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Dissertation Report

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To study the effect of the phase change material on the performance of a solar still

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CERTIFICATE

This is certified that the dissertation report entitled **“To study the effect of phase change material on the performance of a solar still”** prepared by **Krishan Avtar Saini** (ID-2013PME5241), in the partial fulfillment of the award of the Degree **Master of Technology** in **Energy Engineering** of Malaviya National Institute of Technology Jaipur is a record of bonafide research work carried out by him under my supervision and is hereby approved for submission. The contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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I **Krishan Avtar Saini** hereby declare that the dissertation entitled **"To study the effect of phase change material on the performance of a solar still"** being submitted by me in partial fulfillment of the degree of **M. Tech (Energy Engineering)** is a research work carried out by me under the supervision of **Dr. Nirupam Rohatgi** and the contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this dissertation work has been copied or borrowed from anyone else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

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(Krishan Avtar Saini)

ABSTRACT

Worldwide many methods are used for producing the pure water. Water desalination is oldest and most general process for producing potable water from brackish water. Water desalination can be done by giving energy inputs like electricity energy, fuel energy and solar energy. When solar energy is given as input for water desalination, it is called solar water desalination. Solar water desalination is very useful and efficient method to get potable water because solar distillation system is simple in design and easy to maintain, and uses solar energy that is free of cost and abundant in nature. Solar radiations are available in most of the areas in India, so solar water desalination is good alternative.

The present work shows effects on distillate output and efficiency as varying parameters in single slope passive solar still. The experiments are performed on single slope passive solar still by using paraffin wax as a thermal storage material under MNIT jaipur. In this research the experiment were carried out in 10 summer days at MNIT jaipur and the result were measured in the same manner for each day.

By using paraffin wax as storage material overall efficiency goes to **52.56%**, while for without using paraffin wax the efficiency is only **43.69%.** The overall efficiency increases to **8.87%** with paraffin wax as a thermal storage medium in solar still compared to solar still without paraffin wax.

The day output of distillate water decreases with paraffin wax, but the night output increases. The total output of distillate water combining day and night increases when we use paraffin wax as a thermal storage medium.

By using the different quantity of water in solar still basin we calculated the effect on solar still efficiency. For **20 liter** of water overall efficiency is **52.56%** and for **10 liter** of water efficiency is **54.14%** .So when we decrease the depth of the water in basin the overall efficiency increases by **1.58%**.

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Nomenclature

A	Area of solar still [m^2]
C	Specific heat of water [kJ/kg K]
H	Heat transfer coefficient [W/m^2 K]
I	Solar intensity [W/m^2]
K	Thermal conductivity [W/m K]
L	Thickness [m]
L_g	Latent heat at glass temperature [kJ/kg]
L_w	Latent heat at water temperature [kJ/kg]
M	Mass of water in the basin [kg]
M_w	Mass of distillate output [kg]
P_w	Saturated pressure at water temperature [kPa]
P_g	Saturated pressure at glass temperature [kPa]
Q	Heat transfer from various surfaces [KJ]
T	Temperature [$^{\circ}C$]
U	Heat loss coefficient [$W/m^2.K$]
V	Wind velocity [m/s]

Chapter 1

Introduction

1.1 Need and availability of water

Water is the necessity of human along with food and air. Water plays an important role in the development of a country. But the access of potable water is narrowing with the time. Rivers, lakes and underground water reservoirs are the main resources of fresh water. Around 71% part of this earth is covered with water, yet of all of that 96.5% of the earth water is found in oceans 3.4% in groundwater glaciers and the ice cabs and 0.001 in the air as vapour and clouds only 2.5% of the earth's water is fresh water and 98.8% of that water is in ice and ground water. Less than 1% of all freshwater is in river, lakes and the atmosphere.

The world's water consumption rate is doubling every 20 years. The United Nations Environment Programme (UNEP) stated that 1/3 of world's population live in areas with insufficient freshwater. Almost 1/5 of the world's population lives in countries where water is scarce. Till year 2025, water demand exceed supply by 56% due to persistent regional droughts, and shifting of the population to the urban coastal cities and regular pollution of water and because of that two third of world's population will have not fresh water even for their household.[1]

Today, majority of the health issues are due to the non-availability of clean drinking water. In the recent time, most parts of the countries receive insufficient rainfall which results increase in the water salinity. The pollution of water resources is increasing drastically due to a number of factors including growth in the population, industrialization, urbanization, etc. These activities adversely affected the water quality in rural areas and agriculture. In the world, 3.575 million people die each year from water related diseases.

1.2 Indian scenario

The X-rays and other very short wave radiations of the solar spectrum are absorbed highly in the ionosphere by nitrogen, oxygen and other atmospheric components. Most of the UV rays are absorbed by ozone. At wavelength longer than about 3.0 μm is absorbed by CO_2 and H_2O i.e. only very little energy beyond 3.0 μm reaches the ground. Thus from application of solar energy only radiation of wavelength between 0.3 and 3.0 μm need to be considered.

This solar radiation is transmitted through the atmosphere and undergoes variations due to scattering and absorption. A portion of solar radiation and some scattered radiation reaches the ground as diffuse radiation. There will be always some diffuse radiation, even in the periods of very clear sky. The amount of depletion of solar radiation depends upon the amount of dust particles, water vapour, ozone content, atmospheric pressure, cloudiness etc., and on solar altitude. Practically all the radiation that reaches the ground is diffuse radiation.

Areas lying on the earth between 35˚ N to 35˚ S latitudes receive maximum solar radiation. Thus India (8˚ N to 35˚ N) is blessed with vast amount of solar radiation.

1.3 Water Desalination Technologies

Desalination is a process in which saline water is separated into two parts using different forms of energy, one that has a low concentration of dissolved salts fresh water), and the other which has higher concentration of dissolved salts than the original feed water. Saline water is classified as brackish water and sea water depending on the salinity of water and water resources. Currently there are more than 14,000 desalination plants in operation worldwide producing several billion gallons of water per day.

The water desalination processes mainly divided into two types: membrane processes and thermal processes as shown in Fig.1.1.The other alternative technologies of freezing and ion exchange are not widely used. These are operated by a conventional or renewable energy sources to produce potable water. [1]

1.3.1 Membrane Desalination

These collectors are designed for application requiring energy at low to moderate temperatures (up to about 100˚ C above the atmospheric temperatures). These devices are mechanically simpler and use both direct and diffuse radiation. A flat-plate collector is installed in a fixed position facing the sun at an optimum inclination to the horizontal depending on the latitude of the location. The major applications are in water heating and air heating.

In case of conventional solar air heater, the air to be heated is passed through a rectangular duct below a blackened light gauge steel or aluminium absorber plate. The absorber, whose sun facing surface is blackened, absorbs the incident solar radiation and transfers the heat to the air flowing below it.

1.3.2 Thermal Desalination

These collectors consist of a device to concentrate the solar radiation on to a small absorbing surface and thus are capable of delivering heat energy at temperatures higher than possible with ordinary flat-plate collectors. The losses from the collector are lower due to small area of the absorbing surface. During diffuse radiation these collectors are not so much effective; they require a tracking mechanism to follow the sun’s movement so that the radiation is directed on the absorbing surface.

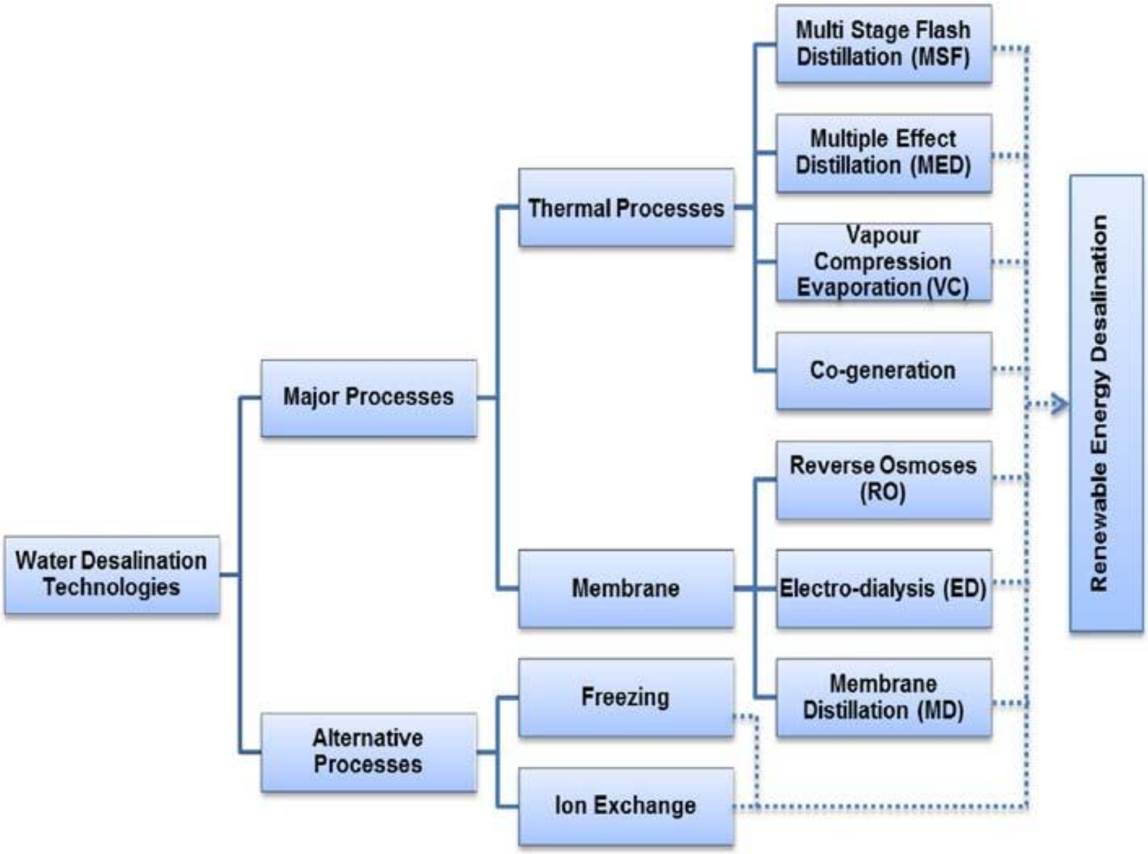


Figure 1.1 Water desalination technologies

1.4 Solar Water Desalination Technologies

Solar water desalination has a long history. The first documented use of solar energy for desalination of water in the sixteenth century and in 1872, the Swedish engineer, Carlos Wilson, built a large scale solar desalination plant (i.e. solar still) to supply drinking water for a mining community in Chile at Las Salinas in a desert area [1].

Efficient, inexhaustible, clean and environmental-friendly solar energy coupled with desalination technologies would be an appropriate alternative to produce fresh water on both small and medium scales. This solution is suitable for supplying upto a half of rural population living in arid regions where average global solar radiation is of 6-7 kWh/m^2/day.

Generally two types of solar still are there, one as passive and other active solar still. In a passive solar still the solar energy is received directly by the basin water and the basin water temperature is increased by direct solar radiations only because of this the productivity of solar still due to low temperature difference between basin water and glass temperature.. We know that the productivity of any type of solar still will be determined by the temperature difference between basin water and glass temperature. This is main drawback of passive solar still. But these types of solar still are easy in construction and operation. [2]

Several active solar still have been developed to increase the basin water temperature. The additional heat is given to increase basin water temperature by coupling with heat sources like flat plate collector, waste heat by heat exchanger to enhance the performance of solar still. The amount of distillate output increases in active solar still.

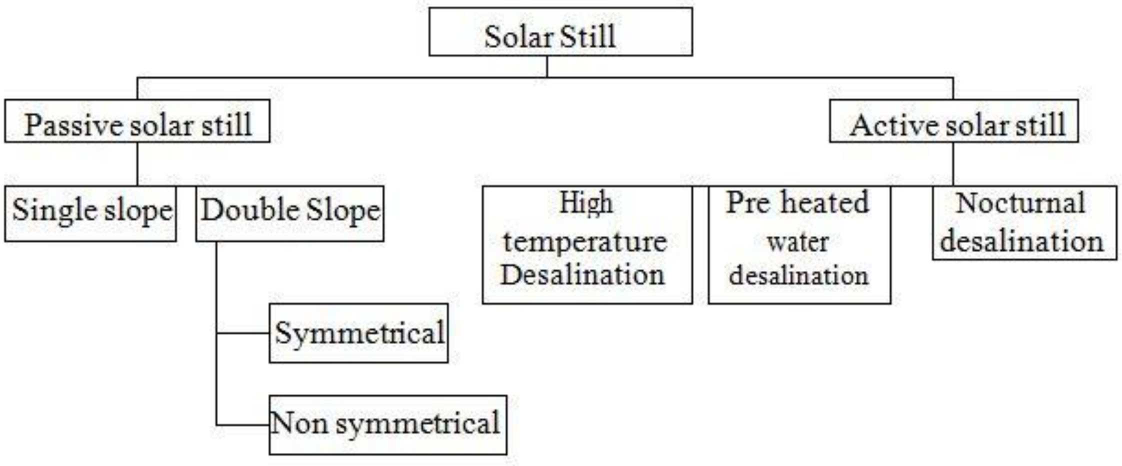


Figure 1.2 Classification of solar still

1.4.1 Single Slope Passive Solar Still

Single slope solar still consists of a water basin and a glass cover at top. The water fed in basin. The solar radiations enter the glass reach to basin and water evaporates, finally condensed at inner surface of glass. Due to gravity effect water droplets collected on the tray attached at bottom of glass.

1.4.2 Passive Solar Still Double Slope

Double slope solar still consists of two-storey water basin. The water is fed in both the basins. The solar radiations enter after passing through two glasses and the water at first basin evaporates & condensed at inner side of lower glass. The water droplets collected at bottom of lower glass. The water in second basin gets the latent heat of condensed water at lower glass and it evaporates & condensed at the inner side of upper glass. The water droplets collected on the tray attached at bottom side of upper glass.

1.4.3 High Temperature Desalination Active Solar Still

The solar collector used to heat the water and this hot water is fed to solar still for distillation process. This solar collector is coupled with solar still in order to enhance the productivity of solar still.

1.4.4 Pre Heated Water Desalination Active Solar Still

This is the technique in which waste hot water from various industries like chemical industry, paper industry, thermal power plant, food processing industries is utilized in solar still. This waste hot water improves the distillate output due to more evaporation of water and hence solar still becomes very efficient.

