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RESEARCH ARTICLE OPEN ACCESS

Distillation of Water- Using Solar Energy with Phase Change Materials

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Abstract
Fresh water is becoming scarce with time, leading to severe water crisis in many parts of the world. Among the various methods of purification of water solar distillation is more prominent. Solar distillation has the inherent advantage of low energy consumption. Moreover it is simpler and more economical than other methods.
Keywords: Desalination, latent heat, PCM, Solar energy, Solar still, Thermal energy.

I. INTRODUCTION

A Solar Still is a device that produces clean, drinkable water from dirty water using the energy from the sun. This inexpensive device can easily be built using local materials. Presently, basin type solar still is the only device that is being used for water distillation applications. However leakage of water vapors through joints and glass sealing of solar stills was found to be major reason for their limited use. Against this backdrop, research and development in the field of solar stills can be directed to obtain higher distillate yield of the required quality with maximum still efficiency by using advanced stepped type solar still. However, although solar thermal energy entering the still is the driving force of distillation process, its relation with production is not univocal, as one could initially suppose, because thermal energy used for evaporation does not come out directly together with produced water but it is recovered through condensation inside the still. Several efforts have been made in order to improve efficiency of the conventional solar still, concerning interventions in geometry (Satcunanathan and Hansen, 1973), materials (Bahadori and Edlin, 1973; Dhiman, 1990), or other operation parameters with more or less positive results In this efforts using Phase Change Material (PCM) in Solar still is found to be a best option to increase the efficiency of solar still not only at a day time but also at a night. In locations where there is plenty of solar energy and where sources of brackish water are available, supplies of small amounts of fresh water can be produced at reasonable cost by solar still with PCM which are relatively inexpensive to build and easy to maintain.

II. METHODOLOGY

In this present work comparative study is being made between solar still with and without PCM. The detail Methodology is as follows:- It requires simple technology and easy maintenance; hence it can be used at any place without much difficulty. Two single slope stepped solar still were constructed with and without phase change materials in order to compared the productivity of stills at day as well as night during sunny days. Paraffin wax was selected as Phase Change Material (PCM). It is found that the higher mass of latent heat thermal energy storage system with lower mass of water in solar still basin significantly increases the daily productivity and the efficiency. Therefore, the distillate productivity at night and a day for solar still with PCM increases by 127% and 30-35% respectively than the one without PCM.

III. GENERAL CONSIDERATION

Selection of dimensions for stepped type solar still:

- ¬ The outer tray of dimension1067mm x 686mm x 228mm is fabricated of GI sheet of 27 gauges by riveting it.
- ¬ The inner tray of dimension991mm x 610mm x 191mm is fabricated of GI sheet of 27 gauges by riveting.
- ¬ The 8 steps are made of aluminum sheet having the dimension of each is 98mm width, 36mm height and 610mm width. These steps are riveted to the inner tray such that the surface of basin makes an angle of 150 with the ground.
- ¬ The aluminum trough is made of dimension 55cm X 5cm X 5cm and riveted to the lower end of the inner tray to collect the distilled water. The outlet is provided to the trough to take out the distilled water from the solar still.
- ¬ The wooden frame is made of the dimension 139cm X 65cm X to cover the outer tray and glass of 4mm thickness is fixed to the wooden frame. The frame is hinged to the one longer end to the outer tray and the other longer end is free

to open the frame whenever necessary to clean the bottom surface of the basin.

¬ The rubber gasket is fixed on the wooden frame to make it air tight and vapor tight when the cover is close.

¬ The inlet water is provided at the top of the side face of the tray to provide the fresh water for distillation.

¬ The thermocouples are attached at the various positions of the basin water and glass to measure the basin water temperature and glass temperature. The thermocouples are connected to the digital measuring instrument to get the temperature.

¬ The frame is made of steel to support the outer tray and completes unit at the given inclination.

¬ The PUF (poly urethane foam) is filled up in the space between the outer tray to provide the insulation.

IV. EXPERIMENTAL SETUP

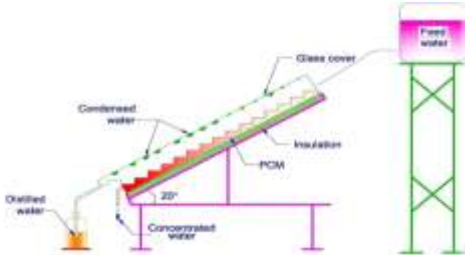


Fig.1 Schematic diagram of experimental setup of solar still with PCM.

