STUDY ON THE FEASIBILITY OF SOLAR DISTILLATION AS HOUSEHOLD WATER SUPPLY IN COASTAL AREAS OF BANGLADESH

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APPROVAL

This is to certify that the thesis submitted by Dewan Mahmud Mim and Md. Ashikur Rahman entitled as “Study on the feasibility of solar distillation as household water supply in coastal areas of Bangladesh” has been approved, in partial fulfillment of the requirements for the Bachelor of Science degree in Civil Engineering.

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DECLARATION

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Md. Rezaul Karim and this work has not been submitted elsewhere for any purpose (except for publication).

November, 2015

Dewan Mahmud Mim

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Dedicated to

Our Beloved Parents

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"*In the name of Allah, Most Gracious, Most Merciful*"

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LIST OF SYMBOLS

A_a	Aperture area of concentrating collector (m^2)
A_c	Area of solar collector (m^2)
A_r	Receiver area of concentrating collector (m^2)
A_{ss}	Area of sides in solar still (m^2)
A_s	Area of basin in solar still (m^2)
C	Constant in Nusselt number expression
C_p	Specific heat of vapor (J/kg ^oC)
C_w	Specific heat of water in solar still (J/kg ^oC)
g	Acceleration due to gravity (m/s^2)
Gr	Grashof number
$h_{c,b-a}$	Convective heat transfer coefficient from basin to ambient ($W/m^2\ ^oC$)
$h_{r,b-a}$	Radiative heat transfer coefficient from basin to ambient ($W/m^2\ ^oC$)
$h_{t,b-a}$	Total heat transfer coefficient from basin to ambient ($W/m^2\ ^oC$)
$h_{c,g-a}$	Convective heat transfer coefficient from glass cover to ambient ($W/m^2\ ^oC$)
$h_{r,g-a}$	Radiative heat transfer coefficient from glass cover to ambient ($W/m^2\ ^oC$)
$h_{t,g-a}$	Total heat transfer coefficient from glass cover to ambient ($W/m^2\ ^oC$)
$h_{c,w-g}$	Convective heat transfer coefficient from water to glass cover ($W/m^2\ ^oC$)
$h_{e,w-g}$	Evaporative heat transfer coefficient from water to glass cover ($W/m^2\ ^oC$)
$h_{r,w-g}$	Radiative heat transfer coefficient from water to glass cover ($W/m^2\ ^oC$)
$h_{t,w-g}$	Total heat transfer coefficient from water to glass covers ($W/m^2\ ^oC$)
h_w	Convective heat transfer coefficient from basin liner to water ($W/m^{2o}C$)
h_b	Overall heat transfer coefficient from basin liner to ambient through bottom insulation ($W/m^2\ ^oC$)
I(t)c	Intensity of solar radiation over the inclined surface of the solar collector (W/m^2)
I(t)s	Intensity of solar radiation over the inclined surface of the solar still (W/m^2)
K_i	Thermal conductivity of insulation material (W/m ^oC)

K_g	Thermal conductivity of glass covers (W/m ^oC)
K_v	Thermal conductivity of humid air (W/m ^oC)
K_w	Thermal conductivity of water (W/m ^oC)
L	Latent heat of vaporization (J/kg)
L_i	Thickness of insulation material (m)
M_w	Mass of water in the basin (kg)
M_a	Molecular weight of dry air (kg/mol)
M_{ew}	Daily output from solar still (kg/m^2 day)
m_{ew}	Hourly output from solar still (kg/m^2 h)
sM_{wv}	Molecular weight of water vapor (kg/mol)
n	Constant in Nusselt number expression
P_{gi}	Partial vapor pressure at inner surface glass temperature (N/m^2)
P_r	Prandtl number
P_t	Total vapor pressure in the basin (N/m^2)
P_w	Partial vapor pressure at water temperature (N/m^2)
$q_{c,w-g}$	Rate of convective heat transfer from water to glass cover (W/m^2)
$q_{e,w-g}$	Rate of evaporative heat transfer from water to glass cover (W/m^2)
$q_{r,w-g}$	Rate of radiative heat transfer from water to glass cover (W/m^2)
$q_{t,w-g}$	Rate of total heat transfer from water to glass cover (W/m^2)
$q_{r,g-a}$	Rate of radiative heat transfer from glass cover to ambient (W/m^2)
$qc_{,g-a}$	Rate of convective heat transfer from glass cover to ambient (W/m^2)
$q_{t,g-a}$	Rate of total heat transfer from glass cover to ambient (W/m^2)
q_w	Rate of convective heat transfer from basin liner to water (W/m^2)
q_b	Rate of heat transfer from basin liner to ambient (W/m^2)
Ra	Rayleigh number
$Ra^'$	Modified Rayleigh number
T	Time (s)
T_a	Ambient temperature (^oC)
T_b	Basin temperature (^oC)
T_{gi}	Inner surface glass cover temperature (^oC)
T_{go}	Outer surface glass cover temperature (^oC)
T_{sky}	Temperature of sky (^oC)

T_w	Water temperature (^oC)
ΔT	Temperature difference between water and glass surface (^oC)
U_b	Overall bottom heat loss coefficient ($W/m^2\ ^oC$)
U_s	Overall side heat loss coefficient ($W/m^2\ ^oC$)
U_{LC}	Overall heat transfer coefficient for solar collector ($W/m^2\ ^oC$)
U_{LS}	Overall heat transfer coefficient for solar still ($W/m^2\ ^oC$)
U_t	Overall top heat loss coefficient from water surface to ambient air ($W/m^2\ ^oC$)
V	Wind velocity (m/s)
X_v	Mean characteristic length of solar still between evaporation & condensation surface (m)
X_w	Mean characteristic length of solar still between basin and water surface (m)
α	Absorptivity
α_υ	Thermal diffusivity of water vapor (m^2/s)
α'	Fraction of energy absorbed
(α_τ)	Absorptance–transmittance product
β	Coefficient of volumetric thermal expansion factor (1/K)
ε	Emissivity
γ	Relative humidity
μ_v	Viscosity of humid air (Pa s)
ρ_v	Density of vapor (kg/m^3)
σ	Stefan Boltzman constant ($5.67\ x10^{-8}\ W/m^2\ K^4$)
a	Ambient
b	Basin liner
c	Collector
eff	Effective
g	Glass cover
s	Solar still

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ABSTRACT

Scarcity of potable water as the result of rapid climate change and saltwater intrusion in groundwater has been a major problem in the coastal regions over the world. In equinoctial countries like Bangladesh, where sunlight is available for more than 10 hours a day, Solar Distillation provides a promising sustainable way for safe drinking water supply in coastal poor households with negligible major cost. Solar distillation presents a great potential as sea water is vastly available and construction of solar still is easy and can be done by local people with locally available materials.

The objective of this research is to supply potable water for a small family of 3-4 members in the coastal poor regions of Bangladesh who need about 15 liters drinking water per day.

In this paper, two passive type solar stills- a Conventional Single Slope Solar still (CSS) and a Pyramid Solar Sill (PSS) is used and relationship is established between distill water output corresponding to four different factors- temperature, solar intensity, relative humidity and wind speed for Gazipur, Bangladesh. Brine was used as input water using the same proportion of salt as seawater which contains average 3.5% of salt. Comparison is analyzed between the two different still outputs for eight months' period (January-August) and efficiency is calculated. Later a thermal mathematical model is developed to calculate the hourly efficiency and hourly yield of distill water which is mainly based on the temperature of water inside the solar still and the inside glass temperature. Model calibration is done by comparing the theoretical data and observed data. The temperature difference between ambient temperature, temperature of water, temperature of outside glass and temperature of inside glass is compared for Gazipur and the difference is added to the ambient temperature of Khulna, Bangladesh for calculating the temperature of water and inside glass temperature for Khulna and the results are put into the mathematical model in order to compute the inside glass temperature of Khulna. Hourly yield distill water for Khulna is calculated and difference between output of the two cities-

Gazipur and Khulna is demonstrated and finally an economic analysis is prepared. Effect of height of brine water, different glass cover thickness and different thickness of galvanized steel is measured. The Water quality is tested for both input water and yield water by testing the pH, TDS and Electric conductivity.

The distillation output has a positive correlation with temperature and solar intensity, inverse relation with relative humidity and wind speed has nugatory consequence. The maximum output of Conventional Solar Still is obtained 3.8 L/m^2/day and Pyramid still is 4.3 L/m^2/day for Gazipur and almost 10% more efficiency is found for Pyramid Solar still. In conventional solar still, temperature of water is maximum 30^{o} more than ambient temperature and inside glass temperature is maximum 10^{o} more than ambient temperature. In pyramid solar still, temperature of water is maximum 35^{o} more than ambient temperature and inside glass temperature is 25^{o} more than ambient temperature. This data is put on the mathematical model to find the Khulna hourly yield of distill water and efficiency and model calibration is done and theoretical data is found maximum 500 ml more for theoretical data than observed data. Productivity in Khulna is found almost 10% more than Gazipur. Yield is maximum in conventional still for a clearance height of 0.21 meter, glass cover thickness of 6 mm and galvanized steel thickness of 1 mm. All the water quality parameters were inside the standard limit instructed by World Health Organization (WHO). The economic feasibility analysis was done and benefit cost ratio of conventional solar still is 1.49 in second year and 1.85 for pyramid solar still in second year. So, the project is feasible.

Finally, for a 3-4-member family, area of 5 m^2 is suggested for Conventional Solar Still and 4 m^2 for Pyramid Solar Still is suggested. Further research should be conducted on this subject matter with other different types of solar stills as solar distillation posits a great potential for household water supply in coastal areas of Bangladesh.

Keywords: Solar distillation, household water supply, coastal areas, Bangladesh.

Chapter 1 Introduction

1.1 General

The procedure through which salt is withdrawn from water is called distillation. Distillation is done by employing a heat source to the water to shift it to steam, thereby purifying the water. By using solar energy to evaporate water and collect its condensate within the identic confined manner is called Solar Distillation. Unlike other appearance of water purification, it can shift salt or saline water into potable drinking water. The models that run the process is known as a solar still and although the size, dimensions, materials, and configuration are varied, all rely on the simple procedure wherein an influent solution enters the system and the more volatile solvents leave in the effluent leaving behind the salty solute behind. Various methods are developed by the researchers to distill the brackish water and sea water. Distillation is a feasible method of water purifying as it is both economically and environmentally convenient and energy efficient. As solar energy is most affluent and less costly source of energy it can be used as a substantial source of water purifying in the water scarce coastal areas. It's a challenge for the researchers to develop advanced and more efficient models so that it can be used more effectively in the coastal areas where saline water is abundant but fresh water is at great scarcity.

1.2 Background

It may look like that there's enough water around us but fresh drinking water is at great paucity. Among all the water sources 97% of all water is saline, among the other 3% only 0.4% water is fresh drinkable water. But according to recent studies, the aquifers around the world is supplying more water that it's being recharged and facing towards a great depletion period.

According to a 2007 World Health Organization (WHO) report, 1.1 billion people lack access to an improved drinking water supply, 88 per cent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, while 1.8 million peoples die from diarrheal diseases each year.

According to a World Bank study, of the 27 Asian cities with populations of over 1 million, Chennai and Delhi are ranked as the worst performing metropolitan cities in terms of hours of water availability per day, while Mumbai is ranked as second worst performer and Calcutta fourth worst.

The impacts of climate change will be particularly severe in remote coastal towns. Firstly, the major challenge in urban areas is the provision of safe water. The worsening incidence of drought is affecting surface water and hand and shallow tube wells, and the situation may further deteriorate. In the coastal zones, salt water intrusion caused by sea level rise may affect the availability of fresh surface water and groundwater. Secondly, drainage is already a serious problem, as sewers frequently back up in the wet monsoon, especially following intense rainfall. In addition, sea level rise may delay discharge from the drainage system in low-lying areas. Moreover, flooding contaminated by waste water can cause serious health risks. Coastal towns are in remote areas, where the consequences of climate change are expected to be particularly severe. In 2010, coastal towns had a population of 7.0 million. Water supply to coastal towns is mainly from groundwater sources drawn from deep and shallow tube wells. Water salinity has increased in and near coastal towns in recent years, recording in 2010 the highest level since 1980. Sea level rise and prolonged dry weather are expected to further drive up salinity in coastal towns.

According to the World Population Report 2012 released by United Nations Population Fund (UNFPA), the government has to provide improved drinking water to an additional 12 million people to reach its MDG (millennium development goal) targets by 2015. The government committed to ensure access to safe drinking water for 28 million people (The Financial Express, 08 January 2013). In urban areas, 23% piped inside dwelling, 8% piped outside dwelling, 68% tube wells and in rural areas less than 0.6% piped inside and outside dwelling, 96% tube-wells, 1% dug wells, more than 2% ponds, lakes and rivers. So it is clear that most of the water is collected from ground water sources.

The coastline shown in Figure 1.1, is of 734 km involving coastal and island communities, residence of nearly 50 million people, about one-third of the total population of Bangladesh. Salinity in drinking water is one of the major problems for the last few decades in coastal areas. According to WHO, salinity level in drinking water should be within 500 ppm where salinity in available sea water is almost 40000 ppm. Excessive salinity can have deleterious effect on human health. In coastal areas due to saline water intrusion in groundwater and continuous lowering of groundwater level makes it difficult to access to fresh water. And as most people of coastal area are poor, they can't afford expensive methods of water supply**.**

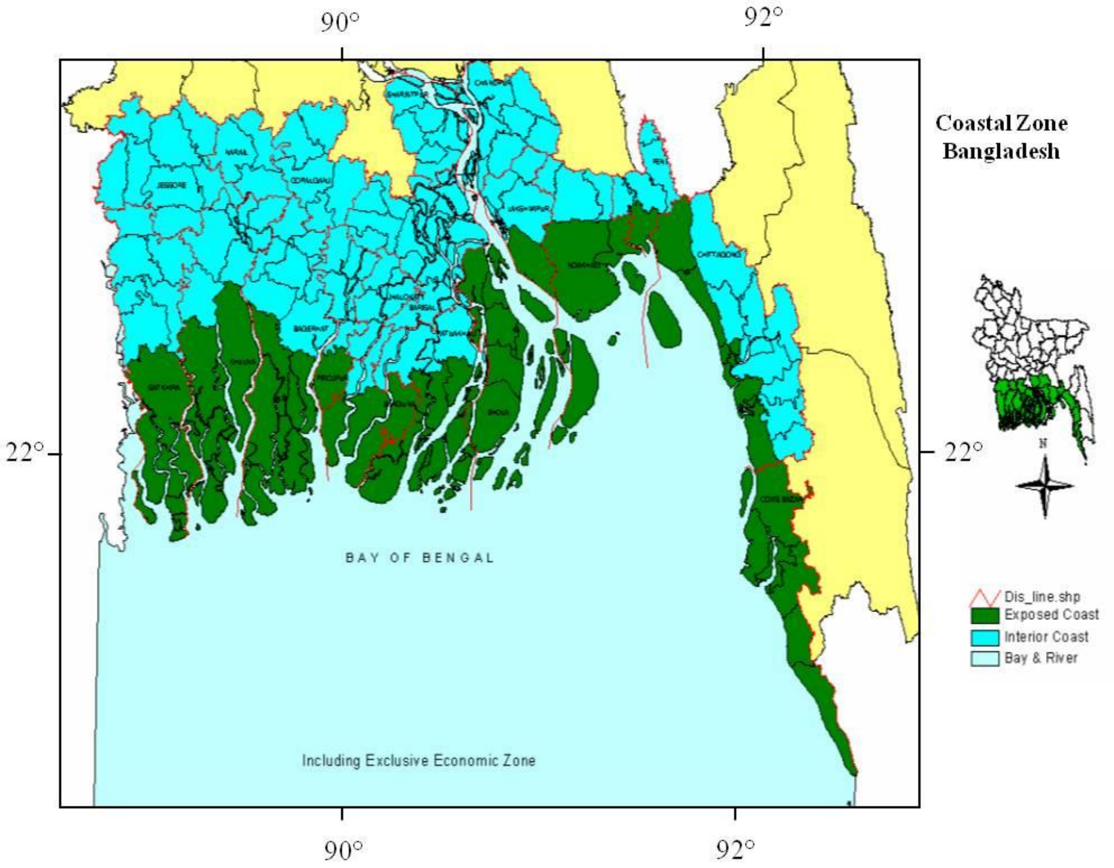


Figure 1.1 Coastal areas of Bangladesh

Several methods of water supply can be used in coastal areas like deep tube-well, dug well, pond sand filter, combined filter, household filter, rainwater harvesting etc. Deep tube well is a great source of supplying drinkable water but it is the main reason for ground water depletion. Dug well can store fresh water but it can be contaminated by different means. Filtration can also be costly for the poor peoples of coastal area. Rainwater harvesting can be hardly effective for everyone as storing a great amount of water can be a difficult task.

Solar distillation is one of the methods of water supply which can be used efficiently as the energy source is sustainable and there's no additional cost for fuel or operation. The only cost is the initial capital cost and there's no additional maintenance cost. The vast coastline of Bangladesh is an abundant source of saline water which can be used as the input brine water in solar distillation plant. About 20 plus districts of Bangladesh can use solar distillation as an efficient mean of water purification. Another major fact is solar stills can be used for many years. Not only in coastal areas, solar distillation can be a potential source to facilitate water purification in rural areas as solar energy is available all over the year.