1.4.5 Nocturnal Desalination Active Solar Still

Nocturnal desalination is the working of solar still in the absence of sunlight. The solar radiation are stored in day time and utilized in night time and the waste heat can also be used during night time. In a conventional solar still, high water depth is taken that is heated in day time and large amount of heat is stored by water within it and the stored heat is utilized in night time.

1.5 Objective of the Study

The objective is to study the effect of paraffin wax as a storage material on the performance of single slope passive solar still. The other sub- objectives are given below.

- To modify the present solar still design by using PCM as a storage material.
- Performance enhancement of a horizontal solar still by applying PCM as a storage medium and comparison with simple horizontal solar still.

Chapter 2

Literature Review

There are several research papers on solar still of various designs and effect of various parameters. The research papers show the enhancement of the performance by changing different parameter of solar still.

2.1 Use of Reflectors

To concentrate the solar radiation on basin of solar still reflectors are used. These are fabricated on inside and outside the solar still to enhance the productivity.

H.Tanaka (2011) [3] utilize a flat plate external bottom reflector to increase the performance of a single basin solar still on three days. We proposed a geometrical model to calculate the direct solar radiation reflected by the external bottom reflector and then absorbed onto the basin liner. Numerical analysis of heat and mass transfer in the still was also performed. We found that the external reflector can reflect the sunrays to the basin liner and increase distillate productivity. The daily amount of distillate of the still with internal and external bottom reflector is predicted to be 41%, 25% and 62% greater than that of a conventional basin type still on the spring equinox and summer and winter solstices, respectively, by setting the external reflector's inclination to the proper values according to the seasons when the glass cover's inclination angle is fixed at 20° from horizontal and the length of the external reflector is the same as the length of the basin liner.

2.2 Use of PCM as Heat Storage Material

Omar et al. [4] dealt transient mathematical models of a passive solar still with a heat energy storage system i.e. Phase change materials (PCMs) put under the basin liner of the solar still are used to store energy in the process of changing the aggregate state from solid to liquid. The energy balance equations for the various elements of the still as well as for the PCM are formulated and numerically solved. Numerical calculations have been carried out for three kinds of PCMs which have different melting temperatures as shown in the Table 2.1. To validate the simulation results, the brackish water temperature is compared with the analytical expression and the existing results in the literature. The obtained results show that the excess energy produced during sunshine times is stored in a PCM for use later during the night and also can be seen that from the results the distillate output and efficiency both are significantly increases with increase in the melting temperature of the PCMs. The thermal efficiency of passive solar still with PCM which having highest melting temperature is approximately 70%. This is only because of heat energy stored within the PCM which enhances both the productivity of the fresh water and the efficiency of the solar still.

Table 2.1 Physical properties of the phase change materials [5].

PCM Type	Specific heat: Solid/liquid Cp (J/kg °C)	Thermal conductivity Solid/liquid K (W/°C m)	Density Solid/liquid ρ (kg/m^3)	Melting temperature T_m (°C)	Latent heat L (kJ/kg)
Paraffin C18	1900/2240	0.376/0.148	814/774	42	242
Paraffin 52-54	2195/2950	0.232/0.15	900/814	52	188
Paraffin wax	2950/2510	0.24/0.24	818/760	56	226

El-Sebaii et al. [5] introduces PCM below the basins liner of the passive solar still to enhance the productivity of the solar still. And shows effect of mass of the PCM on the daylight, overnight and daily productivity and efficiency of the still for different masses of basin water mw has been investigated. It is found that daylight productivity decreases as increases in mass of PCM; but overnight productivity and daily productivity increase significantly with an increase in mass of PCM due to the increased amount of the heat stored within the PCM. During discharging of the PCM, the convective heat transfer coefficient from the basin liner to basin water is doubled; thus, the evaporative heat transfer coefficient is increased by 27% on using 3.3 cm of stearic acid as PCM(T_m = 52^{o}C) beneath the basin liner. Therefore, on a typical summer day (ambient temp. upto

50^{o}C), a value of daily productivity of 9.005 (kg/m^2 day) with a daily efficiency of 85.3% has been obtained compared to 4.998 (kg/m^2 day) when the still is used without the PCM. The PCM is more effective for lower masses of basin water on winter season.

2.3 Effect of Water Depth

The water depth in solar still basin plays important role in distillate output. Several papers are there showing the effect of water depth on performance of solar still. This effect on amount of evaporation process takes place in solar still basin.

Tripathi R., Tiwari G.N. (2005) [6] An attempt has been made to freed out the convective heat transfer coefficient for active solar distillation system. It is a well-known fact that the distillate output (the yield) decreases significantly with the increase of water depth in the basin of the solar still. It is also known that more yields is obtained in case of active solar distillation system as compared to passive solar still due to higher temperature difference between the water and inner glass cover temperatures in the active mode.

It is inferred that the convective heat transfer coefficient between water and inner Condensing cover depends significantly on the water depth in the basin. It is also observed that more yields is obtained during the off shine hours as compared to daytime for higher water depths in solar still (0.10 m and 0.15 m) due to storage effect.(but when PCM is use in case of less water in basin more storage in PCM so night time output is more)

Rajamanickam M.R., Ragupathy A. (2012) [7] In this work, an attempt has been made to study the effect of water depth on the internal heat and mass transfer in the single basin double slope (DS) solar still. The experimental setup was fabricated from Galvanized iron sheet. The bottom and all sides of the still are made from same material. The cover is made from a transparent glass of 3 mm thickness. The solar still was sealed to reduce the leakage of vapor to the surroundings.

The maximum distillate output of 3.07 L/m^2/day was obtained with water depth in still basin 0.01m in the DS solar still with north-south orientation. The results indicated that decrease in depth of basin water, resulted with increase in productivity of the still.

Tiwari A. K., Tiwari G.N. (2006) [8] An attempt has been made to find out the effect of water depth on evaporative mass transfer coefficient for a passive single-slope distillation system in summer climatic condition. The experiments have been conducted on a south

facing, single slope, solar still of 30° inclination of condensing cover, in summer climatic condition for 24 h on different five days for different five water depths from 0.04 m to 0.18m. It is understood that the heat transfer coefficients depends significantly on water depths. It is also observed that the nocturnal distillation is significant in the case higher water depths because of reduced ambient and stored energy within it.

Phadatare M.K., Verma S.K. (2007) [9] An attempt has been made to study the effect of water depth on the internal heat and mass transfer in a single basin single slope plastic solar still. The experimental still was fabricated from Plexiglas. The bottom and all sides of the still are made from a sheet of black Plexiglas (3 mm thick). The cover is made from a transparent Plexiglas of the same thickness. The solar still was sealed to reduce the leakage of vapour to the surroundings.

The maximum distillate output of 2.1 L/m^2/day was obtained with water depth in still basin 2 cm. The maximum efficiency of the experimental still varies from 10% to 34%. The results indicated that with increase in depth of basin water, still productivity decreases.

2.4 Double Effect Solar Stills

Double effect solar still contains two storey water basins. It increases the total distillate output and also improves overall efficiency. The latent heat of water vapour from first basin is utilized by water in second basin

Dutt D. K. et. al (1993) [10] Simple transient analysis of a solar still is presented incorporating the effect of water flowing over the glass cover. An idea of utilizing the evaporated mass of the water flowing over the glass cover has been suggested and investigated. The effects of other system parameters, like addition of dye, basin water mass and basin liner absorptivity, have also been studied.

It is observed that the flow of water over the glass cover enhances the still productivity remarkably and also flowing water at a very low rate and collection of condensed vapour is always advisable to obtain comparably much more distillate output.

Hilal Al-H. al (2002) [11] This paper reports the use of two mathematical models to compare the productivity of single-effect and double effect solar stills under different climatic, design and operationa1 parameters in Oman. The shallow water basin, 23^o cover tilt angle, 0.1m insulation thickness, and asphalt coating of the solar still were found to be the optimum design parameters that produced an average annual solar still yield of 4.15 $kg/m^2/d$ and 6 $kg/m^2/d$ for single and double effect solar stills, respectively.

It has been found that the unit cost for distilled water using an array of single-effect solar stills is \$ 74/1000 gal (16.3 $\$/m^3$) or \$62.411000 gal (13.7 $\$/m^3$) when using a double-effect solar still. The cost saving is 15.7%.

Rajaseenivasan T. et. al (2013) [12] In a simple horizontal or inclined basin type solar still, the basin receive solar radiation through the Transparent cover, heats the water to evaporate, hot saturated air rises, vapour condenses at the cool lower surface of the glass cover, slides down and is collected using a drain. In a single effect still, the latent heat of condensation is exhausted as waste. In multi-effect still, the heat of condensation of the previous effect is utilized in then effect to heather water. This article reviews the different methods tried by different researches to improve the productivity of multi-effect solar still**.**

Zerouala M. (2011) [13] This investigation presents an experimental study using a double slope solar still. This choice is justified firstly by the abundance and low price of solar energy, and by the simplicity of installation and easy maintenance of these devices. The main aim of the present work has been to enhance the yield of the still by improving the performance of its condenser. This was achieved by cooling its outer surface.

This investigation presents an experimental study using a double slope solar still. The main aim of the present work has been to enhance the yield of the still by improving the performance of its condenser. This was achieved by cooling its outer surface.

2.5 Effect of Water Film Flowing Over Glass

Solar still distillate output can be increased by increasing the condensation of vapour. Water film flown over glass takes the latent heat and finally increases the productivity.

Qahtan A. et. al (2014) [14] the study has experimentally and numerically investigated the potential of a Sustainable Glazed Water Film as a low cost alternative to the use of expensive spectrally selective glazing for buildings in the tropics. The study concluded that the Sustainable Glazed Water Film is appropriate in improving thermal and visual comfort and reducing the cooling loads for glazed buildings in the tropics.

Arunkumar T. et. al (2013) [15] This work reports an innovative design of tubular solar still with a rectangular basin for water desalination with flowing water and air over the cover. The daily distillate output of the system is increased by lowering the temperature of water flowing over it. The water production rate with no cooling flow was 2050 ml/day (410 ml/trough). However, with cooling air flow, production increased to 3050 ml/day, and with cooling water flow, it further increased to 5000 ml/day.

Janarthanana B. et. al (2006) [16] A simple transient performance of floating cum tilted-wick type solar still has been presented by incorporating the effects of water flowing over a glass cover, heat capacity of tilted-wick water surface and floating-wick water surface. The following conclusions have been drawn: (i) glass cover temperature decreases significantly; (ii) the effect of water flowing over the glass cover has a fascinating effect on the production of distillate output during peak sunny hours; (iii) water flow rate of 1.5 m/s is optimum, and beyond it the efficiency decreases.

Zurigat Y. H. et.al (2004) [17] In this paper, a regenerative solar desalination unit is modeled and its performance evaluated. The unit consists of two basins (effects), with provision for cooling water to flow in and out of the second effect. This arrangement has the advantages of increasing the temperature difference between water and glass cover in the first effect and utilizes the latent heat of water vapor condensing on the glass of the first effect to produce more fresh water in the second effect. The results of the simulations show that the productivity of the regenerative still is 20% higher compared to the conventional still.

Ziabari F. B. et. al (2013) [18] In this study 1 month daily-based experimental data from a solar still site has been reported. Then a detailed analysis is investigated on progress of a prototype which constructed in order to solve the site‘s problems. The model results and experimental data show a significant increase in the fresh water production in compare with the initial site‘s stills.

2.6 Conclusion from Literature Review

Following are the observations on the basis of literature study

- Use the multi effect solar still instead of single-effect still.
- The yield is increased by flowing of water over the upper glass of the multi basin still .
- The flat plate collector should be disconnected during off sunshine hours to reduce the heat loss through collector .
- Multi effect wick stills are produced more the yield than basin still during sunshine hours and reverse in the case of night.
- Providing additional area for condensation increases the condensation rate as well increases the evaporation rate in basin .

- After sunset, the PCM acts as a heat source for the basin water until the early morning of the next day.

- The daylight productivity Pdl is found to decrease slightly with increasing the m mpcm; but, the overnight P and daily P_d productivities are significantly increasing with increasing mass of PCM.

- On a summer day, the daily productivity of the still is found to be 9.005 (kg/m^2 day) with the daily efficiency of 84.3% on using 3.3 cm of stearic acid under the still absorber compared to 4.998 (kg/m^2 day) when the still is used without PCM.

Chapter 3

Working principle and Energy Balance

Theoretical study of our experimental solar still was done developed by writing the energy balance equation. Since the performance of solar still is affected by the different parameter such as isolation, ambient temperature and dimensions of still therefore following assumption were made while writing the equations.

i. Solar still is vapor leak proof.

ii. The heat capacity of the transparent cover absorbing material and insulation is negligible.

This internal heat transfer in the solar still from basin water to the condensing cover can take place by three modes of heat transfer convection radiation and evaporation.