A. *Construction*

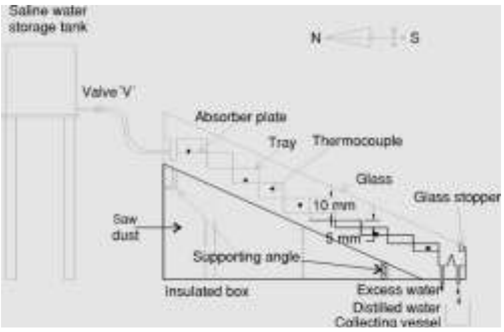


Fig.2 Specification of solar still

i. Outer Tray:

It is made up of GI sheet of 24 gauges. It has a dimension of 1067mm x 686mm x 228mm. The main function of outer tray is to provide the space for insulation and to support wooden frame and glass.

ii. Inner Tray:

It is made up of GI sheet of 24 gauges and its dimension is 991mm x 610mm x 191mm. It encloses the various steps, which contain the water. The inner tray is placed below the outer tray and the space between inner tray and outer tray is filled up with glass wool for insulation. Below the inner tray, glass wool is provided to prevent the heat losses. At the lower end of the inner tray, the distilled water collecting trough is provided to collect the distillate. On the upper side of inner tray glass cover is provided.

iii. Steps:

There are 8 numbers of steps each of 40mm height and base is 98mm. The steps are coated with lamb black so that maximum of the solar energy could be absorbed.

iv. Distillate collecting trough:

It is made up of aluminum sheet of dimension 550mm x 50mm x 50mm. The trough is placed lowermost part of the glass cover so as to collect the condensate. One tap is connected with the trough with a pipe to get the distillate output.

v. Glass:

Glasses used in these solar stills are 3.5 mm thick. The dimension of the glass is same as that of inner tray. It allows the radiation to enter the basin containing water. It also helps the evaporated water to condense when vapor come in contact of it and get it collected in the trough. The glass is provided with the metallic frame with hinges at the one side to open the basin for cleaning when the salt is deposited on the surface of the basin.

B. *Performance Studies*

Experimental validation of Solar Still is briefly discussed along with their performance in day as well as night time.

i. Experimental Procedure:

Experiments done on the fixed conventional design of the solar still were carried out on successive days during the period March 2013- April 2013. Each experiment started from 9:00 am in the morning to 8:00 pm in the evening. The electrical and electronic parts were tested and calibrated before being used on the various designs of the solar stills. The first part of this research work was to test the stepped type solar still in a fixed position towards the south. Thermocouples were installed on the solar still system at different locations. These locations were:
(a) A basin base to measure the temperature of the plate, (b) Inner surface of the glass,
(c) Outer surface of the glass,
(d) Water temperature in the basin, and
(e) Water vapor.

The most important factor that affects level of production of the solar still is the amount of solar radiation on the glass cover, called irradiance. Not all of the solar energy that contacts the glass will actually be used for evaporation of the water in the basin because it gets reflected and absorbed by anything it passes through. If the still is not perfectly sealed and insulated there will be heat losses to the surroundings.

Table I
Measuring Instruments

Sr.No.	Name of instrument	Parameter to be measured
1	Thermo couple	Temperature
2	Collecting vessel	Distillate yield
3	Kipp – Zonan solarimeter	Solar intensity
4	Vane type digital anemometer	Wind velocity

Table II
Equipments

Sr. No.	Component	Description
1	Saline water storage tank	1000 liters capacity
2	Stepped type absorber plate	GI sheet
3	Coating of absorber plate	Black paint
4	Shapes to be provided to the steps	Rectangular plain
5	Metal box	Overall Dimensions: 1067mm(L)*686mm (W)*267mm(H)
6	To compensate loss of water	Every one hour

Table III
Design Parameters

Name of Still	Design Parameter			
	Depth of water in mm	Glass cover thick--ness in mm	Shape of the basin	Additionl features
A	7.5	4	Rectan-gular plain	
B	7.5	4	Rectan-gular plain	Paraffin wax as PCM

Assumptions that are made when performing a theoretical thermal analysis on a solar still:

1) The area of the glass cover is the same as the area of the basin.
2) There is no temperature gradient across the depth of the water or the glass.
3) The change in density and specific heat of the water with change in temperature is negligible.
4) The heat capacity of the glass is negligible.
5) The still is airtight.
6) The energy that the water absorbs contributes to the temperature rise of the water, which leads to evaporation.

