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Productivity Enhancement of Solar Still Coupled with Evacuated Glass Tubes Using Black Wick and Charcoal

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Abstract —*Water is a primary need of life, health, sanitation and is the most important issue on the international agenda. Solar distillation is a promising method for the supply of freshwater to rural communities. Worldwide passive solar still is used for solar distillation plants due to its simplicity in construction and operation, low cost and however the yield is low. Various active methods have been developed to overcome this issue. These developments create additional costs for the system. The main objective of this research study is to effectively utilize the solar water heater for solar still productivity enhancement, which works as a hybrid system. The experimental setup was designed and installed at solar lab MBM Engineering College. Experiments were conducted simultaneously on both stills for the same basin condition solar lab (26° 27'N, 73° 04'E) Jodhpur, Rajasthan, India during the months of March–May, 2012. The major element of the experimental setup active solar still coupled with evacuated tubes.*

***Keywords**-Black Wick; Charcoal; Solar Still; Evacuated Glass Tube*

I. INTRODUCTION

Water is a precious natural gift and is being polluted by human activities, urbanization and industrialization. The ground water is often over exploited to meet the increasing demand of the people. Less than 1% of earth's water is available for human consumption and more than 1.2 billion people still have no access to safe drinking water. Over 50% of the world population is estimated to be residing in urban areas, and almost 50% of mega cities having population over 10 million are heavily dependent on ground water, especially in the developing countries like India.

The water problem, being either scarcity or pollution of it, has become very large in many areas especially in deserts and in modern industrial areas. These regions (i.e. deserts) are recognized by a high intensity of solar radiation, which makes the district use of solar energy. The solar energy can be utilized to obtain drinkable water from salty or brackish water by the use of solar still to capture the evaporated (or distilled) water and by condensing it onto a cool surface, and the output will be clean water. Such kind of system is suitable for low productions and particularly application in rural areas.

Solar distillation is an ancient way of purifying water and making saltwater potable. Methods of solar distillation have been employed by humankind for thousands of years. Aristotle described the process as early as the 4th century BC. From early Greek mariners to Persian alchemists, this basic technology has been utilized to produce both freshwater and medicinal distillates. Solar stills were in fact the first method used on a large scale to process contaminated water and convert it to a potable form.

In 1870 the first US patent was granted for a solar distillation device to Norman Wheeler and Walton Evans. Two years later the first modern, large-scale solar still, built in Chile in 1872, consisted of 64 basins that supplied up to 20,000 litre of water per day to a mining community in the area. It operated continuously for 40 years and produced an average of 22.7 m3 of distilled water a day using the effluent from mining operations as its feed water.

Solar energy is the radiant energy produced by the Sun. It is both light and heat. Solar technologies are characterized as either passive or active depending on the way the energy is captured, converted, and distributed. Active solar techniques use photovoltaic panels and solar thermal collectors to harness the energy. Passive techniques include orienting a building to the Sun, selecting materials with thermal mass properties, and using materials with light dispersing properties. The desalination processes used to make sea water drinkable are more expensive and cannot by employed as a cost effective method. Hence there is a need a cost effective desalination technique. Solar water desalination is water desalination technique, work's on renewable energy resources and fulfilling our need.

II. DEVELOPMENT OF SOLAR STILL COUPLED WITH EGT

In view of geographically culture in temperate zone maximum receipt of solar insolation engineered as a boon of nature. Harnessing solar energy is paradigm to meet the contemporary energy crisis. In view to meet the present requirement of fresh, pure and non-contaminated potable water, affordable measure is needed.

Engineering marvels inspired from nature spreads better acceptability. In line to inclusive growth a cost effective solar still is designed, rooted to intense literature review. Development of solar still to meet house hold potable water requirement, cost effective and efficient product with increased daily productivity.

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2.1 Solar Still Development

The development of still involve various steps from design and construction each still component.

2.1.1 Still Components

The experimental setup was designed and installed at solar lab MBM Engineering College.Experiments were conducted simultaneously on both stills for the same basin condition solar lab (26° 27′N, 73° 04′E) Jodhpur, Rajasthan, India during the months of March–May, 2012. The major element of the experimental setup active solar still coupled with evacuated tubes.

The experimental setup consists of:

2.1.1.1 Basin and Side Wall

The basin was made of Fiber reinforced plastic (FRP) having 1 m2 area. The whole basin surfaces were coated with black paint from inside to increase the absorptivity. The still was insulated from the bottom to the sidewalls with polyurethane from 4 cm thick having thermal conductivity of 0.034 W/m2 Kto reduce the heat loss from the still to ambient as shown in Figure1 and 2.

Figure 1 Solar Still Basin

A Single basin double slope solar still has been fabricated with mild steel sheet as shown in Fig 4.2. Fourteen hole of 49 mm diameter were punched by the pressing operation at lower basin surface in one side of seat with equal distance between each hole.

The overall size of inner basin 1006 mm × 325 mm × 380 mm. the maximum height and that of the outer basin is 1006 mm × 536 mm × 100 mm. the brackish water feed pipe work provided at the top of upper chamber of the basin at middle double basin chamber supports were provided.

