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Efficiency Improvement of Flat Plate Solar Collector using PCM, Reflector, Inserted Twisted Tape and Wire Coil

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Abstract - *Solar energy is the one of the most renewable source of energy here we are conducting an experimental study to improve efficiency of flat plate solar collector with phase changing material, reflector, inserted twisted tape and wire coil. The wire coil is used as turbulator is placed inside the flow tube. The twisted tape inserted into the wire coil to create continuous swirling flow along the flow tube wall. The inserted twisted tape and wire coil improve the heat transfer rate. The phase changing material improves the efficiency of solar collector by decreasing the thermal loss and paraffin wax is used as phase changing material. The efficiency decreases with increasing mass flow rate, because at a high flow rate the water does not get enough time to absorb heat from the collector. The reflector introduced on the solar collector to concentrate both diffuse and direct solar radiation on to the solar collector. To maximize the intensity of solar radiation, the angle of reflector change with the position of sun. A prototype of flat plate solar collector is fabricated and conducting an experimental study .The presence of reflector on solar collector increases the efficiency of the collector. It is observed that solar collector with reflector always produce a higher temperature compare to without reflector.*

Key Words: **Flat plate solar collector, Phase changing material, solar water heating system.**

1. INTRODUCTION

There are three types of solar collector flat plate collector, parabolic trough collector and mirror strip collector. Due to simple in design, the flat plate collector is used for water heating. From the studies there is a proposal to design an efficient and cost effective inserted twisted tape with wire coil solar collector coupled with phase changing material and reflector , is placed into the roof top of a building, as the roof has maximum exposure to sunlight throughout the day. This large amount of unused roof area could be used for water heating purpose for domestic, commercial, and industrial application such as bathing, washing and cooking. The designed solar collector consist of an wire coil used as a turbulator is placed inside the copper tube while the twisted tape is inserted into the wire coil to create a continuous swirling flow along the tube. The inserted twisted tape with wire coil is also increases the heat transfer rate by increasing the heat transfer area and it increase the pressure drop. The inserted twisted tape and wire coil is, kept in a wooden box (collector). The collector consists of a mirror to reflect solar radiation on to the absorber plate. The reflector is introduced here to concentrate both the direct and diffuse radiation of the sun on the collector, which will increase the temperature difference between the inlet and outlet water flow through the collector. To observe the improvement of performance, the collector efficiency for two conditions with and without reflector is obtained in this experiment. The results are also compared. The efficiency of the collector is directly proportional to the difference between the inlet and outlet temperature. PCM with high latent heat, high thermal conductivity and specific heat are suitable for solar water heating system. PCM improve the efficiency of a solar water heating system by decreasing the thermal loss.

2. DESIGN

2.1 Slope of the collector

The slope of the collector is calculated from

$$\beta = Q - d$$

Angle of inclination (d) is calculated by

$$d = 23.45 \sin[.9683(284 + n)]$$

Where, Q is the latitude at the test site & n is the day's number in that year.

$$Q = 12\ north$$

For March 20th

$$d = 23.45 \sin[.9683(284 + 80)] = -3.07$$

$$slope\ of\ collector\ (\beta) = 12 + 3.07$$

$$\beta = 15$$

The slope of the collector is varies between 13^0 to 17^0
For the performance, the slope of the collector is taken as 15^0. The collector is made to face the south direction because the Indian sub-continent lies in the northern hemisphere.

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1 Experimental setup

The prototype of flat plate solar collector with two reflectors is placed on the both side of the collector, the

prototype placed on a roof top of a building. The rectangular flat plate solar reflector consists of two mirror glass that was mounted on both sides of the collector. The collector absorbs the incident solar radiation falling on it and transfers this heat to the water flowing tube. The outlet of the tube is connected storage of 20L capacity. The experiment carried out in a clear sky day on March 21, 22. We studied the thermal behaviour of the collector. Where we measured the water temperature at outlet and inlet of the collector. The collector was designed in such a way that fluid can flow at constant flow rate. The experiments were performed with and without reflector to compare the change in efficiency for the two conditions.

3.2 Components

3.2.1Solar collector

Solar collector absorbs the incident solar radiation falling on it and transfers this heat to the water flowing in tube. The collector consists of a mirror to reflect or concentrate solar radiation on to the copper tube. The collector is covered with a transparent glass which limits the radiation and convection heat losses and to create a vacuum space between the transparent glass and mirror. The box consist of six copper tubes connected by U-bend and is brazed without leakage

3.2.2Inserted twisted tape and wire coil

The twisted tap and wire coil are inserted into to the copper tube to enhance the heat transfer rate. The twisted tape and wire coil used as a turbulator. The turbulator are inserted into the flow to provide an interruption of the boundary layer development, to increase the heat transfer surface area and to cause an enhancement of heat transfer by including the turbulence in the flow.