C. Skills required for building, operating and maintaining a basic still

Craftsmanship and attention to detail in construction are important for an efficient, cost-effective still. In addition, supervisory personnel must be on hand who know how to size stills to meet a community's water supply needs; who now how to orient stills; that are familiar with required construction techniques; and who have the ability to train others in the construction, operation and maintenance of stills.

V. OBESERVATION

The energy required to evaporate water is the latent heat of vaporization of water. This has a value of 2260 kJ/kg. This means that to produce 1 liter (i.e. 1 kg since the density of water is 1kg/liter) of pure water by distilling brackish water requires a heat input of 2260 kJ. The glass, basin water and basin temperatures, as well as the accumulated distillate, were measured every half hour during each experiment for both stills. This data was intended for comparison with a proposed mathematical model for the still with PCM. Table 1 lists the different parameters studied.. The main characteristics of the paraffin wax used were: colorless, density of 51 kg/m3 and void fraction of 88%. When using all the reference parameters above, approximately 10mm of the height of the PCM bowl was below the basin.

Readings were taken in the month of April at RSCE, buldhana from 9 a.m. to 8 p.m.

Table IV
The hourly reading of solar still with PCM on Friday, 26 April, 2013

Sr. No.	Time T (hr)	Temperature in °C						Distil la-te W ml
		Tb	Tw	Tgi	Tgo	Tpcm	Ta	
1	9.00	52.0	50.8	50.0	45.1	40.5	36.4	00
2	10.00	63.2	61.8	54.0	47.0	41.1	39.4	100
3	11.00	66.5	65.2	60.4	53.7	44.0	41.8	145
4	12.00	72.1	71.2	63.3	59.1	50.3	42.8	200
5	13.00	73.8	72.4	67.0	61.2	53.3	44.2	300
6	14.00	74.0	73.3	64.8	59.0	56.0	43.8	390
7	15.00	70.0	69.8	60.9	54.8	54.6	42.0	300
8	16.00	64.5	63.4	55.6	48.2	50.0	41.1	255
9	17.00	58.2	58.0	46.2	39.8	43.3	33.6	255
10	18.00	52.4	51.0	38.0	32.5	35.5	31.8	200
11	19.00	49.0	48.2	33.5	31.2	34.7	29.0	70
12	20.00	47.2	46.9	30.0	29.7	33.0	28.7	40

Table V
The hourly reading of solar still without PCM on Friday, 26 April, 2013

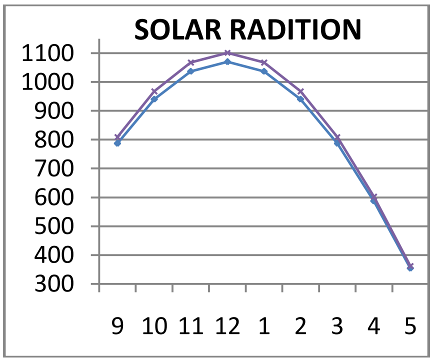
Sr. No.	t hr	Temperature in °C					W ml
		Tb	Tw	Tgi	Tgo	Ta	
1	9.00	61.0	60.4	50.6	45.8	36.4	00
2	10.00	62.0	61.8	53.4	47.0	39.4	130
3	11.00	68.4	67.0	60.4	54.7	41.8	185
4	12.00	73.2	72.4	65.4	60.2	42.8	225
5	13.00	75.3	74.4	68.0	62.6	44.2	280
6	14.00	74.5	72.8	64.8	59.3	43.8	350
7	15.00	70.6	69.4	60.7	54.8	42.0	290
8	16.00	66.8	65.4	57.6	49.7	41.1	245
9	17.00	56.2	55.8	45.8	39.8	33.6	205
10	18.00	49.0	48.6	38.8	33.5	31.8	194
11	19.00	45.2	44.4	35.4	31.8	29.0	00
12	20.00	42.0	41.2	31.4	30.0	28.7	00