Application of solar distillation has a great possibility because it's very simple to use and don't need much skilled or trained personnel to operate. The construction can be done by local people from locally available materials, a small size solar distillation plant can fulfill the small scale drinking water demand.

1.3 Components

There are different kinds of solar stills but the basic mechanism is the same. In the solar still there's a heat absorbing material that absorbs heat, saline water is placed on the surface of this material and water is evaporated using the heat. There's some space between the heat absorbing and condensation surface that maintains the temperature difference. The natural phenomena leave the salt behind and pure water is condensed on a cooling surface where by different methods, pure drinkable water is collected. So, at a glance, Production of vapors above the surface of the liquids, the transport of vapors by winds, the cooling of air-vapor mixture, condensation and precipitation are the basic process of solar distillation. Apart from the basic components there's many other materials are used for improved design.

1.4 Benefits of Solar Distillation

Some advantages of solar distillation are-

1. Renewable Solar energy is a clean energy source.
2. No cost of fuel (during sunlight it can absorb 500 Watt electric consumption per one hour of sunlight)
3. There are no moving parts; it's therefore reliable and almost maintenance free (cleaning is required though).
4. Solar energy causes no pollution.
5. Can be constructed with locally available materials.
6. Don't need any skilled personnel to operate.
7. The input impure water is vastly available and free of cost.

1.5 Limitations of Solar Distillation

The main problem of solar distillation process is the impact of weather. Uncertainty of weather can affect the production during rainy seasons. Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall. Another point is, sun doesn't shine consistently and the production capacity becomes low. In the rainy and winter season solar energy (sun light) is very limited, so automatically production of fresh water will also be limited.

1.6 Research Objective

1. To assess the feasibility of solar distillation output to supply water for a small family of 3-4 members in coastal areas of Bangladesh.
2. To assess economic feasibility of solar distillation.

1.7 Scope and Limitations of Study

The study is carried out in Gazipur city, which is not a coastal area. Though the effect of different parameters is studied in details, measurement in coastal area could make the research more accurate.

Again, the study is carried out between two models- Conventional or simple single basin wick type solar still and pyramid solar steel based on a hypothesis from the previous studies that these two produce the maximum efficiency and the construction difficulty and cost is less of these two solar stills. The study could be more accurate if more solar stills could be constructed and different values could be measured.

1.8 Organization of the Thesis

Organization of the remainder of the thesis is as follows. In Chapter 2, which reviews the previous studies regarding solar distillation in Bangladesh and other parts of the world and also provides an overview of the existing solar distillation models. Chapter 3 describes the methodology of this research. Description about the model selection and the data used in mathematical analysis has been sighted in this chapter. The results of the study, the calibration of mathematical model and economic analysis have been presented in chapter 4. Chapter 5 is the summary and conclusions of the research. This chapter has been divided into four sub sections which describes the main findings of this research, limitations of this study and the recommendations for future studies. The reference section concludes this thesis.

Chapter 2 Literature Review

2.1 General

Solar distillation is a very old process. The first documented account of solar distillation use for desalination was by Giovani Batista Della Porta in 1958. However, no solar distillation publication of any repute leaves out the Father of solar distillation, Carlos Wilson, the creator of the first modern sun-powered desalination plant, built in Las Salinas (The Salts), Chile in 1872. From the beginning it is a challenge to the researchers to invent new models of solar still using different kind of materials and process. Research on this subject matter is continuously going on as it has a great potential to establish as a major source of water supply in coastal areas where water scarcity is a common problem around the world. Many new models have been developed and related research is done for calculating the efficiency and economic feasibility.

2.2 Global Studies on Solar Distillation

Mehta et al. (2011) discussed different parts of solar distillation model and their detail dimensions and measurements and with this conventional solar still distilled water was produced with an efficiency of almost 64% and relation between distilled water output with temperature was established.

Amitava Bhattacharyya (2013) discussed in details about the advantages of capillary solar still over simple solar still which are getting popular because of high efficiency. It consists of a fabric which manages more evaporation of water at minimum heating. The efficiency of capillary solar still with other stills was compared which turn out to be more efficient.

Sengar et al. (2011) studied with corrugated galvanized sheet as absorber for obtaining maximum distillation output with different inclination for load and no load test in winter and summer months. Later discussed about the chemical analysis of distilled and impure water and concluded with details economic analysis of the single basin wick type solar still.

Youssef et al. (2011) investigated different design configurations and suggested an evaporation-condensation box with multiple layers coupled with an evacuated heat pipe solar collector. In the later phase its performance in outdoor condition of Taif city, KSA was measured.

Ranjan and Kaushik (2013) discussed the details economic feasibility analysis of passive solar still using both conventional analysis and modified EDS method incorporating with the factor of equivalent cost of environmental degradation and high grade energy saving for solar still. It was suggested that, double basin solar still costs less than single basin in unit price of distilled water and concluded with studying energy efficiency, useful life, payback period and capital cost.

Biswas and Ruby (2012) designed a solar distillation system that can purify water near any source, a system which is relatively cheap, portable and depends only on renewable solar energy with a prototype of effective geometries and concentration system. Finally, a concentrated type solar still was studied which use the solar energy most efficiently.

Gokilavani et al. (2014) studied a conventional solar still and compared the experimental results with a simulated model and verified the temperature distribution over the glass with computational fluid dynamics model ANSYS and the computational result validated with the experiment work.

Younis et al. (2010) studied effects of different parameters like water salinity, brine depth, glass cover thickness, solar radiation, ambient air temperature, relative humidity, wind speed on distillation output and compare the data with theoretical data from mathematical regression model analysis.

Hamadani and Shukla (2014) experimented effects of phase changing material in distillation output on a passive solar still and recommended that higher mass of phase change material with lower mass of brackish water increase the distillation output under indoor simulated condition.

Ahsan et al. (2010) studied a tubular solar still with more advanced design and discussed the details mathematical formula analysis and compare it with simple tubular solar still.

Arunkumar et al. (2012) discussed in details about various types of solar stills with their design and details explanations and later compared the distillation output for different kinds of solar still.

Ayoub et al. (2010) designed a slow rotating drum solar still and make comparison on effect of solar radiation and temperature and recommended that its 200% efficient than simple solar still.

Belgasim and Mahkamov (2011) designed a dynamic solar thermal desalination unit with a fluid piston and the lumped parameter mathematical model was developed, productivity was calculated 9 L/day.

Omar Badran (2011) investigated the performance of active single slope solar still theoretically using different operational parameters like insulation thickness, solar intensity, overall heat loss coefficient, effective absorptivity and transmissivity, temperature differences and wind speed and compared the value with experimental data.

Tenthani et al. (2012) designed two conventional solar stills with an identical geometry but the internal surfaces of one with black paint and other with white paint and concluded that the efficiency of the experimental white painted still was 6.8% more than the black one.

Saida & Cherif (2010) represented the thermal analysis of a passive solar still, mathematical equation was developed using the Runge-kutta numerical method for temperature of different parts of still which indicates that wind speed has an influence on glass cover temperature. Efficiency of single slope solar still was derived and it was noted that temperature and daytime period maintain the value of solar intensity.

Liu et al. (2013) studied the thermal and economic performance of still with evacuated tube collectors and low collector multi effect distillation. Mathematical and economic model analysis was done with different models like evacuated tube collector model, heat storage tank model, flash effect distillation model and electrical heating and cooling model. It was concluded that, with multiple tank model, the volume of tank changes slightly but the area of evaporator and fresh water production increase. Cost of fresh water had reduced greatly but the proportion of cost of evacuated tube collector is largest which is almost 31% more than simple solar still.

Tripathi and Tiwari (2005) presented the thermal analysis of both active and passive solar still using the idea of solar fraction with AutoCAD for given azimuth and altitude angle and latitude and concluded that the result is more equivalent for active than passive solar still and suggested that solar fraction plays a very significant role in thermal modeling of solar still.

Tiwari and Tiwari (2007) experimented on a setup having latitude 28.35'N and concluded that the annual water yield is 44.28% more for lower depth (.02m) than higher water depth (.18m). It was also suggested that, increasing basin absorptivity from 0.40 to 0.80 can produce 30.59% more water.

Ghosal et al. (2002) studied about seasonal analysis of solar distillation system combined with a greenhouse and suggested that the rate of increase in fresh water yield becomes stable after the length of south roof is 2.5 m. The yield increased with the fall in greenhouse air temperature decrease.

Medugu and Ndatuwong (2009) experimented in Mubi, Adamawa state of Nigeria where energy balance equation was made for each element of solar still, solar time, direction of beam of radiation, clear sky radiation, optical properties of the cover, convection outside the still, convection and evaporation inside were accounted. Theoretical data was compared to the experiment and 99.64% efficiency was resulted in.

2.3 Solar Distillation Studies in Bangladesh

Solar distillation system has gained increased attention over time in Bangladesh as it has potential to become a major water supply method in coastal areas.

Rahman et al. (2001) conducted an elaborate experimental and analytical program on BUET campus with locally available materials. Experiment was done with 11 different types of solar still- Ferro cement plant, Mild Steel plant, 8 different types of brick plant of varying inclination, slope and size and a clay plant, it was concluded that yield of Ferro cement plant was highest with a maximum efficiency of 36% and the lowest yield was gained from clay plant with a maximum efficiency of almost 4%. It was suggested that cost per liter of water for the Brick plant was found to be Bangladeshi Taka (Tk.) 0.92 (US$0.016) per liter, and the corresponding figure was Tk. 0.74 (US$0.013) for the Clay plant.

Islam et al. (2013) conducted an experiment in small scale in the Institute of Marine Sciences and Fisheries, University of Chittagong and Khuruskul of Cox's Bazar district with three solar stills of different sizes and inclination of glass cover and checked the data for about 20 days. Different parameters like ambient temperature, salinity, pH, Unionized NH_3, Iron, NO_2-N, Chlorine, DO and amount of distilled water were studied and the average yield was obtained 1.06 liter/m^2/day for 45° inclinations, 0.98 liter/ m^2/day for 35º inclination.

Rahman et al. (2014) conducted an experiment using flat plate and parabolic solar collector. It was suggested that flat plate collector preheats the water and increase the temperature about 55℃ to 60℃, the parabolic collector increased the heat to 85℃ and provided water supply continuously through flat valve system and suggested that for large water out multi system panel can be applied.

Rahman et al. (2012) experimented on the roof of the office building of Bangladesh Centre for Advanced Studies (BCAS) with a dimension of 3m × 1.5m having a glass cover of 5mm thickness and 20° angle. The time was December 2011 to April 2012 and highest yield was 8.1 liters per day giving an efficiency of 36.4% based on average solar energy and the cost was BDT 23,945.

Previous studies in Bangladesh tried to measure only the yield of different solar stills and compared the efficiency. In this research, besides calculating the efficiency of solar stills, economic analysis and water quality parameters were measured. Also, a mathematical model was developed to compare the yield of two different cities- Gazipur and Khulna.

2.4 Classification of Solar Still

Different types of solar stills are developed over time. The basic principle remains the same but the choices of solar still depend on required distillation yield and economic affluence.

Some popular types of solar still are-

Passive Solar Stills

Conventional solar stills rely only on the sun to distill water. However, their complexity could still reach that of active stills. Passive stills, then, vary widely due to this one constraint and can be further organized into sub-classes. Some common types of passive solar stills include:

- Single-effect
- Multi-effect
- Basin
- Double Slope
- Wick
- Multi-wick
- Diffusion
- Greenhouse

Single-effect stills are the simplest and most common, since only one interface is necessary to convey the energy and collect the condensate. An example of a crucial design challenge in all solar stills is keeping the distiller airtight. If it is not airtight, efficiency drops severely. Often a shallow trough is used, painted black, and flooded. A slanted pane of glass covering allows condensed water vapor to slide down into an output channel. Another approach is molded plastic, e.g. the Water cone. This has the advantage that it can be more easily made airtight, and mass production should make it affordable.

Multi-effect stills require double effort in regards to ensuring tight seals, and could be more difficult to clean, but they can raise the production of freshwater significantly. The way, by which, the water is stored for its time in the liquid phase can also contrast.

Basin-type stills contain the water in an impervious material that is a component of the entire enclosure and are most commonly available.

Wick stills use cloth-like materials that use capillary action to move the water through the system. When efficiency and effectiveness are key, wick stills out-produce basin stills due to the greater surface area of evaporation, lower energy cost to heat the water, and ability to create a much larger effective area for solar radiation to transfer energy into the water.

Multi-wick stills obviously like typical wick stills and much like the multi-effect premise from above; they greatly increase the productivity for increasing the influenced surface area exponentially.

Diffusion-type stills run with the ideas introduced by the multi-effect & wick stills and a further advancement to both. Perhaps, Tanaka & Nakatake best explain the design behind these efficient stills, "which consist of a series of closely spaced parallel partitions in contact with saline-soaked wicks, have great potential because of their high productivity and simplicity."

One more variation on solar stills is caught in the middle of the two predetermined categories of passive and active, and could perhaps be labeled "neutral". Seawater Greenhouses (i.e. Kiva's straw bale greenhouse) accept the concept of solar distillation with the more prominent greenhouse premise. They are neutral because the energy that goes in to create the freshwater, even if active, pays off by the freshwater's invaluable quality to grow the plants that promote the evaporative cooling of the air inside, which, ultimately carries the moisture.

Active Solar Stills

These distillers use additional heat sources to promote existing thermal processes. The foundation of the design of these plants has already been said in the above section, so the sources involved with this branch of solar stills will be discussed in short.

CPCs (Compound Parabolic [Solar] Concentrators)

- Flat Plate Collectors
- Solar Heater
- Novel Waste Heat (i.e. vehicle radiator)

In Figure 2.1, different types of Solar stills are shown. Active stills add more complexity to the simple base design, but once again this alteration can promote faster and larger quantities of freshwater generation.

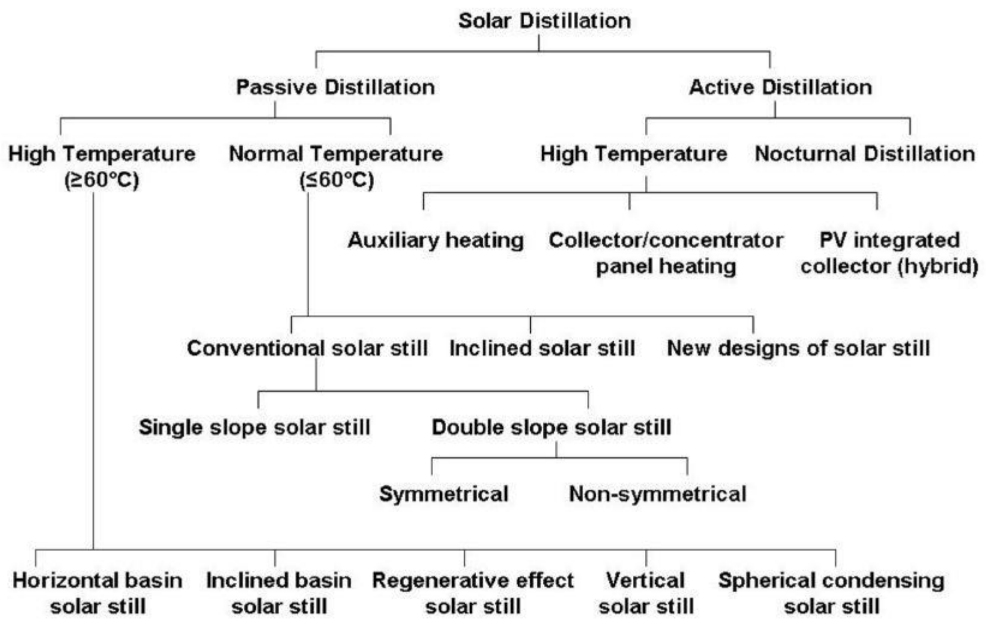


Figure 2.1: Classification of solar still

2.5 Existing Models of Solar Distillation

Based on previous researches, in Table 2.1, some existing models for solar still in present world is shown.

Table 2.1: Existing models of solar distillation

Name of Still	Efficiency	Reference
Simple Basin Type solar still	30%	Sodha et al. (1981)
Single Slope Solar Still	23% to 31%	Dwivedi and Tiwari. (2008)
Double Slope Solar Still	25% to 34%	Dwivedi and Tiwari. (2008)
Multiple Wick Solar Still	34%	Sodha et al. (1981)
Low Cost Thermoformed Solar Still	39%	Flendrig et al. (2009)
Double Effect Multi Wick Solar Still	50% to 60%	Singh and Tiwari (1992)
Capillary Film Distiller (one stage)	50% to 55%	Bouchekima *et al.* (1998)
Tilted Wick Type Solar Still	53%	Mehdi et al. (2011)

Arunkumar et al. (2012) conducted some more experiments on some models which is shown in Table 2.2. From his experiments, he determined the output per day for different solar stills.

Table 2.2: Yield of different types of solar stills

Name of Still	Yield ml/m^2/day
Spherical Solar Still	2300

Tubular Solar Still	5800
Pyramid Solar Still	3500
Hemispherical Solar Still	4800
Concentrator Coupled Single Slope Solar Still	2700
CPC-PSS-CPC-Pyramid Solar Still	7000
Double-Basin Glass Solar Still	3000

Chapter 3 Methodology

3.1 Introduction

At first, based on some criteria two models were selected. One is Conventional Solar Still and another is Pyramid Solar Still. Then after selecting the design parameters two models were installed. Then based on parameters like Internal Heat Transfer, Radiative Heat Transfer, Convective Heat Transfer, Evaporative Heat Transfer, External Heat Transfer and Top Loss Transfer Coefficient a thermal mathematical model was developed. Then the efficiency calculation was done. Then an economic feasibility analysis was done which includes Net Present Value (NPV), Benefit Cost Ratio and Payback Period analysis.

