Performance enhancement of Solar flat plate collectors

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Abstract
Solar flat plate collectors are used for heating water in the temperature range of 30°C to 80 °C. Many methods exist for increasing the amount of solar radiation falling on a solar collector. In this paper, the performance of a flat collector is studied under various conditions in a laboratory under controlled environment. Halogen lamps were used to heat the water in the collector tubes instead of actual solar radiation. The effect of wind and the placement of a reflector near a collector of dimension 915 x 810 x 95 mm were studied experimentally.

The reflector was introduced to improve the performance of the solar collector. The heat transfer rate and the collector efficiency are strongly dependent on solar radiation. The maximum collector efficiency without reflector was 32 % and with reflector was 67 %.

Keywords: flat plate, performance, wind, reflector, efficiency.

Introduction

Solar flat plate collectors are systems that trap solar thermal energy and utilize it for domestic and industrial heating applications[1]. Flat plate collectors have gained popularity because of their simple design, absence of moving parts and the need for little or no maintenance[2].The performance of flat-plate solar collector can be enhanced in many ways such as by using nano fluids, reflectors etc. Nano fluids exhibit superior thermophysical properties when compared to those of ordinary working fluids. Few experimental results indicated the enhancement of the system's exergy efficiency and energy efficiency by using a nanofluid[3].

Sujit Kumar Verma et al[4] experimentally evaluated the performance of flat plate collector using multi walled carbon nanotubes/water and various other nano fluids as a substitute of water as the base fluid.

Authors recorded maximum rise in energy efficiency as 23.47% and exergy efficiency is enhanced by 29.32% under the investigation of identical thermo physical parameters. An increase in volume concentration of nanofluid to 0.6% lead to an increase in thermal efficiency of 6% to 8% at various flow rates. The slope of the efficiency curve depends on the size of nano particles[5]. Nano fluids are used to enhance the performance of system but it has limitations like instability and heat transfer equipment corrosion[6]. A rectangular flat plate solar collector with two pieces of mirror mounted on both sides of the collector gave a 10% increase in efficiency[7]. An analytical model consisting of two modules were generated, one for simulation and other for optimization environment to predict the performance of a combined solar collector-reflector system for an extensive range of angular positions and geometries.

Roberto Baccoli et al[8] developed a mathematical model to analyze the performance of the thermal collector by energy balance equations. The flat plate collector with reflector yielded an average thermal efficiency of 36% on day basis[9].

To enhance the performance of solar flat plate collector, various techniques are experimented as observed from literature of different researchers. In this work, an experimental study has been done on the flat plate collector with reflector and its performance has been compared without the use of the reflector. The reflector is used to trap both the direct and diffuse radiation falling on the flat plate collector. This tends to improve the thermal efficiency of the system. Solar collectors perform three functions. They absorb the incident solar radiation, convert it to thermal energy, and transfer the energy to the water passing through the tubes. The main components of a typical flat-plate solar collector are the black surface, transparent cover, tubes, insulation and outer casing.

Glazing is the top cover of a solar collector. It performs three major functions in particular: to minimize convective and radiant heat loss from absorber, to transmit the incident solar radiation to the absorber plate with minimum loss, and to protect the absorber plate from outside environment. Glass material has highly desirable property of transmitting as much as 90% of the incoming short-wave radiation, while virtually none of the long wave radiation emitted by the absorber plate can escape outwards by transmission. To be specific, glass cover for solar collector normally should be at least 0.33 cm thick[10].

