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Efficiency analysis of Coconut Coir as an Insulation Material for Flat Plate Solar Water Heaters

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Abstract: *Flat plate solar water heaters (FPSWH) are widely used for sustainable and energy-efficient water heating. The thermal insulation of these systems plays a crucial role in minimizing heat losses and improving overall efficiency. This study evaluates the effectiveness of coconut coir as an eco-friendly and cost-effective insulation material for flat plate solar water heaters.*

The research involves experimental testing and thermal analysis to compare the performance of FPSWH insulated with coconut coir versus conventional materials such as fiberglass and polyurethane foam. Key parameters, including water temperature rise, heat retention, thermal conductivity, and system efficiency, are measured under varying solar radiation conditions.

The results demonstrate that coconut coir provides significant thermal insulation, reducing heat losses while maintaining competitive efficiency levels. Additionally, its biodegradability, affordability, and sustainability make it a viable alternative to synthetic insulators. This study contributes to the advancement of eco-friendly solar water heating solutions, promoting renewable energy adoption and sustainable material usage in thermal applications.

Keywords: *Solar water heater, flat plate solar collector, force circulation, coconut coir.*

I. Introduction

A Solar Water Heater is a device which provides hot water for bathing, washing, cleaning, etc. using solar energy. It is generally installed where sunlight is available and heat water during day time [1]. The solar energy is the most capable of the alternative energy sources. Due to increasing demand for energy and rising cost of fossil type fuels ex. gas or oil. Solar energy is considered an attractive source of renewable energy that can be used for water hearing in both homes and industry [2]. In developed countries energy consumption in the building sector represents a major part of the total energy budget. Most of this amount is spend for hot water production and space heating. One way to reduce this amount of energy is to use an alternative energy, clean, renewable, which respects the environment. [3]. Solar water heater seems to be viable alternative to As a result of increase of prices of fossil and nuclear fuels, a feasibility of solar energy as a new energy source can be increased, when a very high energy conversion efficiency and a reduction of cost of equipment is obtained, due above reasons, solar energy is one of the best possible and easily available energy. Flat plate collectors easily attain temperatures of 40 to 70ºC. [4]The experimental model of solar flat plate collector which is set up in Disha Institute of Management And Technology Raipur (CG) (Fig. 1). Our experimental model is completely based on to how to increase the outlet temperature of solar flat plate collector and also they cannot affect by weather condition. So the basic purpose of our experiment is to increase the outlet temperature and the efficiency of the flat plate collector.

Figure 1: Experimental set up of flat plate collector in DIMAT Raipur

And we know that the thermal loss to the surrounding is in important factor in the study of performance of a solar flat plate collector. Heat is lost to the surrounding from (a) the glass and (b) the plate through the insulation (referred as bottom loss). Thus we have to uses of coconut coir, a local vegetable fiber, and chips. Coconut coir is help to reduce the downward as well as side loss of the solar flat plate collector. It is one of the most interesting technological device, the simplest and the most largely widespread of solar energy exploitation.[5]

The Solar flat plate collector is work under a forced circulation system with the help of pump. When a large amount of hot water is required; a natural circulation system is not suitable. In case of forced circulation water heater, water pump at the inlet of a collector is used to transfer the hot water available at the upper header of collector to the insulated tank. The collector can also be a connected in series for higher temperature and also we want to reduce the bottom and side losses of the solar flat plate collector so that we have used coconut coir as an insulator.

2. Materials and Methods

The performance of a flat plate collector depends on its design parameters: Type of absorber, type of glass cover, thickness and type of insulation. The useful energy(Q_u) recovered by the plate collector is expressed by the heat balance of this collectors under steady state condition. It is given by Hottel and Whillier equations (1991):[6]

$$Q_i = AI$$

If (I) is the solar irradiation, in w/m2, incident on the aperture plane area (A) of the collector m2, then amount of solar radiation received by the collector is:

$$Q_0 = m_w \text{ x } C_p \text{ x } \Delta T \text{ watt/m}^2$$

$$Q_0 = m_w \times C_p \times (T_0 - T_i)$$

Design Parameters	*Value*
Length of the collector	1.83 m
Width of collector	1.22 m
Thickness of insulator	0.025 m
Thickness of plate	2 mm
Insulated material	Coconut coir
Material of the absorber plate	Copper
Density of coconut coir	1.40 g/cc
conductivity of the plate	386 kW/m
Moisture in coconut coir	(60-70) %
Maximum thickness of coconut coir	
Length of tube	1.8 m
Length of absorber plate	1.9 m

