A THESIS ON

DESIGN, DEVELOPMENT AND PERFORMANCE ANALYSIS OF A NEW DESALINATION SYSTEM INTEGRATED WITH A LOW COST FABRIC ABSORBER

As a partial fulfillment of the requirements for the degree of MS in Renewable Energy Technology (RET)

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DECLARATION

I am the student of Institute of Energy, University of Dhaka represent the thesis on **"Design, Development and Performance Analysis of a New Desalination System Integrated with a Low Cost Fabric Absorber"** as a requirement of completion for the degree of MS in Renewable Energy Technology (RET). This thesis was performed under supervision of Dr. Nasif Shams, Assistant Professor, Institute of Energy, and University of Dhaka.

This is to declare that the thesis work was done by me and it has not been submitted before, Help that was taken from books, journal and internet is mentioned at references.

Signature of Student

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CERTIFICATE

This is to certify that the M.S. thesis report on **"Design, Development and Performance Analysis of a New Desalination System Integrated with a Low Cost Fabric Absorber"** submitted for the partial fulfillment of the M.S. degree in Renewable Energy Technology (RET) from the Institute of Energy, University of Dhaka, has been carried out by the student bearing Exam Roll: 514 under my supervision. To the best of my knowledge and as per his declaration, the whole work and the complete thesis report has been prepared by the student and has not been submitted to anywhere else.

The thesis report can be considered for evaluation.

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ABSTRACT

In the coastal region of Bangladesh salinity in water pose a serious problem. The chief difficulty in the development of appropriate water supply system for the communities in the affected area is that - deep aquifers containing sweet water are not found at all possible locations in the coastal region. [1] There is various desalination techniques-practiced all over the world but the conventional desalination process is energy intensive and will be an expensive option particularly in the rural area of Bangladesh. Solar energy on the other hand is freely available in nature in sufficient amount. Moreover, the technology involved in distillation of saline water using the solar energy is relatively simple and maintenance can be carried out by semi-skilled or unskilled operators. Therefore, in this study, an attempt has been made to develop a family size solar desalination plant with using the black cotton fabric and produce desalinated water from vapor which meets the drinking water demand in the coastal area and remote regions.

In this system direct sunlight has been utilized long back for desalination of water. Solar stills are easy to construct, can be done by local people from locally available materials, simple in operation by unskilled personnel, no hard maintenance requirements and almost no operation cost. But they have the disadvantages of high initial cost, large land requirement for installation and have output dependent on the available solar radiation. In this paper presents the experimental and theoretical work, conducted to analyses the performance of modified basin type solar still, incorporating multiple low thermal inertia porous absorbers. The porous absorbers were made up of ordinary fabric (woven or nonwoven). The absorbers ensured that the absorber surface was always wet due to capillary action and there were no dry spots. Due to low thermal inertia of the porous absorber, quicker start-up times, as well as higher operating temperatures were achieved resulting in higher distillate yield. Also, the increase in the evaporation surface area further aided the performance. In order to evaluate the improvement obtained by the modification, the performance of the modified still was compared with a conventional basin type solar still of same size, under similar operating conditions on both clear and partially clear days. The results indicate that on clear days more distillate output was obtained by the modified still, whereas it was nearly more on cloudy days.

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NOMENCLATURE

Cpw = Specific heat of water at constant pressure, J/Kg °C

Hs = lncident solar radiation on glass cover per unit area per unit time, W/m2

H =Heat transfer coefficient from water surface to glass cover, W/m2 °C

hca =Convective heat transfer coefficient from glass cover to ambient air W/m2 oC

heff =Evaporative heat transfer coefficient from water to glass cover, W/m2 °C

hfc =Enthalpy ofliquid water at cover temperature, J/Kg.

hgw =Enthalpy of water vapour at basin temperature, J/Kg

hra =Radiative heat transfer coefficient from glass cover to ambient, air W1m2 °C

Me =Daily productivity of distilled Kg =Thermal conductivity of glass, W/m °C

m_e =lnstantaneous distillation rate, KgIhr m2 (mass evaporated per unit area per unit

P_g =Partial pressure of water vapour at glass temperature, Pa

P_w =Partial pressure of water vapour at water temperature, Pa

Q_e =Total amount of solar energy used for evaporation, J/m2 day

Qt =The total amount of solar radiation incident on the still cover, J/m2 day

Q =Amount of heat transferred per unfit area per unit time from water to glass,

qa =Total heat transferred per unit area per unit time from glass to ambient, air W/m2

qca =Heat transferred from glass cover to atmosphere by convection, W1m2

qra =Heat transferred from glass cover to atmosphere by radiation, W/m2

R =Universal gas constant

T =Temperature,oC

Tsky = Sky temperature °C

Tw = Water temperature, °C

$\propto_g$ =Absorption coefficient of glass

$\propto_w$ =Absorption coefficient of water

ϵ_l, ϵ_2 =Emissivity of inside surfaces of two infinite parallel planes

ϵ_g, ϵ_g =Emissivity of glass and water respectively

σ =Stefan-Boltzmann constant, 5.6697xl0-8 $W/m^{2}\,{}^{0}K^{4}$

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Water is one of the most abundant resources on earth, covering three-fourths of the planet's surface. In the world, demand of portable fresh water is increasing day by day because of population explosion all over the world, greater industrial development, expansion of agricultural activities and climate change. Now it is recognized that freshwater is a scare resources and more country is converted into water-stressed country due to the scarcity of freshwater resources.

There is an almost unfathomable amount of water on earth: about 1.4 billion km3 (330 million cubic miles) (Barlow and Clark, 2002). About 97% of the earth's water is salt water in the oceans and a tiny 3% (about 36 million km3) is fresh water contained in the poles in the form of ice, ground water, lakes and rivers, which supply most of human and animal needs (Ahmed and Rahman, 2000). Nearly, 70% from this tiny 3% of the world's fresh water is frozen in glaciers, permanent snow cover, ice and permafrost. Thirty per cent of all fresh water is in underground, most of it is in deep, hard-to-reach aquifers. Lakes and rivers together contain just a little more than 0.25% of all fresh water; lakes contain most of it (Kalogirou, 2005).

The data relevant to water requirements shows that around 25% of the total world populations do not have an adequate fresh water supply, both for quality and quantity (Agha et al., 2005). Water shortages affect 88 developing countries that are home to half of the world's population. In these places, 80-90% of all diseases and 30% of all deaths result from poor water quality (Leitner, 1998). Furthermore, over the next 25 years, the number of people affected by severe water shortages is expected to increase fourfold (Engelmanetal., 2000).

Some of this increase is related to population growth, some is related to the demands of industrialization. Currently, water consumption doubles every 20 years, about twice the rate of population growth (Barlow and Clark, 2002). The ground water source is being polluted by organisms, organic and inorganic compounds due to the ultimate disposal of man-made harmful pollutant into the underground reservoir (Malik et.al, 1982).

Due to climate change, the shortage of safe drinking water is likely to become more pronounced in the Bangladesh, especially in the coastal belt (SDP: FY 2011-25). In the coastal region of Bangladesh, salinity in water poses a serious problem for the communities in the affected area.

For the last couple of decades; Bangladesh has been facing the climate-induced problems in the water sector. Couple with lack of effective emergency response plans; this has seriously affected the water supply of the country, particularly in the salinity-affected coastal districts. Since SIDR (2007) and AILA (2009), two catastrophic cyclone events that hit coastal areas, fresh water has become an invaluable asset for millions of poor people in this region.

The main factors contributing to water scarcity in coastal areas are salinity of surface and groundwater due to sea level rise and tidal surge, bacterial contamination of surface water, chemical contamination (particularly As, Mn and Fe)of groundwater, and unexpected variation in precipitation pattern. Depending on extent of these factors, the impacts show variable spatiotemporal signatures that makes selection of right technology more difficult.

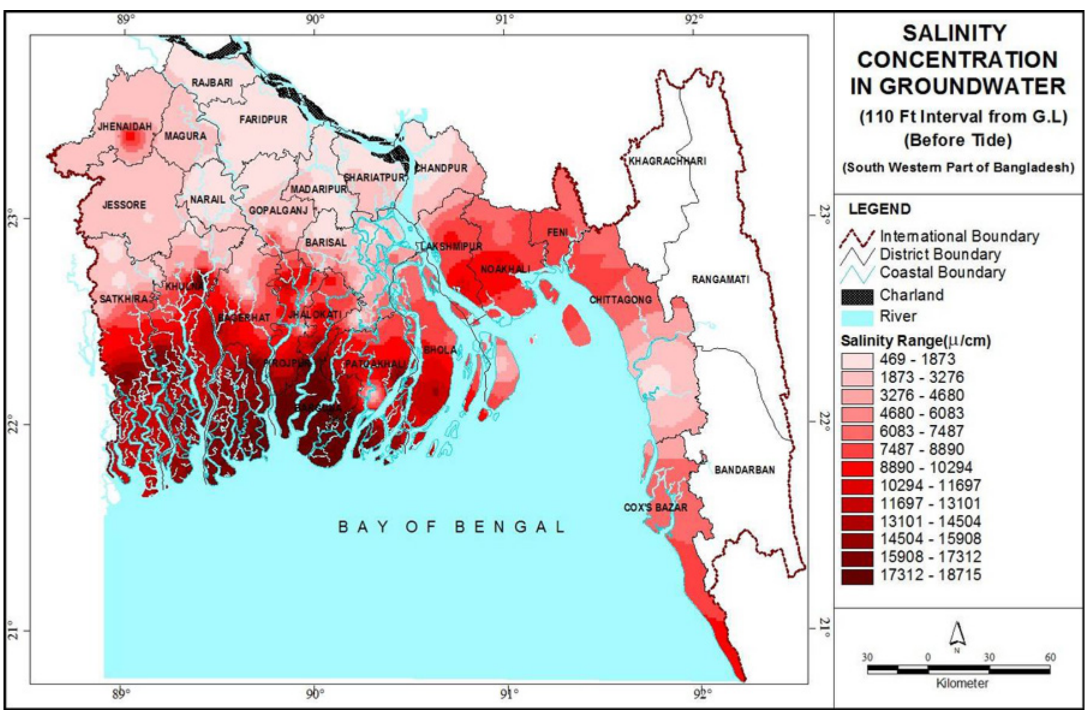

Fig 1.1: Salinity Concentration in ground water in Bangladesh (Source www.newsecuritybeat.org)

Among the coastal districts, Satkhira, Bagerhat and Khulna are severely affected by salinity. In rural areas of these districts, the popular sources of drinking water used to be shallow tube wells, deep tube wells, pond sand filter and rainwater. But due to saltwater intrusion from nearby rivers, the surface water bodies e.g. ponds have been affected by salinity and cannot be used for pond sand filters. The groundwater sources have also been affected by salinity and chemical contamination i.e. arsenic, which leaves only rainwater and a few sparse sweet water ponds as sources of drinking water for people in these areas, a lot of whom belong to low-income communities. High installation cost of rainwater harvesting tanks is beyond the affordability of most of the people living in these areas, which aggravates the water crisis scenario.

Since water in most of coastal rural areas is saline, desalination system has been considered as a potential solution to this problem. But high installation cost of reverse osmosis plants and its operational difficulties have been major reasons for this technology not being so popular. A number of research works have been carried out on solar desalination system that uses solar energy and evaporation-condensation technique to produce fresh water. Some conventional solar desalination system working in that area but most of the desalination system is commonly failure to provide enough fresh water for drinking and also. Moreover most desalination techniques consume a large amount of energy, many remote towns and communities rely on costly and often limited supplies of diesel fuel for their energy needs. These and other forms of fossil fuels are sometimes heavily subsidized by government to meet community service obligations (Water Corporation, 2000). Therefore finding methods of using renewable energy to power the desalination process is desirable. Solar distillation is the simplest desalination technique, compared with other types, e.g., multiple-effect distillation, multi-stage flash, reverse osmosis, electro-dialysis and biological treatment due to no need of fossil fuel or electricity. The main disadvantage of solar distillation is its low productivity of distillate but although it may also be one of the viable options for providing drinking water for a single house or a small community in arid or remote regions. A basin-type solar still is the most popular method of solar distillation, but main drawbacks of the basin type are not easy of construction and the difficulty in rapid and easy removal of basin accumulated salt. Therefore, we improved a new type of low cost of solar distillation unit, Fabric Solar Still (FSS), to overcome such difficulties in the maintenance and management. It is comprised of a Still frame contain with a black fabric and a saline water flow controlling system to produce more fresh water than others conventional Solar Still system. . In this study, a low cost FSS was designed; constructed and field experiments have been carried out at Institute of Energy (University of Dhaka) since May 2016.

1.2 OBJECTIVE OF THE STUDY

The main objectives of the study are:

- To develop a modified Solar Still System addressing the identified problem and ensuing high yield and easy operation and maintenance.
- To assess the performance of the modified Solar Still in terms of construction and O&M, quality and quantity of water.
- To study the seasonal variation of various climatic parameters having direct effect on the plant output.
- The study of efficiency of such plant.