3.2 Model Selection Process

Model is selected based on different criteria:

1. Based on previous researches
2. Based on Efficiency and distill water output
3. Based on flexibility in construction
4. Local materials availability
5. Cost of Construction

Based on previous researches, it is analyzed that conventional single slope solar still (CSS) and pyramid solar still (PSS) provides a reliable source of solar water distillation. While other types of solar stills provide more efficiency and distill water than CSS and PSS, the flexibility of construction of these two is more than others. As this research is for supplying distill water in the remote poor areas of Bangladesh, where lack of skill is a major problem. Construction of CSS and PSS is not difficult and very easy to construct. Any unskilled person with a very few cost of construction and with local materials available, can construct the stills.

3.3 Conventional Single Slope Solar Still

Basin Type: It consist of shallow, bracken basin of saline/impure water covered with a sloping transparent roof solar radiation that passes through the transparent roof heats the water in blackened basin. Thus evaporating water which gets condensed on the cooler under side of the glass and gets collected as distillate attached to the glass.

In Figure 3.1, a 3D model of CSS is shown where, the base of the solar still is made of Galvanized steel box of dimension (3.5' x 2.5' x 1.33'). This box is embedded into another box of wood. Here length L= 4 ft., Breath B= 3 ft., Height H=1.33 ft. and at opposite side = 2.67 ft., Angle Θ = 30°. This also contains Jute bag as thermocol is having 0.5-inch thickness. The channel is fixed such that the water slipping on the surface of the glass will fall in this channel under the effect of gravity. A frame of G.I. pipe is fixed with the wooden box so that glass can rest on it. This completes the construction of the model. The holes for the inlet of water, outlet of brackish water and outlet of pure water is made as per the convenience. The outlet of brackish water is placed at right bottom of the, outlet of the pure water at the end of the channel and inlet at the right wall above the outlet.

Figure 3.1: 3D model of CSS

Figure 3.2: Constructed CSS

In Table 3.1, Different design parameters for the constructed conventional solar still are shown where different design parameters are presented according to previous research on this subject.

Table 3.1: Design parameters of conventional solar still

Name of Parameter	Measurement Used in Ours Design	Reference
Brine depth	6-9 cm	Younis et al. (2010)
Glass cover thickness	6mm	Younis et al. (2010)
wick between wooden outside & steel inside	Yes	Vel murugan et al. (2008)
Outside wood thickness	15 mm	Alpesh et al. (2011)
Horizontal cover inclination	30^o	Ranjan et al. (2013)
Painting back on the bottom steel	Yes	Sengar et al. (2011)
Painting white on the inside side walls	Yes	Tenthani et al. (2012)

3.4 Pyramid Solar Still

The base of the solar still is made of Galvanized steel box of dimension (1’ x 1’ x .5’). In Figure 3.3, this box is embedded into another box of wood where length L= 1.08 ft., Breath B= 1.08 ft., Height H=0.7 ft. and angle $\Theta = 45°$. This also contains Jute bag as thermocol is having 0.5-inch thickness. The channel is fixed such that the water slipping on the surface of the glass will fall in this channel under the effect of gravity. A frame of G.I. pipe is fixed with the wooden box so that glass can rest on it. This completes the construction of the model. The holes for the inlet of water, outlet of brackish water and outlet of pure water is made as per the convenience. The outlet of brackish water is placed at right bottom of the model, outlet of the pure water at the end of the channel and inlet at the right wall above the outlet.

Figure 3.3: Constructed Pyramid Solar Still

3.5 Yield Parameters

Other Design Parameters that must be considered according to previous researches of Anirudh et al. (2012)

There are a number of parameters which affect the performance of a solar still. These are broadly classified as,

(1) Climatic parameters
(2) Design parameters
(3) Operating parameters

[1] Climatic Parameters

- Solar Radiation
- Ambient Temperature
- Wind Speed
- Outside Humidity
- Sky Conditions

[2] Design Parameters

- Single slope or double slope
- Glazing material

- Water depth in Basin
- Bottom insulation
- Orientation of still
- Inclination of glazing
- Spacing between water and glazing
- Type of solar still

[3] Operational Parameters

- Water Depth
- Preheating of Water
- Coloring of Water
- Salinity of Water

3.6 Expenditure of Conventional & Pyramid Solar Still

Table 3.2 shows the Cost of conventional solar still of 1 m^2 area, where cost for different materials are presented.

Table 3.2: Cost of conventional solar still of 1 m^2 area

Category name	Price (BDT)
Galvanized still (1 mm thickness)	2000
Wood for outer cover	2000
Color(spray/permanent)	500
Glass cover (6 mm thickness)	1200
Wick (3 pieces)	100
PVC pipe	500
Labor cost	1500
Miscellaneous	200
Total Cost	8000

Table 3.3 shows the Cost of pyramid solar still of 1 m^2 area, where cost for different materials are presented.

Table 3.3: Cost of pyramid solar still of 1 m^2 area

Category name	Price (BDT)
Galvanized still (1 mm thickness)	2000
Wood for outer cover	2000
Color(spray/permanent)	500
Glass cover (6 mm thickness)	1500
Wick (3 pieces)	100
PVC pipe	500
Labor cost	1500
Miscellaneous	200
Total Cost	8300

3.7 Details of Installment

First, the conventional solar still was made in first of January and was installed in the rooftop of Academic Building of Department of Civil and Environmental Engineering (CEE) of Islamic University of Technology campus, Gazipur, Dhaka, Bangladesh. The climatic condition of Bangladesh is equinoctial and sunlight is available for more than 10 hours a day throughout the year. Annual average temperature maximum 36 °C and minimum 12.7 °C; annual rainfall 2376 mm. Average wind speed of Gazipur District is 2.5-3.0 m/s. The still was installed facing south and the whole equipment was made inclined for some degrees to cause proper circulation of water through the pipes. In late of January, the Pyramid Solar Still was installed using the same process.

3.8 Daily Experimental Process

First, brine water was made every day using 3.5% salt, which is exactly like seawater. Then the saltwater is tested in Laboratory and pH, TDS and electric conductivity was measured. Then the brine was poured inside the stills and every hour different sets of data like the temperature, solar intensity, wind speed and relative humidity and distill water output was measured. Every day after taking the data from 7 am till 7 pm, the distill water was taken to the laboratory and pH, TDS and electric conductivity was measured again. Table 3.4 shows the daily experimental process and water quality before and after the experiment. Pyranometer was used for measuring solar radiation, Hygrometer was used for measuring humidity and Thermo Anemometer was used for measuring temperature and wind speed.

Table 3.4: Daily data collection chart

Brine Volume (L)	**pH**	**TDS (ppm)**	**Electric Conductivity (µS/cm)**
600	6.8	40000	5600

Serial	**Hour**	**Outside Temp. (ºC)**	**Water Temp. (ºC)**	**Inside Glass Temp (ºC)**	**Solar intensity (W/m²)**	**Humidity (%)**	**Wind Speed Km/hr.**	**Per hour Output ml/hr.**
1	7-8	30	33	31	323	60	2	0
2	8-9	31	35	33	351	57	1	120
3	9-10	32	40	37	483	63	2	210
4	10-11	33	46	42	673	55	2	320
5	11-12	35	53	45	721	66	2.5	410
6	12-1	36	59	46	932	72	1.5	600
7	1-2	37	61	47	1063	50	2	680
8	2-3	35	61	45	897	60	4.8	600
9	3-4	34	55	44	785	50	5	450

10	4-5	33	48	43	642	39	6	280
11	5-6	32	40	37	403	30	5	230
12	6-7	30	35	35	291	39	3.2	100

Output Water

Amount Collected (L)	**3.8**
pH	7.8
TDS (ppm)	143
EC (µS/cm)	28.5
Water collected per m²	4.3 liters

Figure 3.4: Pyranometer

Figure 3.5: Hygrometer

Figure 3.6: Thermo Anemometer

Figure 3.4, 3.5 and 3.6 illustrates Pyranometer which was used for measuring solar radiation, Hygrometer was used for measuring relative humidity and Thermo Anemometer was used for measuring temperature and wind speed.

3.9 Thermal Mathematical Model

The equations of Thermal mathematical model are taken from Gupta et al. (2013).

3.9.1 Internal Heat Transfer

In solar still basically internal heat is transferred by evaporation, convection and radiation. The convective and evaporative heat transfers take place simultaneously and are independent of radiative heat transfer.

3.9.2 Radiative Heat Transfer

The view factor is considered as unity because of glass cover inclination is small in the solar still. The rate of radiative heat transfer between water to glass is given by

$$q_{r,w-g} = h_{r,w-g} (T_w - T_{gi}) \quad (1)$$

Where,

$h_{r,w-g}$ = Radiative heat transfer coefficient between water to glass,

$$h_{r,w-g} = \varepsilon_{eff}\sigma \left[\frac{(T_w+273)^2+(T_{gi}+273)^2}{T_w+T_{gi}+546}\right] \quad (2)$$

ε_{eff} = Effective emission between water to glass cover, is presented as

$$\varepsilon_{eff} = \frac{1}{\left[\left(\frac{1}{\varepsilon_g}+\frac{1}{\varepsilon_w}\right)-1\right]} \quad (3)$$

3.9.3 Convective Heat Transfer

Natural convection takes place across the humid air inside the basin due to the temperature difference between the water surfaces to inner surface of the glass cover. The rate of convective heat transfer between water to glass is given by

$q_{c,w-g} = h_{c,w-g}(T_w - T_{gi})$ (4)

Where,

$h_{c,w-g}$ = Convective heat transfer coefficient depends on the temperature difference between evaporating and condensing surface, physical properties of fluid, flow characteristic and condensing cover geometry.

The various models were developed to find the convective heat transfer coefficient. One of the oldest methods was developed by Dunkle and his expressions have certain limitations, which are listed below.

I. Valid only for normal operating temperature (≈50°C) in a solar still and equivalent temperature difference of ΔT=17°C.

II. This is independent of cavity volume, i.e., the average spacing between the condensing and evaporating surfaces.

III. This is valid only for upward heat flow in horizontal enclosed air space, i.e., for parallel evaporative and condensing surfaces.

The convective heat transfer coefficient is expressed as

$h_{c,w-g} = 0.884(\Delta T')^{1/3}$ (5)

Where,

$$\Delta T' = \left(T_w - T_{gi}\right) + \frac{\left(P_w - P_{gi}\right) + \left(P_w + 273\right)}{\left(268.9 \times 10^{-3} - P_w\right)} \quad (6)$$

$$P_w = \exp[25.317 - \frac{5144}{273 + T_w}] \quad (7)$$

$$P_{gi} = \exp[25.317 - \frac{5144}{273 + T_{gi}}] \quad (8)$$

Chen et al. (2010) developed the model of free convection heat transfer coefficient of the solar still for wide range of Rayleigh number ($3.5 \times 10^3 < Ra < 10^6$) and as follows,

$$h_{c,w-g} = 0.2 {R_a}^{0.26} \frac{k_v}{X_v} \quad (9)$$

Zheng et al. (2011) have developed a modified Rayleigh number using Chen et al. model for evaluating the convective heat transfer coefficient,

$$h_{c,w-g} = 0.2 ({R_a}')^{0.26} \frac{k_v}{X_v} \quad (10)$$

Where,

$$Ra' = (\frac{{X_v}^3 \rho_v g \beta}{\mu_v \alpha_v}) \Delta T'' \quad (11)$$

$$\Delta T'' = (T_w - T_{gi}) + [\frac{(P_w - P_{gi})}{(\frac{M_a P_t}{M_a - M_{Wv}}) - P_w}](T_w + 273.15) \quad (12)$$

The convective heat transfer between basins to water is given by

$q_w = h_w(T_b - T_w)$ (13)

The convective heat transfer coefficient between basins to water is given as,

$$h_w = \frac{K_w}{X_w C (G_r \times P_r)^n} \quad (14)$$

Where,

C = 0.54 and N = 1/4

3.9.4 Evaporative Heat Transfer

The performance of solar still depends on the evaporative and convective heat transfer coefficients. Various scientists developed mathematical relations to evaluate the evaporative and convective heat transfer coefficients.

The general equation for the rate of evaporative heat transfer between water to glass is given by

$q_{e,w-g} = h_{e,w-g} (T_w - T_{gi})$ (15)

$h_{e,w-g}$ = Evaporative heat transfer coefficient.

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{e,w-g} \frac{P_w - P_{gi}}{T_w - T_{gi}}$$ (Dunkle) (16)

Malik et al. developed a correlation based on Lewis relation for low operating temperature range and it is expressed as,

$h_{e,w-g} = 0.013\ h_{c,w-g}$ (17)

The total heat transfer coefficient of water to glass is defined as,

$h_{t,w-g} = h_{c,w-g} + h_{e,w-g} + h_{r,w-g}$ (18)

The rate of total heat transfer of water to glass is defined as,

$q_{t,w-g} = q_{c,w-g} + q_{e,w-g} + q_{r,w-g}$ (19)

$q_{t,w-g} = h_{t,w-g}(T_w - T_{gi})$ (20)

3.9.5 External Heat Transfer

The external heat transfers in solar still is mainly governed by conduction, convection and radiation processes, which are independent each other.

3.9.6 Top Loss Heat Transfer Coefficient

The heat is lost from outer surface of the glass to atmosphere through convection and radiation modes. The glass and atmospheric temperatures are directly related to the performance of the solar still. So, top loss is to be considered for the performance analysis. The temperature of the glass cover is assumed to be uniform because of small thickness. The total top loss heat transfer coefficient is defined as,

$h_{t,g-a} = h_{r,g-a} + h_{c,g-a}$ (21)

$q_{t,g-a} = q_{r,g-a} + q_{c,g-a}$ (22)

$q_{t,g-a} = h_{t,g-a} (T_{go} - T_a)$ (23)

The radiative heat transfer between glass to atmosphere is given by

$q_{r,g-a} = h_{r,g-a} (T_{go} - T_a)$ (24)

The radiative heat transfer co efficient between glass to atmosphere is given as,

$$h_{r,g-a} = \varepsilon_g \sigma[(T_{go} + 273)^4 - \frac{(T_{sky}+273)^4}{T_{go}-T_a}] \quad (25)$$

Where,

$T_{sky} = T_a - 6$

The convective heat transfer between glass to atmosphere is given by

$q_{c,g-a} = h_{c,g-a} (T_{go} - T_a)$ (26)

The convective heat transfer coefficient between glass to atmosphere is given as

$h_{c,g-a} = 2.8 + (3.0 \times v)$ (27)

The total internal heat loss coefficient ($h_{t,w-g}$) and conductive heat transfer coefficient of the glass $\frac{K_g}{L_g}$ is expressed as

$$U_{wo} = [\left(\frac{1}{h_{t,w-g}}\right) + \frac{L_g}{K_g}] \quad (28)$$

The overall top loss coefficient (U_t) from the water surface to the ambient through glass cover,

$$U_t = \frac{h_{t,w-g} h_{t,g-a}}{h_{t,g-a} + U_{wo}} \quad (29)$$

3.9.7 Side and Bottom Loss Heat Transfer Coefficient

The heat is transferred from water in the basin to the atmosphere through insulation and subsequently by convection and radiation from the side and bottom surface of the basin. The rate of conduction heat transfer between basin liner to atmosphere is given by

$q_b = h_b (T_b - T_a)$ (30)

The heat transfer coefficient between basin liner to atmosphere is given by,

$$h_b = [\frac{L_i}{K_i} + \frac{1}{h_{t,b-a}}]^{-1} \quad (31)$$

Where,

$h_{t,b-a} = h_{c,b-a} + h_{r,b-a}$ (32)

There is no velocity in bottom of the solar still. By substituting v = 0, to obtain the heat transfer coefficient. The bottom loss heat transfer coefficient from the water mass to the ambient through the bottom is expressed as,

$$U_b = [\frac{1}{hw} + \frac{1}{hb}]^{-1} \quad (33)$$

The conduction heat is lost through the vertical walls and through the insulation of the still and it is expressed as,

$$U_s = (\frac{A_{ss}}{A_s})U_b \quad (34)$$

The total side loss heat transfer coefficient (U_s) will be neglected because of side still area (A_{ss}) is very small compared with still basin area (A_s).The overall heat transfer coefficient from water to ambient through top, bottom and sides of the still is expressed as,

$$U_{LS} = U_t + U_b \quad (35)$$

3.10 Efficiency Calculation

3.10.1 Hourly Yield Distill Water

Hourly yield distilled water,

$$m_{ew} = h_{e,w-g} \frac{(T_w - T_{gi})}{L} * 3600$$ Tiwari et al. (1989)

Where,

$$h_{e,w-g} = 16.273 * 10^{-3} h_{c,w-g} \frac{p_w - p_{gi}}{T_w - T_{gi}}$$ Cooper (1973)

Where,

$$h_{c,w-g} = 0.884 \left[T_w - T_{gi} + \frac{(P_w - P_{gi})T_w}{268.9*10^3 - P_w}\right]^{\frac{1}{3}}$$ Dunkle (1961)

3.10.2 Overall Efficiency

Hourly efficiency,

$$n_i = \frac{q}{I(t)} = \frac{h_{ew}(T_w - T_{gi})}{I(t)} * 100$$ Tiwari et al. (1989)

3.11 Economic Feasibility Analysis

3.11.1 Net Present Value

Net Present Value equation for transformation of future value is:

N.P.V.= $\frac{future\ value}{(1+r)^n}$

where,

r = discount rate

n = no. of years

3.11.2 Benefit Cost Ratio

B/C = $\frac{Overall\ Sale\ or\ Benefit\ Return*SF}{Overall\ Cost*CF}$

Where,

SF = Sale Factor (Factor that tells the probability of rate of water in BDT) ≈ 85% = 0.85

CF = Cost Factor (Factor that tells the probability of amount of cost that will be implemented) ≈ 90% =0.9

Chapter 4 Results and Discussion

4.1 Introduction

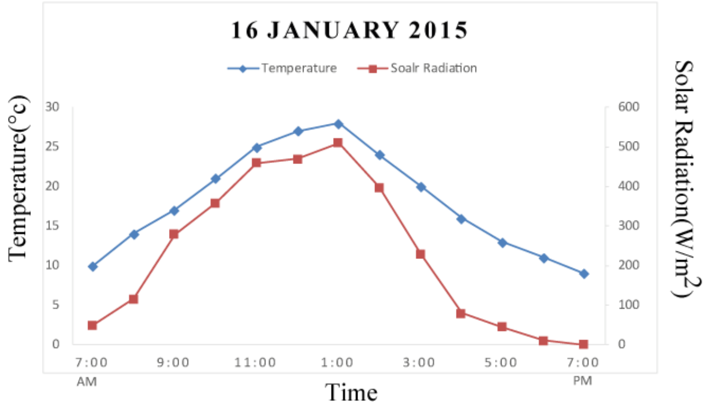
Temperature, solar radiation, Relative humidity and wind speed is taken as variables and relation is established between each of the parameters and distill water output. The distill water output is converted to per m^2 area and graph is plotted for different months for different parameters and comparison is made between Conventional solar still and Pyramid solar still. Then a mathematical model is developed for thermal variation and model calibration is done between observed output and theoretical output determined from the mathematical model. Then the temperature of Khulna, Bangladesh is collected from internet and the data is placed in the mathematical model to determine the output of Khulna for the same day. Then comparison is made between distillation output of Gazipur and Khulna. An economic analysis is done in basis of Net Present Value, Benefit Cost Ratio and Payback Period.

