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Solar Still using Phase Change Material (Paraffin Wax)

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***Abstract* - The fast depletion of exhaustible source of energy has increased the popularization of solar energy. Solar Energy is free, unending and eco-friendly. The high reliability of this source has resulted in number of research works. The present work focuses on Latent heat thermal energy storage system concept in basin type solar still. Solar still has been mainly used for distillation which is one method of getting pot table water form brackish or saline water. In present work solar still with stepped absorber plate, single slope glass plate were constructed with and without latent heat thermal energy storage system (LHTESS). Paraffin wax is selected as the phase change material (PCM) which act as LHTESS. The water condensate on the inner glass is removed with a time interval of 30 minutes with minimum possible velocity. For each modifications hourly output, instantaneous efficiency are recorded and compared with conventional still. This system is new suited for water desalination in remote areas and rural places which have low congestion and limited demand.**

"Solar distilled water is ultra – pure and always free to use"

Key Words: Radiation, Convection, Conduction, Pyranometer, Solar Still.

INTRODUCTION

Energy, the very name indicates the potent backbone behind every force, action, motion, and the list goes on without a pause. Energy is essential for us to do each and every work. Similarly machines also need energy for their function. A water-wheel will not revolve, unless there is no falling water to drive it a railway locomotive will never move out of the station, unless there's coal to burn and make steam (or) oil to burn to drive its diesel engines, great factories, full of machinery will produce nothing, unless there is electricity (or) steam or some form of energy to drive the machineries. The modern era, now termed as "Space Age" or "Computer Age" will be nothing, if we imagine energy as a non-existing one. In today's world we need to search a lot for energy source, it's not an easy thing. According to the prediction of the scientists, the conventional sources of energy in the global level, particularly the heat energy will be lost in eighty to hundred years i.e., the heat energy is obtained by burning wood, charcoal, coal, straw, plant wastes etc. Also the heat energy is released by disintegration of the atoms which is also known as atomic heat energy. Most of the power plants are also using this type of heat energy and they are known as atomic power stations. "But the heat energy released by the sun will last for centuries". Therefore it is necessary to study about the effective utilization of non-conventional energy and the conversion of them as one of the conventional source of energy. In this work performance of solar is still analyzation with and without Latent heat thermal energy storage system (LHTESS). Paraffin wax has been used as PCM which act as LHTESS.

LITERATURE SURVEY

1) A.A. El-Sebail, etal., has proposed a mathematical model to analyze the thermal performance of a single basin solar still with a PCMs storage medium.

In their paper, the authors have presented a transient mathematical model for a single-slope basin type solar still with and without PCMs under the basin liner of the still. Analytical expressions for temperature of still elements and numerical calculations have been carried out, using stearic acid as PCM during typical summer and winter days in Jeddah (latitude 21º42' N, longitude 39º11E) Saudi Arabia. The investigation is mainly based on efficiency and productivity of solar still and the effect of mass of the PCM on the day light.

The tests were conducted during summer and winter days to compare the daily efficiency of still with and without PCM. They reported that the efficiency increases by 85% for a still with PCM than that of the other. Also PCM is effective for lower masses of basin water during winter season.

2) F.F Tabrizi, et al., have conducted an experimental investigation on a weir-type cascade solar still with built-in latent thermal energy storage system.

Two cascade solar stills were constructed with and without latent heat thermal energy storage system by suing stearic acid as phase change material in their study. The experiment was constructed to compare the productivity of solar stills in five sunny days under weather condition of Zahedan city in east of Iran. The total productivity of still without LHTESS was slightly higher than the still with LHTESS in sunny days. There was a significant difference in productivity of still with and without LHTESS.

They have reported that the still without LHTESS was preferred for sunny days due to its simplicity and low construction cost and the still with LHTESS was proposed for partially cloudy areas due to its higher productivity.

3) Farshad Farshahi Tabrizi, et al., has investigated the effect of water flow rate on internal heat and mass transfer and daily productivity of a weir type cascade

solar still. The work was on the internal heat mass transfer and daily productivity of cascaded solar still. The work was on the internal heat and mass transfer coefficients were determined using the experimental data obtained from the modified cascade solar still designed. The results showed a decrease in the internal heat and mass transfer rates as well as daily productivity with an increase in water flow rate. The daily productivity obtained was about 7.4 and 4.3 kg/m^2 day for minimum and maximum flow rates.