1.3 SCOPE OF THE STUDY

The scope of work under the assignment is as follows:

1. Designing a desalination system using only solar energy to provide access to safe water throughout the year. The system would use either groundwater or surface saline water as source of raw water.
2. Stepwise study of the plant construction and its operations and maintenance.
3. Developing a model of plant output in terms of only temperature to calculate the distillate amount.
4. Study of the salt concentration of the input and output water of the plant and its acceptability for drinking purpose.
5. Providing technical and institutional recommendations based on study findings for further improvement of the desalination systems in the context of saline prone coastal areas.

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1.4 ORGANIZATION OF THE THESIS

This thesis presents the analysis, result and findings of the study in Three chapters and Appendices as shown below. In addition a reference of related publications has also been presented.

Chapter 1 presents brief introduction to the study along with its objectives, justification and scope.

Chapter 2 Compiles all relevant literatures and makes reference to the previous studies in the related areas.

Chapter 3 provides a description of the plant construction, operation and maintenance and performance of solar still and list the conclusions drawn thereof and provides some guidelines for future research work in this area.

Reference at the end of the main chapters provides a list of relevant publications and reports which may be useful for any future researcher in this area.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

A solar still is a simple device which can be used to convert saline, brackish, polluted or other water into drinking water. The loss and utilization of heat at various stages of it and the amount of distilled water obtained as calculated from the fundamental laws of heat and mass transfer are described briefly in this chapter. Detailed description of a single basin solar still has been presented with a brief idea about the other types of solar still. The various methods of desalination with their working principles are also narrated in this chapter. Statistics is a strong tool for estimation of probability, correlation of venous interdependent parameters, forecasting and predicting the error of such estimations. The basic approaches of statistics in this context are also depicted in concise form in this chapter. Armstrong type equations are used to calculate the solar radiation without the need of any measuring instrument. Various well established Armstrong type equations and the relevant factors are also mentioned in this chapter.

Salinity in drinking water is a serious problem all over Bangladesh, especially in the coastal region. An idea has been given about this affected region and the salinity amount present in water.

2.2 HISTORICAL REVIEW

The conventional solar distillation apparatus, (commonly known as the solar still), was first designed and fabricated in 1822 near Las Salinas in Northern Chile by Carlos Wilson, a Swedish engineer(Kumar,1982). This was a large basin-type solar still, meant for supplying fresh water to a nitrate mining community (Harding, 1883) as reported by Malik (1982). This device was in operation for about 40 years and yielded more than 4.9 kg of distilled water per square meter of the still surface on a typical summer day. It is worth noting that this output compares very well with the distilled water output from the present day solar stills. No work on solar distillation seems to have been published after 1880's till the end of the First World War. With the renewal of interest, several, types of devices have been described, e.g. roof type, V-covered, tilted wick, inclined tray, suspended envelope, tubular and air inflated stills etc. Use of metal coated reflectors as solar concentrators for application in solar distribution has been described by Kausch

(1920); Pasteur (1928) also used several concentrators to focus solar rays onto a copper boiler containing water. During the Second World War, Telkes (1945) developed air inflated plastic stills for the U.S. Navy and Air Force for use in the emergency life-rafts. To improve the operating efficiency, several investigators have attempted to make use of the latent heat of vaporisation in either multiple-effect systems or for preheating the brine to increase the output of the stills. Several large scale distillation plants and integrated schemes for combining electric power generation and desalination of water have also been suggested as a way of improving the overall operating efficiency of the plant.

Presently, more attention has been paid on basin type solar-still and also on several other types as follows:

1. multiple-effect stills (Oltra, 1972; Bartali, 1976)
2. tilted tray or inclined-stepped solar stills (Howe, 1961; Akhtamov *et al., 1978)*
3. Tilted, wick type and multiple wick type solar stills (Frick and Somer field, 1973; Sodha *et al.,* 1980b; Moustafa, 1979).

4) Solar film covered still and wiping spherical stills(Norov et a!., 1975; Umarov et a!., 1976; Menguy et a!., 1980)

5. Solar still greenhouse combination (Selcuk, 1970, 1971; Sodha et a!., 1980b)
6. Indirectly heated solar stills (Soliman, 1976; Malik et a!., 1973, 1978; Sodha et a!., 1981).

Depending upon their expected life span and application, the various solar stills are categorized into "permanent" (e.g. glass covered stills), "semi-permanent" (e.g. plastic stills) and "expandable" (e.g. double-tube and floating stills) type solar stills.

2.3 BASIC PRINCIPLES

A conventional solar still is simply an airtight basin, usually made put of galvanized iron sheet in rectangular shape. It has a top cover of any transparent material, e.g. glass. Brackish or saline water is poured into the still to fill it partially, which is then exposed to the sun. The glass cover permits solar-radiation to get into the still, which is absorbed predominantly by the blackened base. Consequently, the water gets heated up and hence the moisture content of the air trapped between the water surface and the glass cover increases. The base also radiates energy in the infra-red region which is reflected back into the still by the glass cover; glass is not transparent in the long wavelength region. Thus, the glass cover traps the solar energy inside the still; it also reduces the convective heat losses. The glass cover is usually sloped on one side to enable the water vapor, which condenses on the interior surface, to trickle into a collector.[2]

The most important parameter affecting the output of a solar still is the intensity of the solar radiation incident on the still. If Q_t (in Joules/m2 day) is the amount of solar energy incident on the glass cover of a still and Qe (in Joules/m2 day) is the energy utilized in vaporizing water in the still, then the daily output of distilled (yield or distillate produced) water Me (if 11m2day) is given by

$$\mathbf{M_e = Q_e / \gamma} \qquad (2.1)$$

Where, γ (in Joules/Kg) is the latent heat of vaporization of water.

Fig. 2.1 illustrates the principal energy exchange mechanisms in a basin-type solar still. A very large part of the solar radiation, direct and diffuse, falling on the still is absorbed in the base and wall . Small reflection losses occur at the glass surface, the water surface and to a very small extent at the base and wall. The energy absorbed at the base is largely transferred to the water in the still and a small fraction of it is lost to the ground by conduction through the base. Energy is transferred from the water to the glass cover principally by the water vapour evaporating from the water surface and then losing its heat of vaporization to the glass cover upon condensation. [3] Heat is also transferred to the glass cover from water by free convection of the trapped air in the still. The glass cover absorbs a part of the heat radiated from the water surface. A small part of the incident solar energy is also absorbed by the glass cover. The heat thus absorbed by the glass cover is lost to the atmosphere by convection and radiation. Energy exchange also occurs on account of change of sensible heat content of the saline water entering the still, the distillate leaving the still and the brine that accumulates in the still. Thermal losses may also occur due to the leakage of water vapour and the water from the still. A study of the basin-type solar still must take these factors into account. Thus, while the incoming energy is

1) Solar radiation and

2) Atmospheric radiation

The outgoing energy comprises of

1) Convection to atmosphere

2) Radiation to atmosphere

3) Reflection to atmosphere

4) Ground conduction

5) Edge conduction and convection

6) Vapour leakage

7) Brine leakage from basin

8) Sensible heat of condensate and overflow

Fig. 2.1 illustrates the various components of the energy balance and their direction.

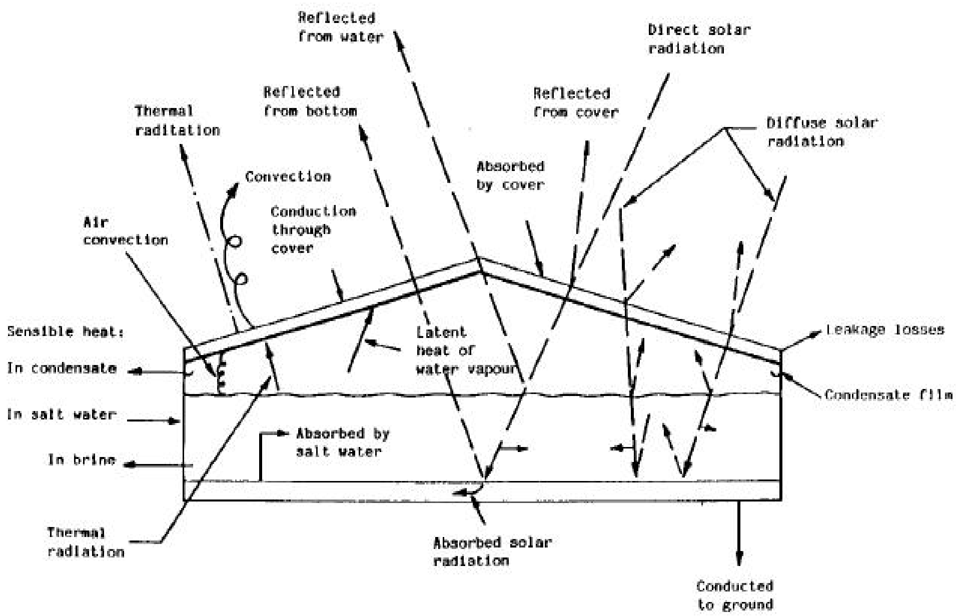


Fig. 2.1 Energy flow diagram of a basin type solar still

The main components of the energy loss for a typical set of parameters are (Bloemer etal, 1961b) presented in Table 2.1.

Table 2.1 various components of heat **loss in a solar still and their amounts (%)**

1)Evaporation of distillate	31
2) Ground and edge heat losses	2
3) Solar radiation reflected from still	11
4) Solar radiation absorbed by cover	5
5) Radiation from basin water to cover	26
6) Internal convection	
7)Re-evaporation of distillate and unaccounted-	17
Total	100

From this tabulation, it is evident that the radiation from the basin water to the cover is the largest single heat loss. The heat loss resulting from reflection and absorption of solar radiation by the cover is also important. Re-evaporation is difficult to determine accurately, but calculations and visual inspection. Indicate that it might constitute a loss of as much as 10% of the available energy. The fact that the ground and edge heat losses are only 2% is especially significant because the bottom of the still was not considered to be insulated (Malik *et at,* 1982).

2.4 BASIC REAT AND MASS TRANSFER RELATIONS

2.4.1 GENERAL

The operation of a solar still is governed by various heat transfer modes and therefore a proper understanding of heat transfer is crucial in designing a still. Convection and radiation are the predominant modes of heat transfer in a solar still. A very small amount of energy is also lost to the ground (or atmosphere) due to heat conduction through the base.

It is very convenient to look at the heat transfer mo.des within the still (hereafter referred to as internal transfer) and between the still and the environment (hereafter referred to. As

external transfer) separately: It is, however, important to note that the heat transfer problem as such cannot be de coupled. The essential distinction between the modes of heat transfer in these two regions is that, while, within the still convective heat transfer occurs simultaneously with evaporative mass transfer, no. such mass transfer occurs outside it. Radiative heat transfer occurs in bath the regions along with others modes.
Thermal convection is the process by which heat transfer taken place between a so.lid surface and the fluid surrounding it. [4] The rate of heat transfer by convection between the fluid and the boundary surface is described by the equation.

$$q=h.A.\Delta T \qquad (2.2)$$

This looks disarmingly simple. However, the crux of the problem lies in evaluating the heat transfer coefficient **h**, which is a complicated function of the geometry of the surface, the flaw characteristics of the fluid and the physical properties of the fluid. In mast practical cases the heat transfer coefficients are evaluated from empirical equations obtained by correlating experimental results using methods of dimensional analysis.

2.4.2 INTERNAL TRANSFER

The modes of heat exchange inside the still between the water surface and the glass cover are convection accompanied by evaporative mass transfer (in the farm of water vapor) and radiation. The modes of heat transfer are discussed briefly in the following Sections.

Convection

Heat is transported across the bulk of the humid air inside the still by free convection of air. It then releases its enthalpy upon coming into contact with the glass cover, which is at a lower temperature. The coefficient of heat transfer is usually incorporated in the Nusselt number (Nu). [5] In the case of heat transfer by free convection, the Nusselt number is related to the Grashof (Gr) and Prandtl (Pr) numbers i.e.