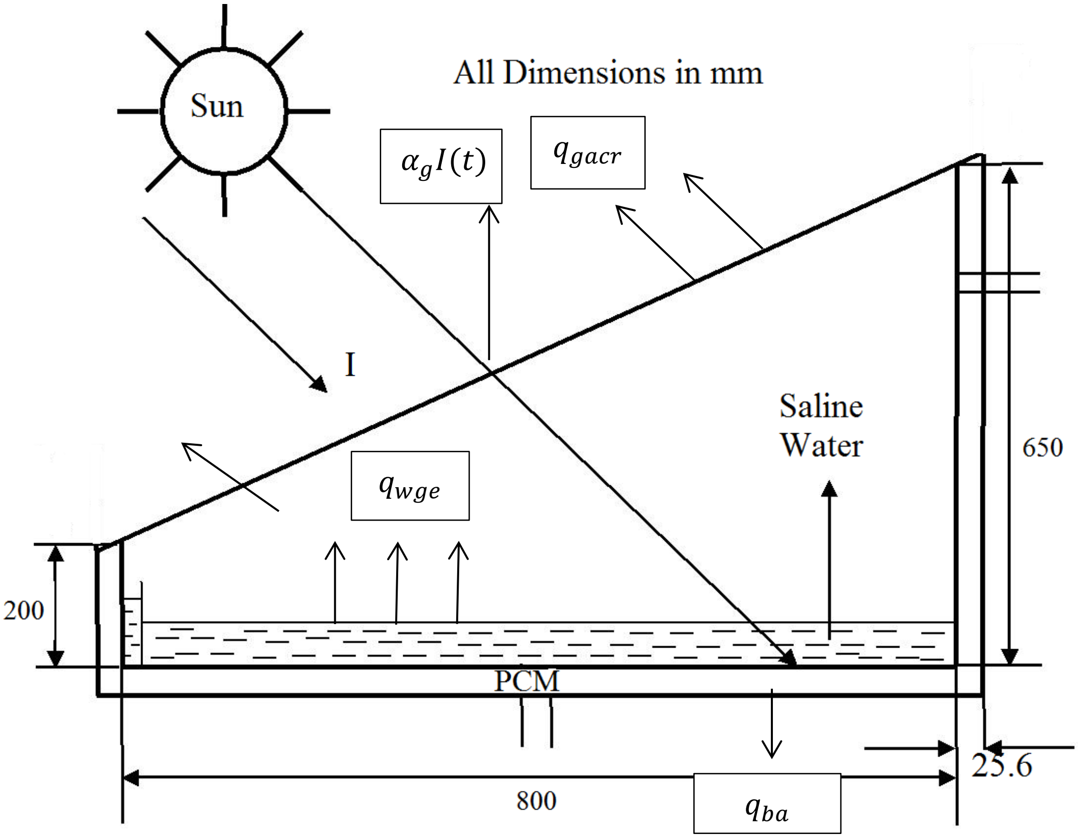


Figure 3.1 Schematic diagram of a single slope solar still

A schematic diagram of conventional single slope solar still is given in figure 3.1. it shows the different components of energy balance and thermal losses.

q_{ba} = Rate of heat loss from basin to ambient.

q_{gac} = Convective heat transfer rate from glass to ambient.

q_{wgr} = Radioactive heat transfer rate from water to glass.

q_{gar} = Radioactive heat transfer from glass to ambient.

q_{wgc} = Convective heat transfer from water to glass.

q_{wge} = Evaporation heat transfer rate from water to glass.

q_{bm} = Rate of heat loss from basin to water.

$\alpha_w I(t)$ = Absorptivity of water and solar radiation product.

$\alpha_g I(t)$ = Absorptivity of glass cover and solar radiation product.

$\alpha_b I(t)$ = Absorptivity of basin liner and solar radiation product.

3.1 Heat transfer equation

3.1.1 Convective heat transfer

Heat transfer inside the still take place by free convection. This is because of the action of buoyancy force due to the variation in density of humid fluid that occurs on account of temperature difference in the fluid. The rate of heat transfer from the basin water surface to condensing glass cover can be estimated by:

$$q_{cw} = h_{cw}(T_w - T_g)$$

The coefficient h_{cw} can be found out from the following equation

$$h_{cw} = 0.884\left[\left(T_w - T_g\right) + \left(P_w - P_g\right)(T_w + 273)/(268.9x10^3 - P_w)\right]^{\frac{1}{3}}$$

3.1.2 Radioactive heat transfer

For a small cover inclination and large width of the still the water surface and cover are considered as infinite parallel surfaces.

The rate of radioactive heat transfer from water surface to the glass cover is given by

$$q_{rw} = h_{rw}(T_w - T_g)$$

The irradiative heat transfer coefficient is given by

$$h_{rw} = \epsilon_{eff}\sigma\left[(T_w + 273)2 + \left(T_g + 273\right)2\right]\left[T_w + T_g + 546\right]$$

$$\varepsilon_{eff} = \left[\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - l\right]^{-1}$$

$$\varepsilon_g = \varepsilon_w = 0.9$$

3.1.3 Evaporative heat transfer

The rate of heat transfer per unit area from the water surface to the glass cover can be obtained by:

$$q_{rw} = h_{rw}\left(T_w - T_g\right)$$

The evaporative heat transfer coefficient is given by:

$$h_{ew} = 16.273x10^{-3}h_{cw}\left(P_w - P_g/\left(T_w - t_g\right)\right)$$

The total inner heat transfer coefficient from the water surface to the condensing cover is given by:

$$h_{lw} = h_{cw} + h_{rw} + h_{ew}$$

3.2 Energy balance

The heat flux at various still elements is as in figure 3.1. The energy balance equation for various still elements can be written with the following assumption :

1. The solar still is vapour leak proof.

2. The heat capacity of the transparent cover, absorbing material and insulations are negligible.

The energy balance for different component of solar still is as follow:

Energy balance for the cover:

$$\alpha_g I(t) + (q_{rw} + q_{cw} + q_{ew}) = q_{rg} + q_{cg}$$

Energy balance for basin water:

$$\alpha_w I(t) + q_w = (MC_w)\frac{t_w}{dt} + q_{rw} + q_{cw} + q_{ew}$$

Energy balance for basin:

$$\alpha_b I(t) = q_w + [q_{cb} + q_s(A_{ss}/A_s)]$$

Heat transfer coefficient:

$$h_{lg} = 5.7 + 3.8\,V$$

Heat is lost from the water in the basin to the ambient through the insulation and subsequently by convection and radiation from the bottom or side surface of basin.

- The bottom loss coefficient:

$$U_b = [1/h_w + 1/(k_i/L_i) + 1/(h_{cb}/h_{rb})]^{-1}$$

- The top loss coefficient:

$$U_t = \left[1/h_{lg} + 1/h_{lw}\right]^{-1}$$

- Overall loss coefficient:

$$U_l = U_t + U_b$$

$$q_{loss} = U_l(T_w - T_a)$$

- The hourly yield is calculated as

$$M_{ew} = (q_{ew}/L) * 3600 = \left[\frac{h_{ew}(T_w - T_g)}{L}\right] x3600$$

- The efficiency of still is as:

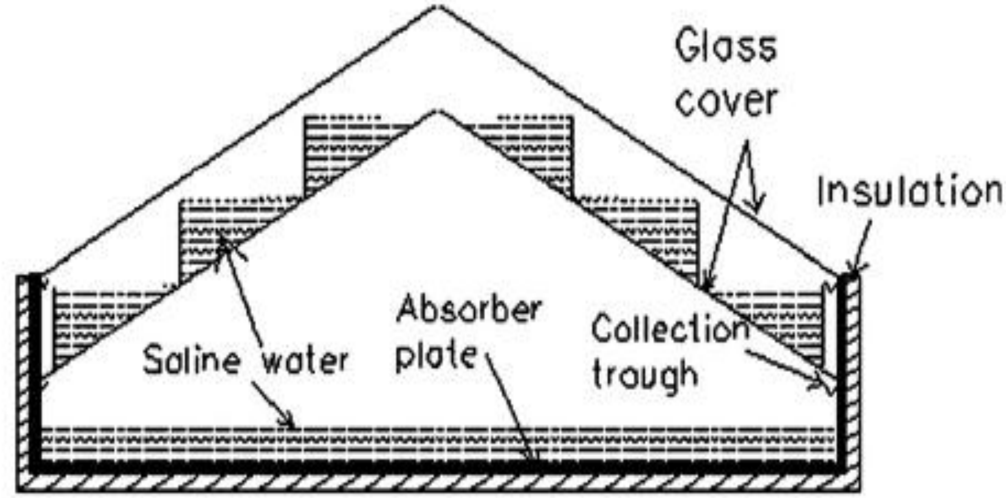
$$\eta = m_{evap}\, L/(I_{av}A)$$

3.3 Working principle

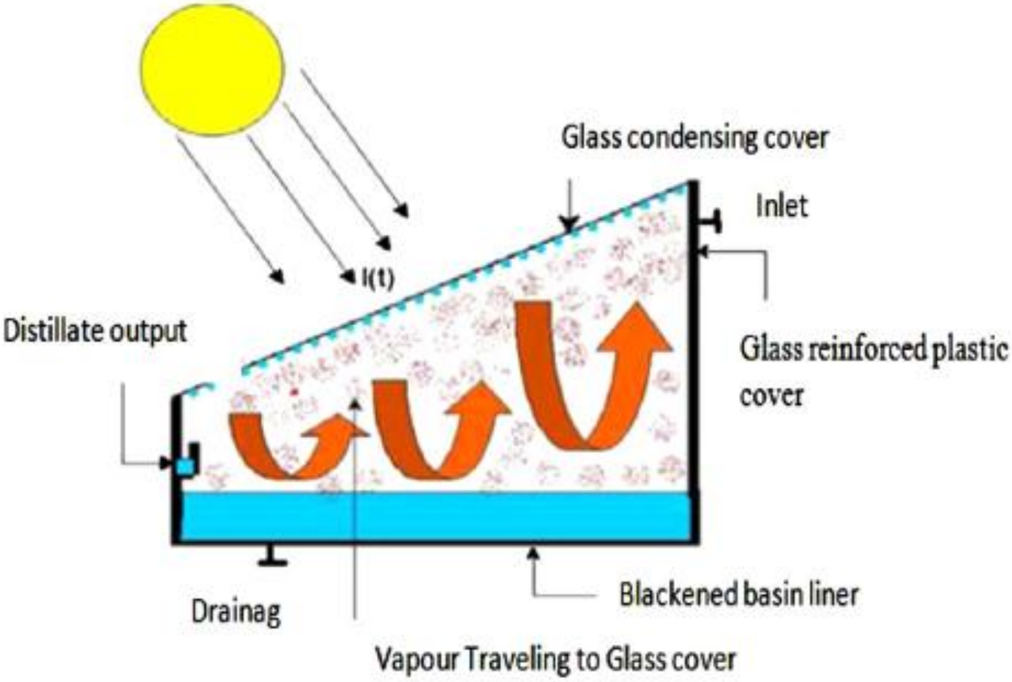
Solar still consists of air tight basin, usually made of metal. We used galvanized iron sheet (GI-sheet) to make the solar still basin and paraffin wax tray with Top cover having transparent material like Glass or plastic sheet. The inner surface of solar still painted black to absorb solar radiations in effective manner. Collecting tray is used to collect the distillate output which is further collected into a beaker. The brackish water is fed into the basin with the help of a pipe to get the potable water as shown in Fig. 3.2.

Solar still works on a principle that is similar to hydrological cycle of evaporation and condensation. When solar radiation incident over the glass cover after reflection and absorption by the glass cover, the solar radiation is transmitted inside the air tight basin where part of it is absorbed, transmitted and reflected by water mass. Finally solar radiation reaches to blackened surface where it is mostly absorbed. Due to this brackish water is heat up and starts evaporation. Salt and microbes which are present in the water exerts no vapour pressure because of that salt is left behind and water is taken away. Due to release of latent heat the water that is evaporates gets condensed on the inner surface of the glass cover. Due to gravity effect the condensed water comes down to collecting tray attached at lower end of glass cover and taken out through pipe in a graduated cylinder.

The paraffin wax tray below the water basin work as a thermal storage medium. In the day time paraffin wax absorbed the heat and goes into the phase change. At night melted wax discharge the latent heat to heat up the water. Due to this productivity at the night time increases.



(a) Double Slope solar still



(b) Single slope solar still

Figure: 3.2 Schematic of (a) Double Slope solar still (b) Single slope solar still

Chapter4

Fabrication and Design of experimental setup

4.1 Major Components of Solar Still

4.1.1 Double Walled GI Sheet Basin

The solar still basin contains the Saline water on which distillation takes place. Solar still is made leakage proof by water tight and in order to absorb the incident solar radiation the surface at bottom is blackened. The resistance of basin liner should be high for hot saline water, and also solar radiation absorption should be high. The conduction loss is reduced by insulating bottom and the sides of the basin. Galvanized Iron sheet(GI-sheet) are used in construction of basin.

Basin is made up of double wall of GI-sheet (24 gauge i.e. of 0.511mm) with base area of 0.98x1.08m^2. A 0.15m height GI sheet cover is there above basin of solar still surrounds the glass Thermocol having thickness of one inch is used between the walls to reduce the conduction losses from bottom and side walls of solar still. In order to increase the absorptivity of solar radiation the basin and side walls of solar still are painted black.

The outlet through distillate channel is collected at the base of glass cover, due to gravity effect. We can pour the saline water to the basin at the inlet. The stopper is used to tighten the inlet to avoid the escaping of vapour.

4.1.2 Glass Cover

The glazing cover for solar still is important component after basin. It should allow maximum solar radiation transmission in order to increase water temperature. However, it must be wettable. Wet ability means the water droplets should not form and the vapour condense in form of film of water inside the glass cover. The performance is reduced if vapours form droplets due reasons given below.

- Water droplets act as small mirrors and reflect the solar radiations and amount of heat enter through glass is reduced.

- Some droplets on the inner side of glass cover will fall back into the basin instead of collected at bottom of glass cover.
- The cost of the material, its weight, life expectancy, local availability, maximum temperature tolerance and impact resistance as well as its ability to transmit solar energy and infrared light are important factors to determine the suitability of glazing material.

In our experimental setup i.e. single slope solar still ordinary transparent glass was used having thickness of 5 mm. The glass transmissivity is maximum approximately 80%. Inclination of the glass is kept 26^0 because the latitude of Jaipur is 26^0. Foam is used to seal glass cover in order make the basin leak proof, finally this makes efficient operation of solar still.

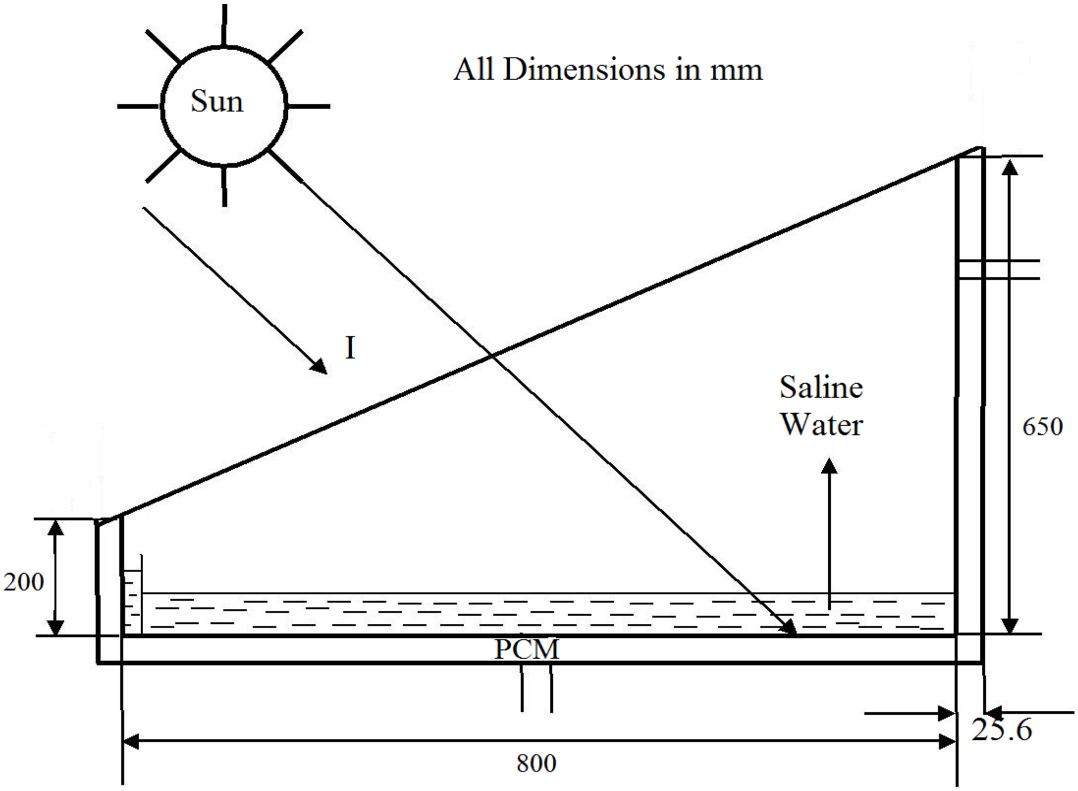


Figure: 4.1 Schematic of Experimental Setup and its Dimensions

4.1.3 Thermocouples

When two dissimilar metals wires are joined at both ends and one of the ends is heated, there are continuous current flows in the thermoelectric circuit. Sir Thomas Seebeck discovered this in 1821. There are several types of thermocouples for different temperature ranges

In our experimental setup of solar still there is five T-types (copper-constantan) thermocouples are connected to measure the temperature at different locations.