SOLAR ENERGY

India being a tropical country is blessed with a lot of sunshine whose availability extends to more than nine months in a year. An important input parameter is the global solar radiation received. This in turn is a function of several variables such as the nature and extent of cloud cover, water vapor content and other atmospheric constituents such as O_2, N_2, CO_2, O_3, dust etc., It is therefore not always possible to predict the actual of irradiant for a given location. Nevertheless the analysis of long term meteorological data on solar radiation makes it possible not only the inter-relationship between its components but also the types of parameters governing the statistics of their characteristics distributions. Attempts have been made to determine the hourly values of total radiation through its relationship with the daily solar radiation.

Accurate methods of determining incident and transmitted solar radiation values on inclined surfaces from horizontal solar data are usually required in the design, dynamic performance evaluation and control of solar energy systems and devices. Hence a thorough study about the structure, energy of the sun becomes very essential.

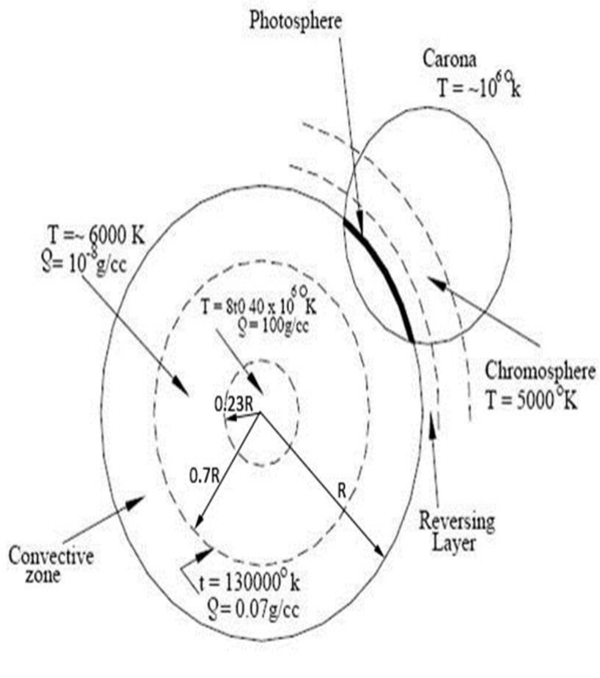

Figure 1: Structure of the sun

The sun is our nearest star, which is a sphere of intensity not gaseous matter. The principal characteristics of the sun are mass

Mass = $(1.991 \pm 0.001) \times 10^8$ m

Radius = $(6.960 \pm 0.001) \times 10^8$ m

Average density = 1.410 ± 0.002 g/m^3

Desistance from the earth = 1.5×10^8 km

Average surface temperature= 5762 ± 50ºK

Temperature of the core = 1.5×10^7 K

The sun's great energy release is the result of an elaborate chemical press in sun's core. The process of thermonuclear fusion like the reaction in hydrogen bomb. At the tremendous heat in the sun's interior, hydrogen atoms fuse with helium atoms to produce the energy that power the planet earth. So the energy can only be released in the form of radiation rays of heat energy. The sun radiates power into earth atmosphere at a fairly constant rate. This regular and dependable energy supply from the sum per unit time, received on a unit area of the surface perpendicular to the radiation in space is called the "Solar constant" and it can be measured just one square foot of the outside of the earth's protective air layer of gets a whopping average of 453.70 kJ/hr. Solar energy represents the only totally non-polluting inexhaustible energy resources that can be utilized economically to supply man's energy needs for all time. Each wave beam of sun-light consists of tiny solar energy nits called "photons" and these photons are being fired at earth. They arrive in shorter wave-length mean more photons and thus more power. Infrared rays which give the heat have longer wave-length and like ultraviolet rays they are invisible to earth. The sun's energy that actually reaches the earth is about 870% visible light 4% ultraviolet light and about 16% infrared

The cover is transparent for the sun's radiation at 0.1h to 3h wave lengths. Hence solar radiation passes through the glass and strikes the metal plate which is blackened with black board paint to increase the absorptive. The black plate by virtue of this temperature limits radiate at wave length above 3 h (long wave radiation). The glass allows short wave radiation to pass through it but it becomes opaque for reradiated long wave radiation. The solar energy once it passes through the glass cannot leave the box and thus the sun's radiation is trapped in a flat plate solar collector. This is called greenhouse effect.

The sunrays comes to earth in three different forms

1. Direct parallel rays
2. Diffused radiation and
3. Global radiation

The penetrated rays are called direct radiation. When there is haze cloud cover, some or dust in the air, the parallel pattern is broken and the rays are reflected off in many different directions by those particles of water or dust in the atmosphere. This is why heat and light often seems to come to earth from all parts of the sky. "Diffused

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radiation", as this is called is a still very strong and is useful to earth if there is a right kind of solar collector.