Nu= f (Gr,Pr) **(2.3)**

The amount of heat transferred per unit area per unit time from water to the glass cover is expressed by the relationship:

$$q_{ew} = 0.884\ [\ T_w - T_{gi} + (P_w - P_g)\ (T_w + 273)\ /\ 268.9\times10^3 - P_w]\ (T_w - T_{gi}) \qquad (2.4)$$

$$= H_{cw}\ (T_w - T_{gi}) \qquad (2.5)$$

Where,

Pg =Partial pressure of water vapor at glass temperature, Pa

Pw =Partial pressure of water vapor at water temperature, Pa

q_{cw} =Amount of heat transferred per unfit area per unit time from water to glass by convection W/m^2

Tw =Water Temperature, °c

Tgi =Temperature inside glass surface, °c

Evaporation

The heat transferred per unit area per unit time by evaporation from the water surface to the glass cover is

$$q_{ew} = 16.273 \times 10^{-3}\ h_{ew}\ (P_w - P_g) \qquad (2.6)$$

Where,

q_{ew} =Amount of heat transferred per unfit area per unit time from water to glass by evaporation, W/m^2

hcw =Heat transfer coefficient from water surface to glass cover by convection, W/m^2 °C

$$m = q_{ew} / \gamma \qquad (2.7)$$

Radiation

In the usual analyses of solar stills, the water surface and the glass cover are considered as infinite parallel planes; this is a valid approximation for stills with small cover slope sand large dimensions in both the horizontal directions. This would not be valid for stills consisting of essentially unconnected strips or long rectangles.

$$\mathbf{q_{ew}} = \frac{\sigma(T_1^4 - T_2^4)}{1/\in 1 - 1/\in 2 - 1} \quad \textbf{(2.8)}$$

qrw =Amount of heat transferred per unfit area per unit time from water to glass by radiation, W/m2

$\in_1, \in_2$ =Emissivity of inside surfaces of two infinite parallel planes (in still $\in_1$=∈g and ∈2= ∈W)

2.4.3 EXTERNAL TRANSFER MODE

Convection and Radiation

Due to the small thickness of the glass cover,the temperature in the glass may be assumed to be uniform. The external radiation and convection losses from the glass cover to outside atmosphere can be expressed as,

$$q_{ra} = \in_g \sigma.\left[(T_g + 273)^4 - (T_{sky} + 273)^4\right] \quad (2.9)$$

and

$$q_{ca} = h_{ca}(T_g - T_a) \quad (2.10)$$

and hence,

$$q_a = q_{ra} + q_{ca} \quad (2.11)$$

Where,

a =Stefan-Boltzmann constant, 5.6697xI0-8 W/m2 °K4

T_{sky} = (Ta-12) is the apparent sky temperature for long wave radiation exchange, assumed to be 120C below ambient. The external convection coefficient hca is a function of wind velocity and is given below (Duffie, 1974),

$h_{ca} = 5.7 + 3.8\ S$ **(2.12)**

Where, S =Wind speed, m/sec

Periodic Heat Transfer in Conducting Media

Energy transfer through the base of the still occurs through thermal conduction. Since the solar insulation is a periodic phenomenon, the heat transfer into the ground is also of periodic nature. A detailed study of the periodic boundary conditions and the formula derivation regarding the solar still context were developed by Sodha *et.* a/(1982).

2.5. SINGLE BASIN SOLAR STILL

2.5.1 BACKGROUND

A single basin solar still is characterized by a single basin having saline water; it may, of course, have more than one transparent cover. The various designs of solar still differ in structure and materials of construction, but basically, incorporate common elements for different functions. The glass/plastic cover is transparent to the incoming solar radiation, but blocks the long wavelength radiation emitted by the water surface and the base of the still. Besides this, the cover prevents the escape of the humid air trapped inside the still and also provides a cool surface for condensation of water vapour. The cover should be sloped on one side at an angle large enough to facilitate an easy flow of the water droplets, that condense on it, into a condensate trough (or gutter). [6]The trough is also inclined so that the collected water flows out of the still to be collected in bottles.

Obviously, the condensate trough should extend all along the lower edge of the sloped cover. It is important to note that the angle at which the cover is inclined should not be so large as to present a grazing surface to the solar rays at noon, when the solar intensity is maximum; [7]this would cut off a very large fraction of the total daily insulation. The basin of the still should be watertight and the entire still should be airtight, except for the inlets and outlets. Cooper (1973) suggested that the interior surface of the walls of the still may be painted glossy white with a brush able grade of silicone in order to reflect solar radiation incident on them onto the saline water and also to protect the surface from corrosions. However, the white surface is cool enough for condensation of water vapour; this condensate trickles down into the basin, which is not desirable. The still may be placed on the ground with a thin layer of insulation separating it from the ground (Fig.2.2a) this still is called the *ground still.* [8]On the other hand it may be mounted in a box (usually made of wood) such that it is well insulated on all sides except the top to reduce heat losses to a minimum (Fig. 2.2b). Such a still is called a *mounted still* [9]. Use of durable materials such as metals, concrete etc. in constructing the stills increases their life.

2.5.2 SOLAR RADIATION BALANCE

The amount of solar energy absorbed by the saline water and the base of the still depends on the amount of energy reflected and absorbed by the transparent top cover and' on the amount reflected by the saline water surface and the base of the still. The water film formed due to the condensation of water vapour on the interior surface of the top cover also contributes to the reflection of solar energy[10. Since reflectivity is a function of the angle of incidence on any surface, it is natural to expect that the energy absorption by the base of the still should vary with the time of the day, because the angle at which sun's rays are incident on a stationary still varies with time. Fortunately such temporal variations in the reflectivity at the various surfaces of the still are quite small. Cooper (1970) has shown that, for place confined within latitudes 0 and 45 degrees and for the angle of inclination of the top covers ranging from 0 to 60 degrees[11], the variation with time in the energy absorbed by the saline water and the base of the still is very small. Consequently, the reflection and transmission coefficients may be treated as constants for any particular still. In what follows the average values (with respect to time) of these coefficients at the various surfaces of the still will be assumed, to be constant in time for a particular still. Effect of angle of inclination as reported by Cooper (1969) is shown in Table 2.2.

Angle of incidence, °c	0	30	45	60
Cover reflection	5	5	6	10
Cover	5	5	5	5
Cover transmission	90	90	89	85
Water reflection	2	2	3	6
Water	30	30	30	30
Water transmission	68	68	67	64
Basin reflection	5	5	5	5
Basin absorption	95	95	95	95
Basin transmission	0	0	0	0

2.5.3 ANALYSIS OF AN IDEAL STILL:

An ideal solar still is one with zero conductive heat losses and a saline water level shallow enough to enable one to neglect the sensible heat stored in the saline water as compared to the energy transferred to and from the saline water. Consequently, an ideal still would attain a steady state almost instantaneously corresponding to the prevailing circumstances. Cooper (1973 b) has studied the performance of such a still. The interior heat transfer rates (i.e., heat transfer rates inside the still). q_{cw}, q_{ew} and q_{rw} are given by Eqs.(2.4), (2.5), (2.6) and (2.8), respectively [12]. The solar radiation absorbed by the top cover, together with the heat transferred to it by the condensing water vapour, is rejected to the atmosphere through convection and radiation; the convection would be a strong function of the wind velocity outside the still. Under steady state conditions, the heat balance on the saline water surface may be expressed as

$$\propto_w Hs = (q_{cw} + q_{ew} + q_{rw}) + C_{pw}/\gamma\,(T_w - T_a)\, q_{ew} \qquad (2.13)$$

In Eq. it is assumed that, a steady inflow of saline water at temperature Ta replace the water lost through evaporation. Thus, the second term on the right hand side of this equation represents the heat used up in raising the temperature of the incoming saline water from Ta to Tw ' the steady state temperature of the saline water in the still [13].

In order to relate the temperature on the irtterior surface of the top cover, T_{gi}, to the ambient temperature T_a, it is assumed, as a first approximation, that the temperature profile through the top cover is linear and is independent of the solar radiation absorbed by the cover. If the thickness of the cover is small, this absorption may be considered as having occurred at the external surface of the cover. Then it can be written that

$$(q_{cw} + q_{ew} + q_{rw}) = K_g/l_e \, (T_{gi} - T_{go}) \qquad \textbf{(2.14)}$$

Where T_{gi} and T_{go} temperature are the interior and exterior surfaces of the transparent cover. The external radioactive and convective heat transfer rates, qca and qra are given by Eqs.(2.9) and (2.1 0) . Combining all these equations together, the total energy balance equation may be written as

$$0.85\sigma\left[\left(T_{go}+273\right)^4-\left(T_a+261\right)^4\right]+h_{ca}\left(T_{go}-T_{ga}\right)=\alpha_g H_s+\frac{K_g}{\ell_g}\left(T_{gi}-T_{go}\right) \qquad \textbf{(2.15)}$$

Where,

α_g =Absorption coefficient of glass

K_g =Thermal conductivity of glass, W*1m*

ι_e=thickness ofthe glass cover, m

Although no explicit solution exists for this equation, one may always calculate the distillation rate approximately by iteration[14].

2.6 PARAMETRIC STUDIES

2.6.1 EXPERIENCE WITH PLASTIC COVERS

The acceptance of the solar still in a large scale depends very much on its cost and the ease with which it can be transported, installed and repaired. It may be noted that the transparent cover is the single most expensive item of a still, which may also have to be replaced often. Thus, the use of transparent plastic sheets in place of glass cover would substantially reduce the overall cost of the still besides the additional advantages such as flexibility in design and elimination of airtight glass to container joints keeping these points in view, several small solar stills have been designed suitable for short term use (particularly in the developing countries (Lor, 1966). In all these designs plastic sheets are used as the transparent covers and either concrete or black plastic film is employed for the basin of the still [15]. Some of the common problems encountered are the following:

I. Short service life of plastic sheets.

2. Leakage of water vapour and the condensate.

3. Over -heating, and hence melting, of the plastic bottom of the still due to the development of dry spots in course. of time. In the extreme case the black polyethylene sheets used as the basin liner may get heated beyond its melting point [16].

4. The plastic cover surface does not get wetted and this leads to reduced transmission of incoming solar energy and also to dripping of distilled water back into the brine liquid.

5. Susceptibility to damage by wind and other elements of nature.

6. Occasional unforeseen mixing of brine and distilled water in some of the designs. Thus, on whole it appears that plastic sheets may not be the right choice for meeting the fresh water requirements of a community or family on a long term scale, mainly because of its low capacity and doubtful reliability. However, these can be used in cases of emergency, war and in general for short time applications [17]

2.6.2 OTHER MATERIALS

Apart from plastics, one has so many materials to choose for use in the fabrication of solar stills. The deciding factors' are the cost and constraints peculiar to any particular location. Achilov *et at.* (1973a) have conducted extensive studies on the use of several

25 materials such as concrete, sand concrete, ferrocements, foamed plastic, various types of sheet, plate and window glass, zinc coated and rubber piping, various types of

steel, duralumin, various types of thermal insulators, asbestos cement, reinforced cement, dyes, lacquers and other cementing compounds in the fabrication of a still. An important outcome of these studies has been that, if the still is to be installed at any location permanently it is best to construct the basin of the still using sand concrete or water proofed concrete; Baum *et al.* (1970) also arrived at the same conclusion.

In the case of factory manufactured system, prefabricated ferroconcrete is more convenient. The extensive use of prefabricated ferroconcrete offers several important advantages, including the mechanization of constructional work, possibility of construction work throughout the year, reduction in cost.

2.7 EFFECT OF METEOROLOGICAL ANDSTILL PARAMETERS

2.7.1 EFFECT OF WIND VELOCITY

Cooper (1969a) concluded that for average wind velocities from 0 to 2.15 m/sec the output gets increased by 11.5%, indicating the decreasing influence of wind at higher velocities on distillation rate, as has also been concluded by Morse and Read (1968). A suggested fall in productivity with increasing wind velocity by Lof et al. (1961 b) is not consistent with the present understanding of the heat and mass transfer modes. Soliman (1972) has studied the effect of wind velocity on output in detail, considering all heat and mass transfer modes. He has concluded that at high water temperature, the increase in the difference between water and cover temperature by increasing wind speed causes an increase in the rate of evaporation [18]

2.7.2 EFFECT OF AMBIENT TEMPERATURE

Morse and Read (1968) have shown that an ambient temperature change from 26.70C to 37.80C causes an 11% increase in the output, and a change from 26.70C to 15.60C causes a 14% drop. Cooper (1969a) also concluded that decreasing the average ambient temperature decreases the output. In this case, even though both water and glass 26 temperatures decrease and the difference increase, it is not sufficient to compensate the general fall in the overall temperature of the system. This effect becomes evident at relatively lower temperatures. This is in agreement with the earlier work of Lof *et al.* (1961b) [19].

2.7.3 EFFECT OF SOLAR RADIATION AND LOSS COEFFICIENT

In determining the output of a still (having different loss coefficients) solar insulation is the single most important parameter. It will depend to some extent upon how the radiation is distributed throughout the day (United Nations, 1970), however, this is a secured order effect, and it is usually sufficient to consider only the total radiation received each day. The best situation for a solar still is one where both the daily insulation (Akinsete *et al.* J 979) and the mean ambient temperature are consistently high. The loss coefficient has less influence at higher ambient temperatures. The decrease in loss coefficient by a factor of 5 increases the output by about 45% which is in close agreement with the work of Morse and Read (1968).

2.7.4 EFFECT OF SPACING BETWEEN BRINE AND COVER

Bloemer (1963) and Lof (1963) have stated that the productivity is not affected by the spacing between brine and cover in the range of 0.5 ft to 1.5ft, under laboratory conditions. [20]

2.7.5 EFFECT OF BRINE DEPTH IN SOLAR STILL

Lof (1965) found that the total production increased approximately 8 percent by reducing the water depth from one foot to six inches and furthermore the production increased proximately by another 25 percent when the water depth was reduced from 6 inches to 2 inches.