Thermocouple no. 1 is used to measure PCM temperature. Thermocouple no. 2 is dipped into the water to measure basin water temperature. Thermocouple no. 3 and 4 are placed at the upper and lower surface of the glass. Thermocouple no. 5 is stick at the bottom of basin to measure the heat loss.

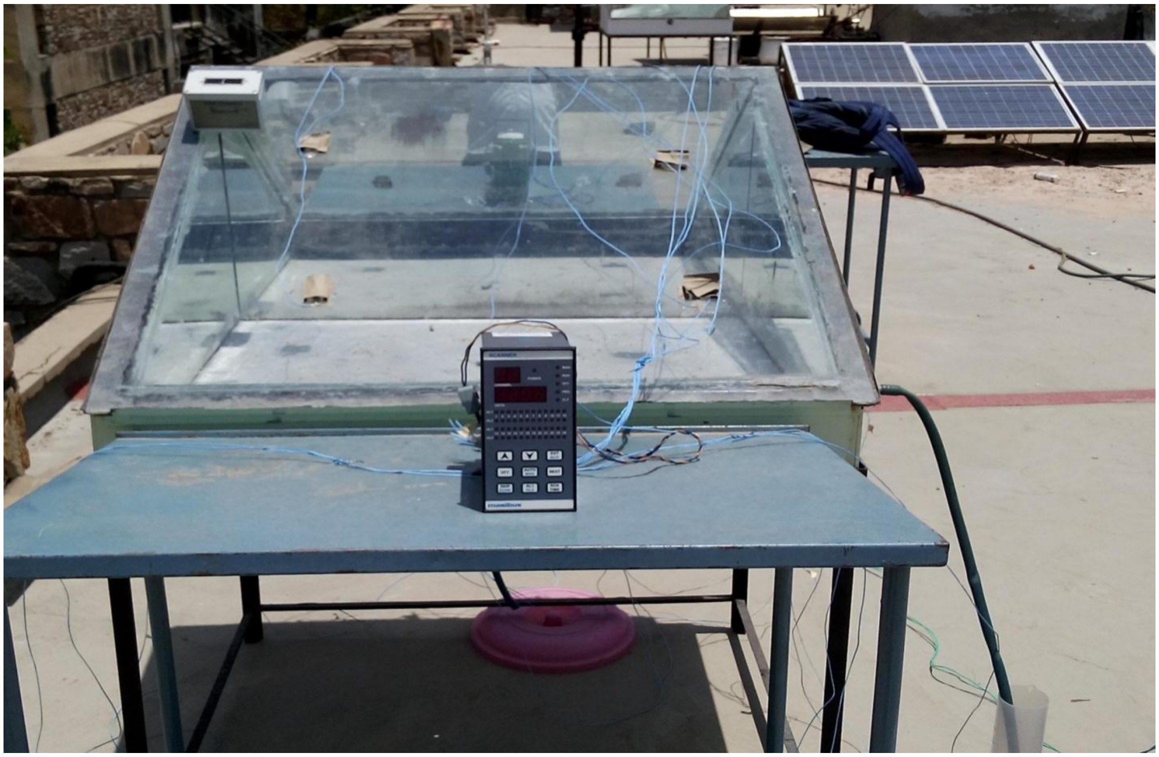


Fig. 4.2 Image of Experimental Setup

4.1.4 Ancillary Components of Solar Still

Ancillary components are there with the main components. In our experimental setup mirror is also used. The mirrors are attached on inner side walls are very useful, because the mirror can reflects the scattered rays of the incident solar radiation enter into glass to the basin water and solar radiations are utilized in a efficient manner.

A Solarimeter is used to measure the irradiation falling on the glass. A 6 channel temperature indicator is used to take reading of thermocouples.

4.2 Orientation of Solar Still

Sun is on the top of that location for a particular location at solar noon. At solar noon solar azimuth angle is 180^0 from the north (i.e. south). So the orientation of solar still is fixed such that it is facing south. And south direction can be measured using a compass.

4.3 Instruments used

Figure: 4.3 Digital Temperature Indicator

The digital temperature indicator is attached for the measurement of water and glass cover temperatures. Cold junction compensator is in built in the instrument and unlike thermocouples wires directly connected to the binding posts of the instrument. The least count of the meter is 1°C. This indicator is connected to a selector which has six channels and a knob, which can be rotated to select a particular channel for temperature measurement.

4.3.1 Solarimeter

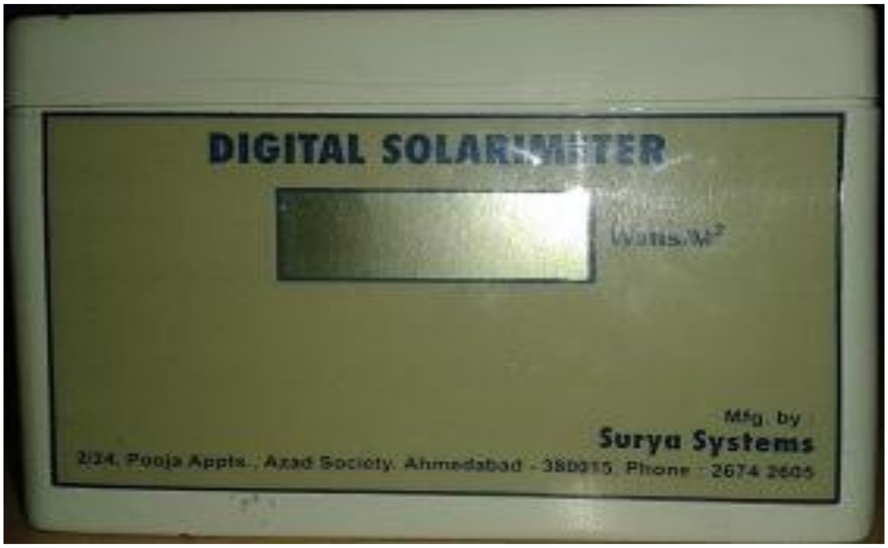


Figure: 4.4 Digital Solarimeter

Solarimeter was used to measure the global solar radiations received from the entire hemisphere on an inclined surface to record the solar intensity. It works on the principle that sensitive is open to solar radiation. The sensitive surface consists of a rectangular photo sensor. When light falls on this photo sensor it is directly converted into solar radiations. The solarimeter gives total radiation directly in watts per meter square.

4.4 Calibration of Thermocouples

A thermocouple is made of two dissimilar electric conductors which are joined at one end called hot junction and another end is attach to the voltmeter (Temperature Indicator) called cold junction. And Hot junction can be prepared in common practice by welding, soldering or simply by twisting the two dissimilar electric conductors to make good electric connection. The output of thermocouple reading is voltage (Seebeck voltage) which is directly proportional to temperature difference of the junctions.

There are two common approaches for measuring temperature using thermocouple circuit. In first one put the cold junction into the ice bath to maintain the known temperature i.e. 0°C because voltmeter reading (i.e. Seebeck voltage) will be directly proportional to temperature difference of the junctions. This says that we can't find the temperature of the hot junction unless we first find the temperature of cold junction.

In second approach measure the temperature of cold junction point by using a temperature sensor like an RTD, a Thermistor, or an integrated circuit sensor which is automatically controlled by the software of the temperature indicator. Even some temperature sensor having its own error and it not gives the actual value of the cold junction temperature because of that there is an error creates in the temperature of hot junction. This error is called cold junction compensation error.

Thermocouples need to be calibrated for errors. Three point calibrations were done. First point is ice point i.e. 0°C obtained in the mixture of ice and water in an insulated thermos flask. Second point is room temperature 28.9 and third point is steam point i.e. 98°C which is the function of pressure.

For all three points i.e. ice point, room temperature, and steam point are to be measured using temperature indicator having resolution 1°C. All the readings are shown in the Table 4.1 are to be measured in °C and Figure 4.6 and 4.7 show the variation of actual temperature according to observed temperature and also show the trends of variation.

Table 4.1. Calibration of T-Type Thermocouples (All temperature are in °C)

Diff. points	T_{actual}	T_1	T_2	T_3	T_4
Ice temp.	0.00	2.1	2.3	3.1	2.5
Room temp.	28.9	31.0	27.2	30.8	27.5
Stem point	98.0	99.8	98.7	99.8	99.2

Figure: 4.5 Thermocouples calibration

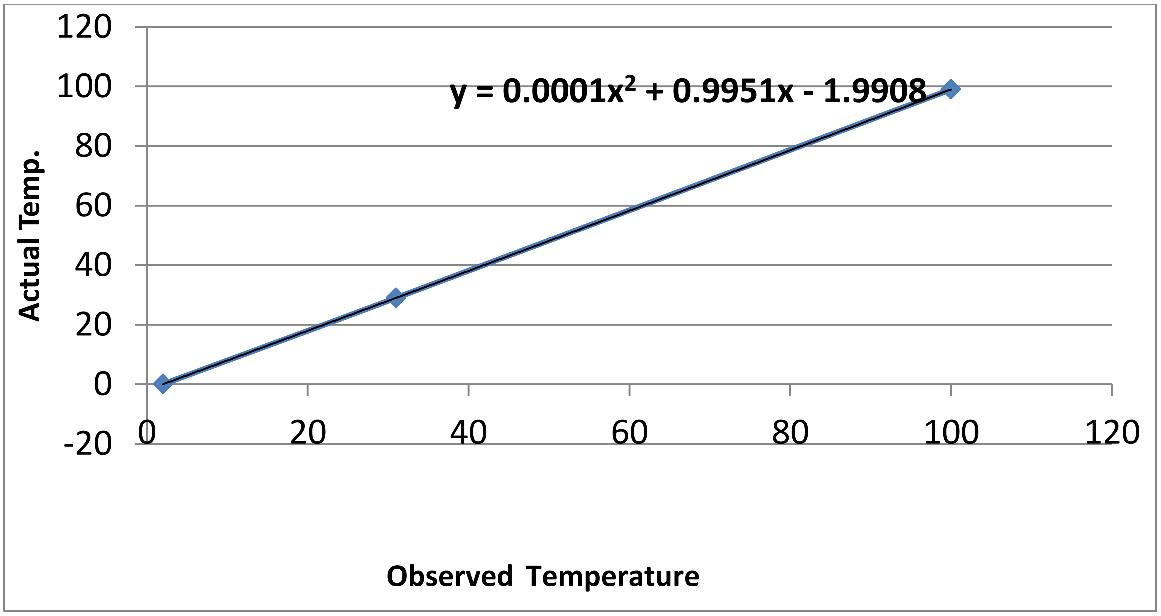


Figure: 4.6 Variation of actual temp.to Observed temperature T_1

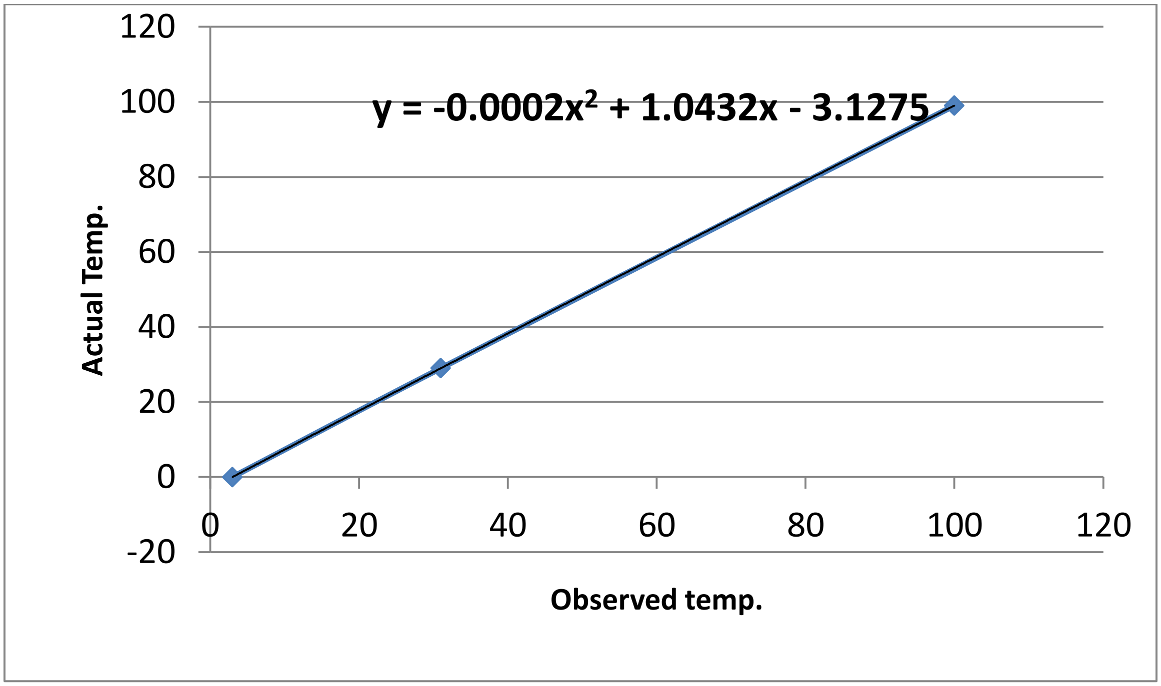


Figure: 4.7 variation of Actual temp.to observed temp. T_3

According to Figure 4.6 and 4.7 we can see how actual temperature varies with observed temperature i.e. linear variation.