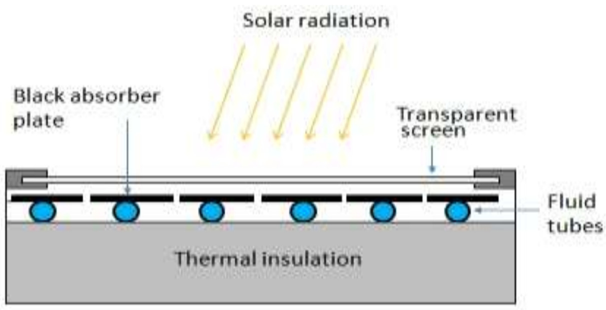

Figure 1: Layout of Flat plate collector

Description of the experimental set up: The experimental set up consists of a hot water tank and 2 cold water tank 1 and

2. The capacity of hot water tank is 50 litres and that of cold water tank is 80 litres. The hot water tank is insulated with poly urethane foam. The collector aperture area is 0.63 m^2. Toughened glass is used as the glazing material. The transmissivity of the glass is 0.85 and emissivity is 0.88. Copper is used as absorber material. 6 riser tubes are used to transport water between the headers. Rockwool of thermal conductivity 0.04 W/mK is used as the insulation. Different valves are used to change the water flow direction. 21 halogen lamps are used to supply the required artificial intensity similar to solar radiation on the collector.

Each halogen consumes a power of 150 W. The radiation falling on the collector can be measured using a radiation meter. The flow rate is measured by turbine meter located at the inlet of the collector. RTD class A sensor is used to measure the inlet temperature, outlet temperature, absorber temperature and the hot water temperature. An AC powered fan is used to simulate the effect of wind above the collector.

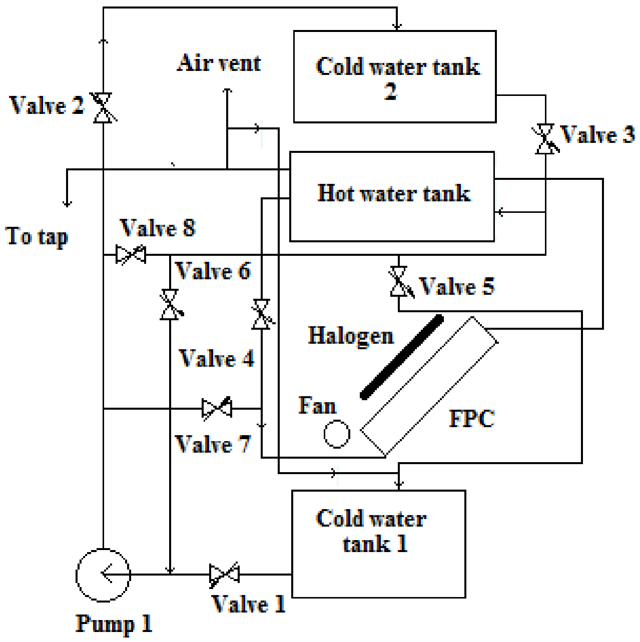

Figure 2: Flat plate collector circuit

The experiment is conducted in natural circulation mode. Initially the readings are taken at zero wind speed .Then the readings are taken at 3.5 m/s. The above 2 cases are performed with the use of a reflector kept at the 4 sides of the collector. The calculations are performed using the measured values.

Theoretical Analysis of heat transfer in collector tubes: The analysis of heat transfer is done based on the equations provided by Duffie and Beckman[11]. In a steady state, the incident solar radiation is equal to the solar radiation absorbed by the plate per unit area and the losses. Losses being the sum of optical and thermal losses. The instantaneous efficiency is given by the ratio of the useful heat gain and the incident energy.

$$\eta = \frac{q_u}{I(t)} = \frac{Q_u}{\tau\alpha A.I(t)} \qquad (1)$$

where I(t) is the incident solar radiation in the plane of absorber in W/m^2. It can be directly measured using a solar power meter. In the above equations, $\tau\alpha$ is the transmittance absorptance product and its value is nearly 0.81. A is the collector area which is equal to 0.74115 m^2. The useful heat gain can be calculated by knowing the difference of the inlet and outlet water temperatures.

$$q_u = mC_p(T_{fo} - T_{fi}) \qquad (2)$$

The fig. 3 and fig. 4 shows the variation of efficiency with respect to time at a wind speed of 0 and 3.5 m/s respectively.