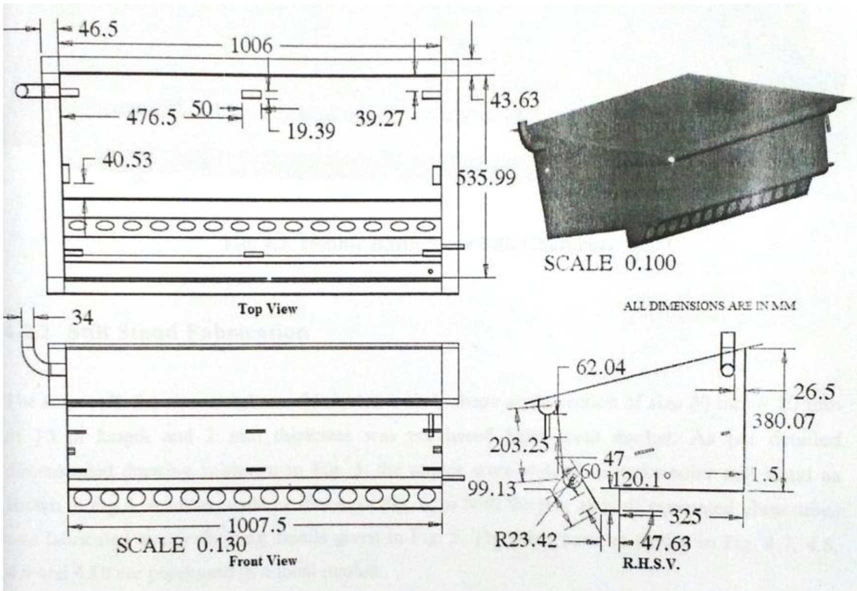

Figure 2 Detail drawing of double basin solar still chamber

2.1.1.2 Evacuated Glass Tube

Evacuated Glass tube (EGT) works on 'Black body heat absorption principle'. The principle says, 'black colour absorbs maximum heat, more than any other colour'. Solar water heating systems using vacuum tubes made of borosilicate glass with special coating to absorb the solar energy are called as Evacuated Tube Collector system (ETC Systems).

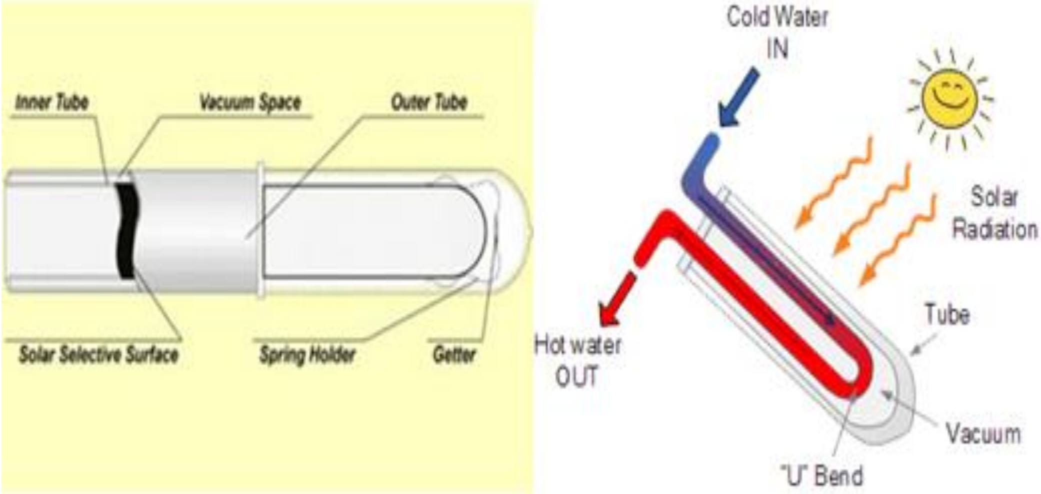

Figure 3 Evacuated Glass Tube

Figure 3 shows the main component of EGT, which absorbs solar energy. The vacuum tube is an assembly of two concentric; borosilicate glass tubes. Air between the gaps of two glass tubes is evacuated. It results in high level of vacuum, which acts as the best insulation to minimize the heat loss from inner tube. The black coating on the inner tube absorbs the solar energy and transfers it to the water. The water on upper side of Vacuum Tube becomes hot and thus lighter, so it starts moving upwards in the tank. At the same time cold water, which is heavy, comes downward from the basin and is stored at the bottom. The phenomenon is called as natural Thermosyphon circulation, which occurs in every tube.