2.1 Experimental study and procedure

The general experimental device of flat plate collector, a solar integrator, a pyrometer and a data acquisition chart. The collector is identical in the design. They are (1.83 × 1.22) m^2 surface area. A diagrammatic representation is presented on fig.1 and their principal physical characteristics are presented in table 1. [6]

Flat Plate Collector

Where m_W = flow rate of the water;

C_p = specific heat of the water;

ΔT = different between outlet and inlet water temperature

2. Solar radiation falling on to the collector = $I_g = I_b + I_d$ watt/m^2.

Where, $I_b = I_{bm} \cos \theta_z$; I_{bn} = Aexp (- $\cos_z$)

I_d = C. I_{bn} ;

$\cos \theta_z = \sin\Phi (\sin\sigma \cos\beta + \cos\sigma \cos\omega \sin\beta) + \cos\Phi(\cos\sigma \cos\omega \cos\beta - \sin\sigma \sin\beta)$

or $\cos \theta_z = \sin\sigma \sin(\Phi - \beta) + \cos(\Phi - \beta) \cos\sigma \cos\omega$

Where, Φ = Latitude angle

σ = Declination

β = Till angle

ω = hour angle

Θ = zenith angle

Where, m is the water mass flow rate (kg sec^{-1}), C_p is the specific heat (J kg^{-1} K^{-1}), T_0 and T_i are outlet and inlet water temperatures (K). A measure of the collector performance is the collector effectiveness.

Table 1: Material selection and Design of the collector

solar irradiations are increases. In fig.-6 that show the maximum irradiation are get in 12 noon and also there is almost same for 1 and 2pm. The irradiation are decreases after comes by 3pm. And the ambient temperature is also decreases with respect to the irradiation. These two terms are more important to increase or decrease the efficiency of solar flat plate collector.

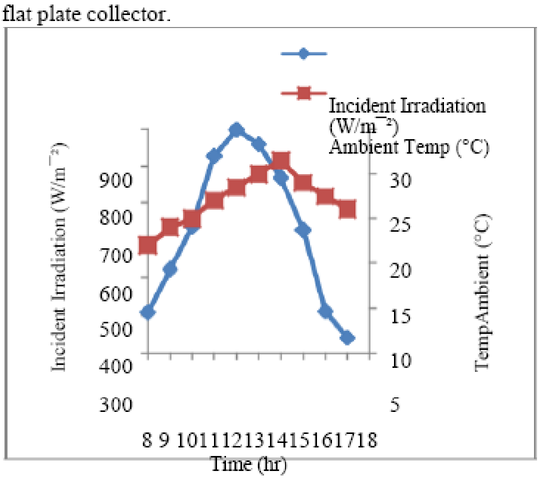

Figure 3: Instantaneous irradiation and ambient temperature for solar water flat plate collector

3.2 Variation of outlet temperature with time

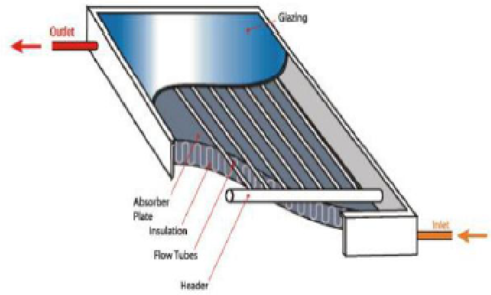

Figure 2: Cross sectional area of flat plate collector

This collector are composed each of a transparent the solar radiation in heat. A 3 cm thickness blade air separates the glass from the absorber (Candonnel, 1983). These absorbers are thermally insulated at the back and on the lateral sides by the coconut coir. Thermal insulation is 2.5 cm thickness. The coconut coir has a lifespan of more than ten years when it is under shelters (Ekoun,20071)[7] .