VI. RESULTS

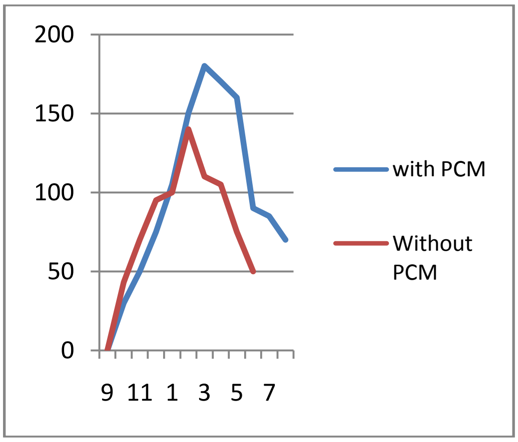
The experimental setup was designed and installed at Workshop, Department of Mechanical Engineering, RSCE, Buldhana (19°51'N / 75°57'E) India. The experiments were started at 9:00 A.M. under simulated conditions with an aim to record the temperatures of ambience, outer and inner surfaces of glass cover, basin liner, stored water and PCM at every one hour interval till 8:00 P.M. Table shows the typical values of the data recorded for 40 kg water of Solar Still with and without PCM on typical sunny days. Figure 8 and 9 show the temperature variations of basin water, outer and inner surfaces of glass cover, basin liner, stored water with the time of the day. It is clear from the figures that the increase in temperature is directly proportional to the input energy which is similar to the trends of solar radiation till 6:00 PM. The latent energy stored in the paraffin wax keeps the system operational during the night to deliver distillate output. However, the decreasing trend of all above temperatures show that the quantity of distillate output is reduced

Table VI
Comparison of distilled water output for with and without PCM

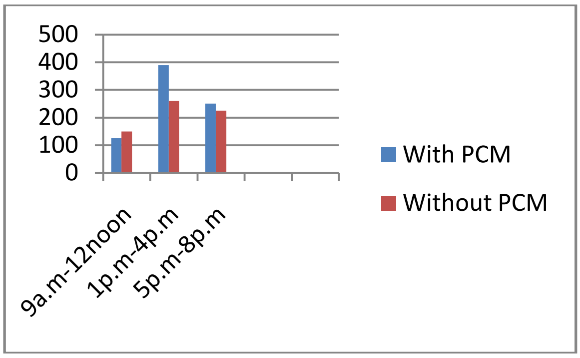
Sr. no.	Time (hr)	Distillate in ml	
		With PCM	Without PCM
1	9.00	0	0
2	10.00	100	130
3	11.00	145	185
4	12.00	200	225
5	13.00	300	280
6	14.00	390	350
7	15.00	300	290
8	16.00	255	245
9	17.00	255	205
10	18.00	200	194
11	19.00	70	0
12	20.00	40	0



Graph 1 Comparison of solar radiation with time



Graph 2 Efficiency of Solar Still with and without PCM



Graph 3 Distillate by Solar still with and without PCM

VII. CONCLUSION

Thermal energy storage is known as one of the best solutions for tackling cooling and heating issues in narrow temperature range, as well as one of the most environment friendly technologies. This study shows the potential of integration of phase change material with solar still system for producing potable water in rural, semi urban and urban areas throughout the day and night. The preliminary results show that the system dramatically increases the productivity of 35-40% as compared to conventional solar stills.

Future Scope

Worldwide experience in researching and marketing solar stills over three decades has provided an ample foundation for a solar still industry. No inherent technical or economic barriers have been identified. Followings may be the future solar still with PCM

1) Where there is a Scarcity of pure drinking water, and
2) At hotels and Dharmshalas as Solar heater, as hot water is available also at night.

Nomenclature

Tpcm- temperature of Phase change material, [^{o}C]
Tb- temperature of base plate, [^{o}C]
Tgi- temperature of inside glass cover, [^{o}C]
Tgo- temperature of outside glass cover, [^{o}C]
Ta- ambient temperature, [^{o}C].
Tw- temperature of water, [^{o}C]
t- time
W- Distillate

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