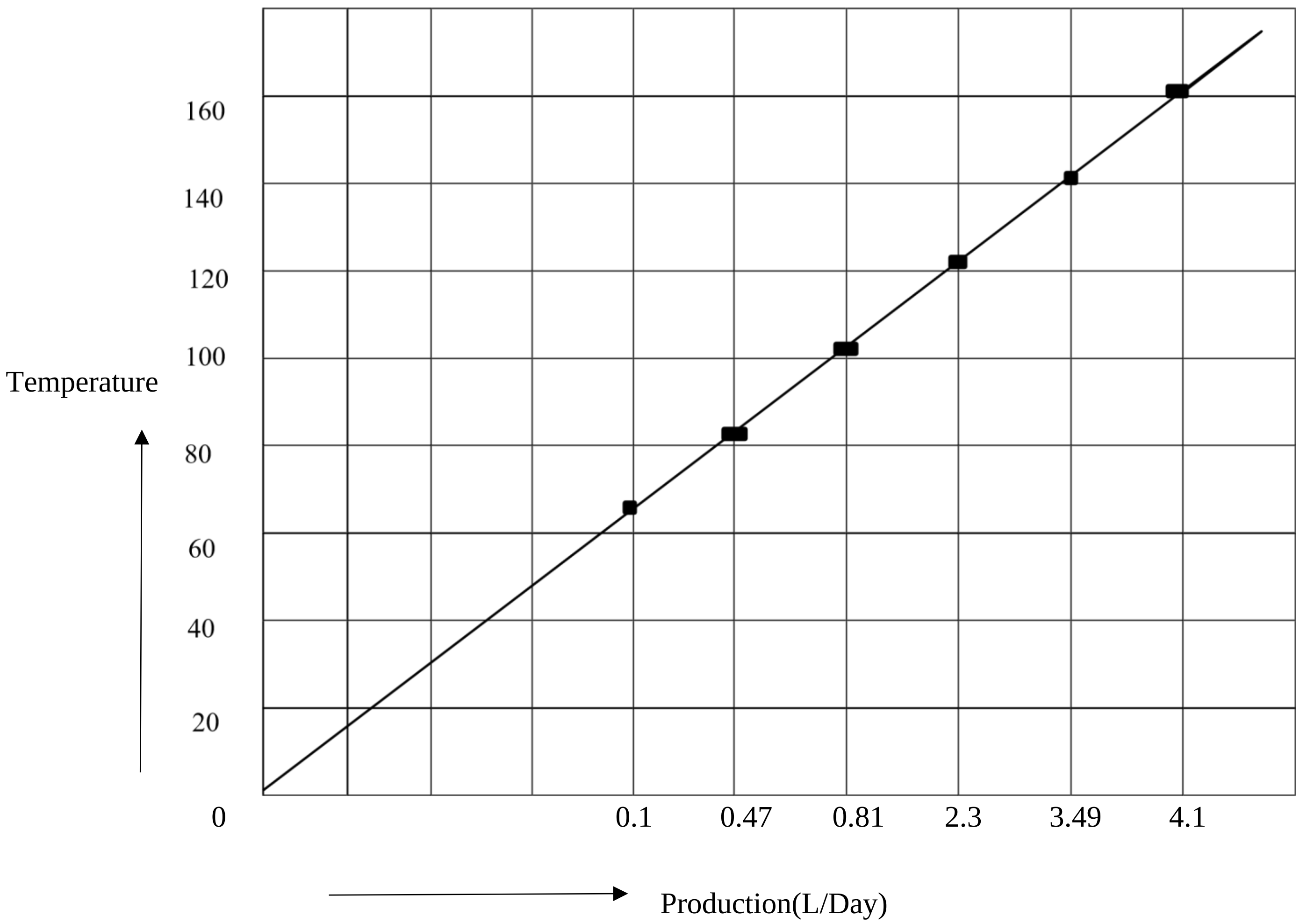


Figure 5.3: Chart of output water

Temperature Analysis with production

Performance of solar still is based on productivity, efficiency as well as internal heat and mass transfer coefficient. Internal heat and mass transfer coefficient in the solar still are based on three parameters called convection, radiation and evaporation. when our production started, water temperature 60 degree Celsius, production amount 0.1 liter in where raw water amount 10 liter .when water temperature 83 degree Celsius, production amount 0.47 liter. When, water temperature 103 degree Celsius, production amount 0.81 liter. when, water temperature 124 degree Celsius, production amount 2.3 liter. when water temperature 140 degree Celsius, production amount 3.49 liter. when water temperature 160 degree Celsius, production amount 4.1 liter



The Cost Estimation for Per Liter of Water

The cost of per liter of water can be calculated. It is calculated using the values of typical day yield per month, total days in a year and the amount of water production each month.

Cost Estimation Dhaka City

According to the typical meteorological year data, drinkable water yield rate per year (except leap year) was calculated. The typical day production and monthly yields in Dhaka city is given below.

Month	Typical Day Yield (Liter)	days of Month	Monthly Yield (Liter)
17 th May	3.3	1	3.3
18 th May	3.7	1	3.7
19 th May	4.1	1	4.1

Total monthly yield is 120 Liters/month and the device service life is considered to be 5 years except for the wick material which is polystyrene foam. It should be changed after every 3 months for better performance. Five year water yield (1440X 5) = 7200 liter. So per litre water price will be BDT 1.422tk.

5.2 Discussion

In this research, the computational model was developed in Excel spread sheet using the required formulas and data.

Best parameters were selected and performance analysis was done for (23.764^0 N and 90.407^0 E) in Dhaka city. The maximum accumulated water production is reached during May which is around 4 Liters/day as shown in graph 5.3. Peak temperature may rise up to 43 ^{0}C at 12 noon.

Analysis was also done for two other locations. Narayangonj (25.030 ^{0}N, 90.368^{0}E) where the solar insolation is one of the lowest with maximum yield output of