The incident solar radiation (I_g) is measured using a pyrometer. It is connected to a numerical integrator, allowing the reading of instantaneous powers and the energy received, by digital display, over one given period. In order to convert directly the radiation received into heat, the pyrometer is tilted in the same position as the collectors.

3. Results and discussion

3.1 Influence of solar irradiation and ambient temperature

In fig.3 that show the inter relation between the solar irradiation and ambient temperature. In the graph we seen that the irradiation are depends on the ambient temperature and yet if increase the ambient temperature respectively the

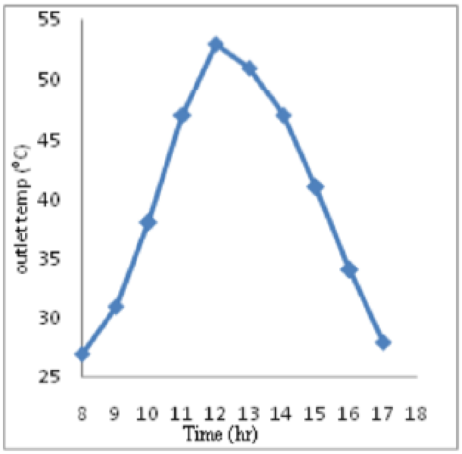

Figure 5: variation of outlet temp with time for 0.01 kg/s mass flow rate with insulation

3.3 Comparison of outlet water temperature with and without insulation

If we considered fig-6 it is show the actual comparison between both the graphs. Here we seen that an insulated region it give the maximum temperatures around 53°C and there is beneficial to the without insulation region. In fig -5, which show in below, in the graph we get the temp difference are 13°C that show the beneficial by using coconut coir as a insulator in Solar flat plate collector.

As well as we seen that in fig-4 which show temperature variation with time in without insulation condition. In fig, we get the temperature in 12 noon is maximum and it is 45°C. after they would be reduced with respect to time in evening.

In fig-5 show that, the variation of outlet temp with time. In fig. show that outlet temp are increase. It has been seen that the outlet temperature are maximum in the 12 noon and after they have decrease with increasing the schedule in evening time. Fig-4 shows the and we found out the maximum temp in 12pm. If we are comparing in both the graph, we get the maximum temperature in insulated condition.

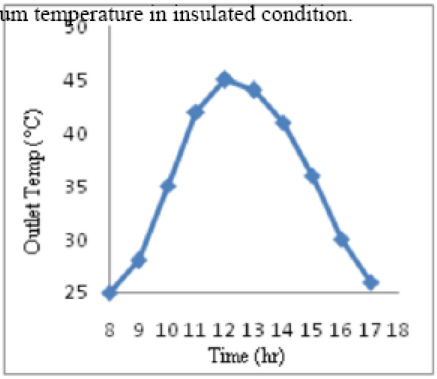

Figure 4: Variation of Outlet Temp with time, for 0.01kg/s mass flow rate without insulation

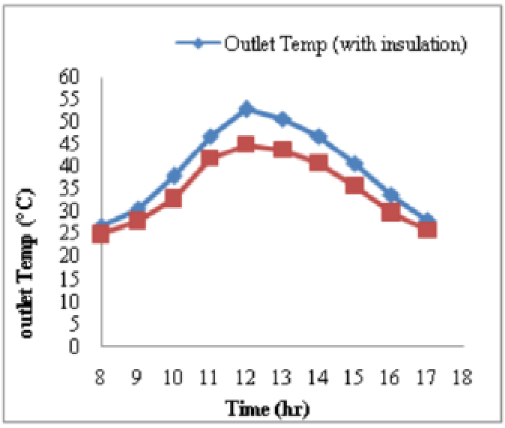

Figure 6: Outlet temperature difference b/w with and without insulation

3.4 Comparison of efficiency by with and without insulation

If we consider about the efficiency of solar flat plate collector than it is varies with respect to time duration. In fig.-7 we have seen that the efficiency is change with time. In fig we get the maximum efficiency in between 12pm to 1pm and the maximum efficiency is 61% in insulated region. the maximum efficiency is 47% & this is the results for the without insulated condition.