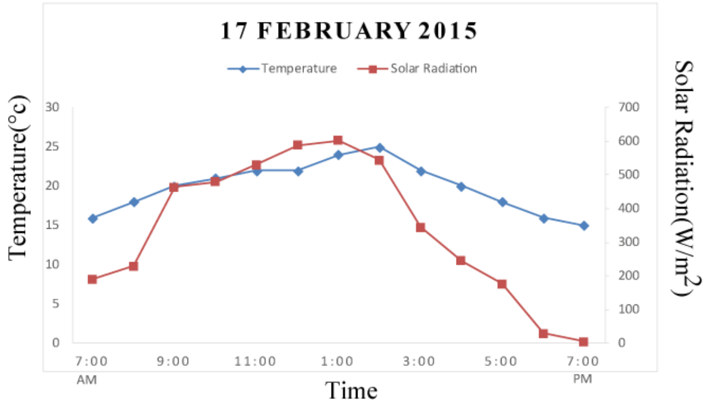
4.2 Measurement of Parameters

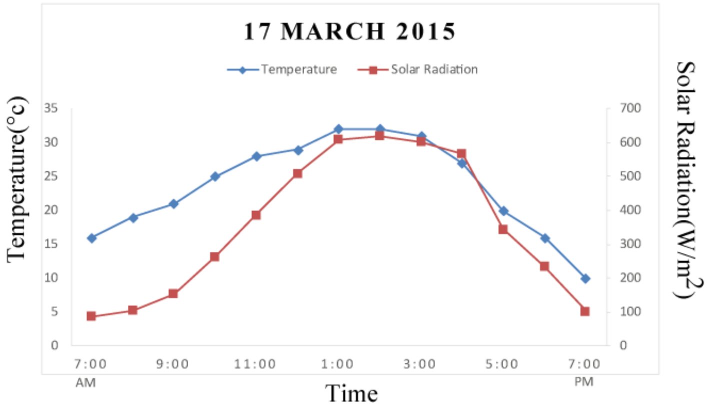
Value of temperature, solar distillation, humidity and wind speed of each month (January-August) for different hours of a particular day is presented. The day is selected based on average yield for that particular month.

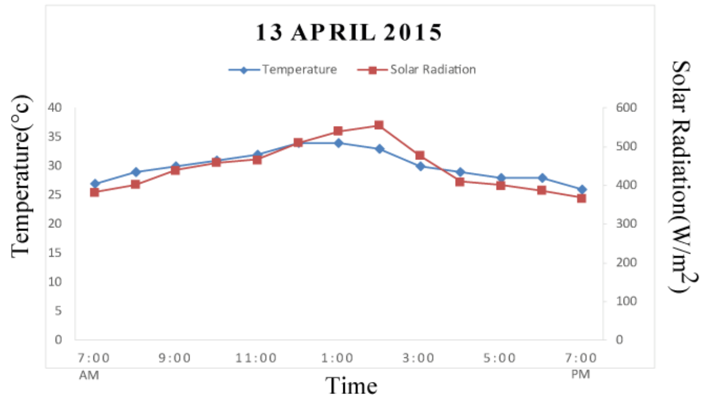
4.2.1 Temperature and Solar Radiation

The following graphs represents the hourly temperature and solar distillation for each of the eight months (January-August).


16 JANUARY 2015
Temperature
Soalr Radiation
Temperature(°c)
Solar Radiation(W/m2)
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


17 FEBRUARY 2015
Temperature
Solar Radiation
Temperature(°c)
Solar Radiation(W/m2)
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


17 MARCH 2015
Temperature
Solar Radiation
Temperature(°c)
Solar Radiation(W/m2)
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


13 APRIL 2015
Temperature
Solar Radiation
Temperature(°c)
Solar Radiation(W/m2)
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time

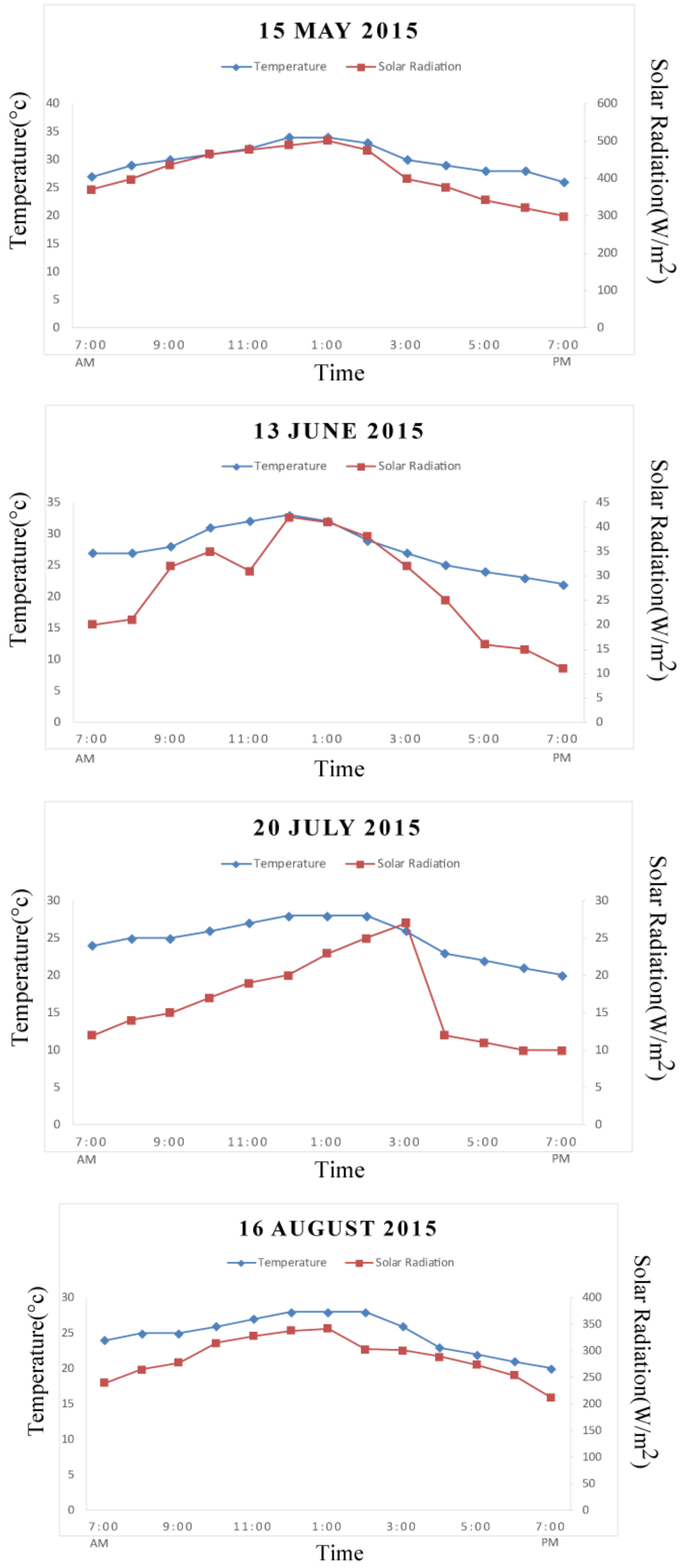
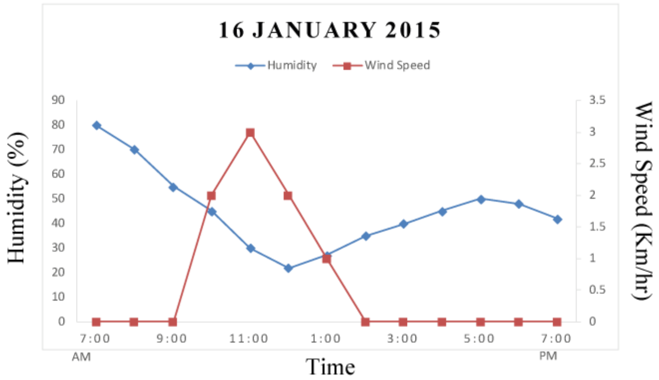


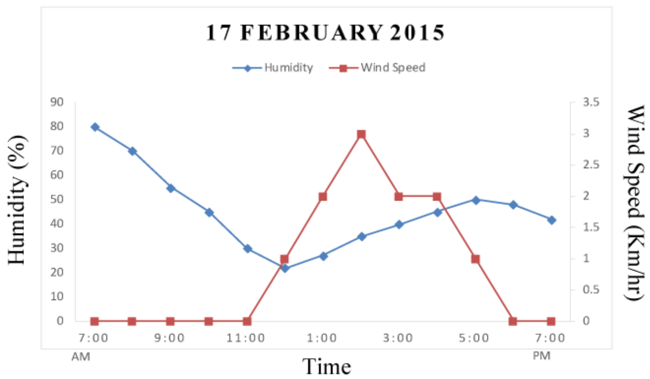
Figure 4.1: Temperature and Solar Radiation of January-August for different times of a particular day which has an average yield of the particular month.

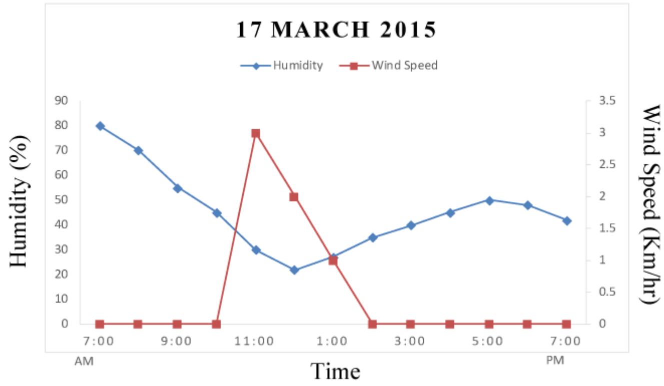
Figure 4.1 illustrates that; temperature is maximum at 1 pm to 2 pm for each of the months. In the month of January and February when winter prevails, temperature is very low. In March, temperature is moderate. In the month of April and May when s summer prevails, temperature is maximum. In the month of June and July due to rainy weather temperature is low. In August temperature is moderate. Again, in the figure when weather is sunny and sky is clear, solar radiation is higher. In the month of January and February, due to fog, weather remains cold and solar radiation is very low. In March, solar radiation is moderate. In the month of April and May due to sunny weather, solar radiation is the highest. In the month of June and July, when Rainy season prevails, sky remains cloudy and solar radiation is the lowest. In the month of August, solar radiation is moderate.

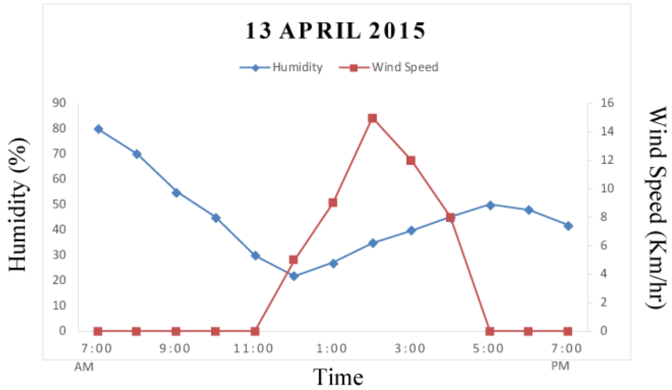
4.2.2 Humidity and Wind Speed

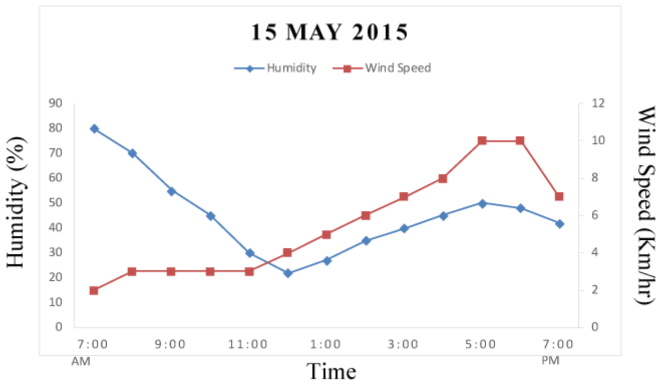
The following graphs represents the hourly humidity and wind speed for each of the eight months (January-August).

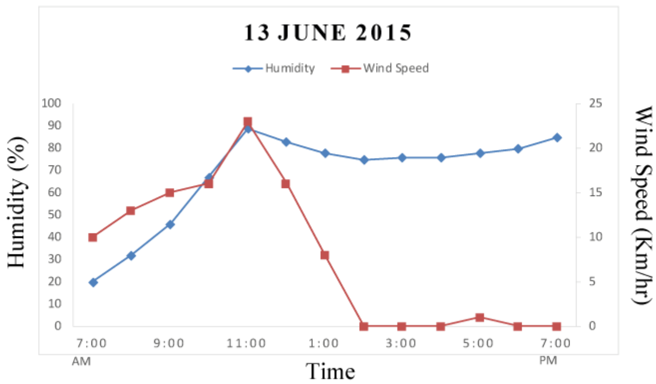


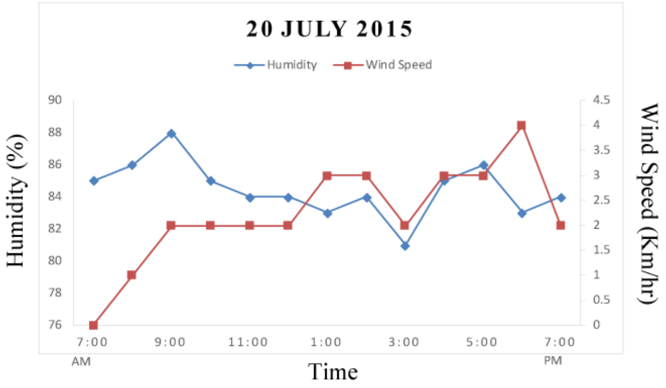



17 MARCH 2015
Humidity
Wind Speed
Humidity (%)
Wind Speed (Km/hr)
Time
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM


13 APRIL 2015
Humidity
Wind Speed
Humidity (%)
Wind Speed (Km/hr)
Time
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM


15 MAY 2015
Humidity
Wind Speed
Humidity (%)
Wind Speed (Km/hr)
Time
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM


13 JUNE 2015
Humidity
Wind Speed
Humidity (%)
Wind Speed (Km/hr)
Time
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM



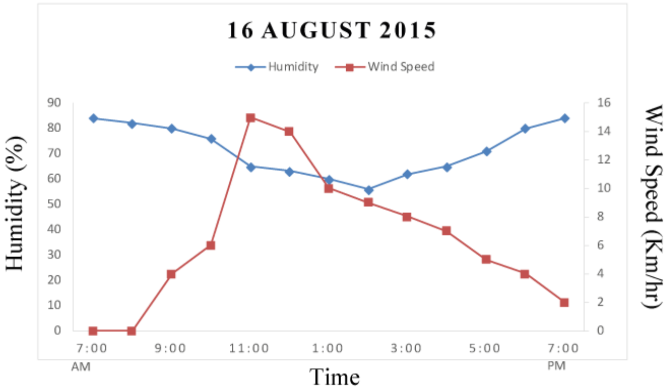
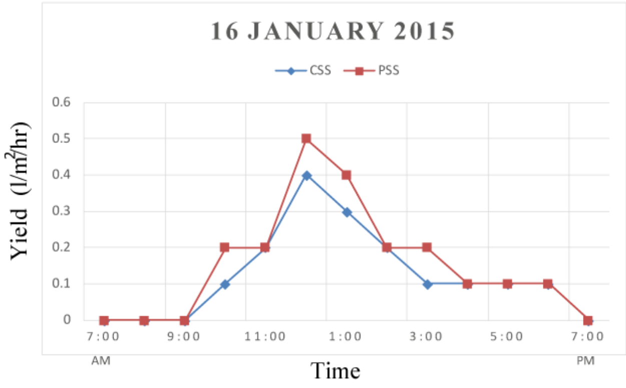


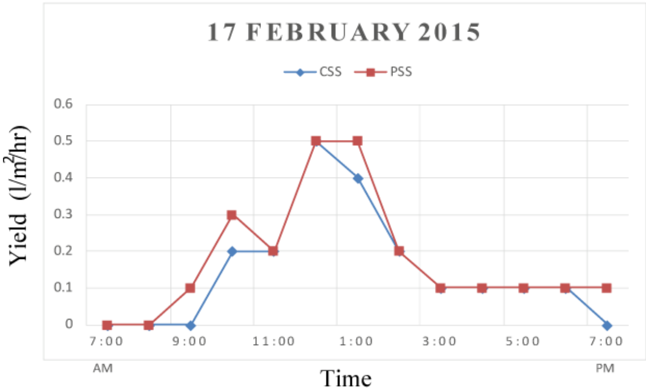
Figure 4.2: Humidity and wind speed of January-August for different times of a particular day which has an average yield of the particular month.