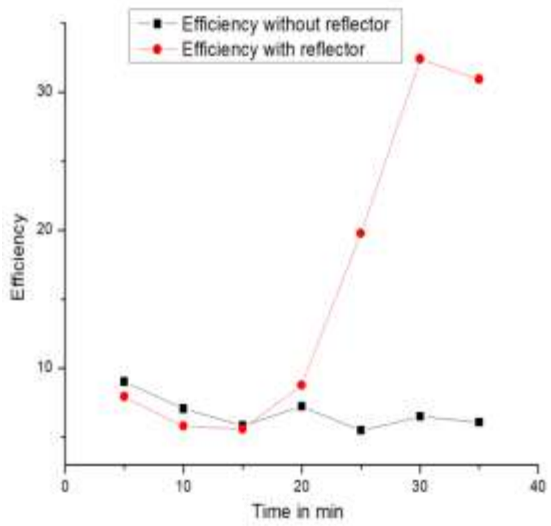

Figure 3: Plot of efficiency with respect to time at v = 0 m/s

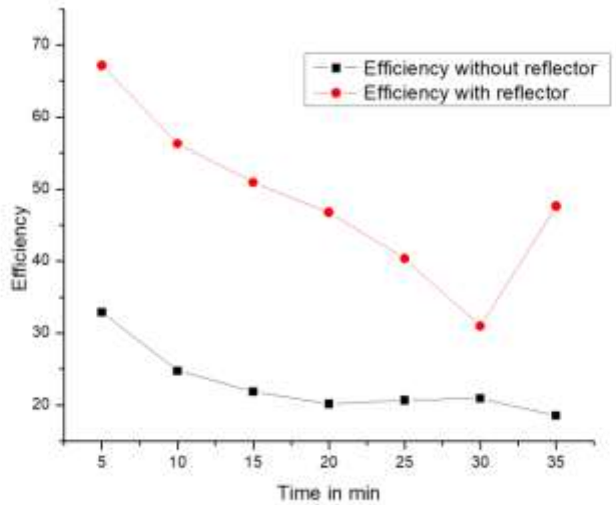

Figure 4: Plot of efficiency with respect to time at v = 3.5 m/s

The efficiency obtained above are calculated based on the incident radiation and rise in water temperature. A detailed methodology to calculate the efficiency takes into account the overall heat transfer coefficient. The overall heat loss coefficient is the summation of top loss, bottom loss and edge loss coefficient.

$U_L = U_t + U_b + U_e$

The top loss coefficient, U_t for a single glass cover system is given by:[12]

$$U_t = \left(\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_a}{N+f}\right]^e} + \frac{1}{h_w} \right)^{-1} + \left(\frac{\sigma(T_{pm}+T_a)(T_{pm}^2+T_a^2)}{\frac{1}{\varepsilon_p+0.00591Nh_w} + \frac{2N+f-1+0.133\varepsilon_p}{\varepsilon_g} - N} \right)$$

where N = number of glass cover, T_{pm} = Mean plate temperature in K, β = Collector tilt angle, C= 414, ε_p = emittance of plate, ε_g= emittance of glass, $h_w = \frac{8.6V^{0.6}}{L^{0.4}}$. L = cube root of the three dimensions of the collector box, $f = (1+0.089h_w - 0.1166h_w\varepsilon_p)(1+0.07866N)$, e = 0.430(1-100/$T_{pm}$).

The bottom loss coefficient, U_b and edge loss coefficient, U_e can be found as mentioned below.

$U_b = k_{ins}/L_{ins}$

$U_e = (UA)_{edge}/A_c$

Based on the overall heat transfer coefficient, the heat loss and the useful heat gain may be calculated. The fig. 5 shows the variation of plate temperature with respect to time with and without reflector. The fig. 6 shows the variation of outlet water temperature with respect to time in the 4 cases.