Here what happens to the solar constant, when solar rays hit the atmosphere.

1. 50% is reflected off the earth itself
2. 20% is reflected off the clouds
3. 23% reaches the ground as diffused sun-light
4. Only 27% actually reaches as the direct parallel rays

After most of the strongest and most harmful rays have been filtered out and a large share of the sun's energy has been dissipated, the average solar intensity on the ground is still 2365 kJ/hr.m^2.

The Indian metrological department has charted out the following table for solar radiation (kJ/m^2) for some cities in India.

Table: Data on SOLAR RADIATION

City	Average	Maximum	Month	Minimum	Month
Ahmadabad	1801	2721	May	1620	Dec.
Kolkata	1745	2269	May	1465	Dec.
Chennai	2013	2445	March	1482	Nov.
Jodhpur	2139	2725	May	1570	Dec.
New Delhi	1946	2625	May	1625	Dec.
Pune	2039	2595	May	1624	Dec.
Trivandrum	2039	2357	March	1741	July

The monthly average is 52.33 kJ/m^2 per month. Thus the earth's surface receives nearly 628.08 kJ/m^2 per year giving a total incident radiation on India of approximately 2512 kJ year.

SOLAR RADIATION MEASURING INSTRUMENTS CLASSIFICATION

1. Pyrheliometer

A Pyrheliometer is an instrument for measuring the intensity of direct solar radiation at normal incidence; it can either be primary standard instrument (or) a secondary instrument scaled by reference to a primary instrument.

2. Pyranometer

A Pyranometer is an instrument for the measurement for the measurement of the solar radiation received from the whole hemisphere. It is easy to measure the global (or) sky radiation with pyranometer. Sometimes the term solar meter is used instead of Pyranometer.

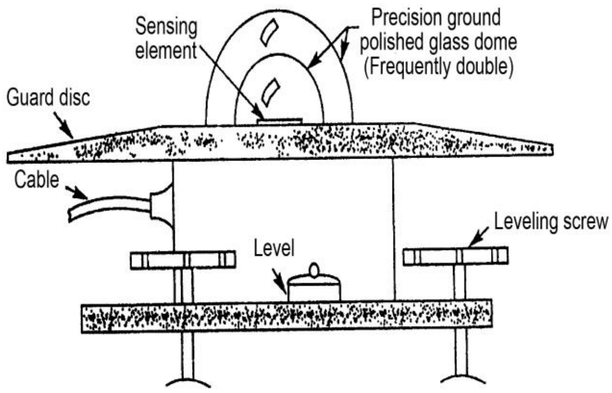

Figure 2: Typical Pyranometer

PHASE CHANGE MATERIALS [PCMs]

1. INTRODUCTION

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units.

A large number of PCMs are available in any required temperature range from -5°C up to 190°C. Within the human comfort range of 20° to 30°C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry, or rock.

2. PCMs SELECTIONS CRITERIA

Thermodynamic Properties

a. The phase change material should possess melting temperature in the desired operating temperature range
b. High latent heat of fusion per unit volume
c. High specific heat, high density and high thermal conductivity
d. Small Volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem
e. Congruent melting

Kinetic properties

a. High nucleation rate to avoid super cooling of the liquid phase
b. High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system

Chemical properties

a. Chemical stability
b. Complete reversible freeze/melt cycle
c. No degradation after a large number of freeze/melt 3 cycles
d. Non-corrosiveness, non-toxic, non-flammable and non-explosive materials

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Economic properties

a. Low cost

b. Large-scale availabilities

SOLOAR STILL

1. INTRODUCTION

Solar still is a way of distilling water, with the help of the heat of the sun (more exactly, the heat & humidity of the soil, and relative cool of the plastic). There are different types of solar stills. But there are two basic types. They are (i)box and (ii)pit type. In a solar still, impure water is contained outside the collector, where it is evaporated by sunlight shining through clear glass plate. The pure water vapor (and any other included volatile solvent) condenses on the cool inside glass surface and drips down off of the weighted low point, where it is collected and removed. The box type is more sophisticated. Solar stills are used in places where rain, piped, or well water is impractical. Solar distillation provides an surrogate source of clean water. Anyhow depending on the environmental conditions, the outcome is relatively small amount of water or even less when the source is saline or brackish. As a still, it eliminates all harmful microbes, chemical contaminates, salt, minerals, and any other impurities from most water.