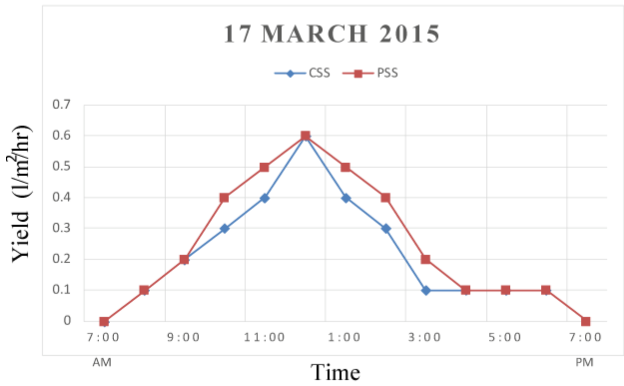
Figure 4.2 shows that, Humidity depends on the availability of water in the atmosphere. The more water in the atmosphere results increase of percentage of humidity. In summer, percentage of humidity is lowest due to dry weather. In winter, due to presence of fog and dew in the atmosphere, percent of humidity is more. And in Rainy season humidity is maximum. Weather condition do not effect wind speed that much. Wind speed can be high or low in any season.

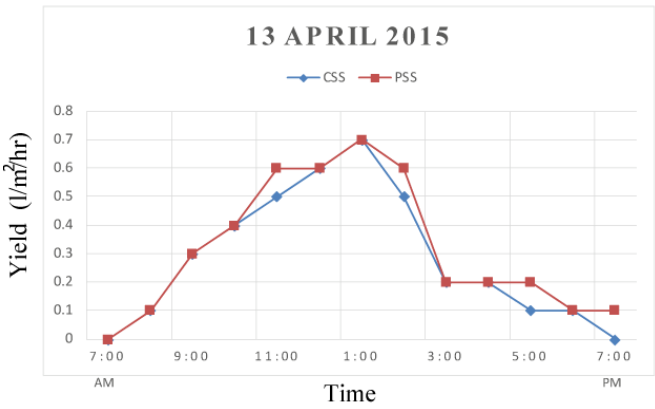
4.3 Hourly Yield

The following graphs represents the hourly yield for a particular day which produce average yield in the particular month for each of the eight months (January-August).


16 JANUARY 2015
CSS
PSS
Yield (l/m²/hr)
0.6
0.5
0.4
0.3
0.2
0.1
0
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


17 FEBRUARY 2015
CSS
PSS
Yield (l/m²/hr)
0.6
0.5
0.4
0.3
0.2
0.1
0
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


17 MARCH 2015
CSS
PSS
Yield (l/m²/hr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time


13 APRIL 2015
CSS
PSS
Yield (l/m²/hr)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7:00 AM
9:00
11:00
1:00
3:00
5:00
7:00 PM
Time

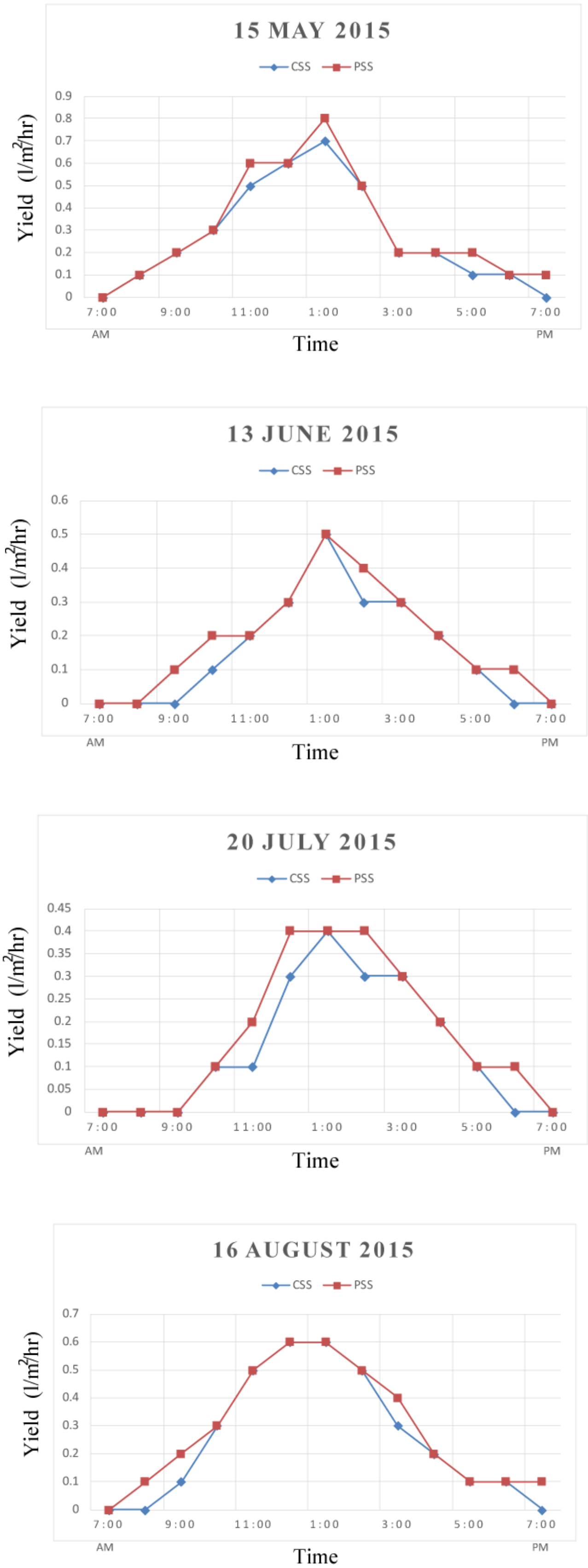


Figure 4.3: Average Hourly yield for January-August

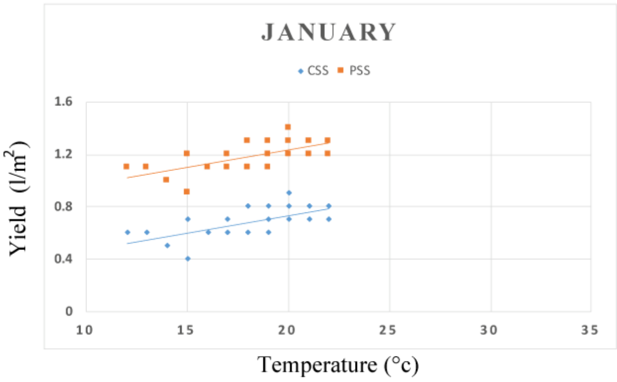
Figure 4.3 illustrates that, for every month temperature is lower in the morning and the average yield is minimum. As the temperature rises, the maximum yield is at around 1:00 PM. Then the temperature begins to fall again and the yield begins to fall too. In all cases, yield of pyramid solar still is more than conventional solar still.

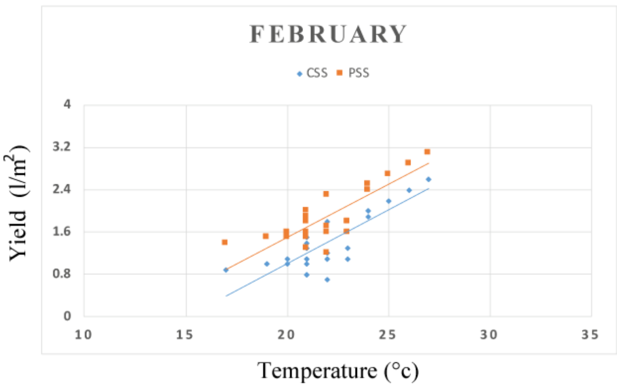
4.4 Parameters vs. Daily Yield

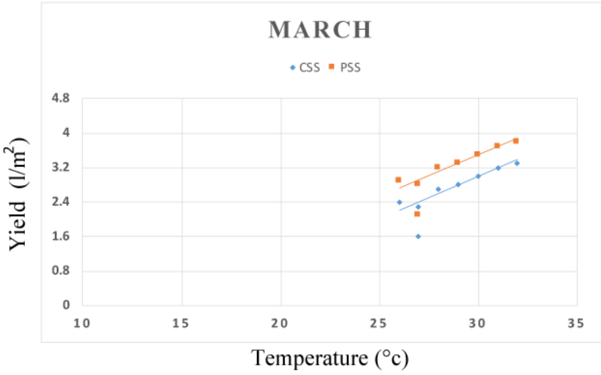
Relation between four parameters (temperature, solar radiation, humidity and wind speed) and daily total yield is represented in this section.

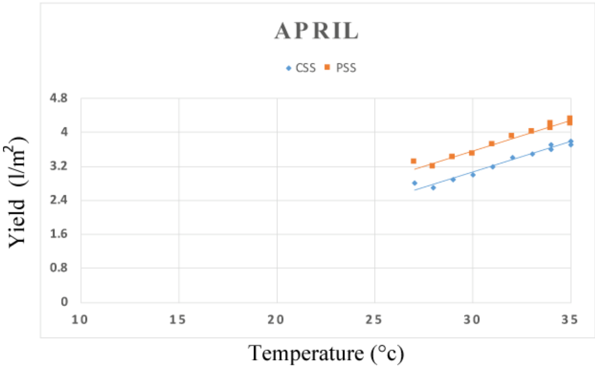
4.4.1 Temperature vs. Daily Yield

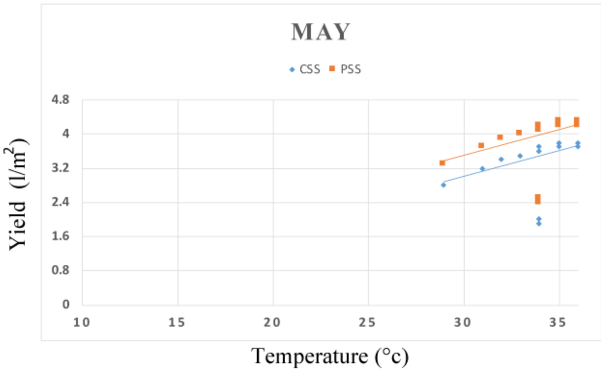
The following graphs represents the relation between temperature and total daily yield for each of the eight months (January-August) for both Conventional and Pyramid solar still.

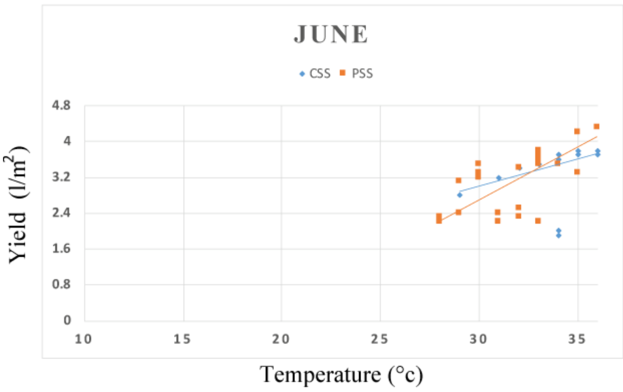


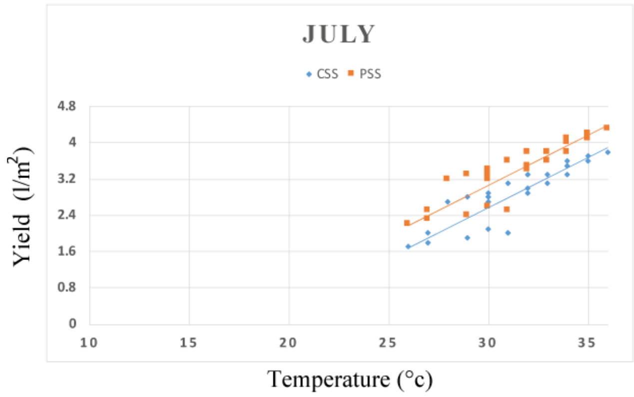



MARCH
CSS
PSS
Yield (l/m2)
Temperature (°c)


APRIL
CSS
PSS
Yield (l/m2)
Temperature (°c)


MAY
CSS
PSS
Yield (l/m2)
Temperature (°c)


JUNE
CSS
PSS
Yield (l/m2)
Temperature (°c)



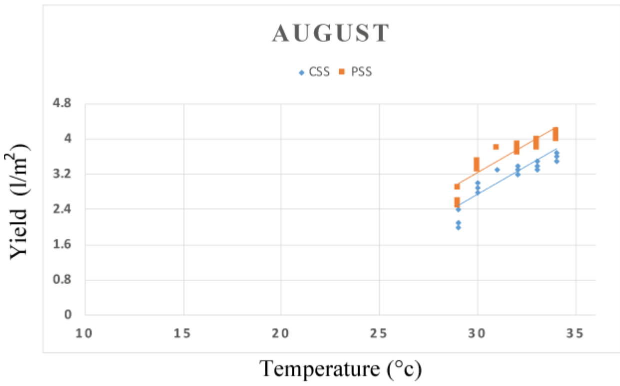
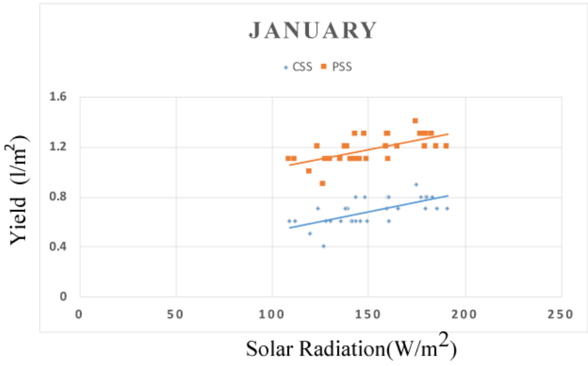


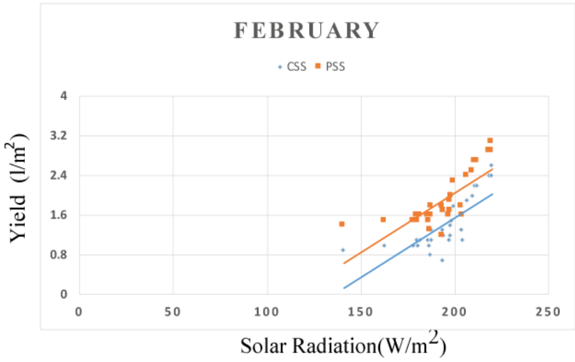
Figure 4.4: Relation between Temperature and daily total yield for January-August

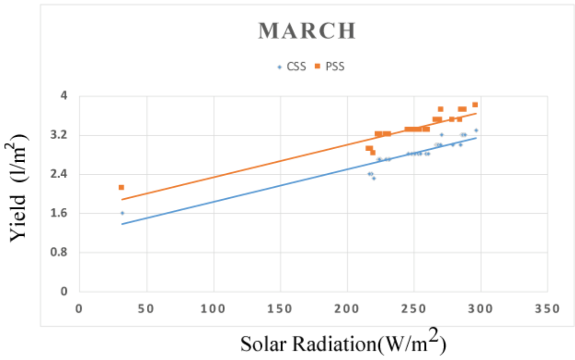
Figure 4.4 shows that, for both conventional and pyramid solar still, increase in temperature results in increase in daily yield. So, temperature and daily yield is positively co-related.