Table 1 Evacuated glass tube parameters

Specifications of Evacuated Glass Tubes	
Material of Glass	Borosilicate Glass
Length	1800 mm and 2100 mm
Outer diameter	47 mm
Inner diameter	37 mm
Thickness of Glass Tube	Outer tube thickness: 1.8 mm, inner tube thickness: 1.6 mm
Selective coating type	AIN/AIN-SS/CU – Sputtering
Value of absorptance and emittance of the black coating	Absorptance: $\alpha \geq 93.5\%$, Emission rate: $\varepsilon \leq 5\%$
Vacuum rate	$P \leq 5.0\times10^{-4}$Pa
Coefficient of Thermal Expansion	3.3×10^{-6}/k

2.1.1.3 Insulation (polyurethane foam)

A wide range of insulation materials is available; however, few meet the requirements of still construction. Selection of insulation material should be based on initial cost, effectiveness, durability, the adaptation of its form/shape to that of the still hold and the installation methods available in each particular area. From an economic point of view, it may be better to choose an insulating material with a lower thermal conductivity rather than increase the thickness of the insulation in the still walls. Polyurethane foam is one of the best commercially available choices of insulation. It has good thermal insulating properties, low moisture-vapour permeability, and high resistance to water absorption, relatively high mechanical strength and low density. Polyurethane is formed by mixing an isocyanate, such as methylene diphenyldiisocyanate (MDI) with a polyol blend. These components are mixed to form a rigid, cellular foam matrixas shown in Figure 4. The resulting material is an extremely lightweight polymer with superior insulating properties. As a result of the high thermal resistance of the gas, polyurethane insulation typically has an initial R-value around R-5 to R-6 per inch.

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Figure 4 Polyurethane Foam

2.1.1.4 Glass Cover

The water in the basin is heatedby the solar energy directly received through the glass cover of the still. The solar radiation, after reflection and absorption by the glass cover, is transmitted inside the enclosure of the distiller unit. Consequently, the water is heated, leading to an increased difference of water and glass cover T temperature. There are basically three modes of heat transfer: radiation (qrw), convection (qcw), and evaporation (qew) from the water surface to the glass cover. The evaporated water is condensed on the inner surface of the glass cover after releasing the latent heat. Under gravity, condensed water trickles into the channels placed at the lower ends of the glass cover. The glass cover temperature was measured at node by copper-constantan thermocouples.

2.1.1.5 Frame and Stand

The solar still chamber stand was fabricated with L shape angel section of size 20 mm × 20 mm of 10 meter length and 2 mm thickness. The detailed dimensional drawing is shown in Figure 6 and 7.To hold the rear and ends of evacuated glass tubeswas fabricated as per drawing shown in Fig. 5.

Figure 5 Solar Still Chamber Stand

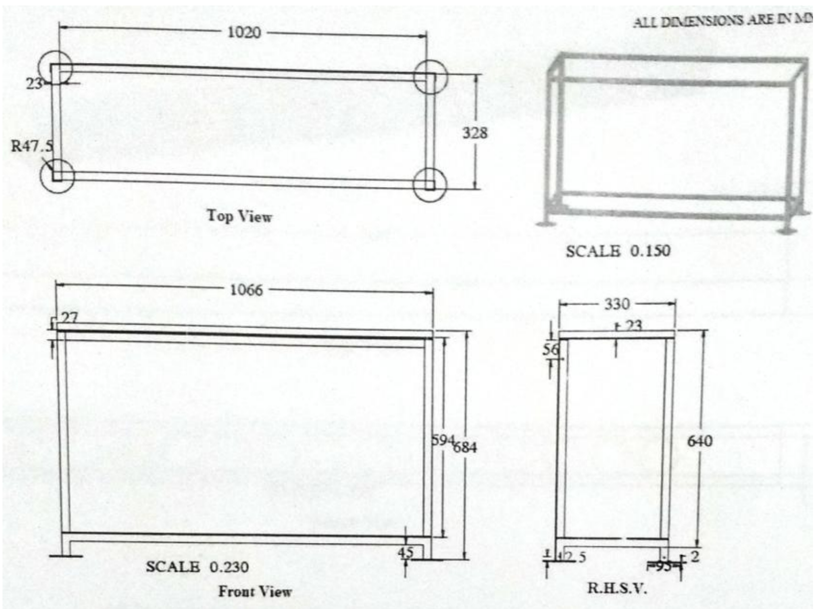

Figure 6 Detail drawing of solar still chamber stand

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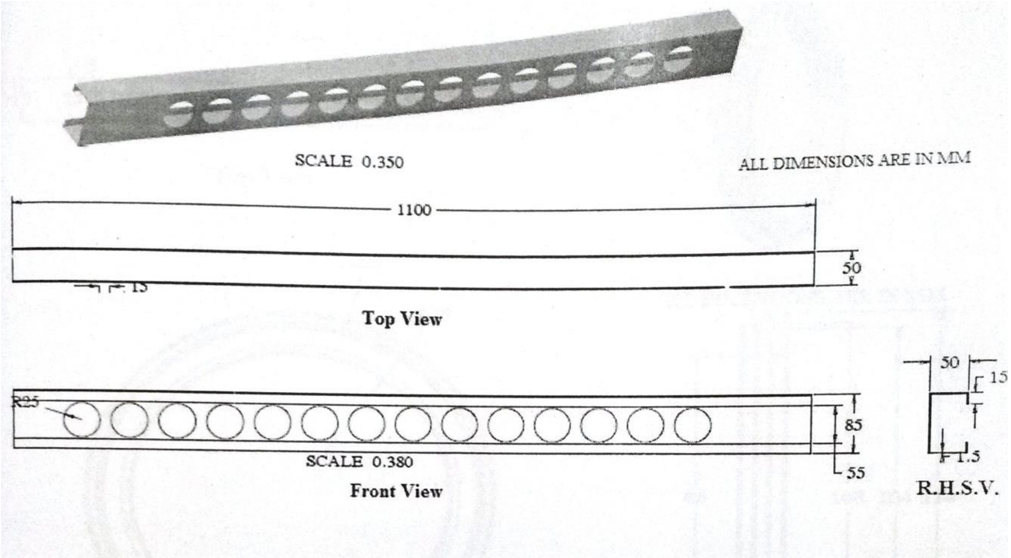