2. WORKING PRINCIPLE OF CONVENTIONAL SOLAR STILL

Below given figure 3 shows the Energy Balance and Thermal Energy of various components of a conventional solar distiller unit. It is an air-tight basin, usually constructed out of concrete/cement/ Galvanized Iron Steel (GI)/fiber reinforced plastic (FRP) with a top cover of transparent material like glass, plastic etc. The inner surface of the rectangular base is blackened to efficiently absorb the solar radiation, incident at the surface. There is provision to collect the distillate at lower end of the glass cover. The brackish or saline water is fed into the basin for purification. The working principle of the distiller unit is described here briefly. The solar radiation, after reflection and absorption by the glass cover is passed-on inside an enclosure of the distiller unit. This carried radiation [τ_g I(t)] is further partially reflected [R'_w I(t)] and absorbed [α'_w I(t)] by the water mass. The attenuation of solar flux in water mass depends on its absorptive and depth. The solar radiation finally reaches the blackened surface where it is mostly absorbed. After absorption of solar radiation at the blackened surface, generally known as the basin liner, most of the thermal energy is convicted to water mass and a small quantity is lost to the atmosphere, by conduction. Sequentially the water gets heated, leading to an increased difference of water and glass cover temperatures. There are basically three modes of heat transfer, radiation (rw), convection (cw) and evaporation (ew) for the water surface to the glass cover. The evaporated water gets condensed on the inner surface of the glass cover after releasing the latent heat. The condensed water dribbles into the channels provided at the lower ends of glass cover, under gravity. The collected water in the channel is taken out of the system for further use. The thermal energy received by the glass cover through radiation, convection and latent heat, is lost to the ambient by radiation and convection.

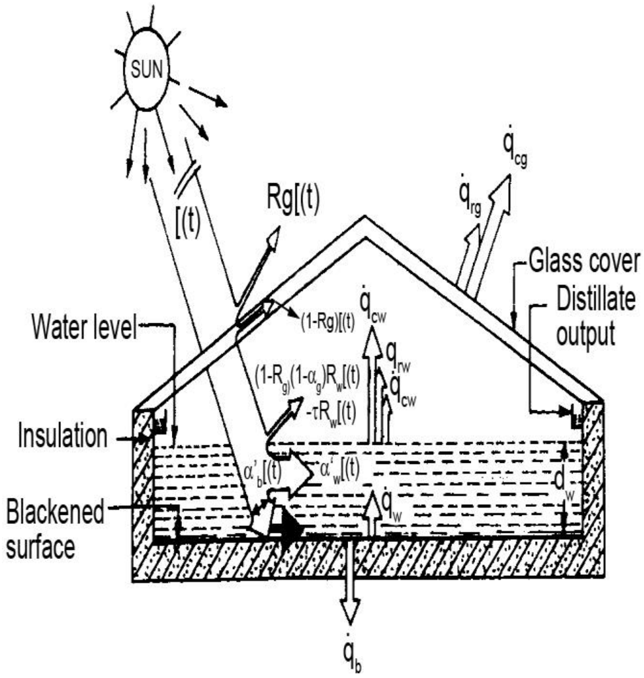

Figure 3: Energy flow diagrams in a conventional solar still

3. FACTORS AFFECTING SOLAR STILL PERFORMANCE

The yield from a solar still depends on the temperature difference between the water in the basin (T_w) and the condensing cover (T_c). The higher the value of $T_w - T_c$, the greater is the yield.

A. Effect of wind velocity

As concluded the output increases by 11.5 percent for average wind velocities from 0 -2.15 m/sec, while the increase is only 1.5 percent for average wind velocities from 2.15 m/sec to 8.81 m/s. Thus, wind blowing over the glass cover causes faster evaporation from it resulting in a fall in the temperature; thus the yield from the solar still increases for larger water depth in the still.

B. Effect of Ambient temperature

With the decrease in the ambient temperature, the glass temperature decrease and the difference ($T_w - T_g$) increases, hence the output increases.

C. Effect of solar radiation and loss coefficient

Solar insolation is an important parameter in the determination of yield for a solar still an any day. The output will, to an extent, depend upon the distribution of the radiation throughout the day, however, this is a second-order effect and it is usually sufficient to take into account the total radiation received on each day.