2.7.6 EFFECT OF NATURAL AND FORCED CONVECTION

According to Crune (1962), natural convective stills gave efficiencies from 13.9 % for a deep-basin unit with a 300 roof-type mylar cover to 38.2 percent for a still with an extended wick -type and a wettable glass cover. On the other hand, forced convection stills gave efficiencies from 50 and 60 %. Cooper (1973) tested an "ideal still" and concluded that the maximum attainable ideal efficiency over one day operation will rarely exceed 60 % and for a practical still during the period of high solar radiation intensity and ambient temperature, the efficiency would be about 50 %.[21]

2.7.7 EFFECT OF COVER INCLINATION

The variation of distillate production with glass cover inclination has been studied by Cooper (1969) in detail. It was found that the evaporation rate decreases with cover slope variation from 00 to 450,rises at about 600and falls again beyond 750 The output changes very little with change of inclination of glass cover; the optimum angle suggested for Indian climates is 100-150(Garg and Mann, 1976). [22]

2.7.8 EFFECT OF THERMAL CAPACITY ON OUTPUT

Morse and Read (1968) have studied the effect of thermal capacity of water on the output of the still. They recommended a water depth of about 3 inch(76mrn), corresponding to thermal capacity of 1.41 KJ/m2 for the CSIRO ground-based still . (Australia) with bottom insulation and 1 inch (25.4 mm)water depth for the still resting on the ground without any insulation. For a daily insulation of 225 KJ/m2 hr, reducing thermal capacity from 1.41 KJ/m2 to zero, increase the output by 9%, while increasing from 1.41 KJ/m2 to 5.64 KJ/m2 0C (equivalent to 0.3 m depth of water) would reduce the output by 7%. It follows therefore that, while the water depth is not a critical parameter, it should be as small as possible (Morse and Read, 1968). [23]Cooper (l969a) has studied the effect of water depth on the distillate output; He suggested that without insulation, the gains from decreasing the water depth are only marginal, but with the insulation the different is more marked, especially at shallow water depths. A 30% variation was found for water depths from 5 inch (12.7 cm) to 12 inch (308 mrn)which is in agreement with the conclusions of Bloemer et al. (1965). A characteristic of the deep basin still is that the ground temperature varies more smoothly than that in the case of a shallow basin still. [24]

2.7.9 EFFECT OF SALT CONCENTRATION ON OUTPUT

The effect of salt concentration on the output of a still has been studied in detail by Baibutaev et al. (1970). tests were performed on water samples taken from lakes with different salt concentrations. The experiments have shown that as the salt concentration of the water to be distilled increases right up to the saturation point, the output of the still falls linearly and slowly. However, as the salt concentration of the water to be distilled increase, there is an increase in the corrosion damage to the components .of the still and, consequently, it then becomes necessary to use materials which are not readily oxidized. As reported by Lof (1966), the distillate decreased put 10 percent as salinity was increased from 0 to 20 percent. With the normal range of salinity of 3 to 8 percent, the effect was found to be negligible. [25]

2.7.10 EFFECT OF CHARCOAL PIECES IN THE PERFORMANCE OF A STILL

Akinsets and Durn (1979) have studied the effect of charcoal pieces on performance of a still because of its wet ability, large absorption coefficient for solar radiation and their property to scatter, rather than reflect, the solar radiation. [26] It was concluded that the effect of charcoal is most pronounced in the mornings and on cloudy days when the values of direct radiation are low. This result implies that the presence of charcoal pieces reduces the start up time and utilizes the diffuse radiation much better than the conventional unlined still. They have also concluded that the charcoal lined still is relatively insensitive to basin water depth as tong as a good amount of the charcoal remains uncovered.

2.7.11 EFFECT OF THE FORMATION OF ALGAE AND MINERAL LAYERS ON WATER AND BASIN LINER SURFACE ON PRODUCTIVITY OF A STILL

Cooper (1972) has shown that the presence of deposits on the surface of the basin water and basin liner have a detrimental effect on the output, assuming that no other factor becomes significant. He pointed out that surface reflection appears to be more detrimental than basin liner (bottom of still) reflection because of the absorbing properties of the basin liner except at normal incidence of insulation. There is an increase of 8-15% in the measured albedo as taken on some black surface relative to the scaly surfaces in the solar still. For example a reflection of21.7% was found by Cooper (1972) with a thin, floating, whitish surface scale. The reflection of an identical location at approximately the same time, but a reasonably clean water surface and a black butyl rubber liner gave a measured reflection of only 13.7%. [27]

2.7.12 THE EFFECT OF DROPWISE CONDENSATION ON GLASS SOLAR PROPERTIES

The change of heat transfer characteristics of surface covered with water condensation has been a subject of intense research only insofar as it is related to heat convection. In fact, in the flat plate solar collector, especially in the solar distillator, dropwise condensation on glass surface often occurs and can be a dominating factor affecting the performance of the device. There are two factors which make the study of surface radiative characteristics of drop wise condensation less than trivial the first is the rapid variation of water absorption coefficient with wavelength [28].With the water droplets varying in size in practice, its transmission and reflection cannot be predicted with reasoning. The second complication is the fact that when radiation enters into the water droplet and crosses the water-air interface, because of the smaller refractive index occurring at the air side, total reflection will take place for rays of large incident angles.

These may also experience longer path length of travelling, thereby attenuating more energy. As a result the multireflections in the water droplet cannot be neglected and this complicates the formulation. Hsieh (1975) studied the effect of dropwise condensation on glass solar properties. [29]

According to him a clean glass surface has a surface solar transmittance of 0.958 and reflectance of 0.042 whereas a clean glass plate has bulk transmittance 0.853 and(the term 'bulk glass' has been used to mean the glass having water drops on its surface) bulk reflectance of 0.075. Thus with drop wise condensation occurring on one surface, the bulk solar transmittance of glass drop about II percent while reflectance increases79 percent for the size of the water droplet studied. The presence of drop wise condensation has thus proved to present a serious problem reducing the actual energy that can be received in a solar energy device. [30]

The above discussion enables to know what the real amount of radiation is that enters the solar still. So once the true transmittance and reflectance values of the bulk glass are known- the truly extracted energy can be evaluated.

2.8 DIFFERENT TYPES OF SOLAR STILLS

2.8.1 MULTIPLE EFFECT SOLAR STILLS

A multiple effect solar still is a typical high performance still, in that, it produces a larger area. This is accomplished by utilizing the latent heat released by the condensing water vapour, which would otherwise be rejected into the atmosphere, to heat more saline water at a lower temperature. Thus, one essentially has a multi-stage system in which the successive stages yield progressively lesser quantity of distilled water. Naturally, the multi-effect stills involve sophisticated designs, are expensive and operate efficiently only at .relatively high temperatures compared to the conventional single-stage still (Howe and Tleimat, 1974; Talbert *et af.,* 1970; Henrik, 1972). the compensation is, of course, the much higher yield of distilled water and if this be taken into account, the capital cost of a standard multi-effect still may become comparable (though higher to that of a single stage system (Howe and T1eimat, 1974). [31]The multi-effect still would, therefore, be particularly suitable for arid regions, where the land occupied by a distillation unit is at premium on both, economic as well as aesthetic grounds. The ultimate acceptance of multi-effect solar stills will depend on their long term performance and yield during periods of both high and low insulation; yield of distilled water during high solar insolation should compensate the low yield during low insulation. Considerable work on performance of multi-effect still over extended periods need to be done before their feasibility is established. Some of the multi-effect solar stills as designed by various researchers are as follows:

i) Chimney Type Solar Still

This type of still, developed by Bartali et al. (1976), resembles a conventional still except that a chimney containing a heat exchanger is appended to one end of the still (Fig.2.3). The saline water enters the chimney, flows through the heat exchanger and than enters the still.

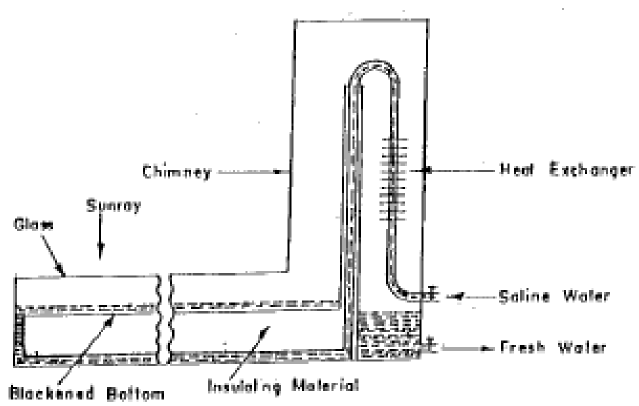


Fig 2.3 The chimney -type solar still

ii) Heated Head Solar Still

In this design, Bartali et.al. (1976) used the concept of having separate units for heat collection and distillation (Fig.2.4). The heat liberated, by the condensing vapours is utilized to preheat the inflating saline water.

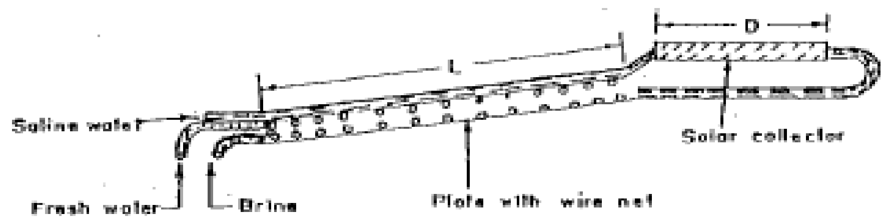


Fig. 2.4 The healed head solar still

iii) A simple multi-effect basin type solar still

With a view to minimize the capital cost of a multi-effect solar still, a new design based on the conventional basin type still was evolved and developed by Lobo *et al.*(1977). The fact that the sealing and other constructional problems in a basin type still stand solved is an additional bonus. The main structure of the still is identical to the standard still. The extra production of distilled water is obtained through the evaporation of saline water kept in several transparent basins set between the top glass cover and the base of the still as shown in Fig. 2.5

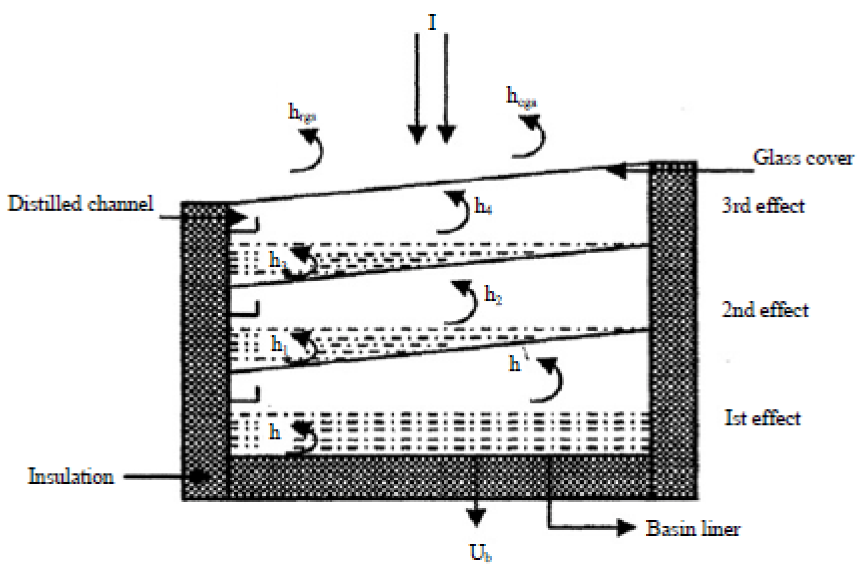


Fig. 2.5 Multiple effect Solar Still

iv) Three-effect multiple solar still

The feed water flow is continuous and it increases the distillate output with increasing insolation and temperature, thus decreasing the discharge brine flow and hence the heat loss is reasonable (Cooper,Appleyard,1967). Due to increases thermal loss at higher insulation and temperatures, it. is expected that the increase in distillate output with increasing insulation will tend to flatten out (Fig.2.6)

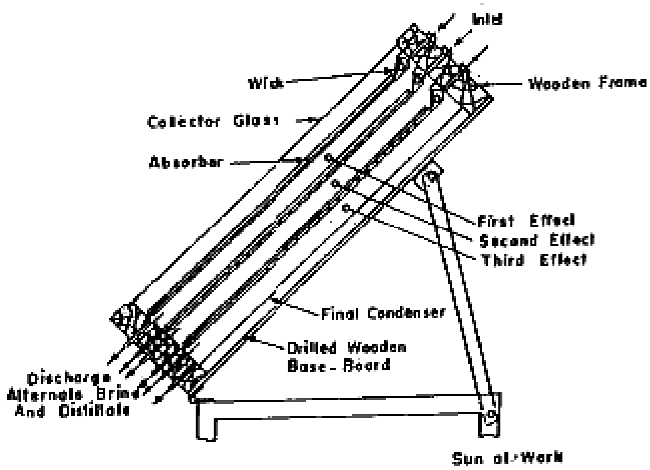


Fig. 2.6 Cross section of still (Three effect multiple solar still)

v) Double basin solar still

The novelty in this design (Fig. 2.7) is that the latent heat released at the lower surface of the inner glass cover by condensation of vapour from the lower basin (the still has two glass covers) is utilised to heat a thin layer of water on the upper surface of the same cover(Lobo,Araujo,1977). This again causes evaporation of water and the vapour from the upper basin condense on the second (outer) glass cover. On a typical winter day in Delhi the distillate output from such a still was observed to be about 36% higher than that from a still with a single glass cover of the same area,

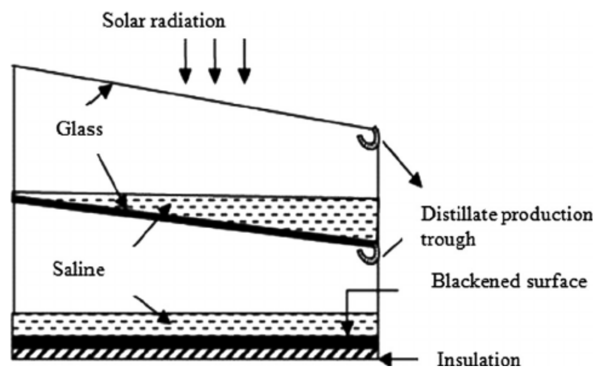


Fig. 2.7 Double basin still

vi)Tubular solar still

Tubular solar still is illustrated in Figure 2.8. The solar radiation, after transmission through a transparent polythene cover, is mainly absorbed by saline water in the trough. The tubular cover and trough absorb the remaining small amount of the solar energy. Thus the water in the trough is heated and then begins to evaporate.The evaporative water is transferred to the tubular cover and then finally condensed on the tubular cover inner surface, releasing its latent heat of vaporization. The condensed water trickles down the bottom of the tubular cover inner surface due to gravity and is stored in a collection bottle through a pipe provided at the middle.