Chapter5

Experimentation

5.1 Experimental Procedure

The solar still was instrumented with T-type of thermocouple connected to a 6 channel temperature digital indicator. the temperature readings were taken at the following points water to be distilled

- Phase change material (paraffin wax) temperature.
- The water temperature.
- The lower surface of glass (condensing cover) temperature.
- The glass upper surface temperature.
- The bottom surface of solar still.

Thermocouple is immersed into the paraffin wax to measure the temperature. The global incident solar radiation were measured by placing the solarimeter along the plane of the glass cover with sensor facing directly the sun. the amount of water distillate was measure by graduated cylinders. The readings were taken for 10,15 and 20 liter water quantity. Water was filled daily to maintain the certain depth. Before starting the experiment, Glass of still was cleaned properly. For hourly readings following steps are taken

1. Glass upper and lower surface, PCM and water temperature were measured.
2. Solar intensity was measured.
3. Distillate output was measured.

5.2 Observations

A total of 10 sets of readings were done from 21 April to 2 may 2015. By changing the various depth of water which affect efficiency of the solar still with PCM and without PCM. Experimental data are taken and feed into the tabular form. Graphs are plotted to make better understanding of results.

Nomenclature used in the observation tables:

T_{PCM}= PCM temperature

T_W = Basin water temperature

T_b=Temperature of bottom of solar still

Overall efficiency of solar still has been calculated as

Energy input: $E_i = \int_0^{24\ hrs} IAdt$

Distillate Output (in terms of energy): $E_0 = m * h_{vap}$

Overall Efficiency: $\eta = \frac{E_0}{E_i} x\ 100\%$

Where, A= Aperture area in m^2

m = mass of water condensed in one day in kg,

L = Latent heat of Vaporization of water (i.e. 2373.2kJ/kg)

Table 5.1 Observation table for with PCM and without PCM for 20 liter water (21-4-2015)

			DATE: 21/04/15											
SOLAR STILL WITH PCM										**SOLAR STILL WITHOUT PCM**				
TIME	**Tpcm**	**Tw**	**T_g (u.s)**	**$T_{g(L.S)}$**	**T_b**	**Area (m^2)**	**I (W/m^2)**	**Energy input(J)**	**Output (ml)**	**T_w**	**output**	**I**	**Energy input(J)**	**Avg.**
9:00	45.9	49.8	47.4	50.1	35.2	0.8544	310	476755.2	10	35.8	10	310	476755.2	310
10:00	53.1	52.3	50.8	53.1	36.4	0.8544	450	1168819.2	40	44.8	30	677	1517927.0	760
11:00	54.8	62.2	59.1	61.2	44.6	0.8544	630	1660953.6	100	53.7	100	685	2094647.0	1080
12:00	56.9	69.1	59.6	67.8	46.8	0.8544	720	2076192.0	200	61.7	220	785	2260742.4	1350
13:00	56.8	74.5	63.3	73.1	48.9	0.8544	780	2306880.0	320	69.6	290	804	2443754.9	1500
14:00	60.1	75.5	65.9	74.9	49.2	0.8544	760	2368396.8	470	70.6	450	740	2374548.5	1540
15:00	59.9	73.1	64.2	70.1	49.8	0.8544	578	2057736.9	370	69.7	430	600	2060812.8	1338
16:00	59.6	68.4	55.7	65.2	47.6	0.8544	430	1550223.3	360	64.7	420	475	1653264.0	1008
17:00	59.1	57.6	48.7	53.6	46.3	0.8544	250	1045785.6	310	58.6	300	254	1121143.7	680
18:00	58.9	53.3	46	50.1	46.1	0.8544	130	584409.6	180	51.7	230	98	541347.8	380
Day output									2360		2480			
Night output									780		440			
Total output									3140		2920			

SOLAR STILL WITH PCM				SOLAR STILL WITHOUT PCM		
	Total solar energy input	Total distillate output(ml)	Overall efficiency	Total solar energy input	Total distillate output	Overall efficiency
Day	15296152.32	2360	36.62	16544943.4	2480	35.6
Day Night	15296152.32	3140	48.72	16544943.4	2920	41.9

Table 5.2 Observation table for with PCM and without PCM for 20 liter water (22-04-2015)

			DATE 22/4/2015										
SOLAR STILL WITH PCM										**SOLAR STILL WITHOUT PCM**			
TIME	**T_{pcm}**	**TW**	**Tg (u.s)**	**Tg (L.S)**	**Tb**	**Area (m^2)**	**I(W/m^2)**	**Energy input(J)**	**output(ml)**	**output**	**I**	**Energy input(J)**	**Avg.**
9:00	44.6	51.6	50.8	51.9	37.4	0.8544	300	461376.0	30	0	435	668995.2	300
10:00	45.8	53.6	52.0	54.5	43.8	0.8544	460	1168819.2	60	30	598	1588671.4	760
11:00	54.9	61.5	59.1	62.4	45.9	0.8544	640	1691712.0	110	110	712	2014675.2	1100
12:00	57.2	72.9	66.4	72.7	46.2	0.8544	712	2079267.8	220	350	769	2277659.5	1352
13:00	57.8	76.1	67.2	75.5	48.1	0.8544	760	2263818.2	330	410	765	2359169.3	1472
14:00	60.4	76.7	67.4	76.2	49.9	0.8544	710	2260742.4	470	510	714	2274583.7	1470
15:00	60.1	76.3	65.4	75.5	50.4	0.8544	568	1965461.7	370	430	586	1999296.0	1278
16:00	59.2	70.0	60.2	67.2	47.7	0.8544	441	1551761.2	360	370	429	1560988.8	1009
17:00	58.6	61.1	52.1	57.7	47.2	0.8544	258	1075006.0	330	280	234	1019641.0	699
18:00	58.7	57.2	47.6	51.9	47.3	0.8544	78	516741.1	210	100	76	476755.2	336
Day output									2490	2590			
Night output									840	400			
Total output									3330	2990			

	SOLAR STILL WITH PCM			**SOLAR STILL WITHOUT PCM**		
	Total solar energy input	Total distillate output(ml)	Overall efficiency	Total solar energy input	Total distillate output	Overall efficiency
Day	15034705.92	2490	39.30	16240435.2	2590	37.85
Day Night	15034705.92	3330	52.56	16240435.2	2990	43.69

Table 5.3 Observation table for with PCM 15 liter water (23-04-2015)

DATE:23/4/15				**With 15 liter water**					
SOLAR STILL WITH PCM									
TIME	**Tpcm**	**T_w**	**T_g(u.s)**	**$T_{g(L.S)}$**	**T_b**	**Area (m^2)**	**I (W/m^2**	**Energy input(J)**	**output(ml)**
9:00	43.7	53.2	50.6	53.3	33.2	0.8544	315	484444.8	30
10:00	51	66.2	59.9	65.1	36.1	0.8544	433	1150364.16	50
11:00	55.4	73.9	67.2	73.7	40.4	0.8544	632	1637884.8	130
12:00	56.9	75.8	67.1	75.2	41.2	0.8544	742	2113102.08	240
13:00	56.5	75.9	67.4	75.4	41.6	0.8544	766	2319183.36	310
14:00	59.6	76.2	67.9	73.7	44.2	0.8544	745	2323797.12	460
15:00	64.4	72.6	66.8	67.9	47.4	0.8544	580	2037744	390
16:00	69.1	68.4	61.1	66.8	45.8	0.8544	426	1547147.52	370
17:00	65.2	56.2	55.8	55.4	44.2	0.8544	246	1033482.24	340
18:00	62.1	54.1	47.2	53.2	42.2	0.8544	102	535196.16	220
Day output									2540
Night output									890
Total output									3430

(with 20 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15034705.92	2490	39.30
Day Night	15034705.92	3330	**52.56**

(with 15 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15182346.24	2540	39.70
Day Night	15182346.24	3430	**53.62**

Table 5.4 Observation table for with PCM for 15 liter of water (24-04-2015)

DATE 24/4/2015				**WITH 15 LITER WATER**					
SOLAR STILL WITH PCM									
TIME	**Tpcm**	**T_W**	**T_g(u.s)**	**$T_{g(L.S)}$**	**T_b**	**Area (m^2)**	**I (W/m^2)**	**Energy input(J)**	**output(ml)**
9:00	46.5	52.2	50.8	52.2	40.1	0.8544	322	495210.24	10
10:00	53.1	60.1	59.1	53.1	44.6	0.8544	440	1171895.04	40
11:00	54.2	62.2	59.6	61.9	47.4	0.8544	638	1657877.76	140
12:00	55.8	69.2	63.3	67.8	48.2	0.8544	758	2146936.32	220
13:00	58.4	78.8	65.9	73.1	49.1	0.8544	771	2351479.68	330
14:00	60.2	75.5	64.2	74.9	49.4	0.8544	748	2336100.48	470
15:00	61.4	73.5	65.7	70.7	49.9	0.8544	586	2051585.28	370
16:00	60.1	68.4	58.7	65.1	46.6	0.8544	414	1537920	360
17:00	59.4	57.6	51.9	53.6	42.2	0.8544	248	1018103.04	340
18:00	58.2	56.3	46.7	52.4	41.1	0.8544	92	522892.8	230
Day output									2510
Night output									840
Total output									3350

(with 15 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15290000.64	2510	38.96
DayNight	15290000.64	3350	**52.00**

Table 5.5 Observation table for with PCMfor 10 liter water (19-05-2014)

25/4/15				**With 10 liter water**					
SOLAR STILL WITH PCM									
TIME	**Tpcm**	**T_w**	**T_g(u.s)**	**$T_{g(L.S)}$**	**T_b**	**Area (sq.m)**	**I (w/sq. m)**	**Energy input(j)**	**output(ml)**
9:00	43.7	53.2	48.2	54.2	45.1	0.8544	328	504437.76	40
10:00	51	58.9	49.1	56.2	45.7	0.8544	451	1198039.68	70
11:00	55.4	65.7	50.8	65.1	46.8	0.8544	624	1653264	140
12:00	56.9	73.6	56.6	73.4	49.2	0.8544	744	2103874.56	230
13:00	56.3	74.8	69.2	74.2	49.8	0.8544	781	2345328.00	310
14:00	59.4	77.1	67.4	75.6	50.9	0.8544	721	2309955.84	470
15:00	61.6	76.6	67.9	72.7	51.4	0.8544	608	2043895.68	410
16:00	59.3	69.2	67.4	67.9	50.8	0.8544	419	1579443.84	365
17:00	58.4	67.2	62.6	64.4	48.4	0.8544	231	999648.00	325
18:00	56.6	61.4	54.4	55.6	46.3	0.8544	105	516741.12	220
Day output									2580
Night output									900
Total output									3480

Table 5.6 Observation table showing comparison of efficiency with depth of water

(with 20 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15034705.92	2490	39.30
Day Night	15034705.92	3330	**52.56**

(with 15 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15182346.24	2540	39.70
Day Night	15182346.24	3430	**53.62**

(with 10 liter water)			
	Total solar energy input	Total distillate output(ml)	Overall efficiency
Day	15254628.48	2580	40.14
Day Night	15254628.48	3480	54.14

Table 5.7 Observation table solar still with PCM and with Sand

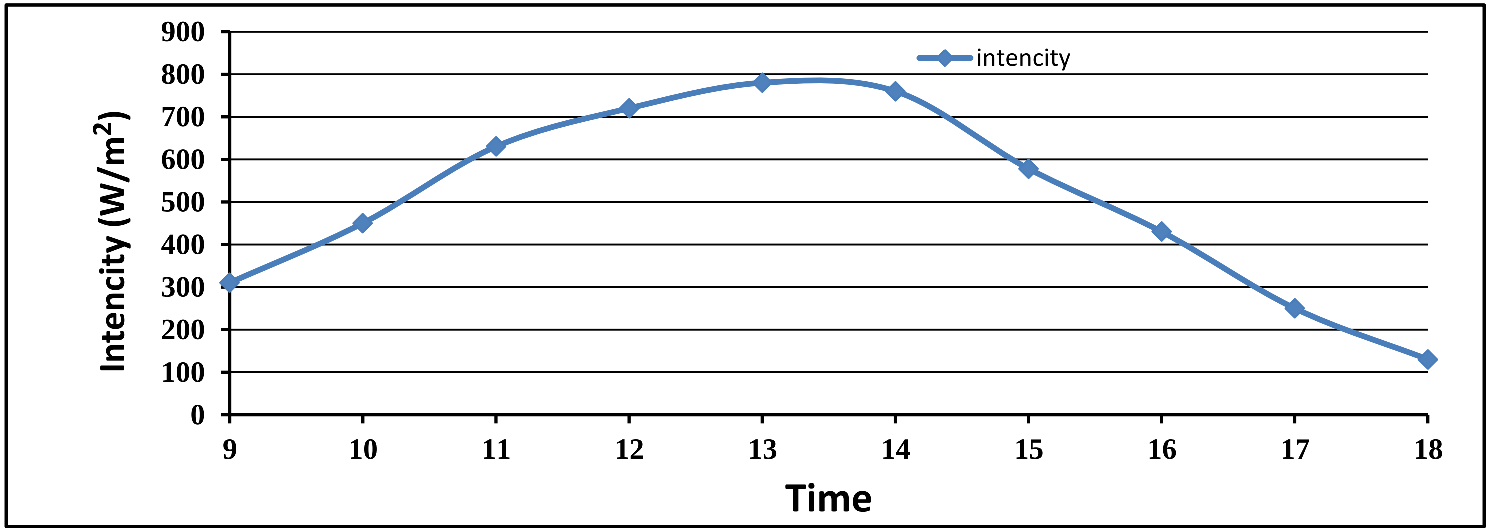
DATE 22/4/2015										19/5/2014				
SOLAR STILL WITH PCM										**solar still with sand**				
Time	**Tpcm**	**T_w**	**T_g (u.s)**	**T_g (L.S)**	**T_b**	**Area (m^2)**	**I (W/m^2)**	**Energy input(J)**	**Output (ml)**	**Ts**	**T_w**	**I (W/m^2)**	**Output (ml)**	**Energy input(J)**
9:00	44.6	51.6	50.8	51.9	37.4	0.8544	300	461376	30	32.2	31.8	408	0	627471.36
10:00	45.8	53.6	52.0	54.5	43.8	0.8544	460	1168819.2	60	39.8	41.7	575	20	1511775.4
11:00	54.9	61.5	59.1	62.4	45.9	0.8544	640	1691712	110	51.3	54.3	692	90	1948544.6
12:00	57.2	72.2	66.4	72.7	46.2	0.8544	712	2079267.8	220	60.3	63.4	765	300	2240749.4
13:00	57.8	76.1	67.2	75.5	48.1	0.8544	760	2263818.2	330	66.6	69.2	767	330	2356093.4
14:00	60.4	76.7	67.4	76.2	49.9	0.8544	710	2260742.4	470	69.1	70.4	715	420	2279197.4
15:00	60.1	75.3	65.4	75.5	50.4	0.8544	568	1965461.7	370	68.5	68	586	430	2000833.9
16:00	59.2	70	60.2	67.2	47.7	0.8544	441	1551761.2	360	66.1	64.5	442	350	1580981.8
17:00	58.6	61.1	52.1	57.7	47.2	0.8544	258	1075006.	330	64	60.4	245	260	1056551
18:00	58.7	57.2	47.6	51.9	47.3	0.8544	78	516741.12	210	60.9	55.4	80	270	499824
Day output									2490				2470	16102022.26
Night output									840				740	
Total output									3330				3210	

SOLAR STILL WITH PCM				SOLAR STILL WITH SAND		
	Total solar energy input	Total distillate output(ml)	Overall efficiency	Total solar energy input	Total distillate output	Overall efficiency
Day	15034705.92	2490	39.30	16102022.4	2470	36.40
Day Night	15034705.92	3330	52.56	16102022.4	3210	47.31

Graphs and Graphs

Graphs have been plotted between Solar radiation, distillate output and water temperature with respect to time on a 0-24 hrs scale. Graphs have been drawn for Distillate Output and Efficiency for different settings of efficiency enhancement parameters.