Figure 7 Detail drawing of supporting stands of EGTs

The still was coupled with rows of parallel transparent evacuated glass tubes (EGT), each of which contains an individual absorber tube covered with selective coating to warm the water additionally prior to sending it to the solar still. Evacuated glass tubes are integrated with the basin type single slope solar still. The whole basin surfaces were coated with black paint from inside to increase the absorptivity. The still was insulated from the bottom to the sidewalls with polyurethane from 4 cm thick having thermal conductivity of 0.034 W/m^2 K to reduce the heat loss from the still to ambient. The basin was covered with a glass sheet of 3 mm thickness inclined at nearly 30° horizontally to maximize the amount of incident solar radiation and sealed with silicon seal to avoid water leakage.
To maximize the productivity of the still, to increase the inner temperature basin and to increase the harness of solar radiation the still was augmented with manual solar tracking mechanism. This solar mechanism consists of four roller wheel bolted at each corner of still frame and chart reflecting hourly Sun's angular position.

2.1.1.6 Water pipes and Distillate collecting Flask
For accumulation of output of still in the form of distillate water proper arrangement of high strength and non-reactive water pipe were installed. Brackish water in flow is facilitated with similar pipe.

III. ECONOMIC ANALYSIS

Good management consists primarily of making wise decisions; wise decisions in turn involve making a choice between alternatives. The ultimate objective of the economic analysis is to provide a decision-making tool which can be used not only for the pilot project but also for demonstration purposes. In considering solar system usefulness we must find the potential benefits and costs of the systems. Costs related to the analysis include the initial investment required to purchase the system, administrative costs and any operation and maintenance costs that may be associated with the systems. Generally there is no operation cost to the utilities associated with solar energy system because the customers do not have to pay for the energy requires running the systems. The Solar technology systems have only installation and maintenance cost but zero operational cost. The economic feasibility of any solar still can be assessed primarily on the basis of 'the unit cost of desalination of saline water' and 'payback period' of the investment made for the solar stills. Though the process of desalinating saline water – evaporating water, condensing and collecting pure water vapours – remains the same, what makes all the difference is its no-fuss, closed-loop design and the total absence of conventional fuels, thus making it totally sustainable, affordable, and eco-friendly. The payback period of the experimental setup depends on overall cost of fabrication, maintenance cost, operating cost and cost of feed water. The cost of feed water is negligible.

Overall fabrication cost to be considered = Rs.10000 (over all)
Cost per litre of distilled water = Rs.10
Productivity of the solar still = (6-7) l/m2/day (including nocturnal yield)
Cost of water produced per day = cost of water / litre x productivity
= 10 x 7 = Rs.70
Maintenance cost = Rs.5/day (estimated)
Net earnings = Cost of water produced – maintenance cost
= 70– 5 = Rs.65
Payback period = Investment/Net earning
=10000/65 = 154 days (approx.)

Table 2 Capital cost of active solar still system

S.No.	Details of component	Quantity	@ materials	Rs
1	Mild still plate	18 kg	R_{MS}=Rs78/kg	1404
2	Evacuated Glass tubes	14	R_{EGT}= Rs 200/ pic.	2800
3	Silicon Seal	14	R_{SS}= Rs 50/ pic.	700
4	EGT Cap	14	R_{CAP}= Rs 50/ pic.	700
5	Glass cover (Glass Thickness 5 mm)	1.043 m^2	R_{GLASS} = Rs 190/ M^2.	198
6	GLASS TRAY (Glass Thickness 5 mm)	1.5 m^2	R_{GLASS}= Rs 190/ M^2.	285
7	Thermocouple wire (k-Type)	30 m	$R_{K\text{-}TYPE}$ = Rs 35/ m	1050
8	Sealant	4 m	R_{SELANT}= Rs 25/ m.	100
9	Fiber reinforced plastic	2.3 m^2	R_{FRP}=Rs 180/ m^2.	414
10	Stand	1		200
11	PU Foam	2 m^2	R_{PU}=Rs 40/ m^2	80
12	Roller Wheel	4	R_{Roller}=40	120
13	Wick		R_{Wick}=50	50
14	Manufacturing cost			1300
Total				9401

3.1 Experiment Setup and Procedure

Figure 8 Experimental Setup

Experiments were conducted at solar lab MBM Engineering College, Jodhpur (26° 270027′N, 73° 06319′E) Rajasthan, India during the months of May-June, 2013. The readings were taken from morning 08:00 AM to 06:00 PM on hourly basis.