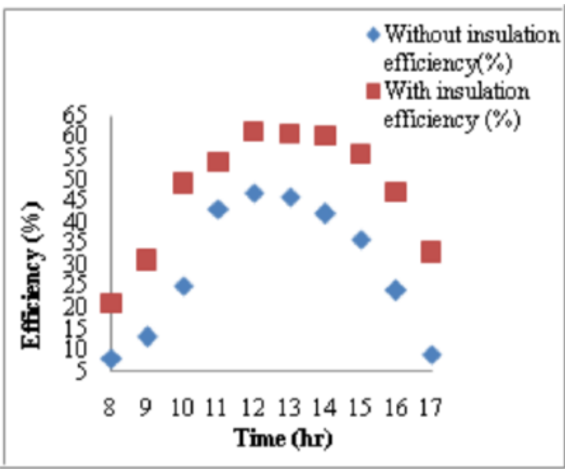

Figure 7: Comparison of Solar flat plate collector efficiency for both insulation and without insulation

3.5 Comparison of efficiencies between insulated and without insulated condition

Fig-8 shows that in graph the efficiency of solar flat plate collector in insulated region is more as compare to the efficiency of without insulated condition. The efficiency of solar flat plate collector found out to be 47% without insulation at 12:00pm, which is considerably less with respect to insulated solar flat plate collector & that are 61%. The minimum efficiency is 20% in insulated condition which is more than as compare to 8% of without insulated condition.

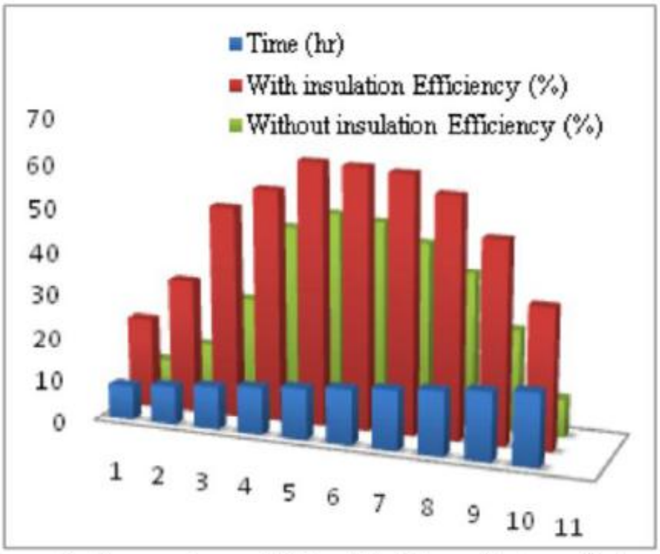

Figure 8: Comparison of Solar flat plate collector efficiency for both insulation and without insulation

Number citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]–[3]. Please note that the references at the end of this document are in the preferred referencing style. Please ensure that the provided references are complete with all the details and also cited inside the manuscript (example: page numbers, year of publication, publisher's name etc.).

4. Conclusions

The performance of a solar collector using coconut coir as thermal insulation has been investigated. The experimental data are analyzed and the correlations resulting are reported for all cases. Based on the experimental results reported herein, the following conclusion can be drawn.

- The experimental arrangement of solar flat plate collector is setup in Dimat Raipur C.G.
- Whatever the meteorological condition, it is possible to have hot water with very good temperature level using solar water heaters with coconut coir as heat insulator.
- The experimental analysis has been done in Disha Institute of management & Technology Raipur CG (22°33' to 21°14'N Latitude and 82°6' to 81°38'E Longitude)
- The Experiment has been done for winter season in the month of February 2015.
- It has been observed during experiment analysis that by using coconut coir as an insulating material gives better result compare to same solar water heater flat plate collector without insulation
- In the month of February average outlet water temperature of water by using coconut coir as a insulated material in the solar water flat plate collector indicates 7°C more temperature of water as compare to without insulated collector.
- By using coconut coir as a insulated material the solar flat plate collector gives 18% more efficiency as compare to without insulation in the month of February2015.
- All these result shows the coconut coir as beneficial , economical and also very useful for an solar plate collector.
- By using coconut coir as an insulating material the side and bottom Heat loss has been reduced and we can also analyze the Heat loss.

Acknowledgment

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