Figure: 5.1 Solar radiation v/s Time



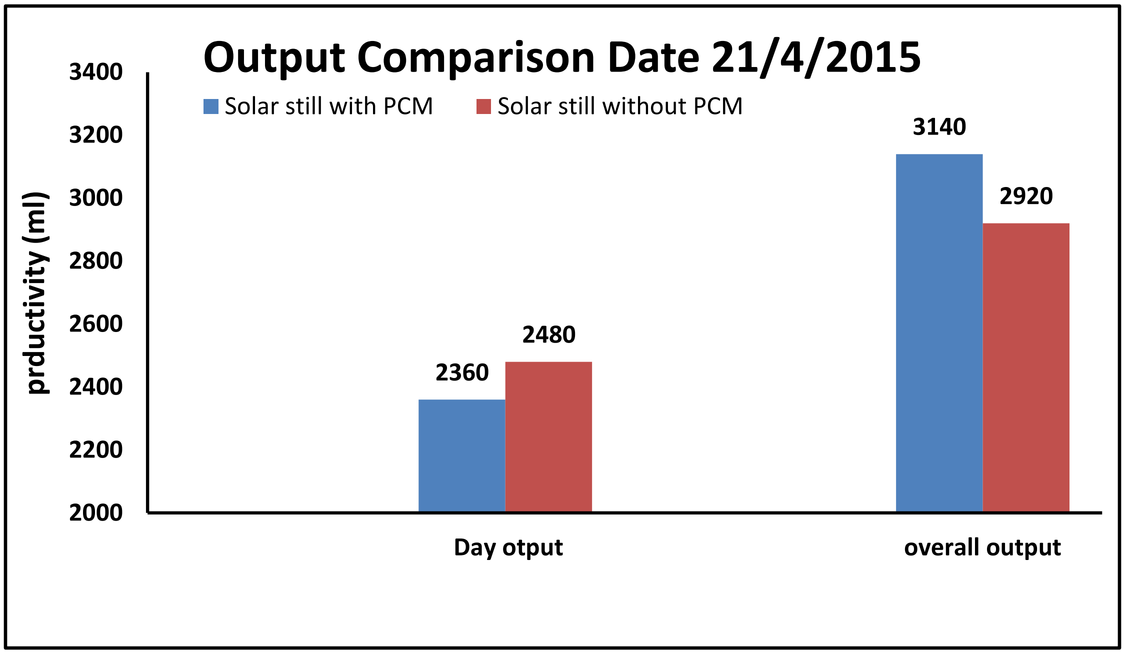


Figure :5.2 Output comparison on (21/4/2015)

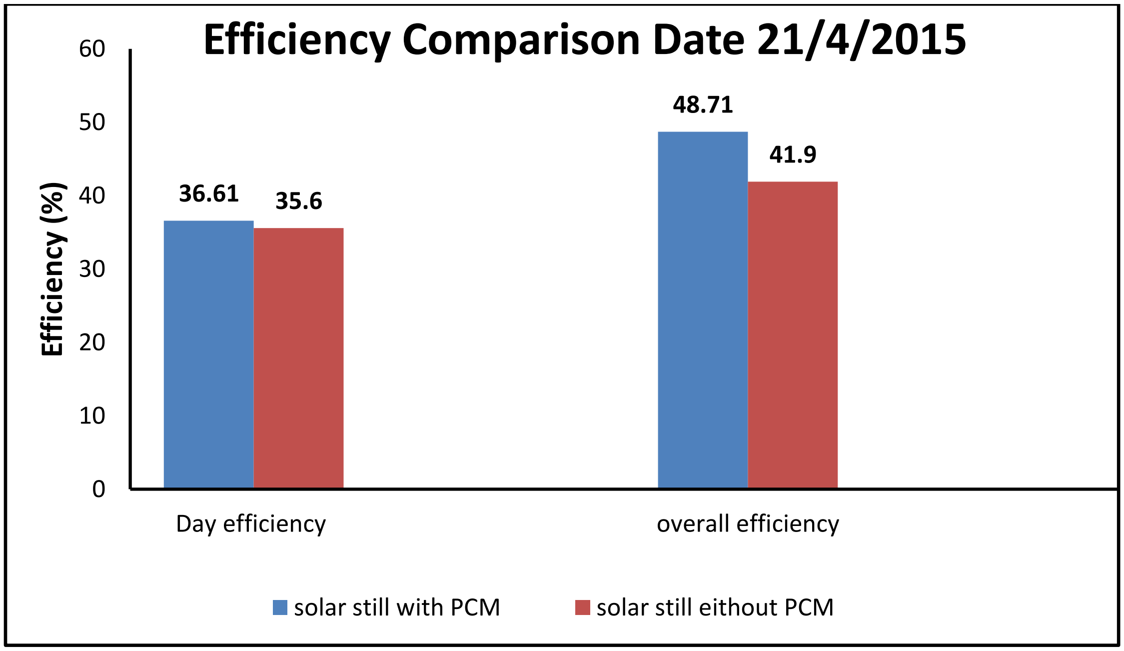


Figure:5.3 Efficiency comparison on (21/4/2015)

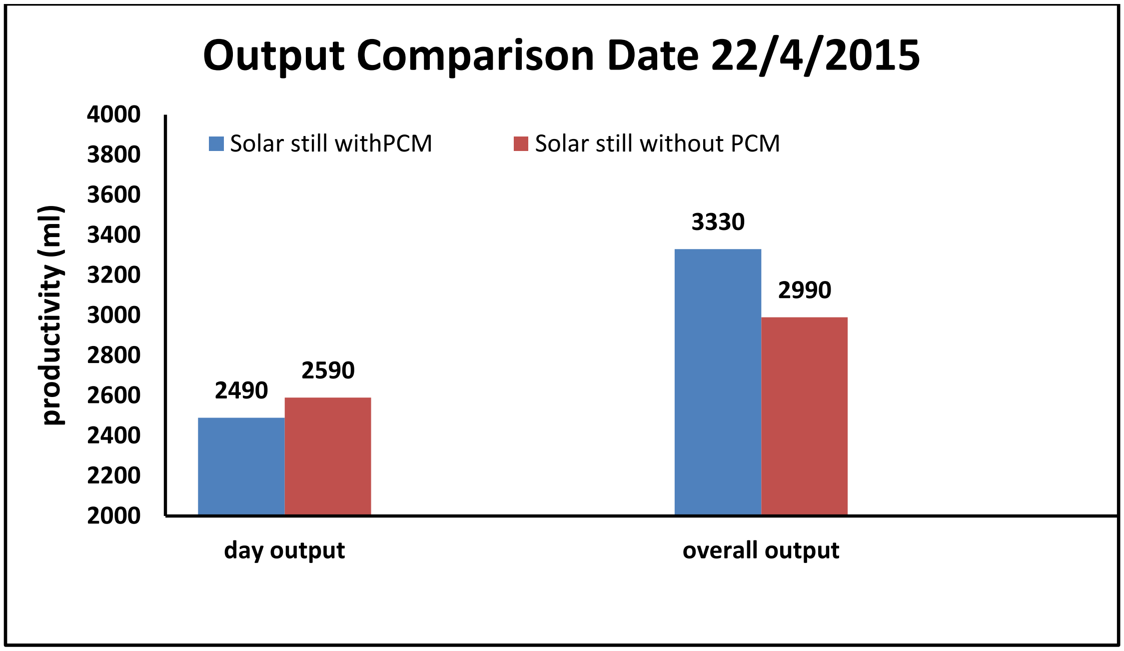


Figure:5.4 Output comparison on (22/4/2015)

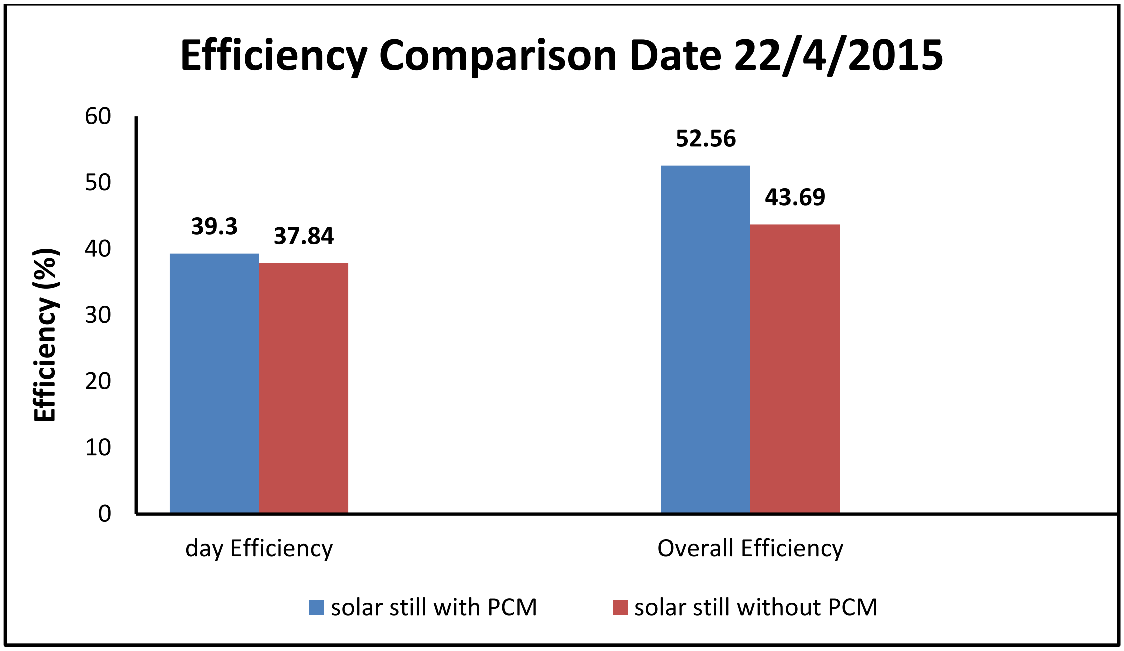


Figure:5.5 Efficiency comparison on (22/4/2015)