3.83 Liters during May. Another location is Dhaka City with maximum water production is around 4.7 Liters during May. The details have been shown in the graphs 5.3 showing maximum water production and graph5.41, showing minimum water production of the three locations. The theoretical efficiency of the whole system was around 30%. Cost estimation was done, the water production cost decreases with increase in production rate due to abundant solar insolation. So, from the analysis it is found that the solar still is highly site specific and performs better if it is placed in any location with abundant solar insolation.

Chapter 6

CONCLUSIONS

6.1 Concluding Remarks

In this research, the prime and foremost goal is to design a cost effective solar still from Bangladesh perspective. Bangladesh is located in a region where sunlight is abundant. Mostly in south-eastern region, solar insolation is received the most. In the designed solar still various enhancement parameters are adopted in order to obtain the best performance. At first a preliminary design was done with the help of documented literature review in chapter 2 then the simulation was done using the developed computational model. A final design was obtained through the simulation process.

According to the local market survey, Each unit of solar still will cost around BDT 10970 tk. The cost of per liter of water for Dhaka city is BDT 1.422tk and for Daksin Mithachari it is BDT 1.06tk. The cost is much lower compared to bottle water with per liter costing around BDT 20tk. A big limitation of the still is related to brine disposal and quality of the distillate water. The detailed limitations are shown in the next section.

6.2 Limitations of the Project

1. Due to the limited thermal property of the used wick material, the system will be unable to achieve the required sterilization
2. As the solar still requires solar radiation to operate, it is highly site-specific and therefore placing it anywhere might not offer the required output.
3. The copper wire mesh may face corrosion. So it may not last for long time.

6.3 Experimental Analysis of the Solar Still

For any future research it is necessary to fabricate the designed solar still. Some additional improvements can be made and clear understanding of the computational model is needed. The suggested experimental and computational analysis for future research works are given below.

1. **Analysis 1:** CuO (Copper Oxide) nanoparticle can be used as a heat storing medium in the still trays. Performance of the still will be observed.

