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PERFORMANCE IMPROVEMENT STUDY OF SOLAR WATER HEATING SYSTEM

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ABSTRACT

Heating water for domestic purpose is a simple and effective way of utilizing solar energy. Initial cost of solar water heating system is high. But we get zero green energy cost. This paper discuss improving the performance of a flat plate solar energy collector by changing the design parameters of the number of riser tubes and the arrangement of riser tubes in zig-zag pattern from the existing flat plat collector system. Experiments were conducted using copper tube in header and riser with different dimensions. The performance shows that the efficiency is 59.09% when increasing the number of riser tubes and its 62.90% in the zig-zag arrangement (Z- Configuration) of the riser tube. Now-a-days this system produces higher efficiency than the existing conventional flat plate collector.

Keywords: solar water heating system, flat plate collector, riser tubes, zig-zag arrangement.

Nomenclature

Ac = collector Area (m^2)
C_p = specific Heat Capacity (Jkg^{-1}k^{-1})
I = incident Radiation of Collector (Wm^{-2})
L = length of Collector (m)
m = flow Rate per Unit Collector Area Kgm^{-1}m^{-2}
T = temperature (K)
Q_u = useful heat energy collected (W)
F_R = collector heat removal factor
F' = collector efficiency factor

Greek

α = absorptance
τ = transmittance
η = efficiency

Subscripts

a = ambient
c = collector
f = fluid
i = inlet
o = outlet

INTRODUCTION

Now-a-days, 80% of energy is produced by the fossil fuels, and this massive exploitation is leading to the exhaustion of these resources and imposes a real threat to the environment, mainly through global warming and acidification of water cycle. The distribution of fossil fuels around the world is uneven. Middle East countries possess more than half of the known oil reserves. This fact leads to economical instabilities around the world, which affect the whole geopolitical system. The impact it has on the environment as well as on humans cannot be disputed.

The increase in the rate of combustion of oil and coal will accelerate the deforestation rate. Keeping the above in mind, as well as the fact that the oil is running dry fast, alternatives should be explored. Renewable energy is one of the most promising alternatives to the above problems. The amount of heat delivered by solar system is 7 kW/m^2 in a day. Solar collectors are commonly used for active conversion of solar energy into heat.

Solar water heating system is a natural solar thermal technology. In solar water heating systems, incident solar radiation is converted into heat and transmitted to a transfer medium such as water. Solar water heating is often viable for replacement of electricity and fossil fuels used for water heating. Flat plate collector is an extension of the basic idea of solar energy collector in an oven like box; here riser tubes are connected with the header tube and is placed inside the box under absorber plate. The water enters from the bottom side of the plate and gets heated in the collector area and the hot water is given out. Flat plate collector was first implemented in 1920 at Florida, and in 1953 first prototype was made.

Soteris A. Kalogirou [1] performed an analysis of the environmental problems related to the use of conventional sources of energy and the benefits offered by renewable energy systems. The various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors were followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. The thermal performance of the solar collector was determined by obtaining values of instantaneous efficiency for different combinations of incident radiation, ambient temperature, and inlet fluid temperature.

Bukola O. Bolaji [2] performed design and experimental analysis of flow inside the collector of a natural circulation solar water heater. The result shown was that the system performance depends very much on both the flow rate through the collector and the incident solar radiation and the system exhibited optimum flow rate of 0.1 kg/s-m^2 .Fanney and Klein [3] performed side by side experimental investigations to evaluate the influence of the thermal performance of solar domestic hot water systems. The system was a direct solar hot water system utilizing a natural circulation return tube to the storage tank. Result of the system show improvements in the overall system performance as a result of lowering the collector fluid flow rate.

Volker Weitbrecht *et al*., [4] performed the results of an experimental study conducted in a water solar flat plate collector with laminar flow conditions to analyze the flow distribution through the collector. LDA-measurements were carried out to determine the discharge in each riser, as well as pressure measurements to investigate the relation between junction losses and the local Reynolds number. Analytical calculations based on the measured relations are used in a sensitivity analysis to explain the various possible flow distributions in solar collectors.

Duffie, J.A and W.A. Beckman [5] performed annual simulation to monitor the thermal performance of a direct solar domestic hot water system operated under several controlled strategies. According to [5], higher flow rate leads to higher collector efficiency factor. However, it also leads to higher mixing in tank and therefore, a reduction in the overall solar water heating system efficiency.

The system of Wang X.A., Wu. L.G. [6] performed several collectors with parallel connection and which can be interpreted as a single collector where the number of risers must be multiplied by the number of collectors and were analyzed.

Various studies reviewed above have shown the importance of performance improvement of the collector in solar water heating. In this study fluid flow system of a density gradient solar water heater is designed and constructed with the aim to reduce the cost and to bring out better efficiency.