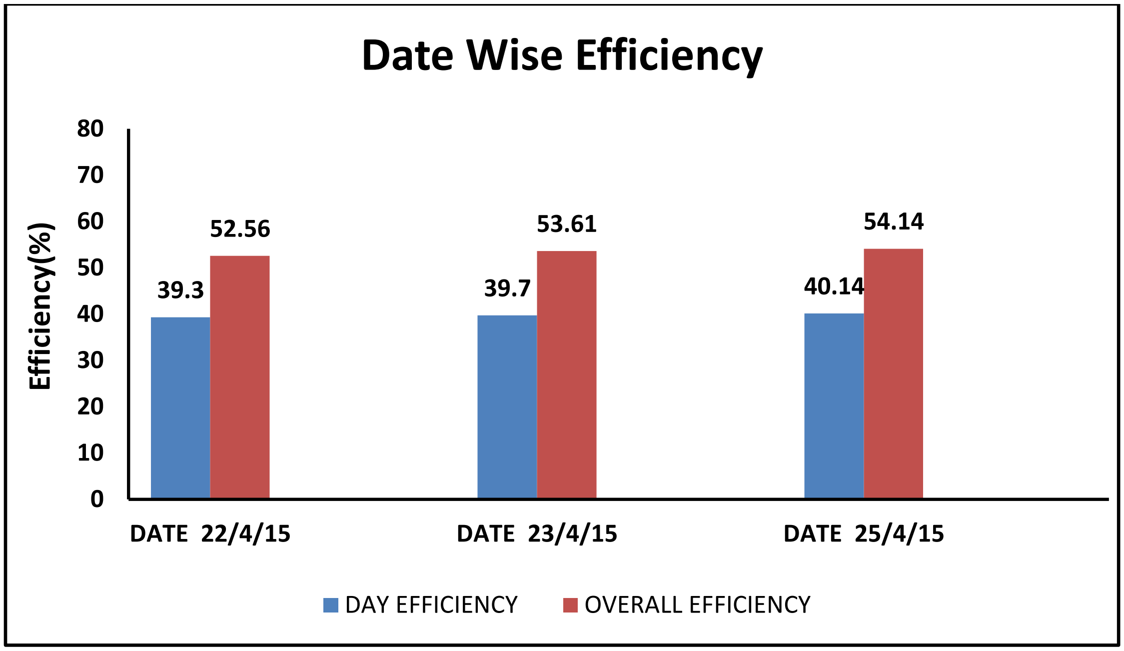


Figure:5.6 Date wise Efficiency comparison

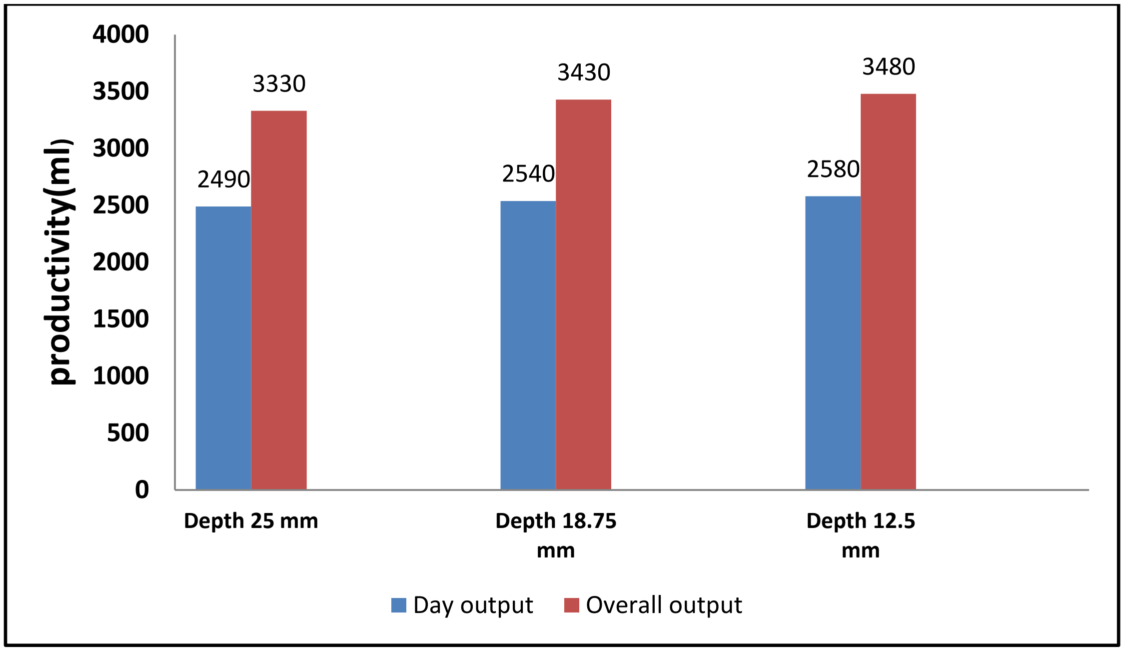


Figure:5.7 Output v/s Water depth

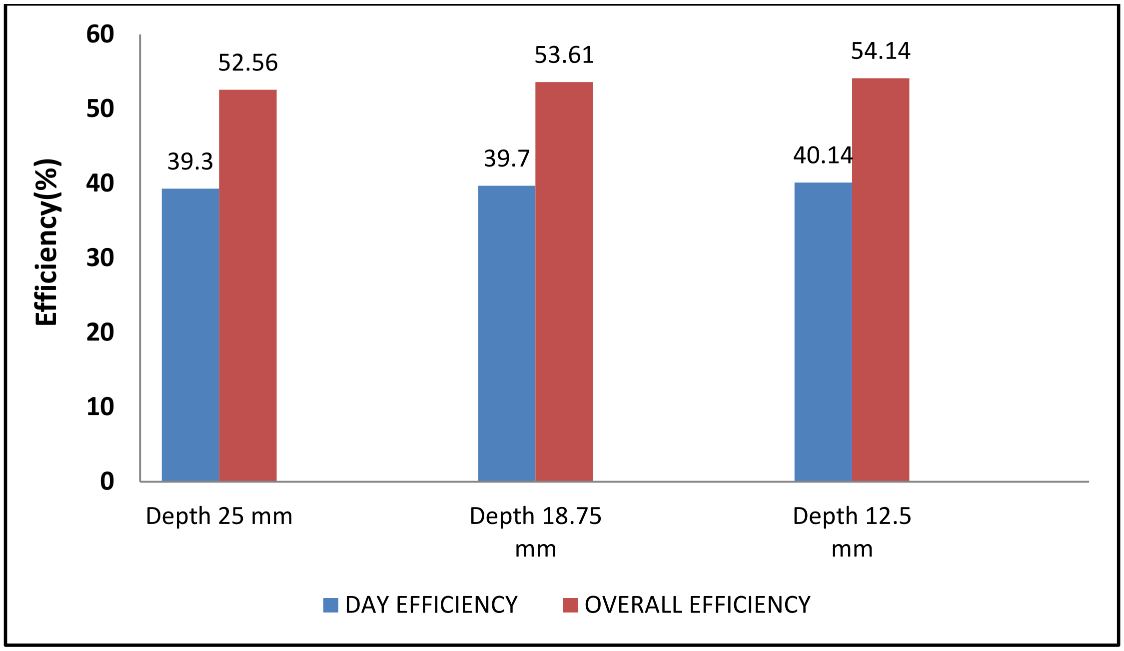


Figure:5.8(a) Efficiency v/s Water depth

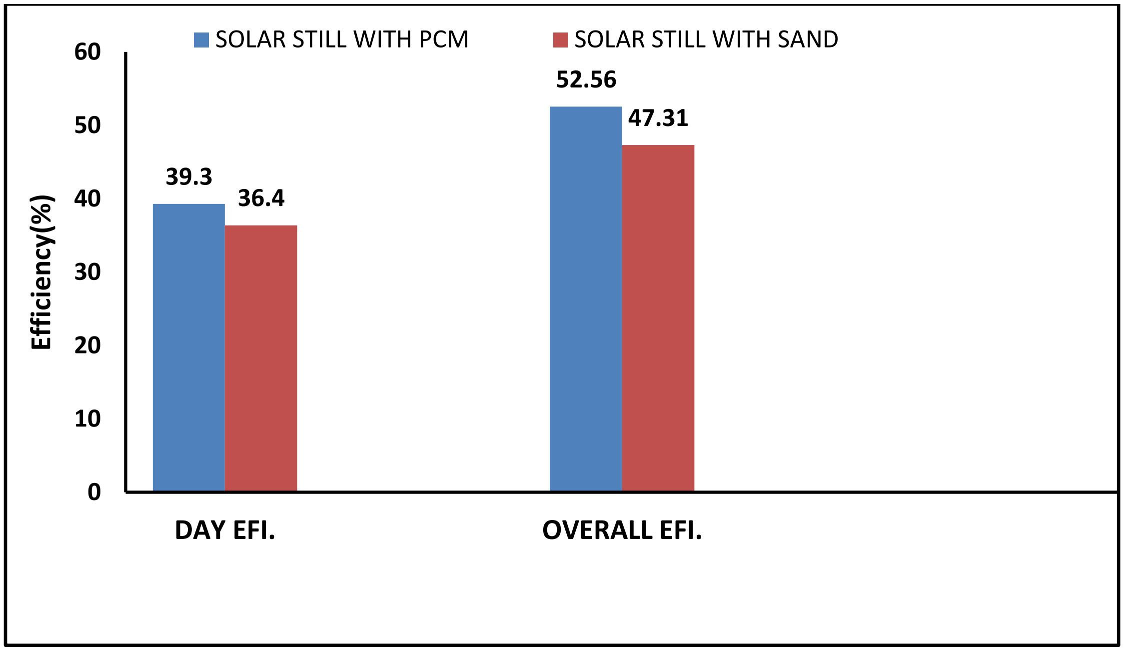


Figure:5.8(b) Efficiency comparison with Sand and PCM

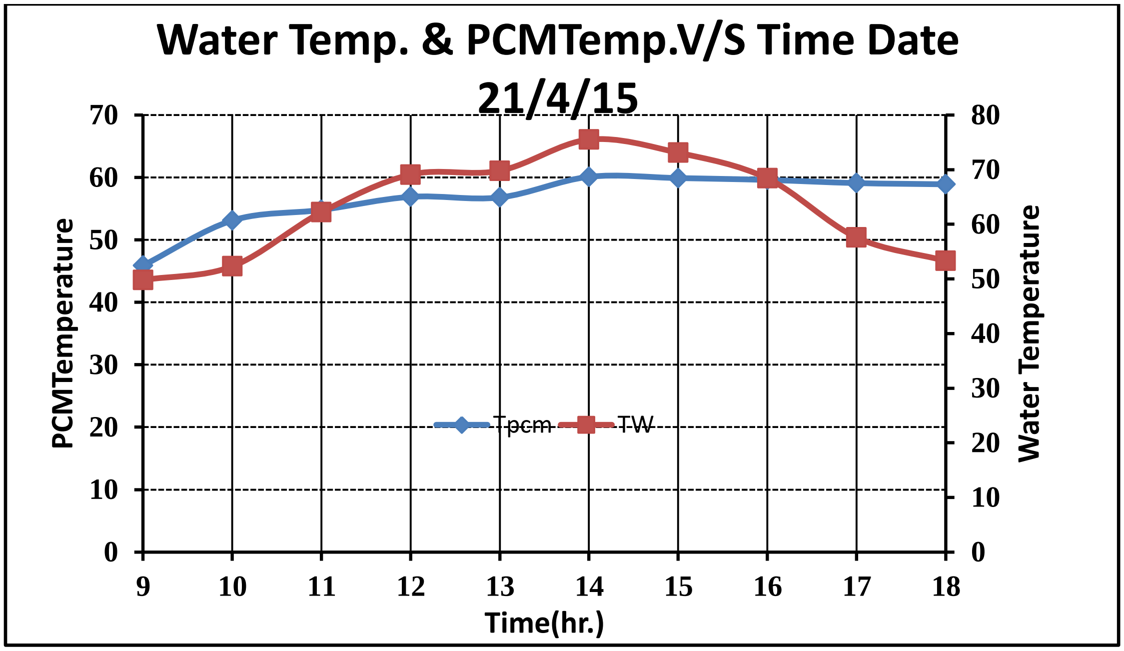


Figure:5.9 Water temp. & PCM temp. v/s Time (21/4/2015)

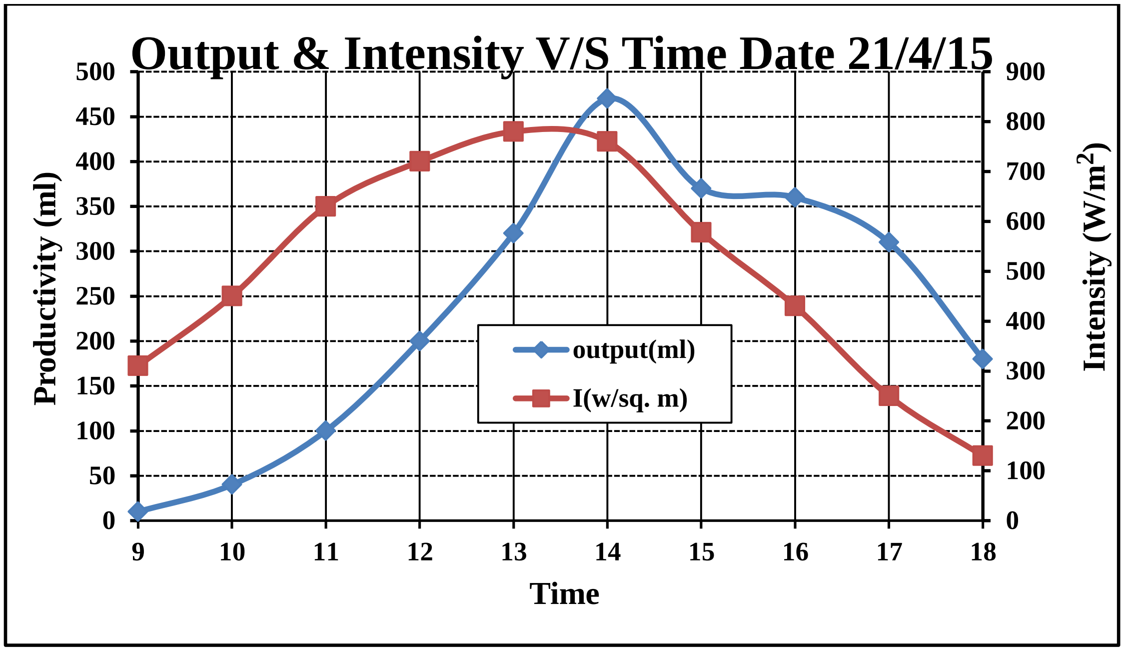


Figure:5.10 Output & intensity v/s Time (21/4/2015)