3.2.3Reflector

The both side of the solar collector is provided with a reflector to concentrate both diffuse and direct radiation of the sun towards the collector. The reflector generally consists of two pieces of mirror with a dimension of 1.1×.52×.004m that were mounted on both side of the collector.

3.2.4Phase changing material

PCMs with high latent heat, high thermal conductivity and specific heat are suitable for solar water heating applications. Paraffin wax is suitable for solar water heater due to its availability, non-corrosiveness, low melting point and low cost. The paraffin wax provides higher thermal efficiency for longer duration.

3.2.5Water supply and storage tank

The water tank of 30 liter capacity is used to supply the water to the solar collector. The tank is placed at 2meter height from the collector inlet for creating necessary pressure head for easy circulation of the water in the system. A tank of 20 liter capacity is placed at exist of the solar collector to collect the hot water. It should be insulated by aluminum foil to store the hot water for long time

3.2.6Flow tube

The flow tubes are the tube used to circulation of working fluid .The copper tube of diameter 28mm is used as flow tube in this experimental study and the thickness of the copper tube is .8mm. The thickness of copper tube is kept minimum for better heat transfer rate. Copper is selected as the flow tube material because of it thermal conductivity 401 $Wm^{-1}K^{-1}$.

Table 3.2.1 measuring instrument used

Sl no	Instrument	Range
1	Thermocouple	120°C
2	Pyranometer	1600Wm^{-2}
3	Measuring jar	500ml
4	Stop watch	---------

Figure 3.2.1 fabricated solar water heating system

3.3Experimental procedure

All the component of the flat plate collector is assembled together. The arrangement is placed on the roof top with clean sky day facing south direction with an inclination of 15 degree. Fill phase changing material paraffin wax in

PCM box. The cold water supply tank is filled with fresh and clean water and is placed at the height of 2meter. The collector is exposed to the sun. The water supply is started from 9.00 am. While the water is passing through the collector the Inlet temp and outlet temperature of water are noted down. Mass flow rate of water is measured by observing the time taken for the collection of 1liter of water using measuring jar and stop watch. Each experiment is conducted for 1 hour duration by maintaining constant flow rate of water. The readings are taken after every hour and are tabulated and the experiment procedure is repeated for the next day

4. RESULT AND DISCUSSION

The experiment is conducted several time in a day the position of reflector is changed with the position of sun. The solar rays always strike perpendicularly, the solar radiation losses or the reflection of the energy from the collector surface will be decreased, and the efficiency of a solar water heating system will be maximized. The experiment is conducted on 2019 march 20, 21 with and without reflector and the results are compared. The water supplied at a constant flow rate .0051kgs^{-1} and the hot water is should be insulated with aluminum foil to reduce the heat loss to environment

4.1 Efficiency of solar water heating system.

$$efficency = \frac{Qw}{Ac \times I}$$

Qw = Heat absorb by water (watts)
Qw =mCp(To-Ti)
m = mass flow rate(kgs^{-1})
Cp = specific heat of water(jkg^{-1}K)
Ti = inlet temperature(K)
To =outlet temperature(K)
Ac = Area of the collector(m^2)
I = solar radiation(w/m^2)

Table 4.1 Experimental readings taken on 20 march 2019 with reflector

Sl no	Time (hrs)	In temp Ti(^{0}C)	Out Temp To(^{0}C)	Change in temp	Solar Radiation (Wm^{-2})	Efficiency η
1	9.00	28	36	8	550	50.9
2	10.00	28.6	38.6	10	630.1	58.9
3	11.00	30.3	45.5	15.3	817	65.1
4	12.00	36	62.3	26.3	1160	79.3
5	13.00	36.3	68.1	31.8	1299.6	84.4
6	14.00	37	66.1	29.1	1290.02	78.9
7	15.00	38	60	22	1100.3	70
8	16.00	36	55.2	19.2	990	67.9

Table 4.2 experimental reading taken on 21 march 2019 without reflector

Sl no	Time (hrs)	In Temp Ti(^{0}C)	Out Temp To(^{0}C)	Change in temp	Solar Radiation (Wm^{-2})	Efficiency η
1	9	28	35	7	560	43.7
2	10	28.6	38	9.4	633.3	51.9
3	11	29.9	42.2	12.3	827.1	56
4	12	33.2	53.9	20.7	1127.2	64.3
5	13	34.5	59.3	24.8	1217.9	71.3
6	14	36	57	21	1100.1	68.4
7	15	36.2	54.2	18	1098.1	57.4
8	16	36	52.5	16.5	990	54