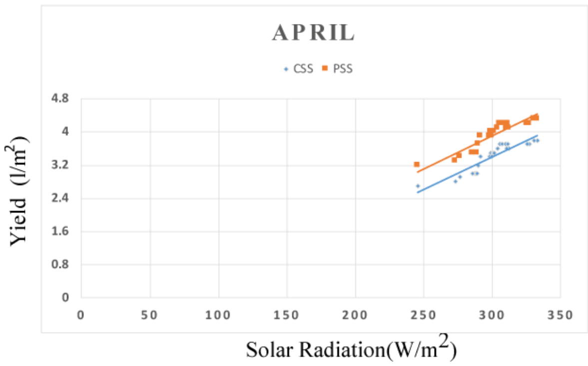
4.4.2 Solar Radiation vs. Daily Yield

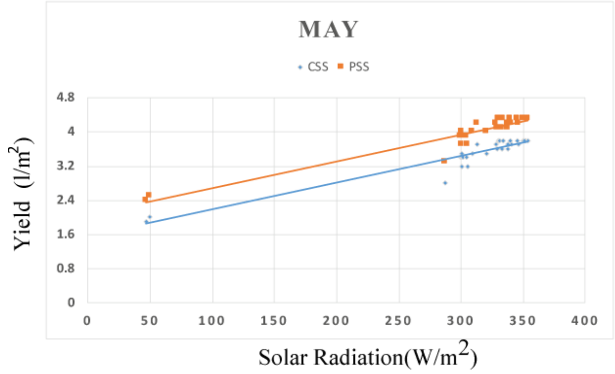
The following graphs represents the relation between solar radiation and total daily yield for each of the eight months (January-August) for both Conventional and Pyramid solar still.

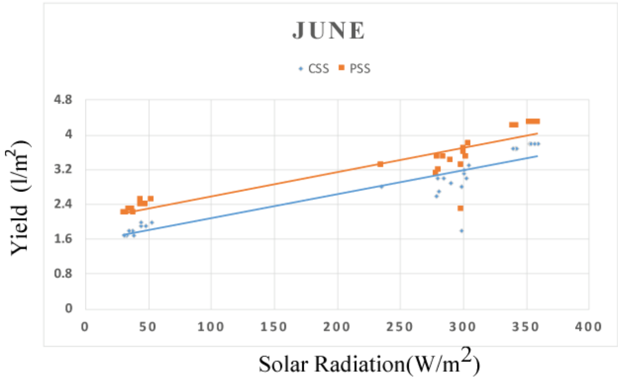

JANUARY
CSS PSS
1.6
1.2
0.8
0.4
0
0 50 100 150 200 250
Yield (l/m^2)
Solar Radiation(W/m^2)

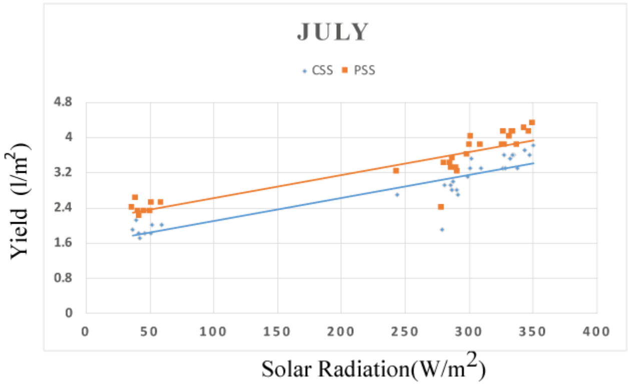

FEBRUARY
CSS PSS
4
3.2
2.4
1.6
0.8
0
0 50 100 150 200 250
Yield (l/m^2)
Solar Radiation(W/m^2)


MARCH
CSS PSS
4
3.2
2.4
1.6
0.8
0
0 50 100 150 200 250 300 350
Yield (l/m^2)
Solar Radiation(W/m^2)


APRIL
CSS PSS
4.8
4
3.2
2.4
1.6
0.8
0
0 50 100 150 200 250 300 350
Yield (l/m^2)
Solar Radiation(W/m^2)







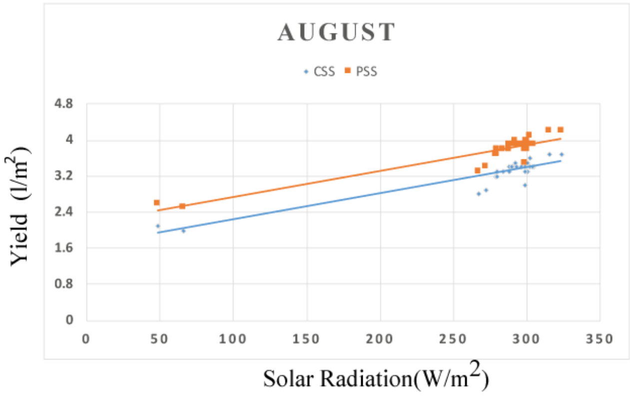
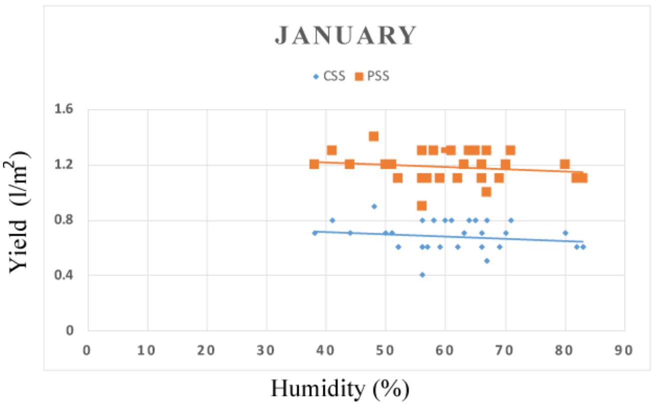


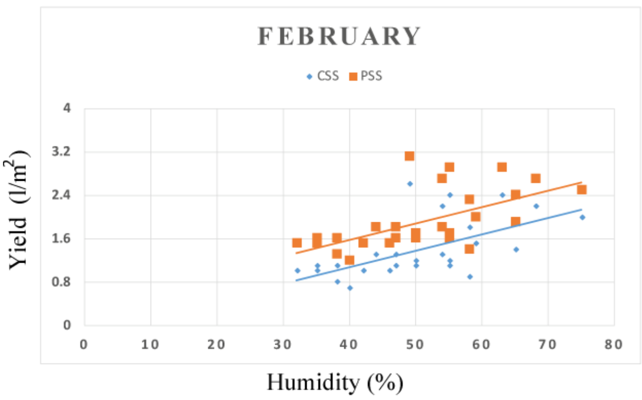
Figure 4.5: Relation between solar radiation and daily total yield for January-August

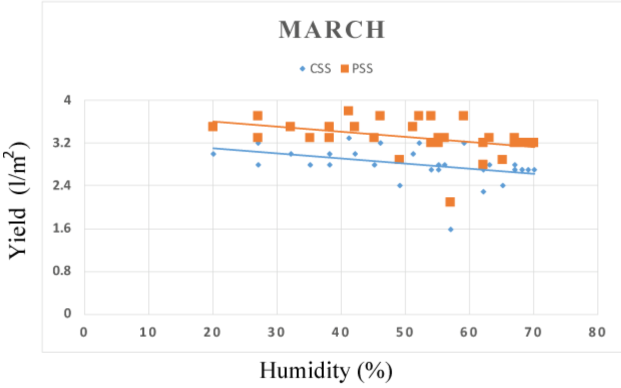
Figure 4.5 shows that, for both conventional and pyramid solar still, increase in solar radiation results in increase in daily yield. So, solar radiation and daily yield is positively co-related.

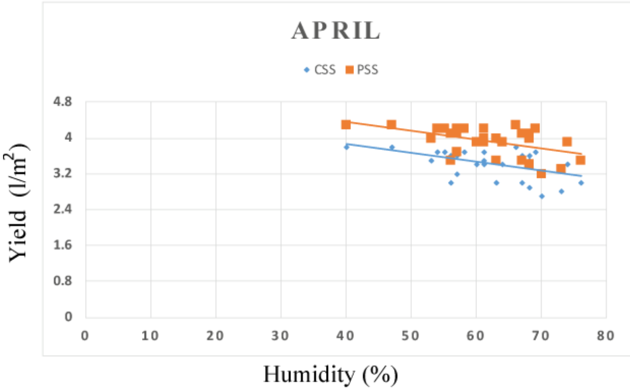
4.4.3 Humidity vs. Daily Yield

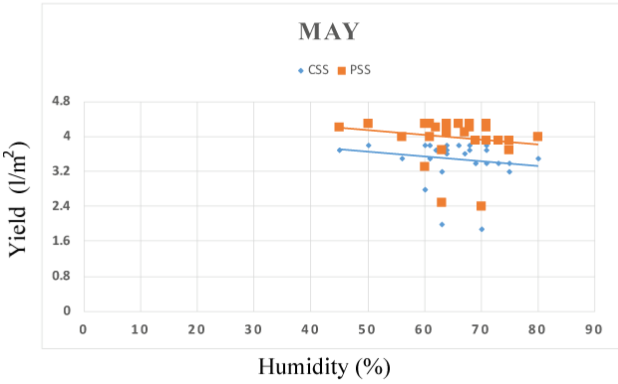
The following graphs represents the relation between humidity and total daily yield for each of the eight months (January-August) for both Conventional and Pyramid solar still.

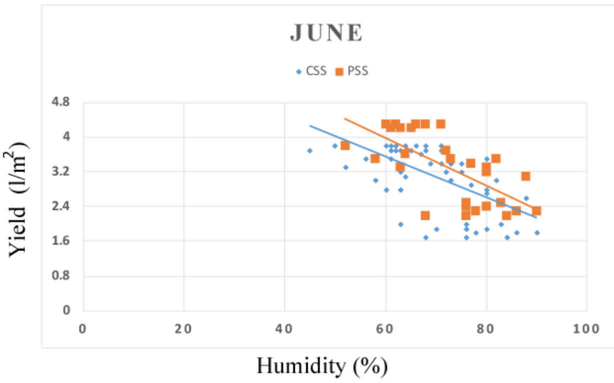


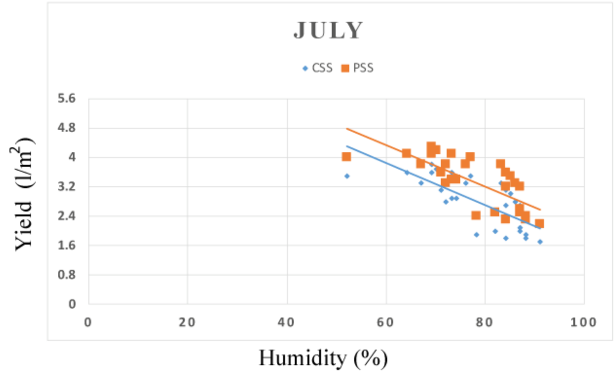



MARCH
CSS
PSS
Yield (l/m2)
0
0.8
1.6
2.4
3.2
4
0
10
20
30
40
50
60
70
80
Humidity (%)


APRIL
CSS
PSS
Yield (l/m2)
0
0.8
1.6
2.4
3.2
4
4.8
0
10
20
30
40
50
60
70
80
Humidity (%)


MAY
CSS
PSS
Yield (l/m2)
0
0.8
1.6
2.4
3.2
4
4.8
0
10
20
30
40
50
60
70
80
90
Humidity (%)


JUNE
CSS
PSS
Yield (l/m2)
0
0.8
1.6
2.4
3.2
4
4.8
0
20
40
60
80
100
Humidity (%)



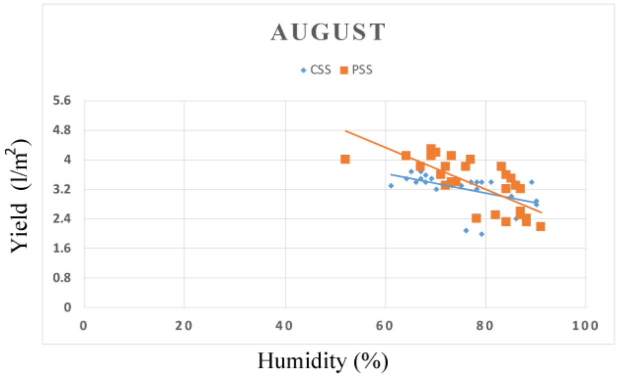
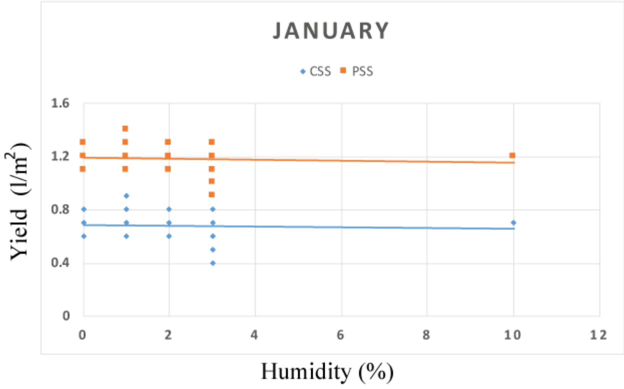


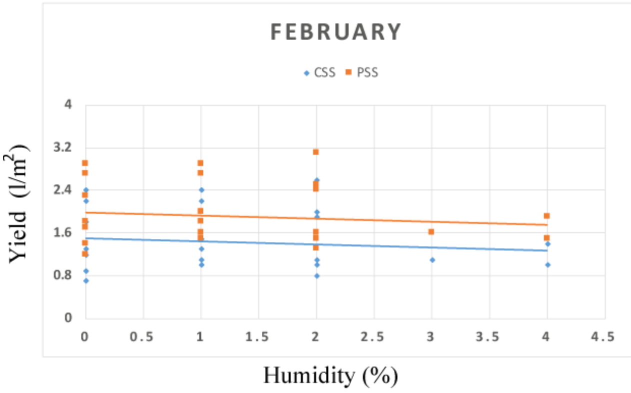
Figure 4.6: Relation between humidity and daily total yield for January-August.

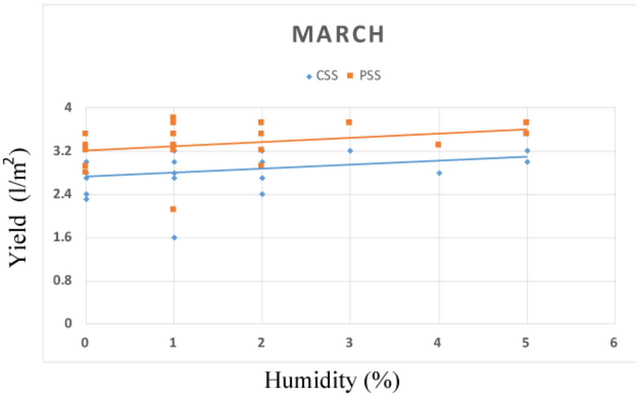
Figure 4.6 illustrates that, for both conventional and pyramid solar still, except for February, increase in solar radiation results in decrease in daily yield. So, humidity and daily yield is negatively co-related.

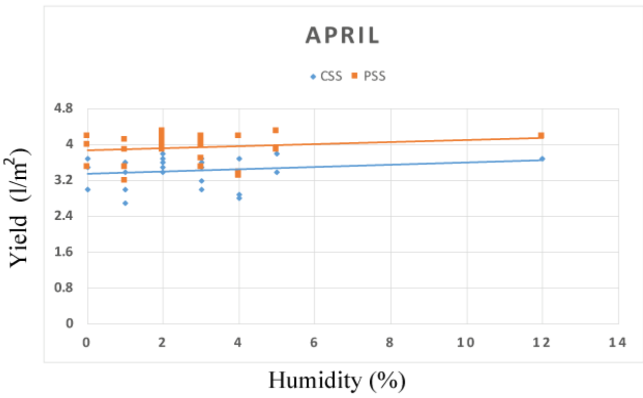
4.4.4 Wind Speed vs. Daily Yield

The following graphs represents the relation between wind speed and total daily yield for each of the eight months (January-August) for both Conventional and Pyramid solar still.