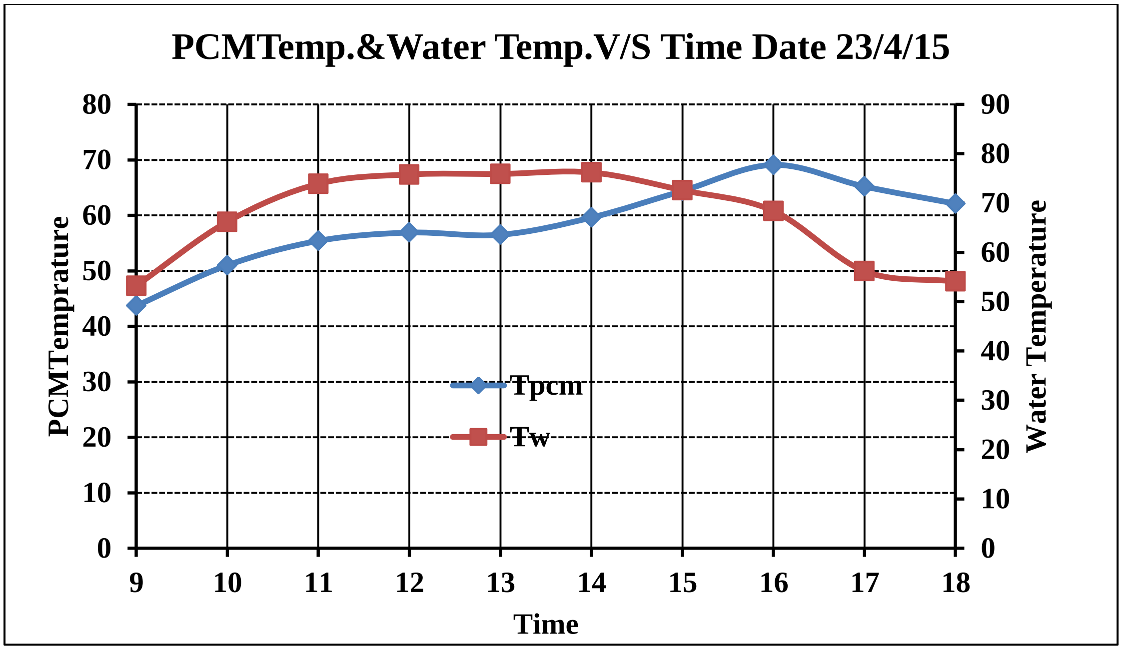
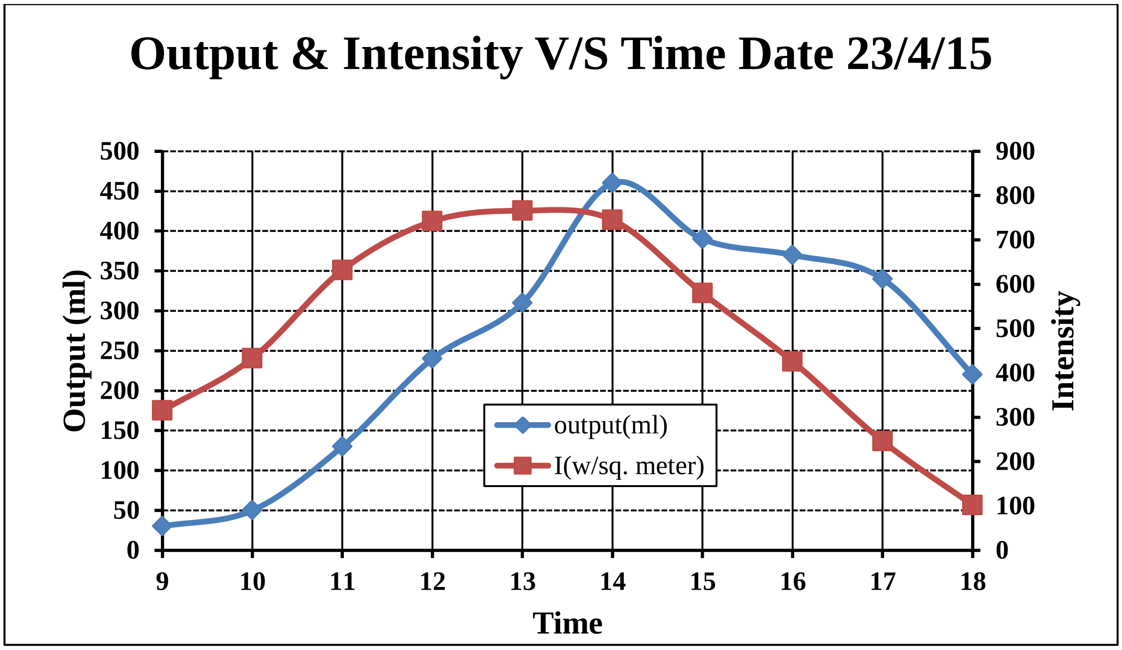


Figure:5.11 PCMtemp. & water temp. v/s Time (23/4/2015)



Graph:5.12 Output &intensity v/s Time (23/4/2015)

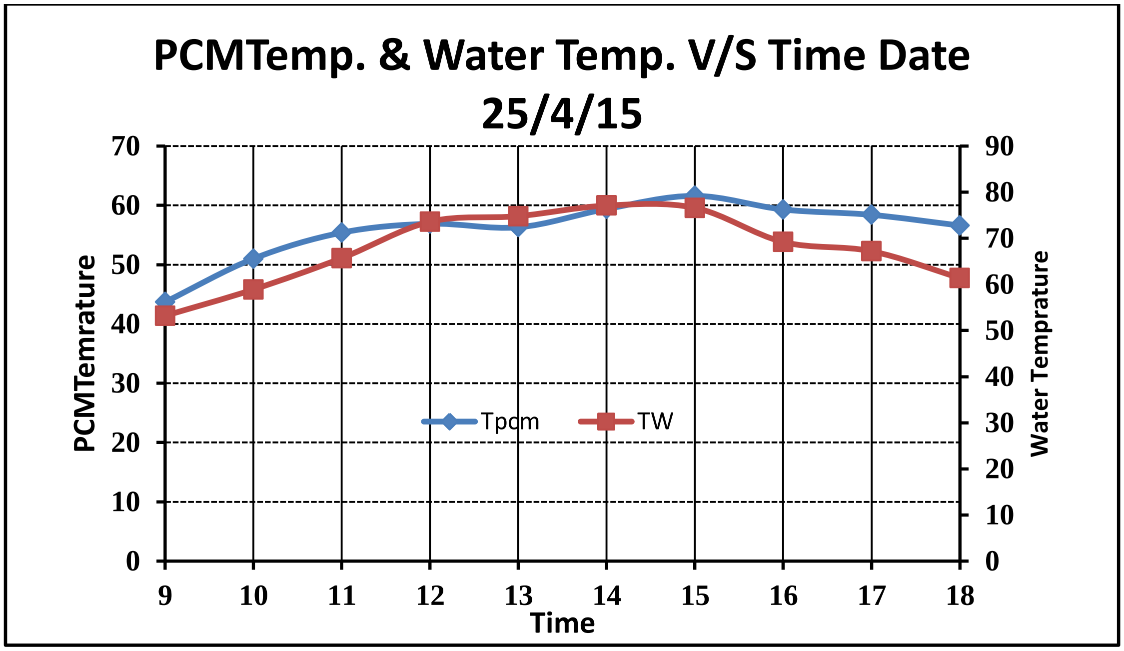
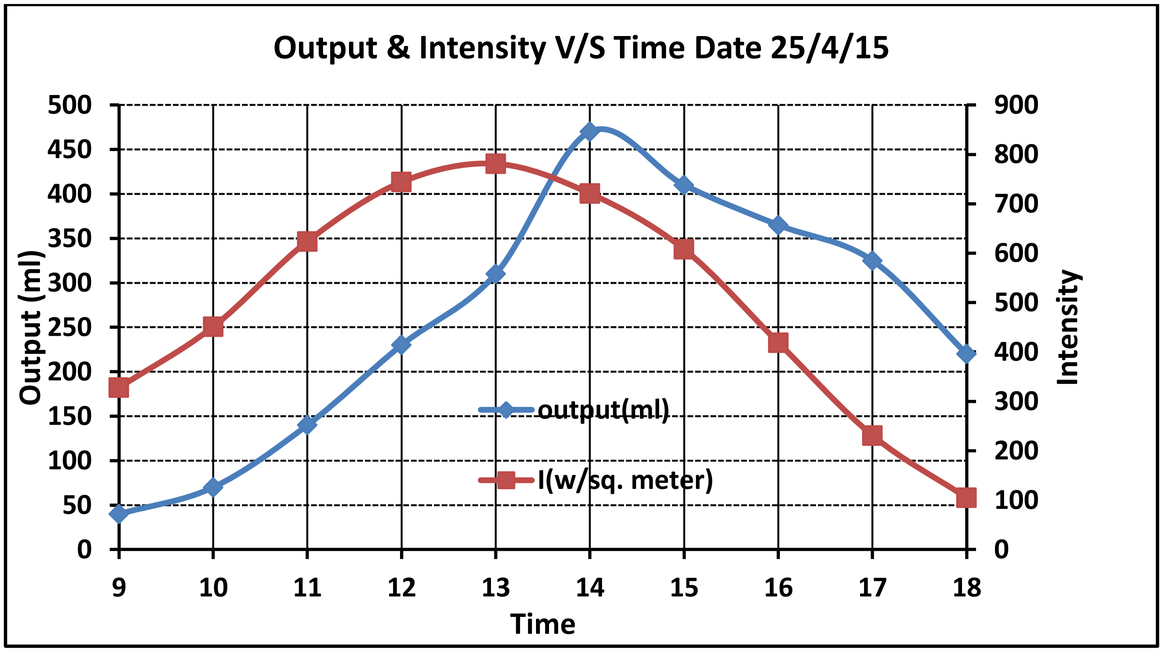


Figure:5.13 PCMtemp. & Water temp. v/s Time (25/4/2015)



Graph:5.14 Output &intensity v/s Time (25/4/2015)

Chapter 6

Result and Discussion

Result and experimental study are presented and discussed in paragraphs given below

Graph 5.2 shows the distillate output comparison for date **21-4-2015** solar still with PCM reservoir and solar still without PCM reservoir. The sunshine distillate output for solar still with PCM is 2360ml and for solar still without PCM is 2480ml. The distillate output is slightly smaller for solar still with PCM reservoir. But night output for solar still with PCM reservoir 780 ml and for solar still without PCM reservoir is 440 ml. The night distillate output for solar still with PCM is very higher. Overall (day and night) distillate output of solar still with PCM reservoir is 3140ml and solar still without PCM is 2920ml. The overall distillate output is **7.53%** higher for solar still with PCM as a thermal storage medium.

Graph 5.3 tells about efficiency comparison for date **21-4-2015** solar still with PCM reservoir and solar still without PCM as a thermal storage. The sunshine efficiency for solar still with PCM is 36.61% and for solar still without PCM is 35.6% The efficiency is slightly higher with PCM reservoir. The overall efficiency of solar still with PCMis48.71% and solar still without is 41.9%. The overall efficiency of solar still with PCM reservoir is **6.81**% higher than solar still without PCM reservoir.

Graph 5.4 shows the distillate output comparison for date **22-4-2015** solar still with PCM reservoir and solar still without PCM reservoir. The sunshine distillate output for solar still with PCM is2490ml and for solar still without PCM is2590ml. The distillate output is slightly smaller for solar still with PCM reservoir. But night output for solar still with PCM reservoir 840 ml and for solar still without PCM reservoir is 400 ml. The night distillate output for solar still with PCM is very higher. Overall (day and night) distillate output of solar still with PCM reservoir is 3330ml and solar still without PCM is2990ml. The overall distillate output is **11.37%** higher for solar still with PCM as a thermal storage medium.

Graph 5.5 tells about efficiency comparison for date **22-4-2015** solar still with PCM reservoir and solar still without PCM as a thermal storage. The sunshine efficiency for solar still with PCM is39.3% and for solar still without PCM is37.84% The efficiency is slightly higher with PCM reservoir. The overall efficiency of solar still with PCM is 52.56% and solar still without is 43.69%. The overall efficiency of solar still with PCM reservoir is **8.87** % higher than solar still without PCM reservoir.

Graph:5.6 shows date wise efficiency comparison at the date 25-4-2015 day time efficiency is 40.14% which is maximum in all days. The overall efficiency is also maximum on 25-4-2015 and its value is 54.14%.

Graph:5.7 shows the distillate water output for the different water quantity. For **20 liter** of water the maximum day output is 2490ml and maximum overall output is 3330ml. For **15 liter** of water in solar still basin the maximum day output is 2540ml and maximum overall output is 3430ml. So by reducing 5 liter water in solar still basin overall distillate output increases is **100ml**.For **10 liter** of water the day output is 2580ml. and overall output is 3480ml.so when we reducing 10 liter of water in solar still basin the distillate water output increases by **150ml**. The overall output is **4.5%** higher for solar still with 10 liter water than the solar still with 20 liter of water.

Graph:5.8(a) shows the efficiency for the different water quantity. For **20 liter** of water the maximum day efficiency is 39.3% and maximum overall efficiency is 52.56%. For **15 liter** of water in solar still basin the maximum day efficiency is 39.7% and maximum overall efficiency is 53.61%. So by reducing 5 liter water in solar still basin overall efficiency increases is **1.05%**.For **10 liter** of water the day efficiency is 40.13% and overall efficiency is 54.13%.So when we reducing 10 liter of water in solar still basin the overall efficiency increases by **1.57%**.

Graph: 5.9 ,5.11 and 5.13 shows the variation in phase change material (paraffin wax) temperature and water temperature with the time. At morning time PCM temperature is less than the water temperature. So In morning time the water output of solar still with PCM is less than the solar still without PCM. In afternoon time both PCM temperature and water temperature gets their peak value. In day time PCM absorb some heat so at evening time PCM temperature is significantly high, it discharge heat at the night time so night output of solar still with PCM is very higher than the solar still without PCM.

Graph: 5.10, 5.12 and 5.14 are plotted to show the variation of distillate water output and solar intensity with time. Peak distillate output occurs after peak of solar intensity. The distillate output keeps on rising until heat input (i.e Solar radiation) is more than the heat losses including loss of heat due to evaporation of water. Similarly water temperature starts falling when heat input (i.e solar radiation) is less than the heat loss including loss of heat due to evaporation of water thus distillate water keeps rising until the solar radiation increasing. In all the graphs the maximum intensity and output is in the afternoon time.

Chapter 7

Conclusion

A total of 10 sets of readings were done from 21 April to 2 May 2015 by changing the water quantity and using the paraffin wax a thermal storage medium reservoir.

1. Overall efficiency of solar still with PCM reservoir and without PCM reservoir are shown in table 7.1 for 20 liter of water. it is maximum for solar still with PCM is**52.56%** and for solar still without PCM reservoir is **43.69%** on date 22-4-2015. Thus use of paraffin wax as a thermal storage medium increase overall efficiency about **8.87%** as compared to that without paraffin wax reservoir.

Table 7.1% increase in efficiency

% increase in efficiency			
	With PCM	without PCM	% increase in efficiency
Date 21-4-2015	48.71	41.9	6.81
Date 22-4-2015	52.56	43.69	8.87
Date 28-4-2015	50.48	42.44	8.04

2. Overall output of solar still with PCM reservoir and without PCM reservoir are shown in table 7.2 for 20 liter of water. It is maximum for solar still with PCM is**3330ml** and for solar still without PCM reservoir is **2990ml** on date 22-4-2015. Thus use of paraffin wax as a thermal storage medium increase overall output about **340ml** as compared to that without paraffin wax reservoir.

Table 7.2 increase in output

	With PCM	without PCM	increase in output
Date 21-4-2015	3140	2920	220
Date 22-4-2015	3330	2990	340
Date 28-4-2015	3230	2960	270

3. Overall efficiency of solar still with PCM reservoir and with different quantity of water are shown in table 7.3. It's maximum value is 54.13% for 10 liter of water on date 25-4-2015.

Table 7.3 % Overall efficiency

% Overall efficiency		
	Water quantity	% increase in efficiency
Date 22-4-2015	20 liter	52.56
Date 23-4-2015	15 liter	53.61
Date 25-4-2015	10 liter	54.13

Future work scope

1. Double effect solar still can be made by varying height of second-stoery basin of double effect solar still.
2. Reflector can be use in the solar still to increase the reflectivity of incident radiation.

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