Temperature were measured at more than one location and averaged was considered for the case of base plate temperature and basin water temperature. Thermocouples were integrated with a temperature indicator and selector switch. To measure the solar radiation a calibrated Pyranometer was used. The hourly weather data, i.e., solar radiation and wind speed were measured.

IV. RESULT DISCUSSION

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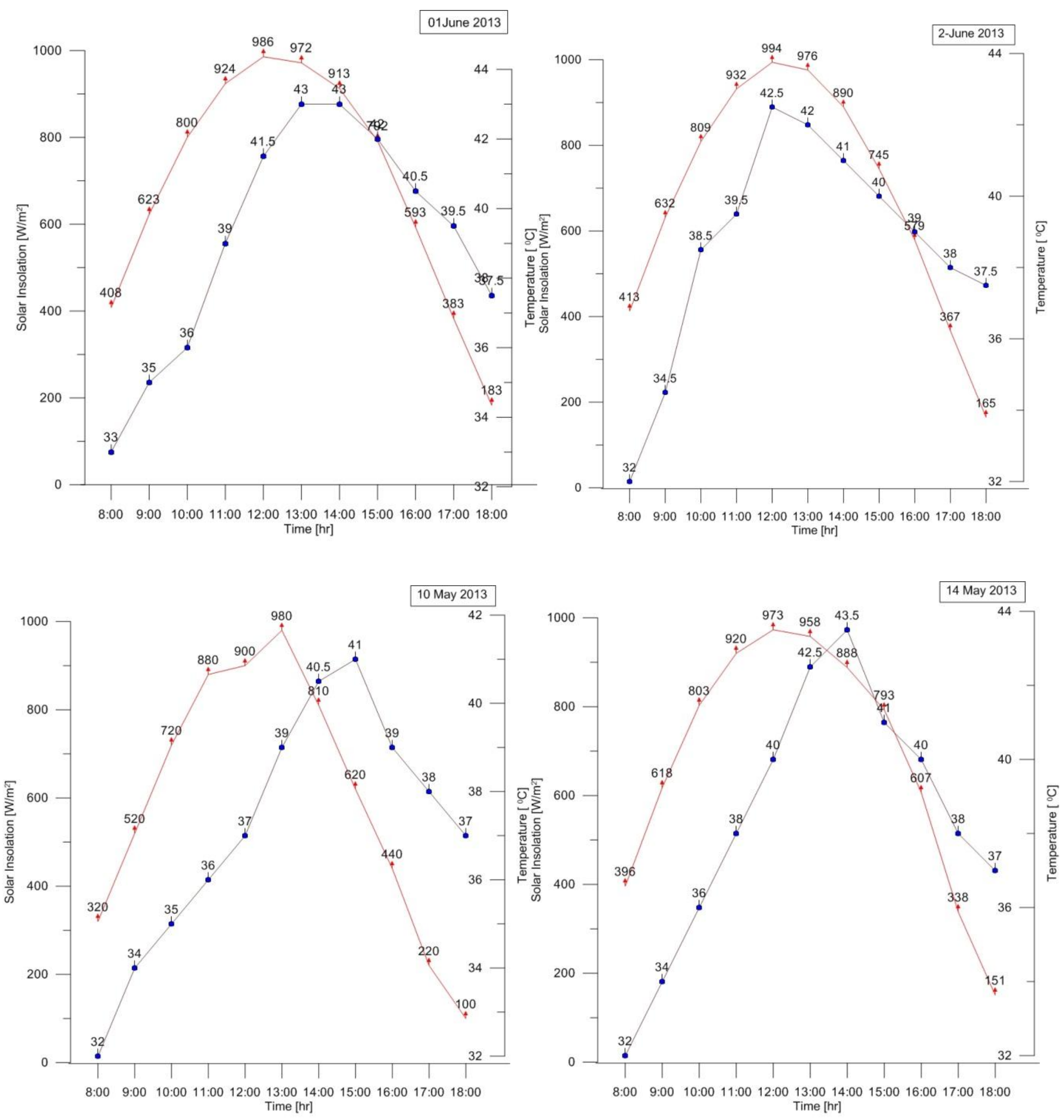
The experiments were conducted on both single double basin stills under local climatic conditions. The system was operated during the summer month of May and June 2013. The observations of the days with the average radiation conditions were considered for analysis. Totally, 20 combinations of readings were taken in solar still by varying water depth, water sample, absorbing material, double basin and solar tracking. The proposed model can accurately predict the distillate yield for a double basin evacuated solar desalination system operating at high temperatures.
Depending upon the weather conditions the wind speed is variedfrom0.13 to 1.81 m/s and the ambient temperature is varied from27 to45 °C at different days and solar intensity is varied from30 to1100 W/m2 during day time.