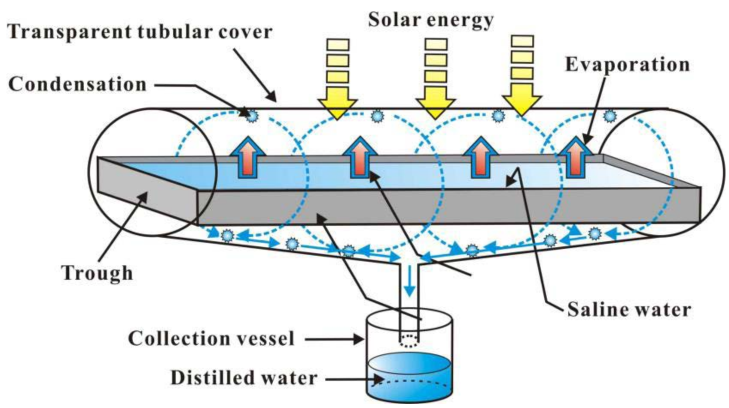
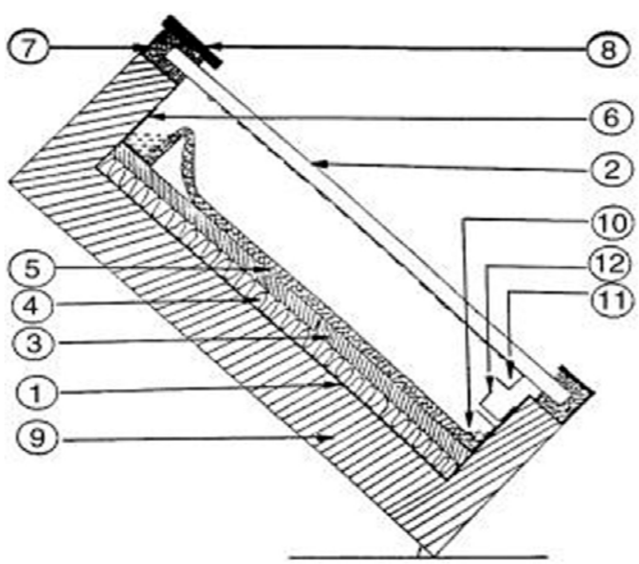


Fig 2.8 Tubular solar still

vii) Capillary Still distiller:

Highly efficient solar capillary distillation systemic the most promising to overcome all the problems of conventional solar stills. Figure 3 describes the components of a typical capillary still distiller unit [32] A wick-type solar still consists of a porous black fabric or film supported by a tray or a frame, covered by glass or plastic sheet and in an airtight enclosure. The still can be inclined or tilted to the solar radiation to avoid dripping back the distillate into the wick. Both insulated and un-insulated models are used (Jundi, 1982). The porous, blackened cloth serves as the surface for absorption and evaporation. Distilled water condenses on the inside surface of transparent cover and collects in a trough at the lower edge of the cover. A drain for the concentrated saline water is set at the lower edge of the fabric. The flow rate of the saline water is most critical as the efficiency of capillary still increases with the decrease in flow rate. The advantages of the cloth are many. It increases the surface area of the brine for more evaporation. The thermal capacity of the still reduces which in turn provides faster response to solar radiation. The still can easily be tilted or shifted to intercept the maximum solar radiation as compared to basin type stills. In a diffusion type still, the distance between the cloth surface and the top cover is reduced to a few millimeters which increase the evaporation rate (Elsayed, 1983). Lof (1980) observed that a tilted wick still has high productivity during the winter months as compared to basin type stills.



(1) Galvanised steel tray,
(2) Glass cover,
(3) Support board,
(4) Polystyrene,
(5) Charcoal cloth,
(6) Aluminum channel,
(7) Rubber gasket,
(8) Steel strip,
(9) Styrofoam,
(10) Brine gutter,
(11) Distillate gutter, and
(12) Distillate outlet channel
(Mahdi *et al.*, 2011

Figure 2.9: Cross sectional view of a capillary solar still

viii) Multiple -ledge tilted stills

This is another variety of small solar distiller, having limited commercial use, combines the efficiency of the tilted model with the simplicity of the basin type (MacLeod and McCracken, 1961), In an improved form of this still, shown in Fig-2.10, Iia tilted, shallow, glass-covered box contains a stepped series of shallow, narrow horizontal trays, Although productivity is somewhat lower than that with the wick type, it appears that there are fewer operating and maintenance difficulties.

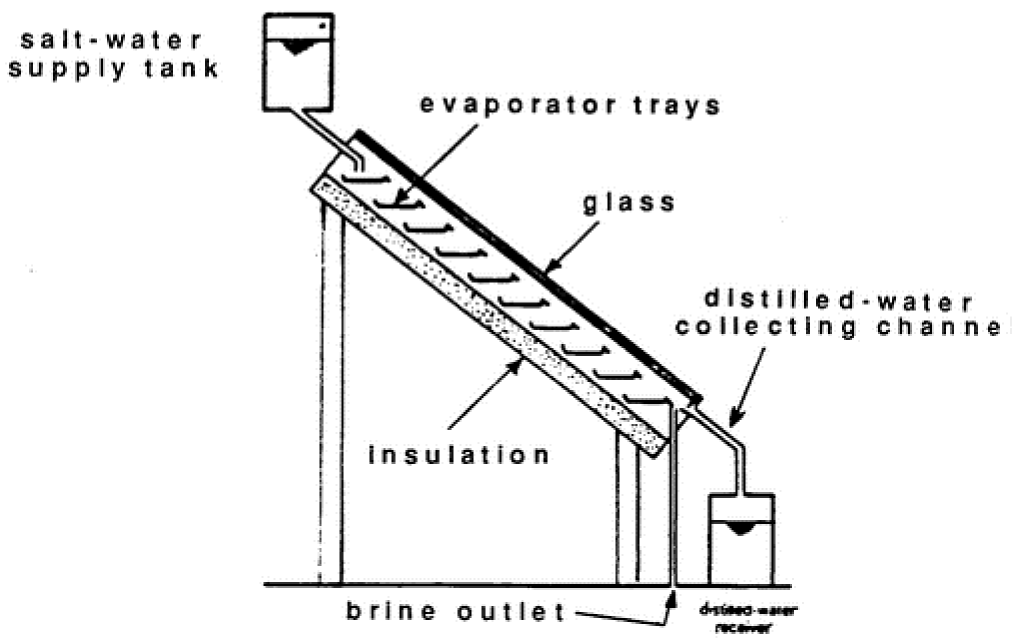


Figure 2.10: Cross sectional view of a Multiple -ledge tilted stills

ix) Simple multiple wick solar stills

On a typical cold sunny day in Delhi (viz. February 6, 1980) the distillate output was 2.5 kg/m2 day, corresponding to an efficiency of 34%. The stil1 (Fig. 2.11) costs less than half the cost of a basin type still of the same area. Also, the overall efficiency of the basin type stil1is 30% or lower (Moustafa *et al.* ,1979).

Advantages of the Multiple Wicks Still

Some of the noteworthy advantages in a multiple wick still are listed below:

1. 1t is light and hence easily portable. A collapsible model which can be nearly folded can also be developed.

2. It costs less than half of the cost of a basin type still of the same area.

3. The distillate output is significant even on a cloudy day; on a fully cloudy day in winter in Delhi the output was little more than 1 kg/m2 day.

4. The water surface on the cloth can be oriented at any optimum angle to receive maximum solar insulation.

5. There is no shadowing effect due to the small height of the side walls.

6. The silt formation occurring on blackened cloth can be brushed off easily or a black day injected in saline water can alleviate the effect of the silt formation.

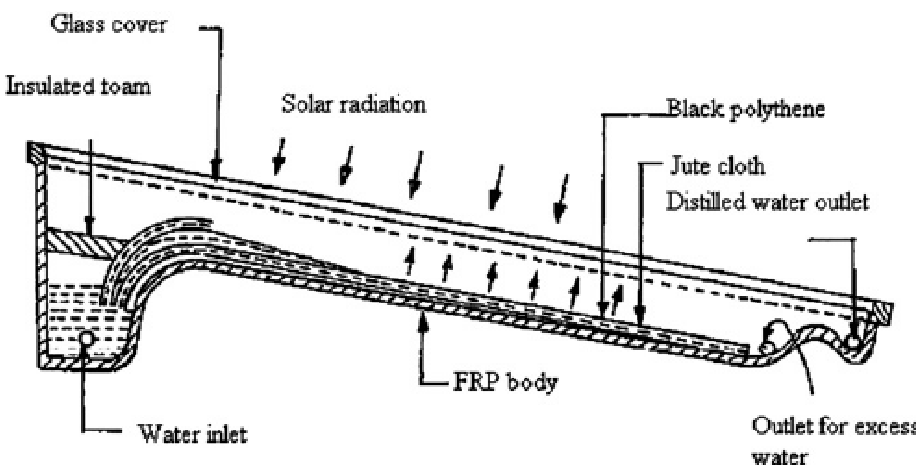


Figure 2.11: Multiple Wicks Still

2.8.2 OTHER DESIGNS OF SOLAR STILL

There are also various other types of solar still which are in practice at various places of the world. Few of the well practiced ones are:

- Life raft time type solar still,
- Film covered solar still,
- Concentric tube solar still,
- Solar earth water still,
- Combined solar collector - basin type still system,
- Air supported plastic still,
- Solar still with reflectors,
- Extruded plastic still.

2.9 CALCULATION OF EFFICIENCY

The conventional efficiency terms represents the efficiency (output/input) as follows:

$$\eta = 57.78 \times 10^{2} \times Y/R \qquad (2.16)$$

Where,

η= efficiency values expressed as percentage

Y = distillate produced by the plant (l/m2 day)

R= incoming solar radiation (cal/cm2 day)

It is worthwhile to note that the efficiency of a typical basin-type solar still is quite low and is not greater than 35% (Farid, 1992), It is seen that the presence of drop wise condensate on the glass cover causes an obstruction for the solar energy to enter into the plant through the condensate cover. So, the total solar radiation measured by the pyranometer is actually not coming in and hence not received by the stored water or absorber. So, in reality, the actual plant efficiency is somewhat higher than the value found by the equation Eq,(2.16), This demands a modification in the calculation of efficiency, This modified efficiency concept however could not be utilized in this study due to lack of an appropriate apparatus to measure the true incoming energy also the short time interval. [33]

CHAPTER 3

FABRICATION OF THE EXPERIMENTAL PROTOTYPE

3.1 CONSTRUCTION OF SOLAR STILL

The proposed solar desalination system is very simple and very easy to make. In the figure we see that, this system looks like a rectangular box and its consists of a feed water bottle, glass cover, metal body and the output of the brine water and fresh water pipe in lower part of the system. The total area of the Solar Still is approximately $1m^2$ (0.850m x 1.112 m).