JANUARY
CSS PSS
Yield (l/m2)
1.6
1.2
0.8
0.4
0
0 2 4 6 8 10 12
Humidity (%)


FEBRUARY
CSS PSS
Yield (l/m2)
4
3.2
2.4
1.6
0.8
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Humidity (%)


MARCH
CSS PSS
Yield (l/m2)
4
3.2
2.4
1.6
0.8
0
0 1 2 3 4 5 6
Humidity (%)


APRIL
CSS PSS
Yield (l/m2)
4.8
4
3.2
2.4
1.6
0.8
0
0 2 4 6 8 10 12 14
Humidity (%)

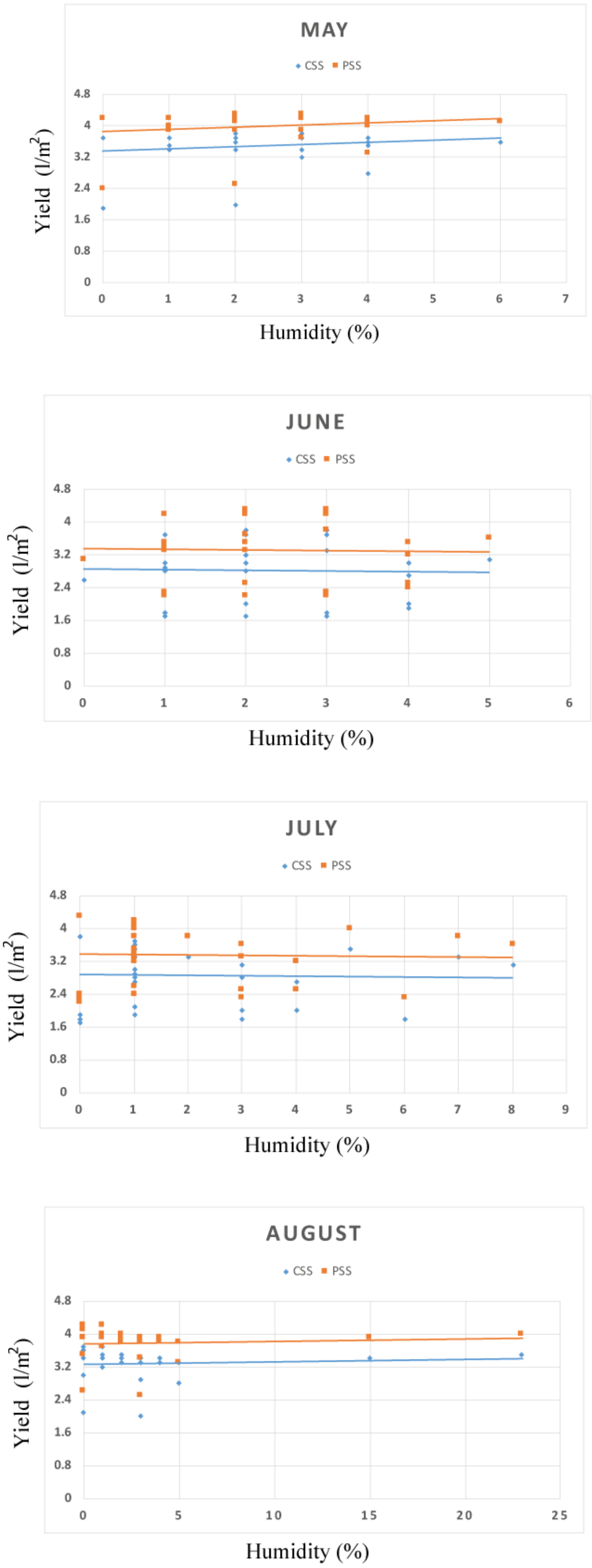


Figure 4.7: Relation between wind speed and daily total yield for January-August

Figure 4.7 illustrates that, for both conventional and pyramid solar still, the effect of wind speed is not consistent for daily yield. For some month yield is increasing with increasing wind speed and for some month yield is decreasing with increasing wind speed. So, the effect of wind speed is nugatory.

4.5 Calculation of Thermal Mathematical Model

Based on the equations mentioned in Chapter 3.9, the calculation of thermal mathematical model is shown in Table 4.1, which is depended on the inner glass temperature and temperature of water. The thermal mathematical model is based on the different heat lost coefficients, and they are inter-dependent on each other. After calculating different temperatures and heat loss coefficient V, T_a, T_w, T_{gi}, T_{go}, P_w, P_{gi}, h_{cw}, h_{ew}, h_{rw}, the hourly yield and hourly efficiency is calculated. Then average efficiency is calculated.

Table 4.1: Thermal mathematical model calculation for a particular day

Eg	0.93
Ew	0.997
εeff	0.927405
σ	5.67E-08
L	2500000

T(h)	I(t)	V	T_a	T_w	T_{gi}	T_{go}	P_w	P_{gi}
8:00 AM	210	1.3	28	29	27	29	3959.557	3534.522
9:00	327	1.9	29	31	28	32	4429.081	3741.714
10:00	359	2.2	29	35	30	36	5517.617	4188.518
11:00	444	1.2	30	47	35	44	10321.66	5517.617
12:00PM	607	1.9	31	60	41	47	19332.69	7591.879
1:00	702	2	34	64	45	55	23223.15	9329.152
2:00	1024	2.3	36	67	44	60	26571.33	8865.039
3:00	917	3	32	58	34	54	17609.86	5225.468

4:00	613	2.5	29	49	32	44	11405.43	4681.745
5:00	420	3.2	29	41	30	37	7591.879	4188.518
6:00	222	3	27	39	29	30	6835.06	3959.557

$\Delta T'$	h_{cw}	h_{ew}	h_{rw}	m_{ew}
2.046524	1.12234	3.881386222	1.58279E-05	0.011178392
3.08057	1.286262	4.795837218	1.59070E-05	0.020718017
5.176619	1.529212	6.614887585	1.60654E-05	0.047627191
12.8732	2.0718	13.4971212	1.65174E-05	0.233230254
21.82268	2.47033	24.8408787	1.70255E-05	0.679646441
22.61945	2.500036	29.750048	1.72357E-05	0.813961313
27.89551	2.681001	33.58647976	1.72950E-05	1.11238421
26.85843	2.647357	22.23021628	1.67980E-05	0.768276275
18.27949	2.328664	14.98762715	1.64972E-05	0.366897113
11.534	1.99731	10.05607406	1.62273E-05	0.159288213
10.42793	1.931308	9.037182058	1.61475E-05	0.130135422

Total yield per day= 4.3433 liters

(Tw-Ta)/I(t)	η_i	Daily efficiency
0.004762	3.6965583	
0.006116	4.3998507	
0.016713	9.2129354	
0.038288	36.478706	41.29940693
0.047776	77.755633	
0.042735	80.520073	
0.030273	75.438382	

0.028353	58.181591	
0.032626	41.564382	
0.028571	26.337337	
0.054054	40.708027	

4.6 Model Calibration

After developing the thermal mathematical model, the model was calibrated comparing the theoretical yield and observed yield for both conventional still and pyramid solar still. The theoretical value was found more than the observed yield. Maximum difference was found 500 ml more for a particular day for both solar stills.

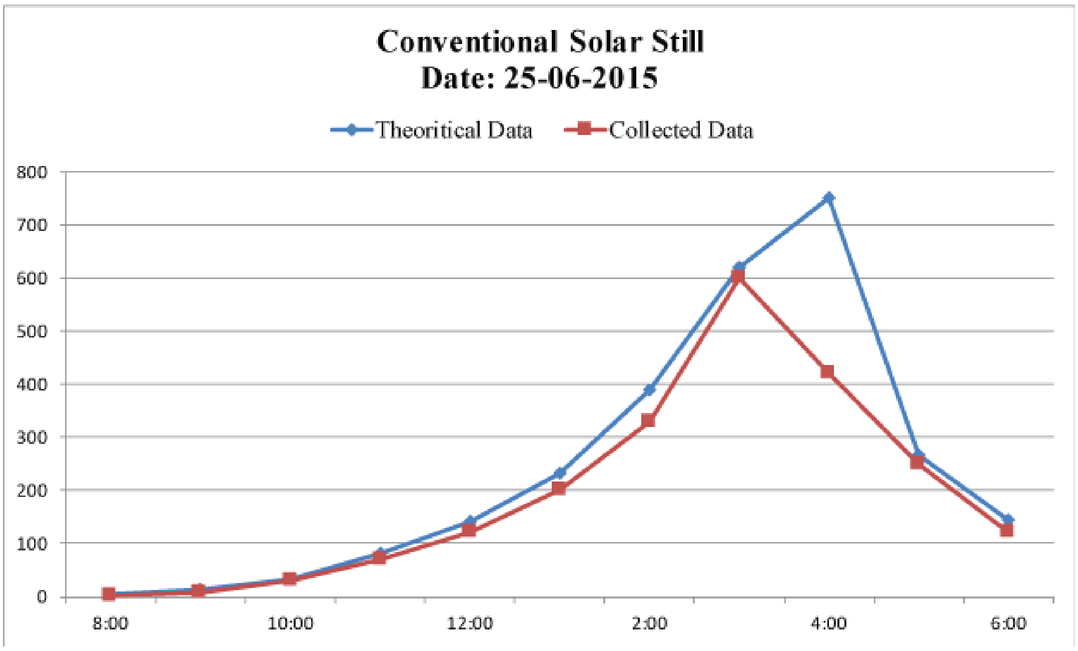


Figure 4.8: Model Calibration for Conventional Solar still.

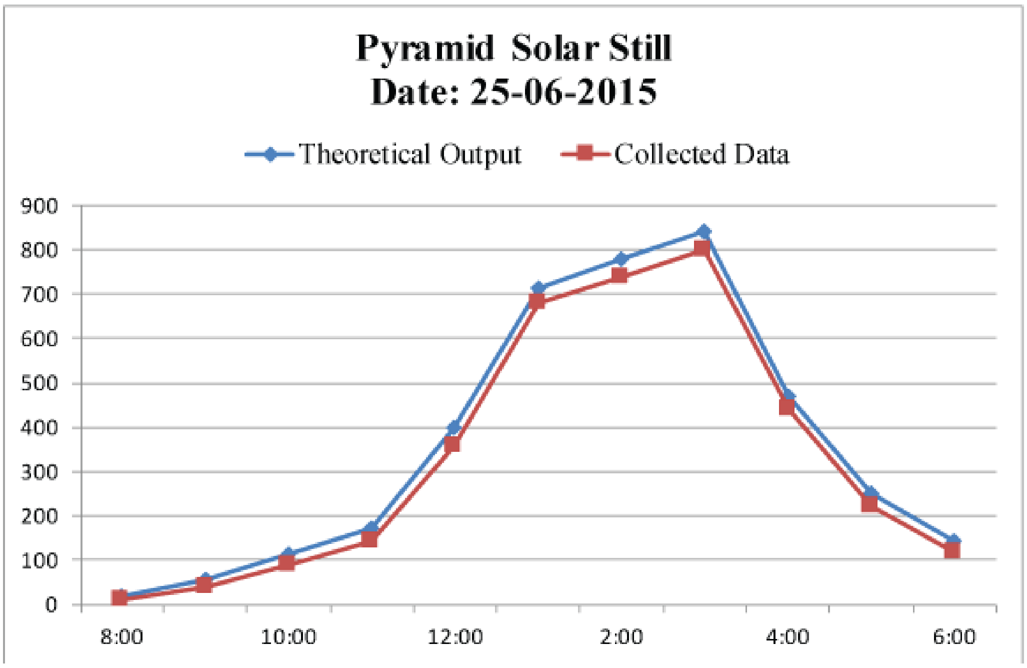


Figure 4.9: Model Calibration for Pyramid Solar still.

4.7 Khulna Data Simulation

As the thermal mathematical model is based on two factors, inner glass temperature and temperature of water, this two factors is needed for calculating the output of Khulna. In case of Gazipur it is observed in Figure 4.10 that, in Conventional solar still, water temperature T_w is maximum 30° more than ambient temperature of Gazipur T_a and inner glass temperature T_{gi} is maximum 10° more than ambient temperature T_a. So, the ambient temperature of Khulna is collected from the internet and 30° is added to find the water temperature of Khulna and 10° is added to find out the inner glass temperature of Khulna for conventional single slope solar still. For Pyramid solar still, shown in Figure 4.11, it shows that water temperature T_w is maximum 35° more than ambient temperature of Gazipur T_a and inner glass temperature T_{gi} is maximum 25° more than ambient temperature T_a. So again, the ambient temperature of Khulna is collected from the internet and 35° is added to find the water temperature of Khulna and 25° is added to find out the inner glass temperature of Khulna for pyramid solar still. Then the same process is followed in the thermal mathematical model to find out the efficiency and yield for the same day as done for the conventional solar still.

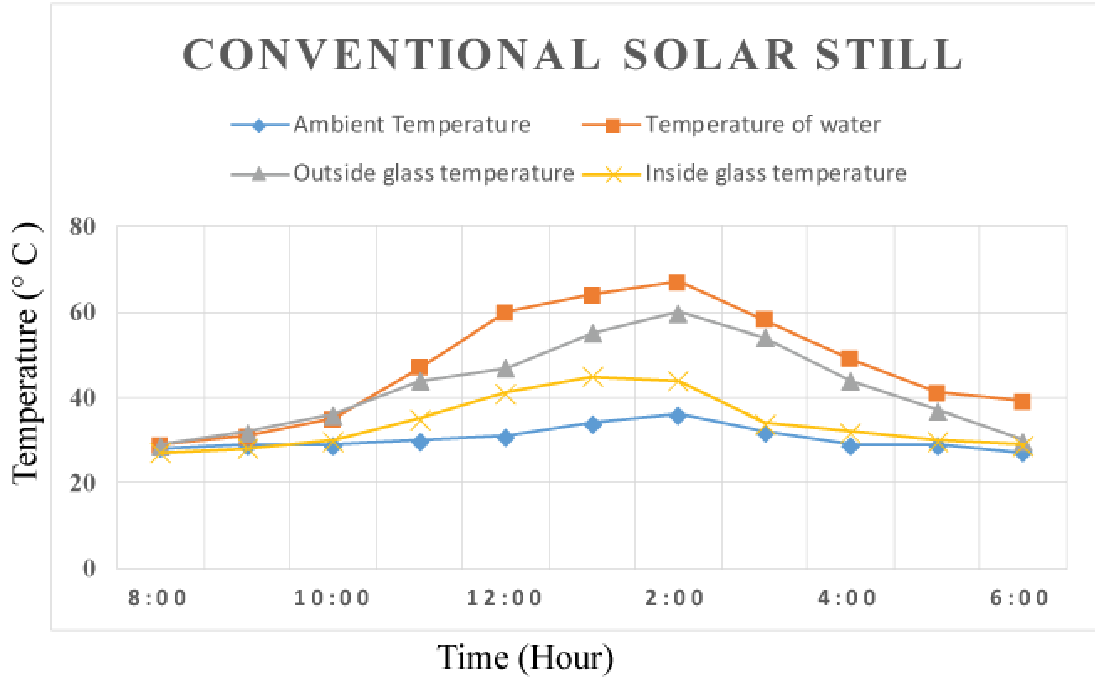


Figure 4.10: Temperature difference of conventional solar still in Gazipur

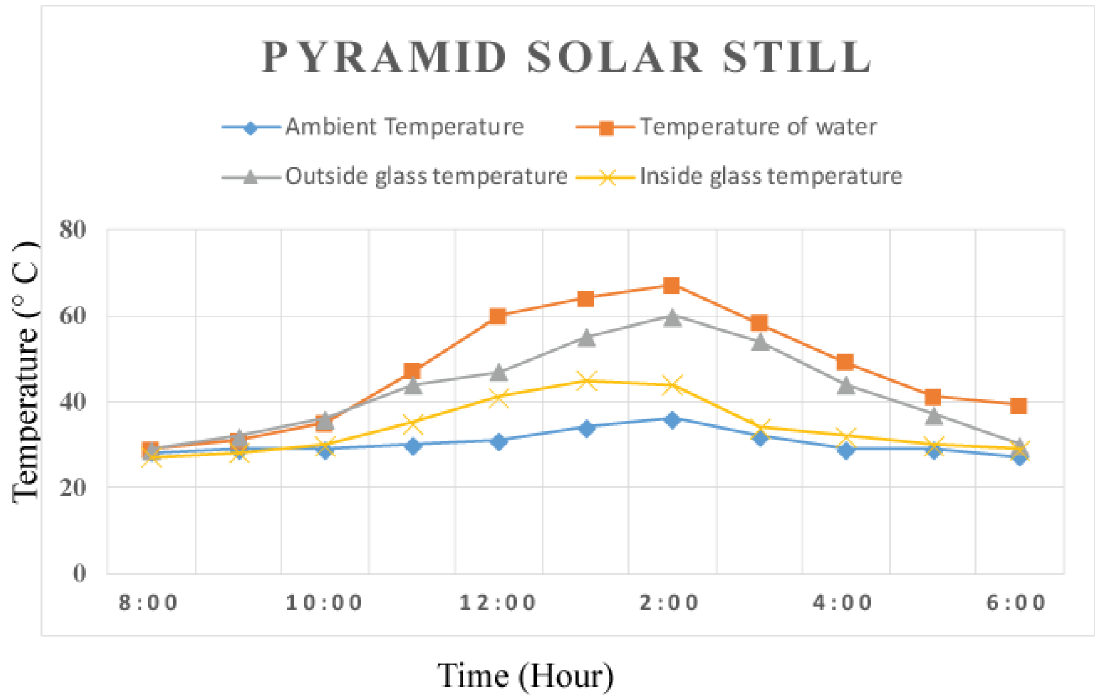
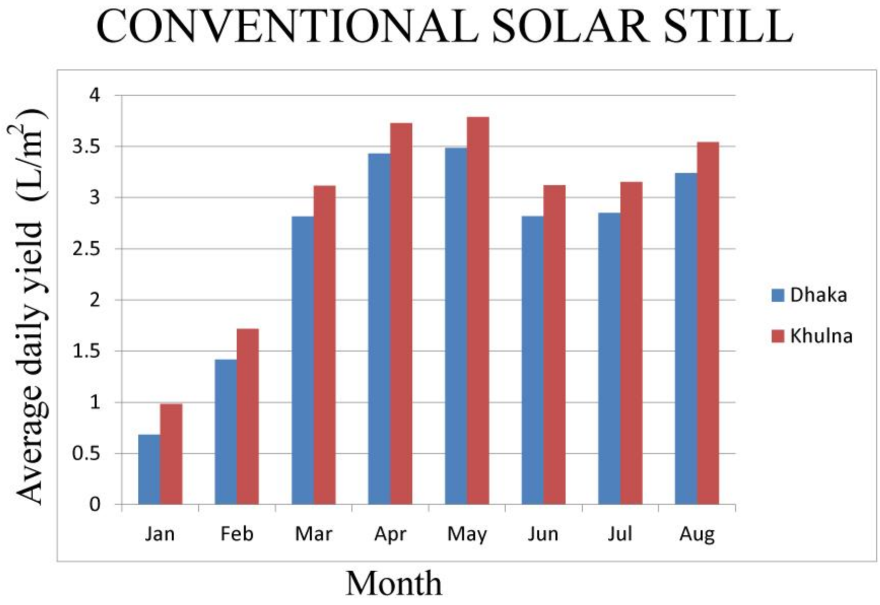


Figure 4.11: Temperature difference of pyramid solar still in Gazipur

4.8 Average Daily Yield Comparison Between Gazipur and Khulna

In the Figure 4.12, comparison is made between the average yield output for eight months for both conventional and pyramid solar still.