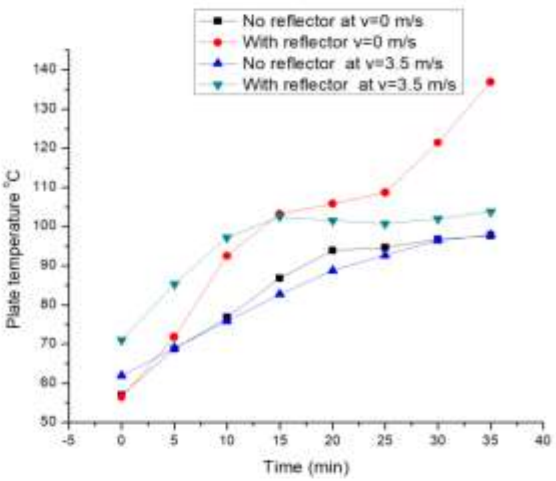

Figure 5: Variation of plate temperature with time

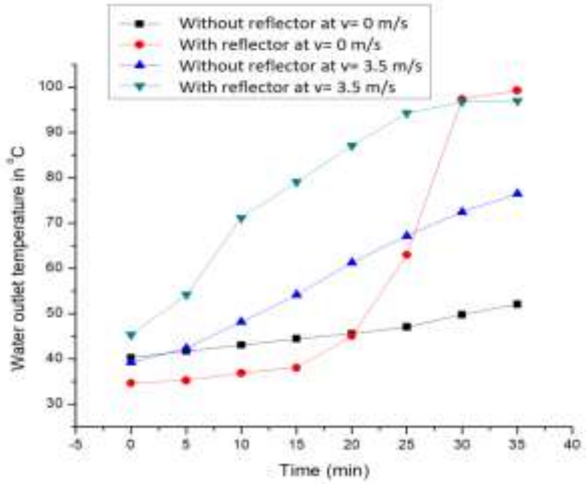

Figure 6: Variation of outlet water temperature with time

Economic analysis: The temperature of hot water with reflector was observed as near to 97°C and without reflector, it was 78 °C. If water can be heated to 97°C without the usage of any electricity, it will lower the wastage of the high grade energy. This in turn will minimize the energy bills. The ambient temperature is taken as 27 °C and the quantity of water heated is 30 litres.

Amount of energy required, E to raise the temperature of m litres of water by ΔT is given by $mc_p\Delta T$. For a temperature rise of 51 °C without reflector, the energy gain is 6426 KJ. The energy gain, E using reflector is 8820 KJ.

$E = mc_p\Delta T$ = 30 x 4.2 x 70 = 8820 KJ

Thus, there is a gain of 2394 KJ of thermal energy using reflector. If a 3 KW water heater is used, the heating time, t in hours can calculated as follows:

$$t = \frac{\text{Energy gain in KJ}}{\text{Heater capacity in KW} \times 3600} = \frac{2394}{3 \times 3600} = 0.22\ \text{hr}$$

Energy consumption for 0.22 hr = 0.22 x 3
= 0.66 kWh.

Cost of electricity at the rate of Rs 6/unit
= 0.66 x 6
= Rs 4

For 365 days, the savings through the way of using FPC with reflector = 4 x 365
= Rs 1460 per year

So, it can be seen that there is a profit of Rs 1460/- per year on using a FPC with reflector.

Results and Discussion

The reflector sheet prevents the escape of diffuse radiation from the top surface of the collector. The radiation that falls on the reflector is reflected back to the collector. This causes more radiation to be absorbed by the water and consequently a higher temperature rise is obtained. At zero wind speed, the efficiency varies between 5.4% to 9 % without using reflector. But with the use of reflector, the efficiency reaches a peak of 32%. Similarly, at a wind speed of 3.5 m/s, the efficiency varies between 18% and 32 % without reflector and between 30% and 67 % with reflector. Similarly, in both the cases with reflector, the outlet temperature reaches a temperature above 90^{o}C.

Practical significance: This analysis helps to evaluate the amount of savings obtained by using a reflector in a flat plate collector. This system can help in reducing the electrical energy consumption that is used for water heating purposes. The use of solar energy for heating can have a large potential to reduce the greenhouse gases (GHG) emissions.

Acknowledgement

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