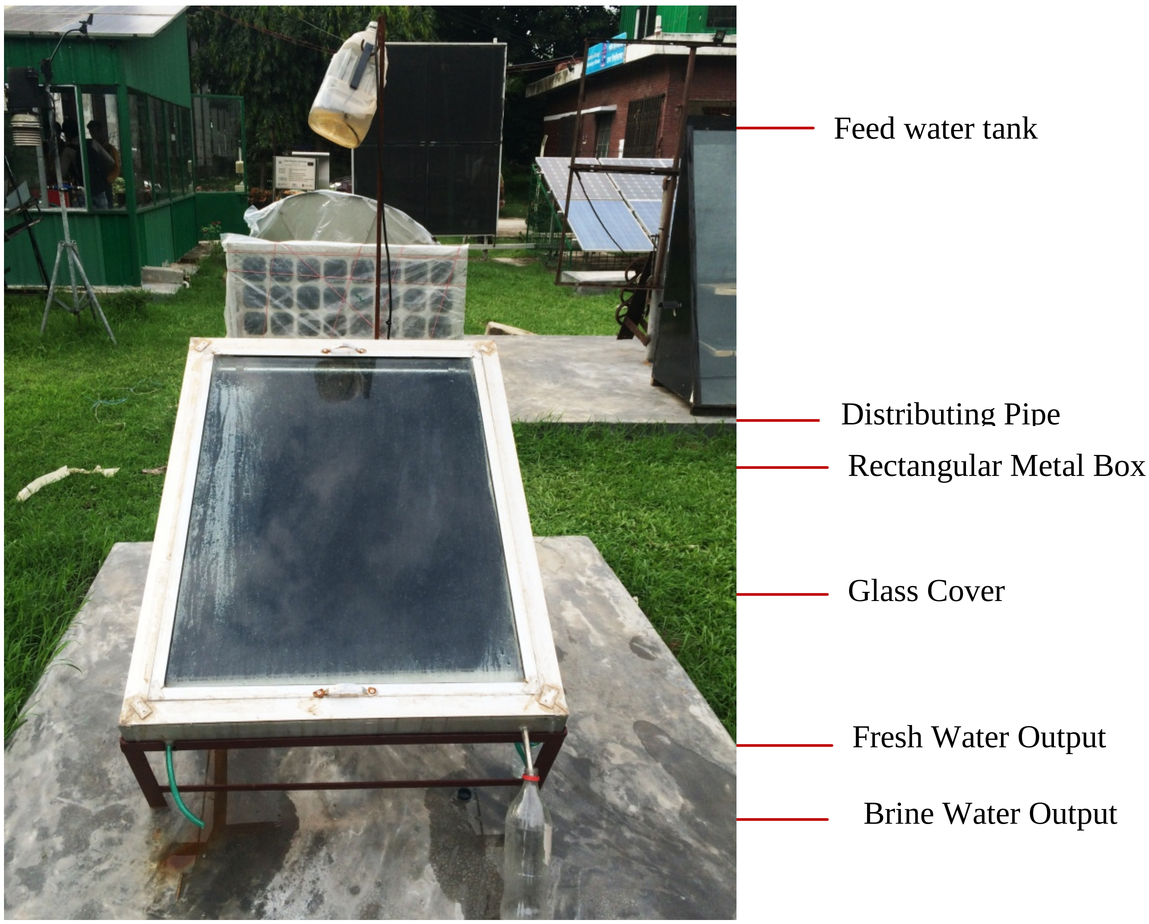


Figure 3.1- Solar Still desalination with fabric absorber

Total system placed on Iron angel fame and an additional iron stand for raw water tank. From the raw water tank the saline water passes through inside the absorber with the gravitational force by a pvc pipe. Here is no need to adding extra device to lifting or distributed the raw water in the system.

3.2 SELECTION OF MATERIAL

3.2.1 Still base and wall material: The wall and base of the still were made of the same material. Hard aluminum frame was selected for this purpose because the aluminum is a good conductive material for heat and it is light weight and cost effective.

Figure 3.2- Aluminum fame

3.2.2 Cover Material: Glass and transparent plastic sheet can be used as cover material. The present construction used ordinary window glass of 0.197 inch (5 mm) thickness for top surface. Glass was given preference over plastic because of short service life of the latter. Leakage of water vapor and the condensate, over-heating and melting of the plastic at its inner face, less susceptibility to withstand wind and other elements of nature are the other problems arising with plastic which can be solved by using glass (Badawi , 1969 ; Aftab ,1975 ;Malik, 1982)

Figure 3.3- Glass Cover

3.2.3 Fabric Slection: Pure cotton fabric is used for the solar still to increases the surface area of the brine water of the brine for more evaporation and the cotton fabric hold more water in it and also spread out the water in whole surface area of the fabric.

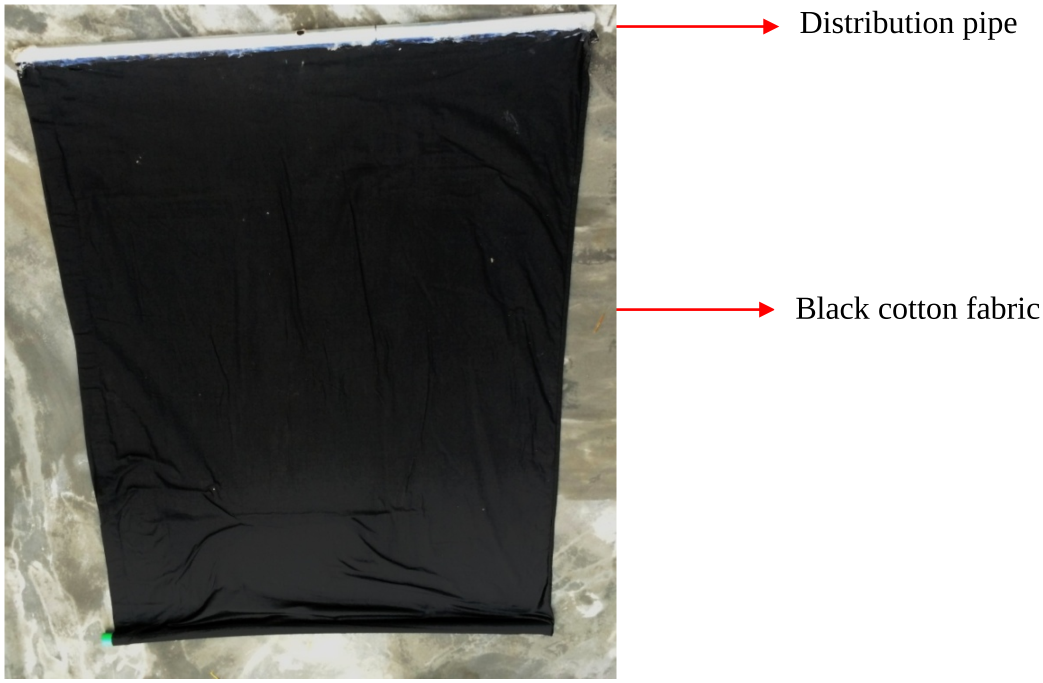


Figure 3.4- Fabric for absorber

3.2.4 Tray Selection: In this solar still using an aluminum tray for supported the fabric and get out the extra brine hot water out of the solar still.

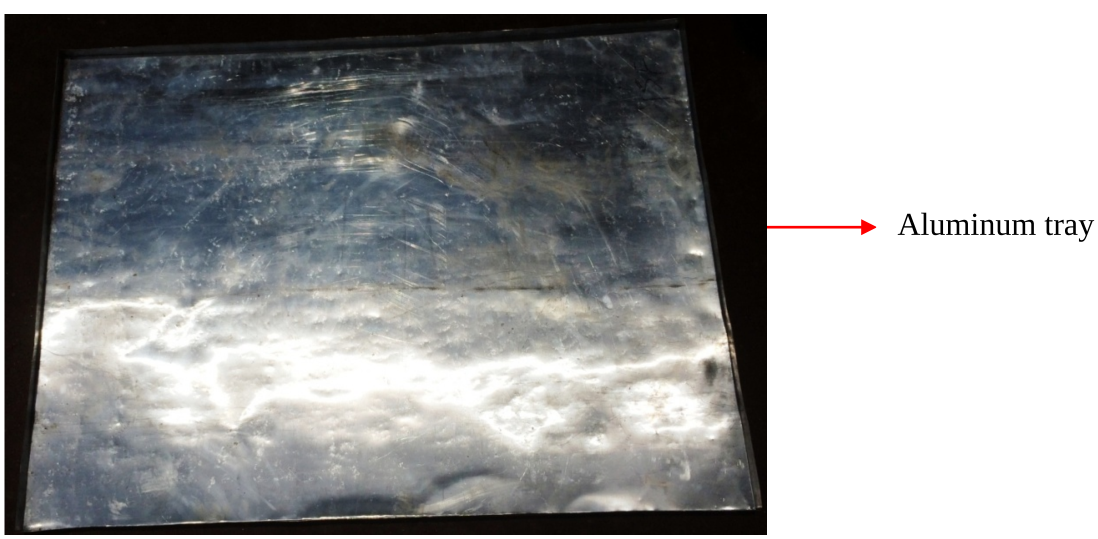
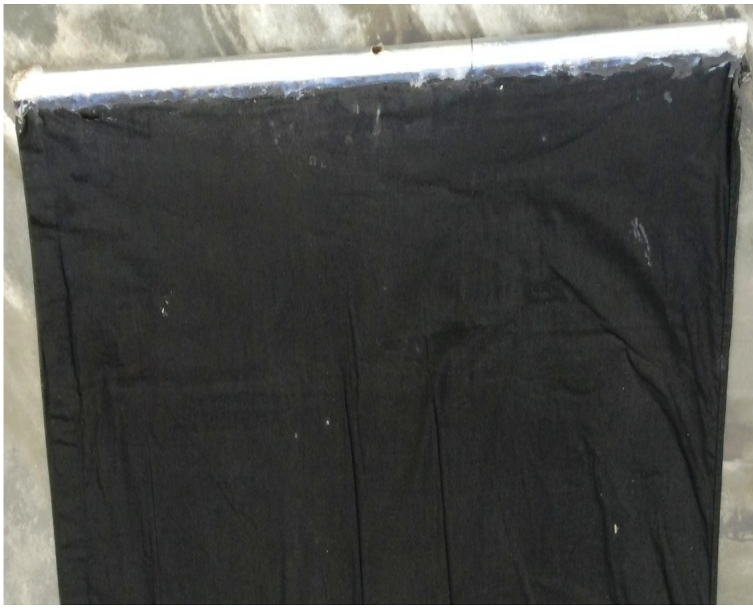


Figure 3.5- Black fabric absorber

3.2.5 Distribution Pipe: In this solar still using an aluminum pipe (0.5 inch diameter) for distribute the saline water in equally in the surface of black fabric or the absorber.



Distribution pipe for feed water

Figure 3.6- Distribution Pipe

3.2.6 Feeding Pipe and Controlling Valve: From the feed water tank a flexible pvc pipe with a controlling valve for carry the saline water to the distribution pipe.

Feeding Pipe

Controlling Valve

Fig 3.7- Feeding Pipe and Controlling Valve

3.2.7 Sealant Material: Sealant material is required to prevent leakage of water vapour and condensate. Flexible rubber was used for this purpose.

3.2.8 Distillate Storage Tank Connection: Initially plastic bottle is use which is connected with the outlet gutter.

3.3 CONSTRUCTION PROCEDURE:

In the plant the following steps were made:

- In the fig-3.7 shows firstly constructed the rectangular solar still box by aluminum bar which is available in the local market and the box manufactured with air-tight enclosure.

Figure 3.8- Construction of main frame of the Solar

- Selected a cotton black cloth and its sewing in two part carefully used as an absorber for solar still system.

Figure 3.9- Prepare the main instrument of fabric absorber

- Make an aluminium tray for support the fabric absorber with an aluminium distribution pipe.

Figure 3.10- Assemble the aluminum tray with the rectangular frame

- Setup plastic cover in a metal frame and connected with the rectangular solar still box and make a provision for fresh water outlet.

Figure 3.11- Setup the bottom side plastic cover

- The aluminum tray and the distribution pipe with the black fabric absorber grab with the metal box and make an inlet point in the distribution pipe for raw/saline water. Here also make a provision for outlet gutter for extra brine hot water.

Figure 3.12- Setup the absorber with distribution pipe with the main frame

- Next setup a glass covers in the rectangular metal frame and connected and sealed with water resistive gum and makes a provision for fresh water outlet.

Figure 3.13- Setup the top glass cover

- Finally the whole system inclined or tilted to the sun in 24.5^0 angle to the sun and in an iron frame.

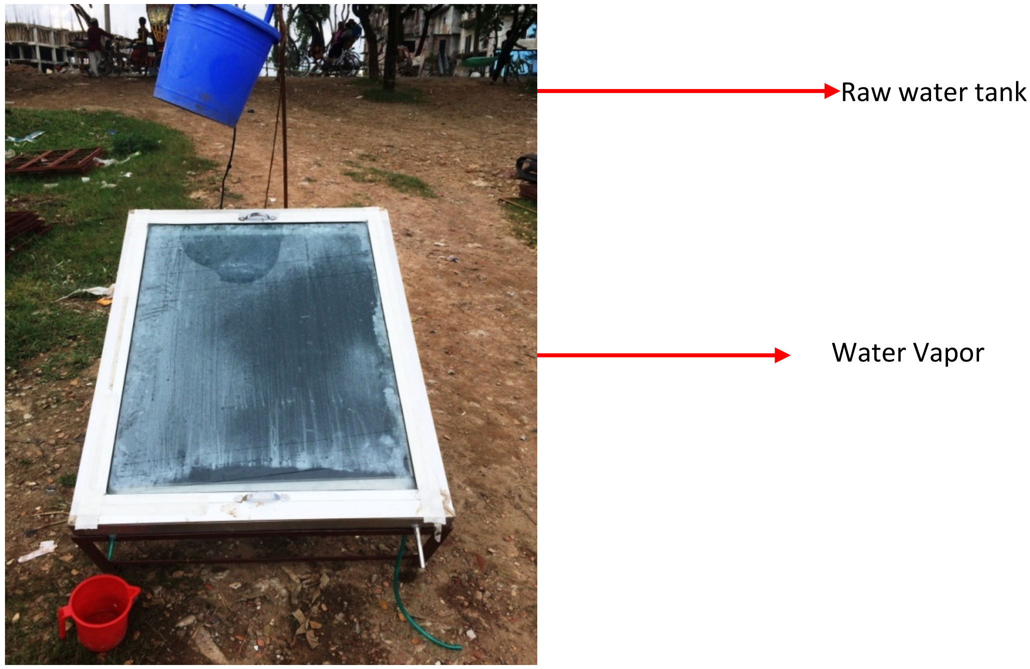


Figure 3.14- Final view of the Solar Still system with the supply of raw/saline water and produces vapor inside the system

3.4 COST ESTIMATION

The initial cost of each Solar Still was found as Tk 10,000. Initially cost is high but in mass production it can be reduces. Table 3.1 shows the cost estimation of Fabric Type Solar Still.