2. **Analysis 2:** Copper wire mesh can be placed on top of polystyrene sponge and partially submerged in water containing CuO nanoparticles. Performance of the still will be observed.

3. **Analysis 3:** Ag_2O (Silver Oxide) powder can be used as nanoparticles in order to observe the performance. Silver has a high thermal conductivity around 420 W/mK over Copper. So there may be a possibility of increase in efficiency.

4. **Analysis 4:** An artificial neural network (ANN) based model will be developed by using 70% training data and 30% test data set obtained from specific sources. The ANN model will be compared with the newly developed computational model. In this case the computational model will be validated with performance result of the still experimental model.

5. **Analysis 5:** The artificial neural network (ANN) model will be compared with the performance result of fabricated solar still experimental model.

REFERENCES

01-Abdullah, A. S. (2013). Improving the performance of stepped solar still. *Desalination*.

Administration, U. E. (2020). U.S Energy Administration.

02-Agrawal, A., Rana, R., and Srivastava, P. K. (2017). Heat transfer coefficients and productivity of a single slope single basin solar still in indian climatic condition: Experimental and theoretical comparison. *Resource-Efficient Technologies*, 3(4):466– 482.

03-Ahmad, M. (2012). Iron and Manganese removal from groundwater Iron and manganese removal from groundwater. *DUO Research Archieve*.

05-Akram, M. W., Motin, S. M., Hoque, M. A., and Mustafi, N. N. (2019). Design, construction and performance test of a solar still for water desalination in Bangladesh perspective. In *AIP Conference Proceedings*.

06-Arunkumar, T., Vinothkumar, K., Ahsan, A., Jayaprakash, R., and Kumar, S. (2012a). Experimental study on various solar still designs. *International Scholarly Research Notices*, 2012.

Arunkumar, T., Vinothkumar, K., Ahsan, A., Jayaprakash, R., and Kumar, S. (2012b). Experimental Study on Various Solar Still Designs. *ISRN Renewable Energy*.

07-Begum, H. A., Yousuf, M. A., and Rabbani, K. S. e. (2018). Effect of top cover material on productivity of solar distillation unit. *Bangladesh Journal of Medical Physics*, 9(1):11–16.

08-Cengel, Y. (2013). Heat Transfer: A Practical Approach. *Journal of Chemical Information and Modeling*.

09-Cengel, Y. A. and Boles, M. A. (2015). *Thermodynamics: an Engineering Approach 8th Edition*.

10-Chowdhury, S. A. (2021). National Solar Energy Roadmap , National Solar Energy Roadmap ,. pages 2021–2041.

11-Cooper, T. A., Zandavi, S. H., Ni, G. W., Tsurimaki, Y., Huang, Y., Boriskina, S. V., and Chen, G. (2018). Contactless steam generation and superheating under one sun illumination. *Nature communications*, 9(1):1–10.

12-Dimaano, M. N. R. and Watanabe, T. (2002). Performance investigation of the capric and lauric acid mixture as latent heat energy storage for a cooling system. *Solar Energy*.

13-Dunkle, R. (1961). Solar water distillation: the roof type still and a multiple effect diffusion still. In *Proc. International Heat Transfer Conference, University of Colorado, USA*, volume 5, page 895.

14-El-Said, E. M., Elshamy, S. M., and Kabeel, A. E. (2020). Performance enhancement of a tubular solar still by utilizing wire mesh packing under harmonic motion. *Desalination*, 474(August 2019):114165.

15-El-Samadony, Y. A., El-Maghlany, W. M., and Kabeel, A. E. (2016). Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still. *Desalination*.

16-El-Sebaii, A. A., Al-Ghamdi, A. A., Al-Hazmi, F. S., and Faidah, A. S. (2009). Thermal performance of a single basin solar still with PCM as a storage medium. *Applied Energy*.

17-F-cubed (2020). Solar water purifier,F-Cubed ltd. .

18-Gawande, J. S. and Bhuyar, L. B. (2013). Effect of Shape of the Absorber Surface on the Performance of Stepped Type Solar Still. *Energy and Power Engineering*.