D. Effect of Double-glass cover and cover inclination

The effective thermal barrier between the two glass covers impedes the rejection of heat through the condenser

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as a result the output is reduced. (This is beneficial in the case of flat plate collector, as the heat loss is reduced). Even with very high water temperatures the governing factor is the low water-glass temperature difference. Although a high water temperature leads to a higher evaporation, the low temperature difference results in a considerably reduced total energy transfer.

E. Effect of Salt concentration on output

Experiments have shown that as the salt concentration of the water to be distilled increases right up to the saturation point, the output of the still falls linearly. However, as the salt concentration of the water increases, there is an increase in the corrosion damage to the components of the still and thus it becomes necessary to use materials which are not readily oxidized.

F. Effect of thermal capacity on output

Cooper (1969 a) has studied the effect of water depth on the distillate output. As can be seen from the figure, without insulation, the gains from decreasing the water depth are only marginal, but with insulation, the difference is more marked, particularly, at lower water depths.

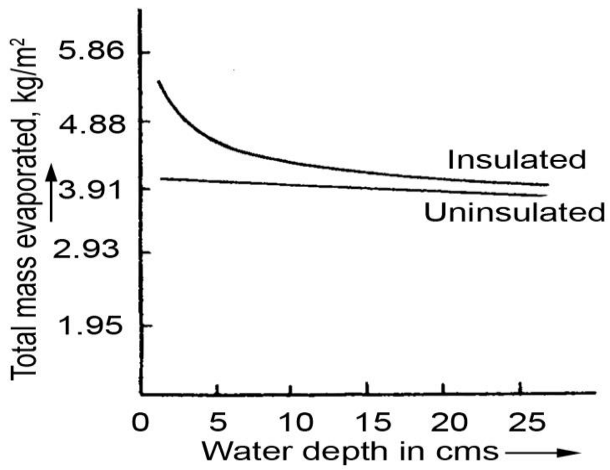


Figure 4: Effect of water depth on daily yield

G. Effect of charcoal pieces on the performance of a still

Charcoal pieces affect the performance of a still because of their wet ability, large absorption coefficient for solar radiation and their property to scatter, rather than reflect, the solar radiation.

H. Effect of the formation of algae and mineral layers on water and basin

As reported by Cooper (1972), the presence of deposits on the surface of the basin water and basin liner has a detrimental effect on the output, assuming that no other factor becomes significant. He showed that surface reflection appears to be more detrimental than basin liner reflection because of the absorbing properties of the basin liner, except at normal incidence of isolation.

DESIGN OF THE PROJECT

Material : G.I

Length of collector : 1 m

Width of collector : 0.75 m

Area of collector: 1 X 0.75 = 0.75 m^2

Air gap between glass

plate and Collector : 5 cm

Size of step : Horizontal surface - 5 cm

Vertical surface - 3 cm

Number of steps: 15

All dimensions are in mm

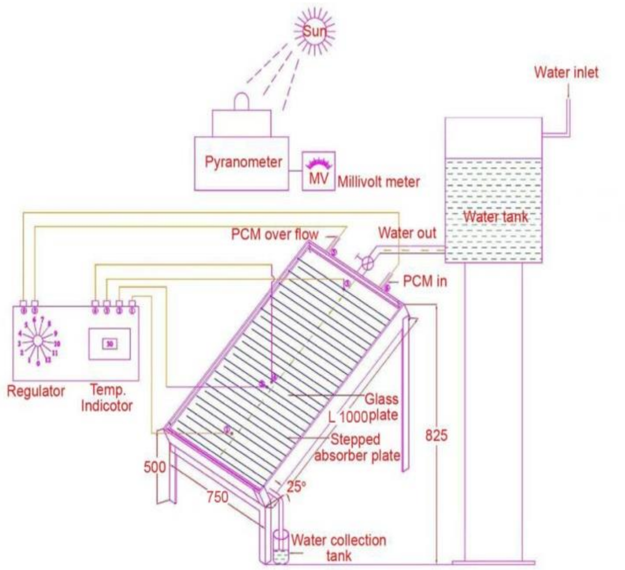


Figure 5: Schematic diagram of Solar-Still

RESULT AND DISCUSSION

Table: Result tabulation for without PCM

DATE- 10/10/2019				**DAY**- THURSDAY		
Sl. No.	Time	Absorber plate temp. (°C)	Glass Plate temp. (°C)	Solar Intensity (kJ /hr m^2)	Efficiency (%)	Condensate collected (ml/hr)
1	10.00	61	45	2439.32	38.29	
2	10.30	66	48	2800.70	43.69	
3	11.00	70	64	3026.57	51.83	280
4	11.30	72	68	3162.09	61.40	
5	12.00	77	75	3162.09	64.33	330
6	12.30	79	78	3207.26	66.97	
7	13.00	82	80	3162.09	61.42	350
8	13.30	82	80	2981.40	60.52	
9	14.00	80	77	2710.36	55.70	320
10	14.30	79	75	2620.01	53.44	
11	15.00	75	71	2168.29	47.74	300
12	15.30	72	67	1942.42	41.47	
13	16.00	71	66	1806.91	38.31	250