Table 3.1 Cost Estimation of Fabric Type Solar Still

SL No	Item Description	Amount in TK
1	Aluminium Frame	2500
2	Aluminium Tray	1500
3	Front Glass Cover	1200
4	Back Plastic cover	800
5	Iron Angle	1200
6	Distribution Pipe	400
7	Fabric and others equipment	600
8	Labor Cost	3000
Total Cost		**10,000**

CHAPTER 4

EXPERIMENTAL INVSTIGATION

4.1 METHODOLOGY:

A Fabric type Solar Still is designed and constructed using locally available materials. It is consisted of rectangular box covered with a transparent normal glass and a transparent plastic sheet in top and bottom side of the box. . Field experiments are conducted using the constructed Solar still. Daily distilled water production and hourly production of some typical days are recorded. Collected data was analyzed and correlations are proposed for daily output. Finally, the water production cost is estimated and conclusions are drawn. The steps of the methodology are shown in the flow chart given in Figure 3.1

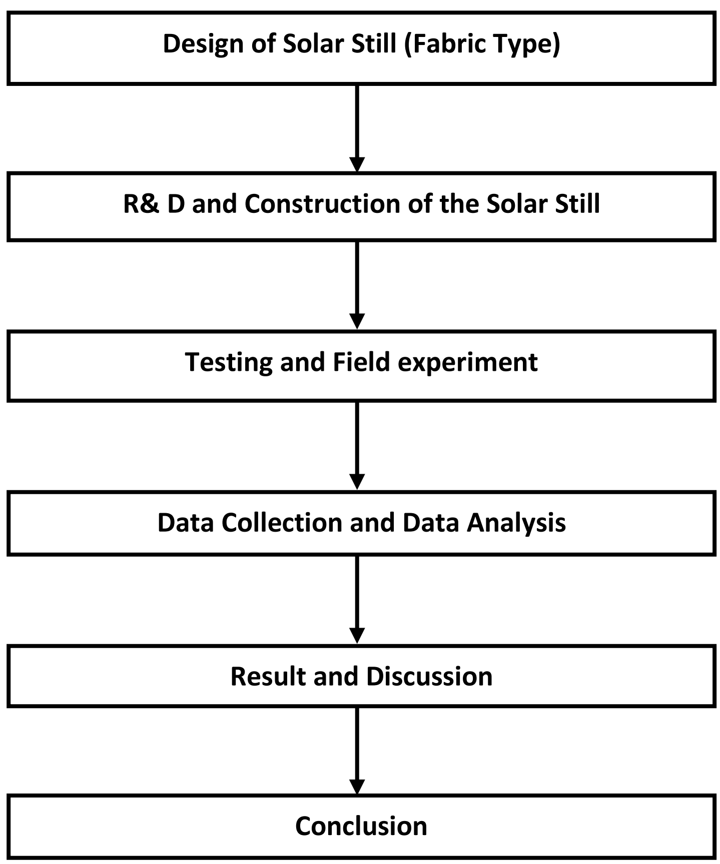


Figure 4.1- Flow chart for steps of the work

4.2 PRODUCTION PRINCEPLES

The basic principle in this solar still to expose a considerable larger amount of water to sun light than that exposed in conventional stills. Increasing the evaporating surface increases the output of the solar distillation unit. Although some studies have addressed this fact by modifying solar stills to increase the evaporation area by using metal box, black fabric, metal tray and controlling flow system for feed water.Figure-4.2 shows the whole solar still like a rectangular aluminium box and its consists of a cotton black fabric supported by an aluminium tray or a frame covered by a glass in front side and plastic sheet in bottom site with an airtight enclosure.

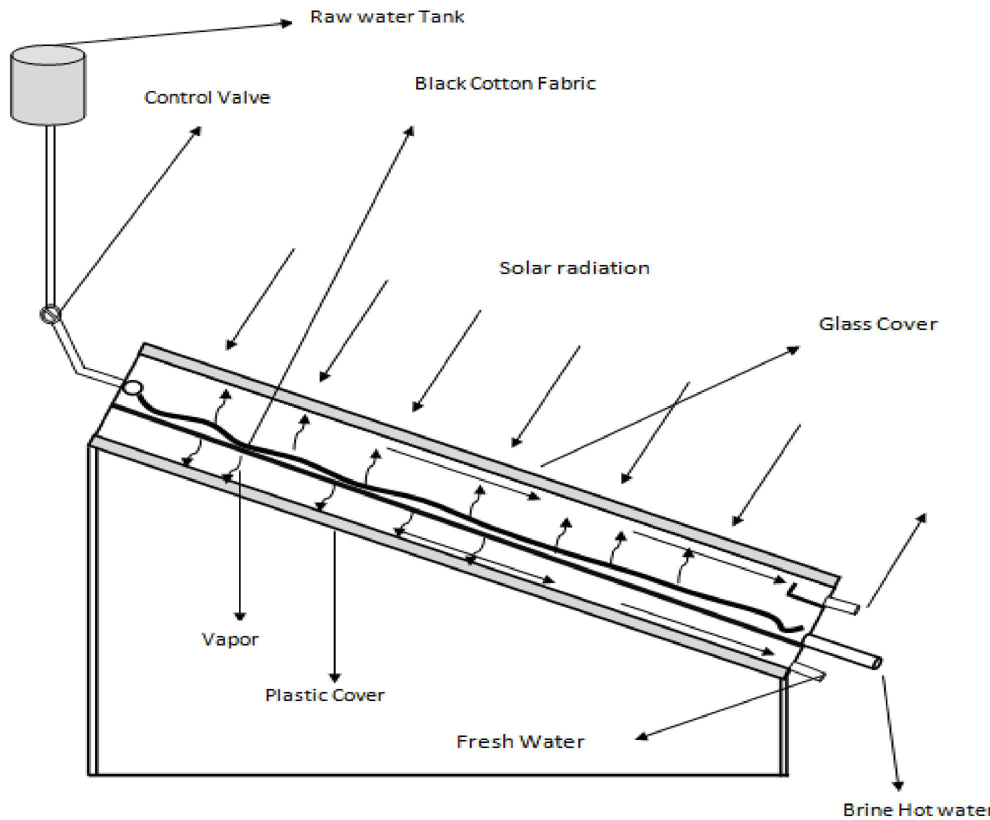


Figure 4.2- Inclined Solar Still (Water Distillation System) with fabric

The fabric is colored with black so that the heat absorption would be high. Firstly when the saline water flow from the feed water tank to the distribution pipe by a control valve (controlling the water flow) in to the fabric and the fabric turn in to wet with the saline water, the solar radiation transmitted through the transparent glass cover. The solar radiation is mainly absorbed by saline water in the fabric. Thus the water in the fabric is heated and then begins to evaporate and turn into the vapor. The vapor go through the upper glass cover and the lower plastic cover, the temperature difference to the inside and outside the distilled water condenses on the inside surface of top and bottom transparent cover and collects the water at the lower edge of the cover. The solar still tilted to the solar radiation to avoid dripping back the distillate into the fabric and for the south facing in 24.5^0 angel the maximum solar radiation cover by the solar still and produce more fresh water than other conventional solar still system.

4.3 FIELD EXPERIMENT:

The field experiments have been carried out in front premises of the Institute of Energy building of University of Dhaka in August to September 2016. Figure 4 shows the photograph of the field experiment. An Iron frame is used to support the Solar Still System so that free circulation of air occurs beneath the still. The saline water in the plant was supplied through the inlet pipe from a feed water tank. The saline water was supplied 2 times (10 lit) in a day (at 9 a.m. and 2.30 p.m.) and the amount of this water supplied was fixed based on the objective of maintaining a thin layer depth of water in the absorber fabric to generate more vapor using the controlling valve. Two plastic pet bottles is used for collecting the fresh water from top and bottom side of the system and using a pvc flexible pipe for drain out the brine water.

Fig 4.3- Field experiment on Institute of Energy

4.4 DATA COLEECTION:

The output of a solar still depends largely on the climatic factors. The prediction of these parameters is essential to predict the still output for a given period .This prediction is helpful in decision making process for the installation of solar still as a provision for fresh water from saline water. However, the measurement of some climatic factors requires expensive apparatus.

4.4.1 Solar Radiation: Solar radiation one of the most important parameters for the current study is quite difficult to measure. It requires the use of an expensive apparatus called pyranometer which may not be possible to install and maintain due to the financial constraints. But the radiation data used in this study by Institute of Energy which possesses only one pyranometer which used for the institutional research.

Figure 4.4- Pyranometer

Basically the pyranometer consists of a black surface which heats up when exposed to solar radiation. Its temperature increases until its rate of heat loss by convection, conduction and re-radiation. The hot junctions of a thermopile are attached to the black surface, while the cold junctions are located in such a way that does not receive the radiation.

As a result an e.m.f is generated, this e.m.f, this is usually in the range of 0 to10mV. The detector is covered by two concentric hemispherical optical glass covers. The output of thermopile is unaffected by detector orientation. The outer precision-ground hemisphere can be either optically clear glass or one of several filter glasses. The ring is used to allow continuous recording of diffuse radiation without the necessity of continuous positioning of smaller shading devices; adjustments need to be made for changing declination only and can be made every few days. The ring shades the pyranometer from part of diffuse radiation and a correction for this shading must be estimated and applied to the observed diffuse radiation. Sensitivity of Pyranometer = **5.02 $\mu V/Wm^{-2}$** =**5.02 $x10^{-3}$ mv/Wm^{-2}**

4.4.2 Air temperature: Air temperature is measured with thermometers. Common thermometers consist of a glass rod with a very thin tube in it. The tube contains a liquid that is supplied from a reservoir or bulb, at the base of the thermometer. Sometime the liquid is mercury and some time it is red colored alcohol. As the temperature of the liquid expands, it rises up in the tube. The tube is marked with a scale, in degrees Fahrenheit or in degree Celsius. When we measuring the air temperature be sure to have the thermometer in the shade to protect the direct heat from sunshine then the reading is higher than the true air temperature.

Figure 4.5- Thermometer

4.4.3 Measuring Fresh water: Measuring the fresh water from the solar still using a measuring tube (Graduated Cylinder) and using a stop watch for time duration.

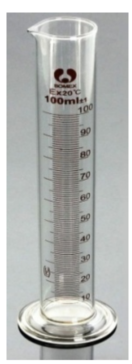


Fig 4.6- Graduated Cylinder

4.5 ANALYSIS OF THE EXPERIMENT RESULT:

4.5.1 Observed Sunshine Radiation, Air Temperature and Production in a Day:

Hourly and daily distilled water output from the Solar Still are used to calculate the daily and hourly production rate per unit surface area of the saline water in the system. Figure 4.2 shows the observed diurnal variations of hourly production per unit saline water surface area, solar radiation flux and ambient air temperature for the Solar Still desalination system at Institute of Energy, University of Dhaka for August 17 of 2016.

It is observed from the figure that the solar radiation flux rose rapidly after sunrise (approximately 6:30) and peaked approximately 12:00 after declining gradually. The air temperature also rose gradually in the morning (approximately 7:00) till 13:00, and declined gradually in the afternoon. Whereas the production was recorded from 9:00 in the morning (clearly indicating that there is a distinct time lag between evaporation and production or condensation), increased gradually up to 13:00, and then declined in the afternoon. It was also seen that the slope of the hourly production rate in the morning is steeper than that of the afternoon. The total distillate output for the day is found as 3.2 lit/m^2.