19Ghoneyem, A. and Ileri, A. (1997). Software to analyze solar stills and an experimental study on the effects of the cover. *Desalination*.

20-GlobalSolarAtlas (2020). ESMAP2020.

21-Gupta, B., Shankar, P., Sharma, R., and Baredar, P. (2016). Performance Enhancement Using Nano Particles in Modified Passive Solar Still. *Procedia Technology*.

22-Hansen, R. S., Narayanan, C. S., and Murugavel, K. K. (2015). Performance analysis on inclined solar still with different new wick materials and wire mesh. *Desalination*, 358:1–8.

23Johnson, A., Mu, L., Park, Y. H., Valles, D. J., Wang, H., Xu, P., Kota, K., and Kuravi, S. (2019). A thermal model for predicting the performance of a solar still with fresnel lens. *Water (Switzerland)*, 11(9).

24-Kabeel, A. E., Khalil, A., Omara, Z. M., and Younes, M. M. (2012). Theoretical and experimental parametric study of modified stepped solar still. *Desalination*. 25-KEISAN (2021). KEISAN.

26-Nagano, K., Ogawa, K., Mochida, T., Hayashi, K., and Ogoshi, H. (2004). Thermal characteristics of magnesium nitrate hexahydrate and magnesium chloride hexahydrate mixture as a phase change material for effective utilization of urban waste heat. *Applied Thermal Engineering*.

27-NFA (2020). NFA.

28-Omara, Z. M., Kabeel, A. E., and Younes, M. M. (2014). Enhancing the stepped solar still performance using internal and external reflectors. *Energy Conversion and Management*, 78:876–881.

29-Patel, P. and Kumar, R. (2016). Comparative Performance Evaluation of Modified Passive Solar Still Using Sensible Heat Storage Material and Increased Frontal Height. *Procedia Technology*.

30-Pavlović, Z. T. and Kostić, L. T. (2015). Variation of reflected radiation from all reflectors of a flat plate solar collector during a year. *Energy*, 80:75–84.

31-pveducation.org (2021). Azimuth angle

32-PVGIS (2021). PVGIS.

33-Reclamation (2020). BUR.

34-Rubio, E., Fernández-Zayas, J. L., and Porta-Gándara, M. A. (2020). Current status of theoretical and practical research of seawater single-effect passive solar distillation in mexico. *Journal of Marine Science and Engineering*, 8(2):94.

35-Rutala, W. A. and Weber, D. J. (2013). Disinfection and sterilization in healthcare facilities. In *Bennett & Brachman's Hospital Infections: Sixth Edition*.

36-Sharshir, S., Elsheikh, A., Peng, G., Yang, N., El-Samadony, M., and Kabeel, A. (2017a). Thermal performance and exergy analysis of solar stills–a review. *Renewable and Sustainable Energy Reviews*, 73:521–544.

37-Sharshir, S. W., Peng, G., Wu, L., Essa, F. A., Kabeel, A. E., and Yang, N. (2017b). The effects of flake graphite nanoparticles, phase change material, and film cooling on the solar still performance. *Applied Energy*.

38-SolarEng (2021). Sun*path.*

39-Tanaka, H. (2010). Monthly optimum inclination of glass cover and external reflector of a basin type solar still with internal and external reflector. *Solar Energy*.

0-Tanaka, H. (2011). A theoretical analysis of basin type solar still with flat plate external bottom reflector. *Desalination*.

41-UNICEF (2021). UNICEF MICS.

42-USGS (2014). How Much Water is There on Earth?

Velmurugan, V., Senthil Kumaran, S., Niranjan Prabhu, V., and Srithar, K. (2008). Productivity enhancement of stepped solar still - Performance analysis. *Thermal Science*.

43-WHO (2008). Guidelines for Drinking-water Quality. *World Health Organization*.

44-Zuthi, M. F., Biswas, M., and Bahar, M. N. (2009). Assessment of supply water quality in