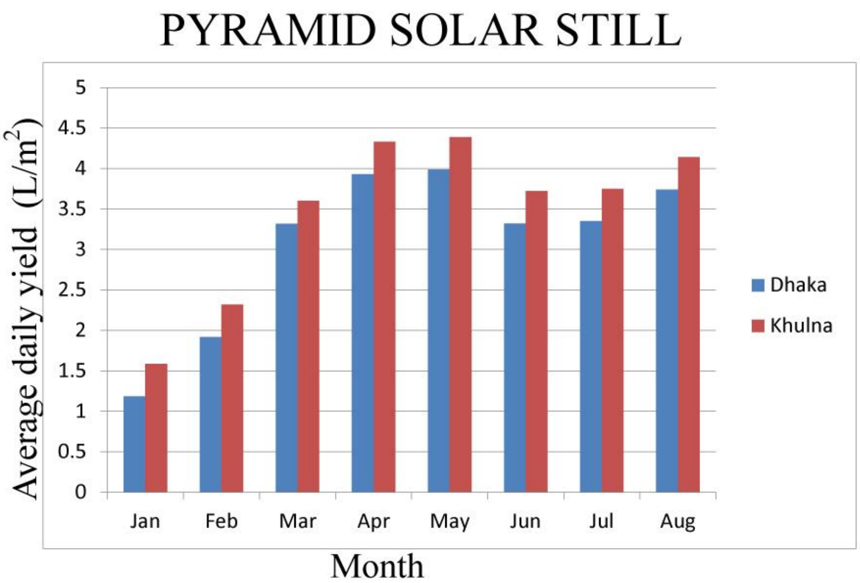


Figure 4.12: Average daily yield comparison for conventional and pyramid solar still between Gazipur (Dhaka) and Khulna

Figure 4.12 shows that, the average daily yield of Khulna is more than Gazipur. For conventional solar still it's about 300 ml/day and for pyramid solar still it's about 400 ml/day.

4.9 Height vs. Yield

This section represents the effect of different clearance height of water on yield per day only for conventional solar still.

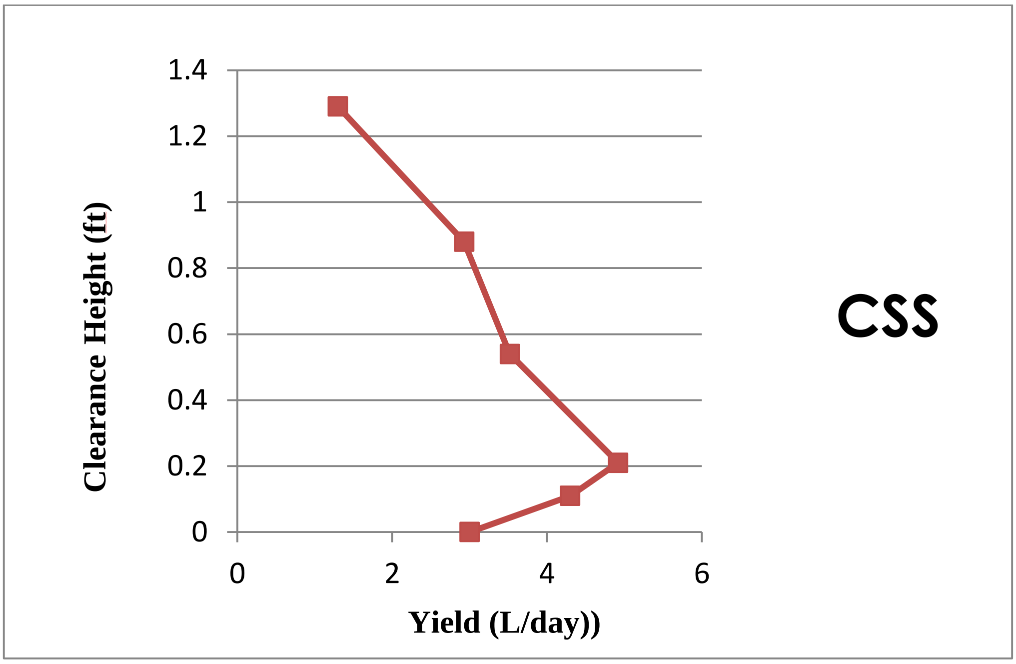


Figure 4.13: Clearance height vs. daily yield of Conventional solar still

Figure 4.13 illustrates that, for conventional solar still the maximum yield can be found at clearance height 0 ft. from the front side of the still.

4.10 Water Quality Parameters

Water quality parameter test was done for both the brine water given and the yield water.

Table 4.2: Water quality parameters

Parameters	Input water	Standard	Output Water
pH	6.8	6.5-8.5	7.8
TDS (ppm)	40000	Within 500	143
Electric conductivity (μS/cm)	5600	5-50	28.5

Table 4.2 indicates that, for each of the parameters the output water value is satisfactory. So, the water is potable for drinking purpose.

4.11 Economic Feasibility Analysis

Economic analysis must be done to ensure the feasibility of an experiment. Table 4.3 and Table 4.4 shows the Cost comparison against alternative fuel for Conventional solar still and Pyramid solar still respectively.

Table 4.3: Cost comparison against alternative fuel for conventional solar still

Energy Measure	Solar System	Electric System
Energy required to evaporate average 3.5 liter water daily $E=m * C_p * \triangle t + m * \tau$ where, m= mass of water (3.5 kg) C_p= specific heat of water (1 kcal/kg/◦c) $\triangle t$= average temperature difference of water (50◦c) τ = Latent heat of vaporization (540 kcal/kg)	2.5 kwh	2.5 kwh
Energy required for 875 L (250*3.5=875 L) distilled water in 250 days in a year (kwh)	625 kwh	625 kwh
Electricity tariff to produce 875 L distilled water in BDT (per unit average 7 taka)	0	4375 BDT
Revenue generated from 875 L distilled water at rate 10 BDT	8750 BDT	8750 BDT
Net profit from system	8750 BDT	4375 BDT

Table 4.4: Cost comparison against alternative fuel for Pyramid solar still

Energy Measure	Solar System	Electric System
Energy required to evaporate average 3.5 liter water daily $E=m * C_p * \triangle t + m * \tau$ where, m= mass of water (3.5 kg) C_p= specific heat of water (1 kcal/kg/◦c) $\triangle t$= average temperature difference of water (50◦c) τ = Latent heat of vaporization (540 kcal/kg)	2.7 kwh	2.7 kwh
Energy required for 875 L (250*3.5=875 L) distilled water in 250 days in a year (kwh)	675 kwh	675 kwh
Electricity tariff to produce 875 L distilled water in BDT (per unit average 7 taka)	0	4725 BDT
Revenue generated from 875 L distilled water at rate 10 BDT	11250 BDT	11250 BDT
Net profit from system	11250 BDT	6525BDT

So, in terms of fuel energy saving, pyramid solar still is better than conventional solar still.

For conventional solar still,

Discount rate 10%.

After 5 years maintenance cost 2000 BDT.

Yearly maintenance cost = 10% of 8000 BDT = 800 BDT

Table 4.5: Net Present Value Analysis for conventional solar still

Year (1)	Cash Outflow (2)	PW(present worth) of Cash Outflow at 10% discount rate (3)	Cash Inflow (4)	PW(present worth) of Cash Inflow (5)	NPW(net present worth) (5-3) (6)
0	8000	8000	0	0	-8000
1	800	727.2727	8750	7954.545	7227.273
2	800	661.157	8750	7231.405	6570.248
3	800	601.0518	8750	6574.005	5972.953
4	800	546.4108	8750	5976.368	5429.957
5	2000	1241.843	8750	5433.062	4191.219
6	800	451.5791	8750	4939.147	4487.568
7	800	410.5265	8750	4490.134	4079.607
8	800	373.2059	8750	4081.94	3708.734
9	800	339.2781	8750	3710.854	3371.576
10	2000	771.0866	8750	3373.504	2602.417
11	800	280.3951	8750	3066.822	2786.427
12	800	254.9047	8750	2788.02	2533.115
13	800	231.7315	8750	2534.563	2302.832
14	800	210.665	8750	2304.148	2093.483
15	2000	478.7841	8750	2094.68	1615.896
16	800	174.1033	8750	1904.255	1730.152

17	800	158.2757	8750	1731.141	1572.865
18	800	143.887	8750	1573.764	1429.877
19	800	130.8064	8750	1430.695	1299.889
20	2000	297.2873	8750	1300.632	1003.344
21	800	108.1045	8750	1182.392	1074.288
22	800	98.27678	8750	1074.902	976.6255
23	800	89.34253	8750	977.1839	887.8414
24	800	81.22048	8750	888.349	807.1285
25	0	0	8750	807.59	807.59
Total		16861.2		79424.1	62562.9

Table 4.5 shows that, Net Present Worth of conventional solar still= 62562.9 BDT.

For Pyramid solar still,

Discount rate 10%.

After 5 years maintenance cost 2000 BDT.

Yearly maintenance cost = 10% of 8300 BDT = 830 BDT.

Table 4.6: Net Present Value Analysis for Pyramid solar still

Year (1)	Cash Outflow (2)	PW (present worth) of Cash Outflow at 10% discount rate (3)	Cash Inflow (4)	PW(present worth) of Cash Inflow (5)	NPW (net present worth) (5-3) (6)
0	8300	8300	0	0	-8300
1	830	754.5455	11250	10227.27	9472.727
2	830	685.9504	11250	9297.521	8611.57
3	830	623.5913	11250	8452.292	7828.7
4	830	566.9012	11250	7683.901	7117

5	2000	1241.843	11250	6985.365	5743.522
6	830	468.5134	11250	6350.332	5881.818
7	830	425.9212	11250	5773.029	5347.108
8	830	387.2011	11250	5248.208	4861.007
9	830	352.001	11250	4771.098	4419.097
10	2000	771.0866	11250	2337.362	3566.275
11	830	290.9099	11250	3943.056	3652.146
12	830	264.4636	11250	3584.597	3320.133
13	830	240.4214	11250	3258.724	3018.303
14	830	218.5649	11250	2962.477	2743.912
15	2000	478.7841	11250	2693.161	2214.376
16	830	180.6322	11250	2448.328	2267.696
17	830	164.2111	11250	2225.753	2061.541
18	830	149.2828	11250	2023.411	1874.129
19	830	135.7116	11250	1839.465	1703.753
20	2000	297.2873	11250	1672.241	1374.954
21	830	112.1584	11250	1520.219	1408.061
22	830	101.9622	11250	1382.017	1280.055
23	830	92.69287	11250	1256.379	1163.686
24	830	84.26625	11250	1142.163	1057.897
25	0	0	11250	1038.33	1038.33
Total		17388.9		102116.7	84727.8

Table 4.6 shows that, Net Present Worth of conventional solar still= 84727.8 BDT. Pyramid solar still is more feasible than Conventional solar still.

Table 4.7: Benefit cost ratio of Conventional solar still

Year	B/C Ratio
1	.85
2	1.49

3	1.98
4	2.33

Table 4.8: Benefit cost ratio of Pyramid solar still

Year	B/C Ratio
1	1.06
2	1.85
3	2.44
4	2.89

Table 4.7 and Table 4.8 shows that, benefit cost ratio of conventional solar still is 1.49 in second year and 1.85 for pyramid solar still in second year. So, the project is feasible.

Payback Period of Conventional Solar Still

Profit after 12 months 8750 BDT

so, Profit after 1 day (8750÷365) = 23.97 BDT

23.97 BDT profit in 1 Day

so, 8000 BDT profit in (8000÷23.97) = 333.8 Days ≈ 334 Days

So, It takes 11 month and 4 Days.

So, Payback Period = 11.13 Month.

Payback Period of Pyramid Solar Still

Profit after 12 months 11250 BDT

so, Profit after 1 day (11250÷365) = 30.82 BDT

30.82 BDT profit in 1 Day

so, 8300 BDT profit in (8300÷30.82) = 269.3 Days ≈ 270 Days

So, It takes 9 month

So, Payback Period = 9 Month.

Internal Rate of Return for Conventional Solar Still

If the 1st 5 Years or 1st cycle is taken for measuring IRR

$$0 = -\frac{8000}{(1+r)^0} + \frac{8750}{(1+r)^1} + \frac{8750}{(1+r)^2} + \frac{8750}{(1+r)^3} + \frac{8750}{(1+r)^4} + \frac{8750}{(1+r)^5}$$

Now, using Trial and Error method, taking r = 20%

$$-\frac{8000}{(1+.20)^0} + \frac{8750}{(1+.20)^1} + \frac{8750}{(1+.20)^2} + \frac{8750}{(1+.20)^3} + \frac{8750}{(1+.20)^4} + \frac{8750}{(1+.20)^5}$$

=18167.86

From other values of r (30, 40, 50) it is sure that as the Payback Period is in the 1st year the IRR is surely over 100%. As it is more than 10%, so, the project is surely feasible.

Internal Rate of Return for Pyramid Solar Still

If the 1st 5 Years or 1st cycle is taken for measuring IRR

$$0 = -\frac{8300}{(1+r)^0} + \frac{11250}{(1+r)^1} + \frac{11250}{(1+r)^2} + \frac{11250}{(1+r)^3} + \frac{11250}{(1+r)^4} + \frac{11250}{(1+r)^5}$$

Now, using Trial and Error method, taking r = 20%

$$-\frac{8300}{(1+.20)^0} + \frac{11250}{(1+.20)^1} + \frac{11250}{(1+.20)^2} + \frac{11250}{(1+.20)^3} + \frac{11250}{(1+.20)^4} + \frac{11250}{(1+.20)^5}$$

=25344.39

From other values of r (30,40,50) it is sure that as the Payback Period is in the 1st year the IRR is surely over 100%. As it is more than 10%, so, the project is surely feasible.

Chapter 5 Conclusion

5.1 Introduction

The coastline is of 734 km which is the residence of nearly 50 million people of Bangladesh. Salinity in drinking water is one of the major problems for the last few decades in coastal areas. Though several methods of water supply can be used like deep tube-well, dug well, pond sand filter, combined filter, household filter, rainwater harvesting, the methods can't be applied all the time or costly in price. As seawater and sunlight is freely available in an unlimited amount, the research is based on the objective to provide potable drinking water for a 3-4-member family of the coastal area.

5.2 Summary and Major Findings

The distillation output has a positive correlation with temperature and solar intensity, inverse relation with relative humidity and wind speed has nugatory consequence. The maximum output of Conventional Solar Still is obtained 3.8 L/m^2/day and Pyramid still is 4.3 L/m^2/day for Gazipur. Almost 10% more efficiency is found for Pyramid still. In conventional solar still, temperature of water is maximum 30° more than ambient temperature and inside glass temperature is maximum 10° more than ambient temperature. In pyramid solar still, temperature of water is maximum 35° more than ambient temperature and inside glass temperature is 25° more than ambient temperature. This data is put on the mathematical model to find the Khulna hourly yield of distill water and efficiency and model calibration is done and theoretical output is found maximum 500 ml more than observed data. Productivity in Khulna is found almost 10% more than Gazipur. Yield is maximum in conventional still for a clearance height of 0.21 meter, glass cover thickness of 6 mm and galvanized steel thickness of 1 mm. All the water quality parameters measured were inside the standard limit instructed by World Health Organization (WHO). The economic feasibility analysis was done and benefit cost ratio of conventional solar still is 1.49 in second year and 1.85 for pyramid solar still in second year. So, the project is feasible. The payback period is found 11 months 4 days for conventional solar still and 9 months for pyramid solar still. So, the project is feasible. Finally, for a 3-4-member family, area of 5 m^2 is suggested for Conventional Still and 4 m^2 for Pyramid Solar Still is suggested.

5.3 Limitation of the Study

The study is carried out is in Gazipur city, which is not a coastal area. Though the effect of different parameters is studied in details, measurement in coastal area could make the research more accurate.

Another limitation in the study is carried out between two models- Conventional or simple single basin wick type solar still and pyramid solar steel based on a hypothesis from the previous studies that these two produce the maximum efficiency and the construction difficulty and cost is less on these two solar stills.

Effect of many other design and weather parameters like the angle of slope, the thickness of outside wall is not studied. The research could be sturdier if these parameters were studied.

5.4 Recommendation for Future Study

Production of safe drinking water is major problem not only in the coastal region of Bangladesh but also in the whole country. And Solar Distillation is one of the cheapest but very effective means of supplying potable drinking water. So, a broad research in this regard is a crying need. In our thesis, we have worked only on two solar still. But there are several passive solar stills available in present time. So, in future other models can be used in this research. Besides change of different physical parameters like thickness of glass cover, inclination angle, height of still etc. may increase the productivity of potable drinking water. New design should be invented to increase the productivity.

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