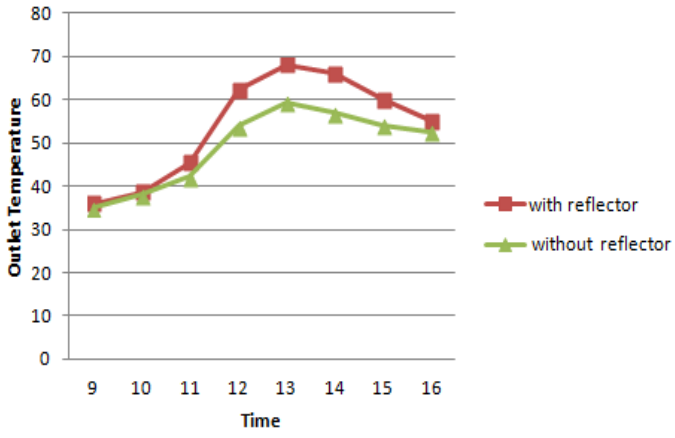

Figure 4.1.1 Hourly variation of outlet temperature with and without reflector

Figure 4.1.1 shows hourly variation of outlet temperature with and without reflector. The maximum of the outlet temperature of the solar collector with and without reflector achieved as 68.2^{0}C and 59.3^{0}C. It is observed that solar collector with reflector always produce a higher temperature compare to without reflector. The reflector

improves the outlet temperature by 10^0C. By adding reflector on both side of the solar collector it concentrates both diffuse and direct radiation on to the collector. The intensity of solar radiation on 20 march 2019 at 1.00 pm is 1299.6Wm^{-2} and the intensity of radiation on 21 march 2019 at 1.00 pm is 1217.2 Wm^{-2}. There is a slight variation in intensity of solar radiation on march 20 and 21.the outlet temperature is directly depends on the solar radiation the solar radiation increase the outlet temperature also increase and the radiation decreases the outlet temperature also decrease.

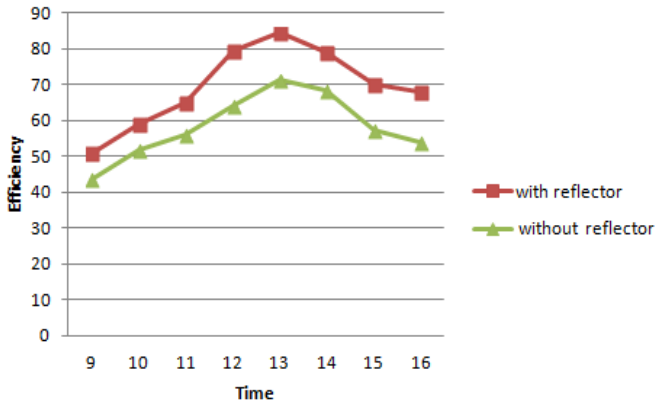

Figure 4.1.2 Hourly variation of efficiency with and without reflector

Figure4.1.2 shows the hourly variation of efficiency with and without reflector at flow rate of .0051kgs^{-1}. The maximum collector efficiency with reflector is 84% and without reflector is 71%. The presence of reflector on solar collector increases the efficiency of the collector by 13%. The efficiency of solar water heating system is directly proportional the outlet temperature. Finally it concluded that the present solar collector with reflector is performed better than solar collector without reflector. Find that the collector efficiency also decreases with increase in flow rate, because at high flow rate the water does not have enough time to absorb heat from the collector.

5. CONCLUSION

A proto type of flat plate collector with or without reflector was constructed and conducting and experimental study. the reflector introduced here to improve the efficiency of the solar water heating system and concentrate both diffused and direct solar radiation on to the solar collector. From the experiment study it is obtained that the efficiency of solar water heating system depends on solar radiation and temperature difference. The radiation emitted by the absorbing plate of solar collector cannot escape through the transparent glass it maximize the collector efficiency. The maximum collector efficiency obtained with reflector is 84% and without reflector is 71%. The presence of reflector on solar collector increases the efficiency of the collector by 13%. The maximum of the outlet temperature of the solar collector with and without reflector achieved as 68.2^0C and 59.3^0C. it is observed that solar collector with reflector always produce a higher temperature compare to without reflector. The reflector improves the outlet temperature by 10^0C.

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