Total condensate collected = **1830 ml/ day**

GRAPHICAL REPRESENTATION

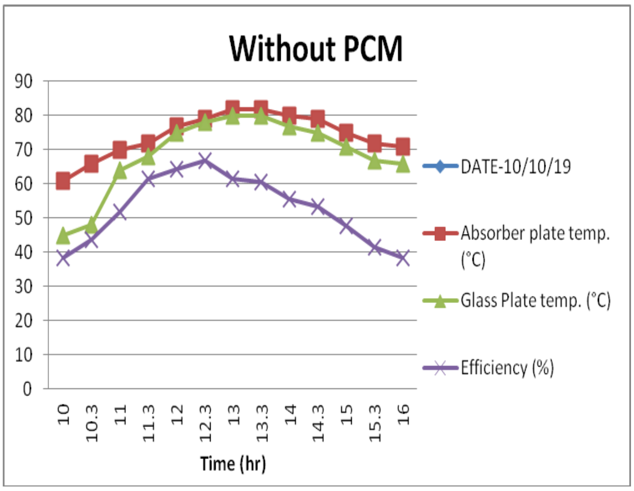
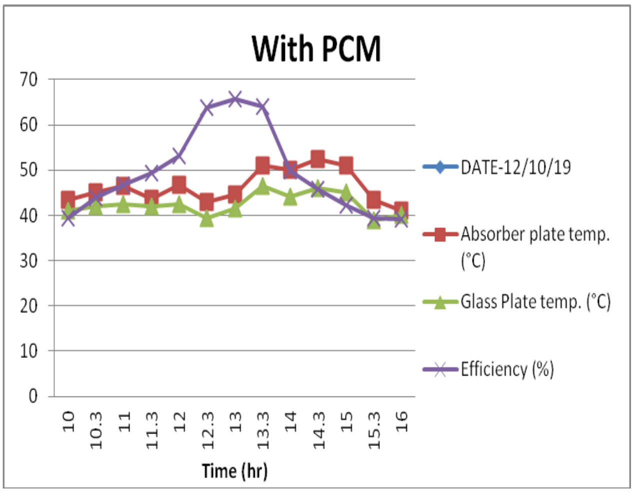


Table: Result tabulation for with PCM

Total condensate collected = 1910 ml/ day

GRAPHICAL REPRESENTATION



EXPERIMENTAL SETUP OF SOLAR-STILL

Photographic View Of Experimental Setup

DATE- 12/10/2019				**DAY-** SATURDAY		
Sl. No.	Time	Absorber plate temp. (°C)	Glass Plate temp. (°C)	Solar Intensity (kJ /hr m^2)	Efficiency (%)	Condensate collected (ml/hr)
1	10.00	43.33	41	2348.98	39.29	
2	10.30	45.00	42	2574.84	43.81	
3	11.00	46.50	42.5	2845.88	46.83	260
4	11.30	43.70	42	1626.22	49.27	
5	12.00	46.70	42.5	3116.91	53.18	290
6	12.30	43.00	39.5	3207.26	63.87	
7	13.00	44.50	41.5	3297.60	65.71	395
8	13.30	51.00	46.5	3252.43	64.12	
9	14.00	50.00	44.2	3026.57	49.81	300
10	14.30	52.50	46	2710.36	45.81	
11	15.00	51.00	45	2529.67	42.12	285
12	15.30	43.50	39	2348.98	39.29	
13	16.00	41.00	40	2258.63	39.12	380

Photographic View Of PCM (Paraffin Wax)

CONCLUSION

The proposed design of stepped solar still with and without phase change material shows great potential in terms of higher distillation yield per unit area as compared to other available designs of solar still.
The concluded results are presented as follows:

- Using stepped solar still will increase the residence time which enhances the condensation process leads to higher productivity.
- The total productivity of still with phase change material is slightly higher than the still without phase change material.
- Increasing the flow rate results in decreasing in total productivity highest total productivity is achieved in the lowest possible flow rate.
- Preliminary tests on the distilled water proved that the distilled water is suitable for domestic usages.

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