5.1 Hourly variation of Solar Insolation and temperature

The solar productivity is depends on the influence of climate conditions as, solar insolation and ambient temperature prevailing the experimental location. Figure 9 shows the hourly variation of the solar intensity and the ambient air temperature on the clear days of the month of May and June. The solar radiation gradually surges with time till 14 hour and declines towards evening. It can be seen that the solar intensity was maximum at the mid noon whereas, the ambient air temperature reached its maximum in the afternoon hours. This time lag of the maximum ambient air temperature and maximum solar intensity is mainly due to the thermal capacity of the atmospheric air, besides, factors like air density, humidity, quality and others may also affect.
The variation of global solar radiation and ambient temperature is shown in Figure 9. The maximum radiation and ambient temperature is observed as 1067 W/m2 and 45.5 °C on 22 May and 6 May respectively the months of March and May respectively.



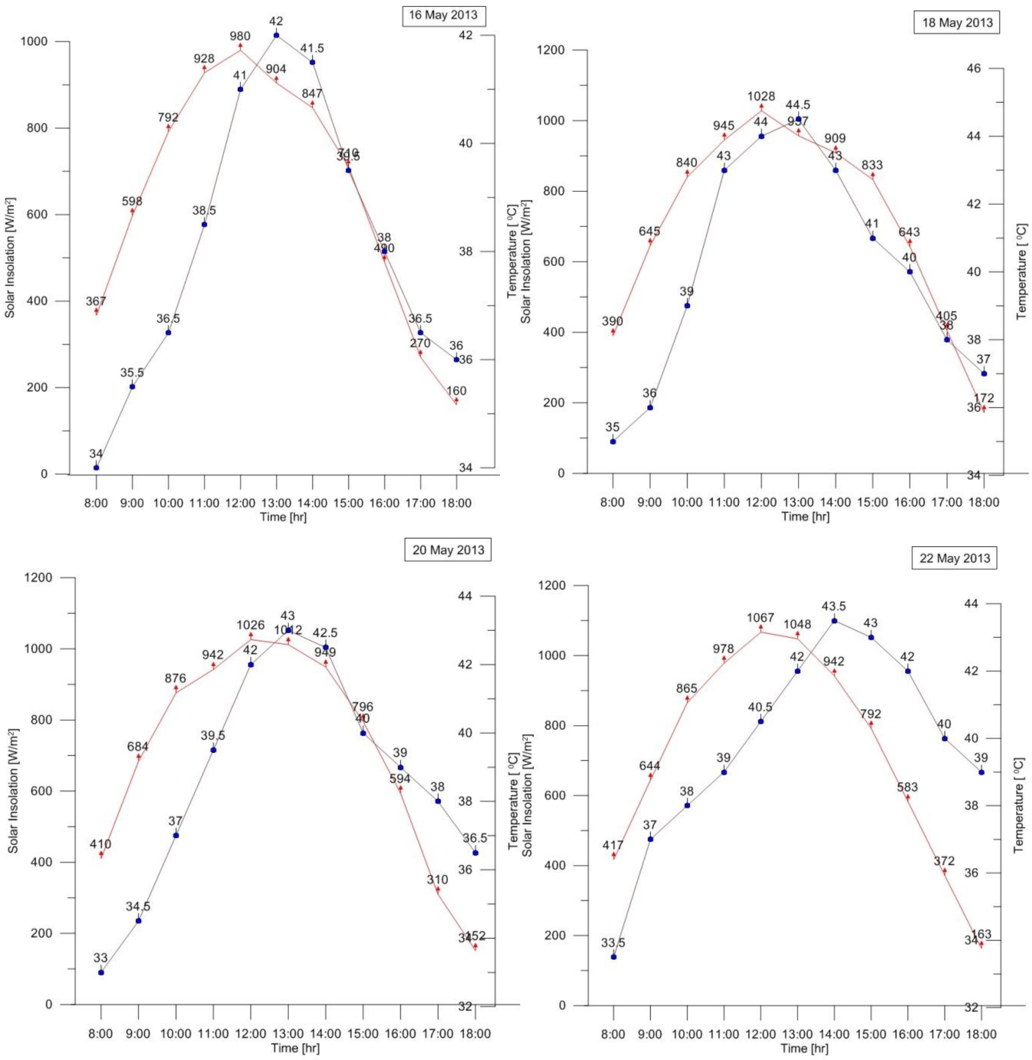


Figure 9 Date wise hourly Temperature Distribution with respect to Solar Insolation.

5.2 Water Sampling

Water from three most commonly used sources are collected for better study of water quality is used. The aim of water sampling is to determine the impurities and quantity of minerals present in sample water. Samples are as mention in Table 3.

Table 3 Water sample and there location

S. No.	Sample	Source
1	Tap water	Solar Lab MBM Engg. College
2	Tube well water	Farm near UmedBhavan
3	Pond water	Mechanical Engg. Dept. MBM Engg. College

Water of all the three samples was collected from the sources in clean plastic bottles. Samples were deposited on the same day at a certified test centre district headquarters. The physico chemical test for 13 parameters and bacteriological examination for total coliformbacteria was done at the test house. Results of test house are presented.