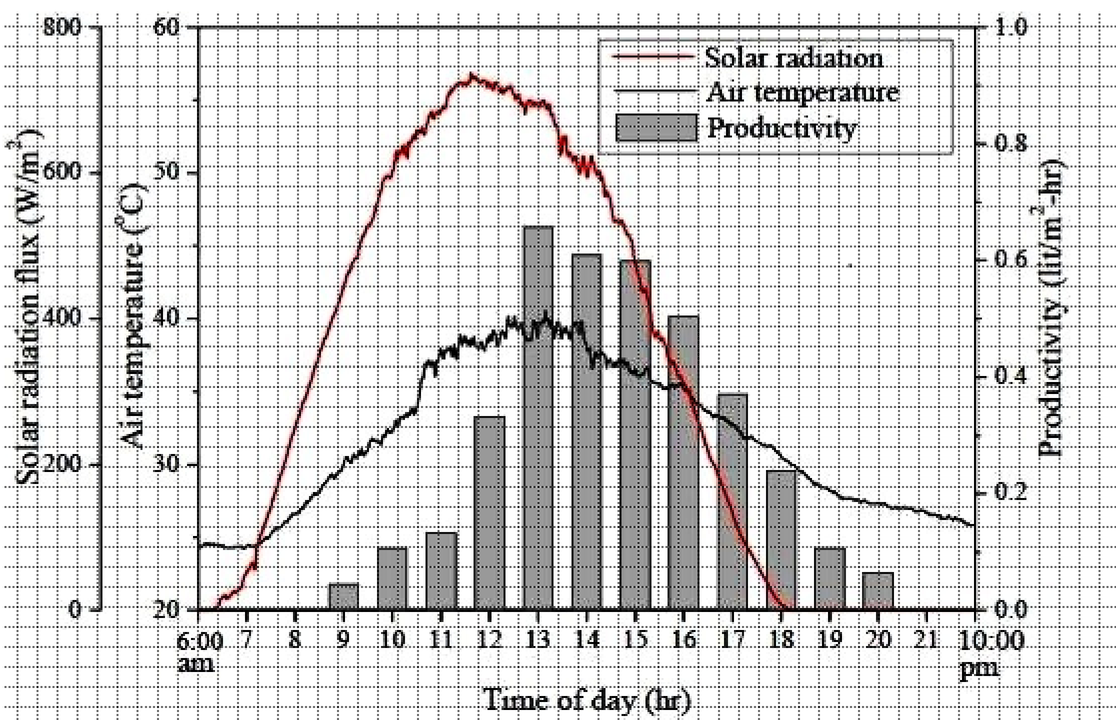


Figure 4.6: Observed diurnal variations of the sunshine radiation, air temperature and production for the Solar Still on August 17 of 2016 at Institute of Energy.

4.5.2 Monthly Observation of the Production of the Solar Still

One month basis field work on the Solar Still has been carried out at Institute of Energy, Dhaka from 5th August 2016 to 4th September 2016 and average daily productions for each day are calculated and tabulated in Table 4.1. For calculating the daily production, non-sunshine days and remarkable very low-sunshine days due to cloud, rain etc. are not considered in the calculation. Figure 3.22 shows the variations of the maximum daily production per unit saline water surface in the absorber for the Solar Still for all day in the month of August to September 2016.

Amount of Saline water: 8 to 10 liter

Starting time: 8:00 am

Ending Time: 5:00 pm

Fresh water collection time: 9:00 am – 7:00 pm

Table 4.1- The daily production of Solar Still for 20 days from August to September

Day (10th August to 8th September)	Amount of fresh water in a day (Liter)
1(10-08-2016)	1.1
2	1.3
3	1.8
4	1.1
5	2.0
6	1.7
7	2.5
8	3.2
9	2.8
10	1.2
11	1.5
12	1.0
13	1.6
14	2.1
15	1.7
16	2.3
17	1.3
18	1.8
19	2.6
20 (08-09-2016)	3.4

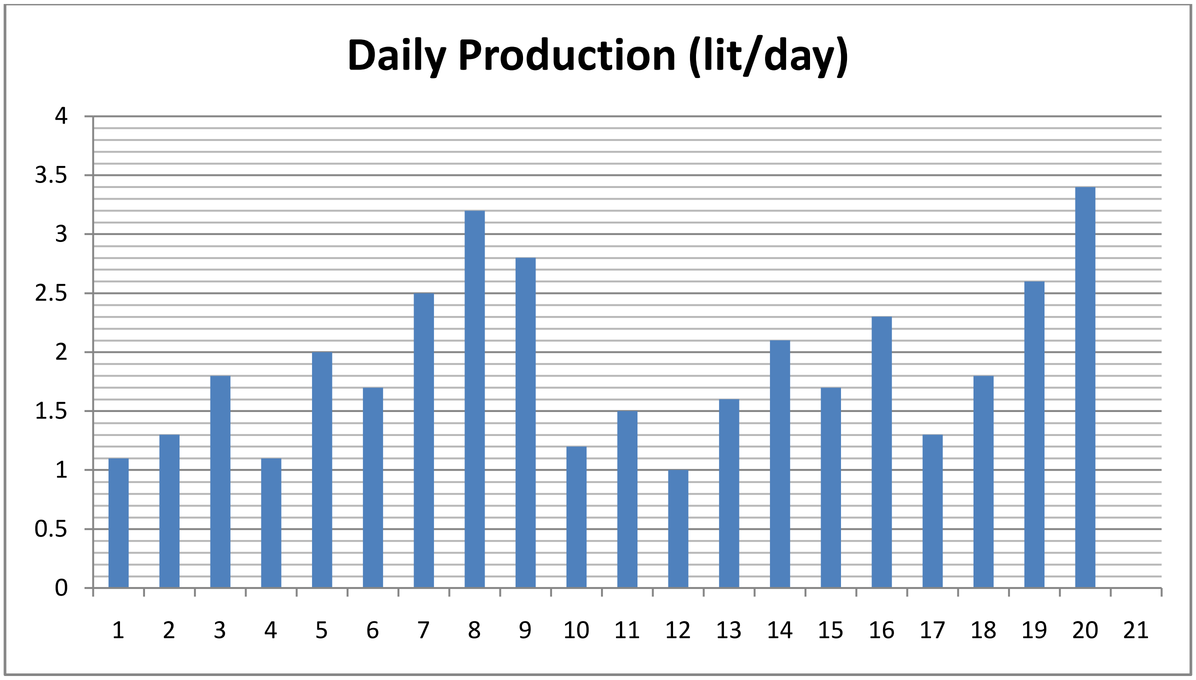


Figure 4.7- Daily production of fresh water for 20 days in August –September

It is seen from the figure that the production in August-September (1.2-3.4 lit/m2-day).The highest maximum daily production is observed in 17th August and 8th September as 3.2 and 3.4 lit. August 10th to September 9th considering 20 days (non-sunshine days and remarkable very low-sunshine days due to cloud, rain etc. is not considered in the calculation) Observation of produce fresh water from Solar Still data.

4.5.3 Water Quantity and Quality Monitoring:

Water Quantity: Since availability of water in adequate amount is a major problem, the quantity of water produced by the system in different seasons will be monitored. The output from desalination unit will be observed against availability of sunlight/solar radiation. The seasonal variation of sunshine hour normally affects output of water from desalination unit which will be studied. Moreover, solar radiation during different time of a day is critical for water output which will also be monitored.

Table: 4.2-Maximum and Minimum Water Output from the System in a Day

Maximum water output	**3.4 lit/day**
Minimum water output	**1.0 lit/day.**

Water Quality: In the experimental time the collected fresh water from the solar still the Water quality tested from BUET (Bangladesh University of Engineering Technology) environmental lab. The parameters that will be tested are: Arsenic (As), Chromium (Cr), Lead (Pb), Total Coliform (TC), Fecal Coliform (FC) and the Salinity.

Table 4.3 Water Quality Result of the Solar Still Desalination System from BUET

Sl. No.	Water Quality parameter	Unit	Concentration Present	Bangladesh Standard for Drinking Water(ECR'97)	WHO Guideline Values,2004
1	Arsenic (As)	mg/l	<MDL	0.05	0.01
2	Chromium (Cr)	mg/l	<MDL	0.05	0.05
3	Lead (Pb)	mg/l	<MDL	0.05	0.01
4	Cadmium (Cd)	mg/l	<MDL	0.005	0.003
5	Total Coliform (TC)	(CFU)/100 ml	Nil	0	0
6	Fecal Coliform (FC)	(CFU)/100 ml	Nil	0	0

4.6 COMPARATIVE ANALYSIS: FSS AND BSS

Comparative data analysis of the Fabric Type Solar Still (FSS) based on water output of the system compared with a conventional Basin Type Solar Still (BSS) collected water output in a same month and same day (**10th August to 8th September)**..

Figure 4.8- Fabric Type Solar Still (FSS) and Basin Type Solar Still (BSS)

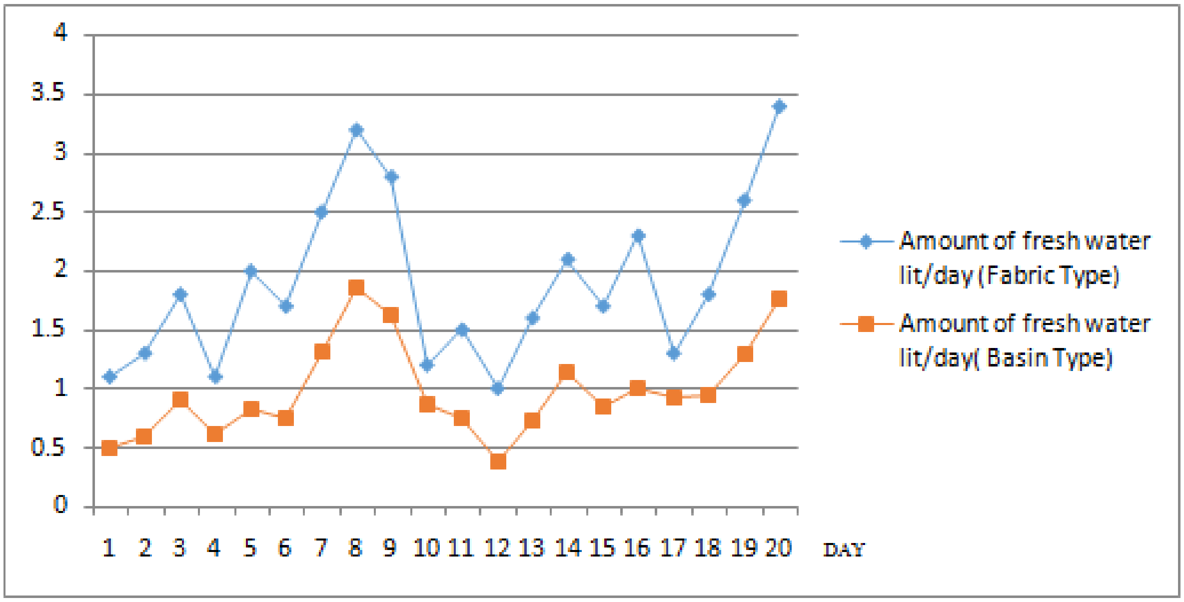


Figure 4.9-Comparative water production 20 days graph of Fabric Type Solar Still vs Basin Type Solar Still

One month basis field work on the FSS and BSS has been carried out. For calculating the daily production, non-sunshine days and remarkable very low-sunshine days due to cloud, rain etc. are not considered in the calculation .In the Figure 4.8 shows the variations of the maximum daily fresh water production of Fabric Type Solar Still (FSS) and Basin Type Solar Still (BSS) for all day in the month of August to September 2016. In the figure the blue line is for FSS and the orange line for the BSS. From the figure we see the comparison of the water output of both systems.

4.7 DISCUSSION AND CONCLUSION:

The production rate of a solar stills is mainly depends on the intensity of solar radiation and the production rate will be higher in the summer season. The Solar Still is constructed using locally available material and the construction is very simple. Also, the operation and maintenance of is very simple and easy.

The average daily production rate for the Still is found as 1.9 lit/m^2; with highest and lowest values are 3.4 and 1.0, respectively. Highest productions are observed in 8th

September 2016.The result presented in this study gives clear information to understand the behavior of production rate and other related information for the Solar Still.

From this study of Solar Still also found some findings-

- The introduced modification in this study significantly increases the productivity than the other conventional solar still
- The fabric is colored with black so that the heat absorption would be high.
- For controlling the flow of saline water in the absorber to create a thin water film continually form and evaporate rapidly.
- The still can be inclined or tilted to the solar radiation to avoid dripping back the distillate in to the absorber.
- The maintenance of the system is very low.
- The water production cost is low than other still system.

It is concluded that due to easy construction, operation and maintenance of the developed Solar Still, one can easily use the system for drinking and other purposes in remote, coastal and arid areas or in an emergency to meet small scale fresh water demand.

4.8 FUTURE RECOMMENDATIONS:

The present study was limited to its scope because of the time constraints. Therefore, the following recommendations are made to extend the present study:

- Huge scope of study on the fabric type absorber on heat transfer and sustainable issues.
- Another scope to removal Iron, Arsenic, Manganese or any other pathogens remove from water.
- Verification of the developed models with further experimental investigations performed for a longer span of time.
- Collect more fresh water in rainy season by including a rain water harvesting system with the Solar Still system.
- Study on promotion of the system for alternative drinking water option in coastal area.
- Further study on the effect of drop wise condensation of water on the glass cover can be done for much more accurate prediction of the true efficiency of the plant.

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[c] www.foreeverpure.com/VaporComp.htm

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