5.3 Effects of Solar radiation distillate

The influence of climatic conditions and mainly solar radiation, on the system production is investigated. The variations of the daily solar still output and the solar radiation for 6th may is shown in Figure 10.The figure shows that the still productivity is proportional to the solar radiation intensity, which depends on climatic condition of each day.

The distillate output of the solar still varies as the total solar radiation intensity with about 2 hours delay. It increases up to a maximum value at 15:00 hr and then decreases as time passes. The maximum yield reached is about 730 ml/m2. Variations of the accumulated distillate during the day for different days are shown in Figure 10. The accumulated water reached 4200 ml/m^2 at 18 hr for day 6 May 2007.

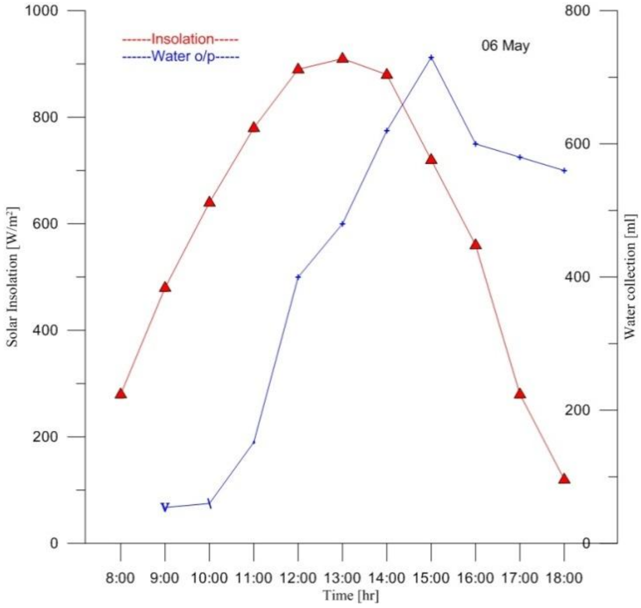


Figure 10 Hourly distillate productivity with respect to solar radiation

5.4 Effect of water depth on the solar stills productivity

The effect of water depth in the still basin on the productivity is shown in Figure 11. It is evident that as the water depth increases, the productivity will be decreased.

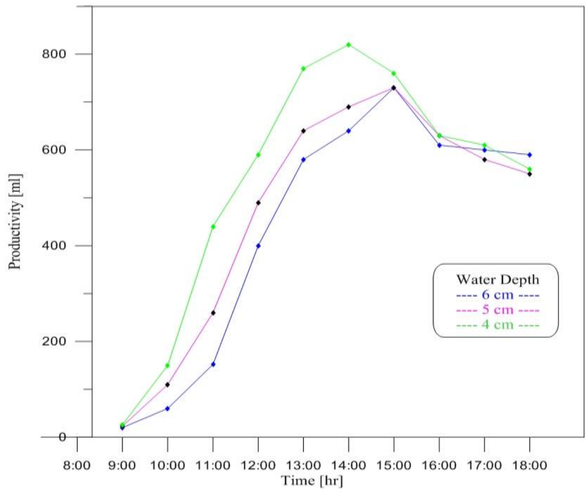


Figure 11 The effect of water depth in the basin on the productivity

This is due to the increase of the heat capacity of the water in the basin, results in lower water temperature in the basin leading to lower evaporation rate.

Table 4 Distillate collection with various water depths

S. No.	Time (h)	Ambient Temperature (^oC)			Output of water collection (ml)		
		Day 1	Day 2	Day3	6 cm	5 cm	4 cm
1	08:00	32	31	32			
2	09:00	34	36	34	20	23	26
3	10:00	35	39	36	60	110	150
4	11:00	36	41	38	152	260	440
5	12:00	37	43	40	400	490	590
6	13:00	39	45	42.5	580	640	770
7	14:00	40.5	44	43.5	640	690	820
8	15:00	41	43	41	730	730	760

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9	16:00	39	42	40	610	630	630
10	17:00	38	41	38	600	580	610
11	18:00	37	39	37	590	550	560

The experiment is conducted for three different water depth that is 6 cm, 5 cm and 4 cm on 10, 11 and 12 May respectively. Table 5.3 dictates the increase in distillate productivity with decrease in water depth. The maximum output of 820 ml/hr is accumulated at 14 hr with 4 cm water depth setup. There is 22.56 % productivity increment during experimental hours with 4 cm water depth as compared to 6 cm water depth. Critical analysis revels that the hourly productivity varies abrupt with higher water depth as in case of lower depth productivity variation is less.

5.4 Effects of Absorbers on still productivity

In view of productivity enhancement charcoal and wick are used as absorbing medium. Firstly charcoal were broken into small pieces and placed in the basin. The water depth was maintained 4 cm by controlling water flow rate manually. The experiment was conducted on 16 and 17 May using tap water as input with charcoal as absorber and on 20 and 21 may with black wick as absorber. Variation in productivity with respect to varying ambient temperature and absorbing medium is postulated in Table 5.

Table 5 Distillate collection with various absorbing medium

S. No.	Time (h)	Ambient Temperature (C)			Output of water collection (ml)		
		Day1	Day 2	Day3	Bare basin	Charcoal	Black Wick
1	08:00	34	32	33			
2	09:00	35.5	34.5	34.5	18	32	36
3	10:00	36.5	37	37	190	360	390
4	11:00	38.5	38	39.5	430	570	580
5	12:00	41	40	42	780	910	890
6	13:00	42	41.5	43	900	940	1010
7	14:00	41.5	42	42.5	870	960	1030
8	15:00	39.5	43.5	40	890	860	910
9	16:00	38	43	39	780	730	880
10	17:00	36.5	41	38	630	610	630
11	18:00	36	39	36.5	580	540	600

Charcoal affects the performance of solar still with its properties: wettability, higher absorptivity for solar radiation due to its black colour and higher scattering property. Charcoal enhanced water productivity 10.45% compared with bare basin solar still augmented with evacuated tubes. . The effect of charcoal pieces enhances the performance of a solar still on partially cloudy days and during the morning hours when solar radiation remains low. The charcoal pieces work to diffuse radiation also. However, from maintenance point of view, the regular cleaning of the charcoal surface and the basin of the solar still is required.

The 8 still basin filled with the wicks which separates the water into banks to increase surface area for heating. The distilled water comes out of the bottom and depending on the quality of construction most of the salt has been purged from the water. The more wicks, the more heat can be transferred to the salt water and more product can be made. The wick type solar still is made vapor tight, as in the vapor does not escape to the atmosphere. To aid in absorbing more heat, some wicks are blackened to take in more heat.

Using black wick replacing charcoal as an absorber resulted higher productivity of 22% compared with bare basin. The production rate was highest when black wick was used. The lowest production rate occurred when water alone was used and there was not any other absorbing material inside the still. This observation was noticeable throughout the day. Figure 12 presenting graphical comparison of both absorber charcoal and black wick. This shows during noon hour wick resulted higher productivity and maintained till the sun sets.

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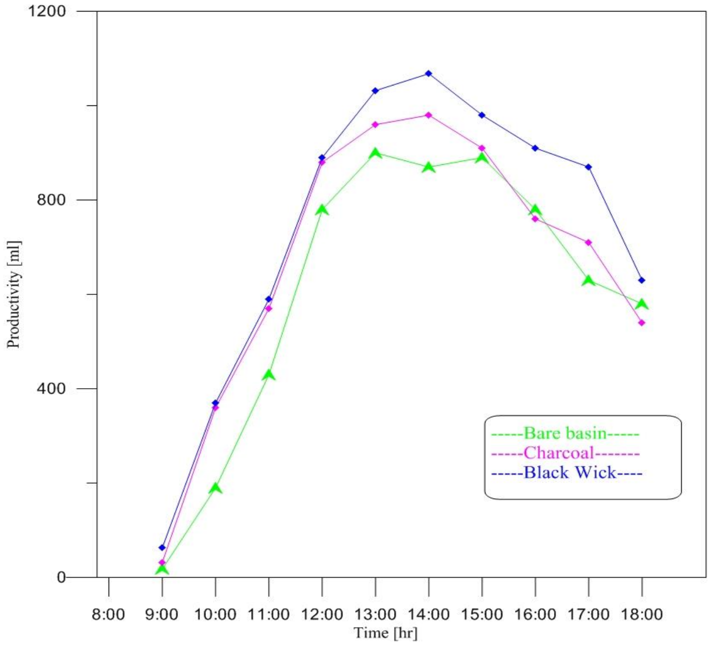

Figure 12 Variation of the accumulation of distillate water with charcoal and wick as absorber

V. CONCLUSION

In this study, a comprehensive review of the available literature on solar still is presented. The review covers fundamentals of solar thermal system, detailed description of various types of solar water distillation systems, performance analysis and thermal modeling of solar still, different solar water distillation technologies, optimization of parameters to enhance the productivity of distilled water and efficiency of solar still.

Different sample of water were analysis for measuring if effectiveness, efficacy and quality of impurity removed with solar desalination technique. Three water sample tap water, pond water and brackish tube well water were experimented on different days. The water samples were tested before and after desalination. Solar desalination proves its quality for all water samples living no scope for impurities after treated.

Using tap water as input source the optimization of water depth inside the solar still basin were conducted. The still were tested for 6 cm, 5 cm and 4cm. As the literature postulated minimum water depth gives higher yield for same testing conditions. There is 22.56 % increment in the distill water collection for 4 cm water depth as compared with the 6 cm. For certain experimental limitation further water depth was not reduced. All further experimentations were conducted with 4 cm as water depth inside the solar still basin.

In line to the productivity enhancement charcoal and black wick were used as absorber. Fine particles of charcoal were placed inside the still basin. Charcoal enhances the greater heat trap and absorptivity leads to higher water productivity. The productivity was increased 7.62% with charcoal as absorber compared with bare basin setup. Black wick absorber shows higher productivity as compare to charcoal and bare basin. The water collection enhances 22.56 % with black wick as absorber

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