DISTRIBUTION OF THE FLOW SYSTEM

Flow system

The density difference of the medium created by the temperature gradients causes the fluid being heated and delivered to storage tank. This type of fluid flow due to density gradient is usually termed the natural convection.

Temperature distribution

The temperature distribution, useful heat energy and the collector efficiency were calculated by using the equations (1) to (8) which were derived from [7], [8], [1] and [9]. To obtain the relationship between the temperature and the mass flow rate (m), the equation for useful heat energy (Q_u), as:

$$Q_u = A_c F_R [I\alpha\tau - U_L (T_f - T_a)] \quad (1)$$

The heat energy is converted into thermal energy of water in the pipes, as:

$$Q = mc_p (T_{fo}-T_{fi}) \quad (2)$$

Then

$$m C_p (T_{fo} - T_{fi}) = A_c F_R [I\alpha\tau - U_L (T_f - T_a)] \quad (3)$$

Therefore,

$$(T_{fo} - T_{fi}) = (A_c F_R / m C_p) [I\alpha\tau - U_L (T_f - T_a)] \quad (4)$$

F_R may be obtained from

$$F_R = mc_p/A_cU_L [1- \exp (U_LF'A_c/mc_p)] \quad (5)$$

Then the collector efficiency is obtained by using the relation,

$$\eta = Q_u /A_cI \quad (6)$$

Substitution of Eqs. (2) and (4) in Eq. (5) yields,

$$\eta = F_R [\alpha\tau - U_L (T_f - T_a) / I] \quad (7)$$

Since F_R, $\alpha\tau$ & U_L are constant, therefore,

$$\eta \ \alpha\ [(T_f - T_a) / I] \quad (8)$$

EXPERIMENTAL ANALYSIS

In this section we present the details of the experiments conducted using 9 riser tubes, 12 riser tubes and zig- zag arrangement of riser tubes.

Case-1: Experimental setup with 9 riser tubes

The schematic diagram of the natural circulation solar water heater is shown in Figure-1. The system consists of a solar flat plate collector, storage tank and connecting pipes. The absorber plate of the solar collector is formed, like, a corrugated sheet to accommodate the water pipes and headers in the grooves to maintain good contacts with the pipes. In this experiment 1980 mm long and diameter of 12.74 mm copper tubes are used. The pipes are placed close together and parallel to each other with a space of 100 mm in between and welded at both ends to the header.

The front surface of the box is then covered with 4 mm thick clear plain glass and the overall dimension of flat-plate solar collector is 2035mmx1035mmx100mm and the effective glazing area is 2.08sq.m. The connection between flat plate collector and the storage tank is a simple design. The flow pipe is connected with the inlet rings, the cold water to the collector and a pipe connected with outlet side gets the heated water out from the collector pipes of 25.4 mm diameter and 1000 mm long.

The flat plate collector is oriented in such a way that it receives maximum solar radiation during the desired season of use. The best stationery orientation in the south is the northern hemisphere. In this position, the inclination of the collector to the horizontal plane for the best all year round performance is approximately 10˚ more than local geographical latitude [2]. This approach is used in this work and a tilt angle of 27˚N is used for location at Tiruchirappalli, Tamilnadu, India (longitude 78˚43', latitude 10˚46'). The absorbing surfaces were painted in black. The absorbing plate and the absorbing surface of the pipes absorb solar radiation and the absorbed heat is then transmitted to the water in the pipes. Under the mode of natural convection the water rises through the pipes by the thermodynamic force and enters the storage tank.

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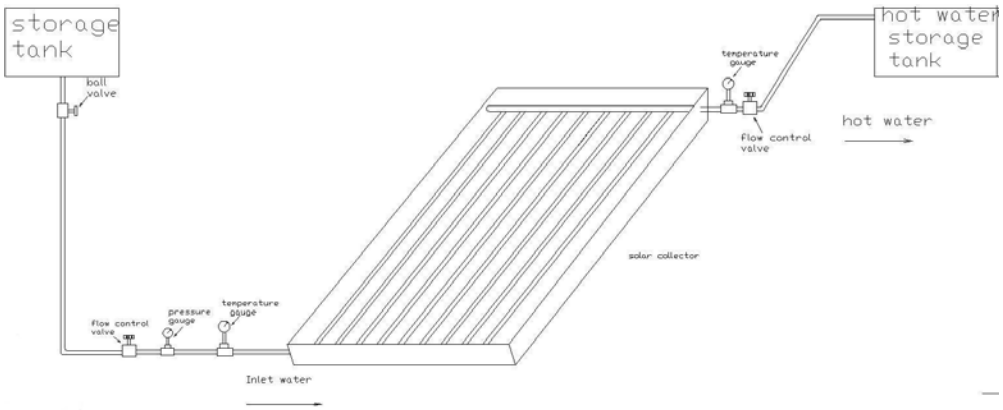

Figure-1. The schematic diagram of flat- plate collector solar water heater.

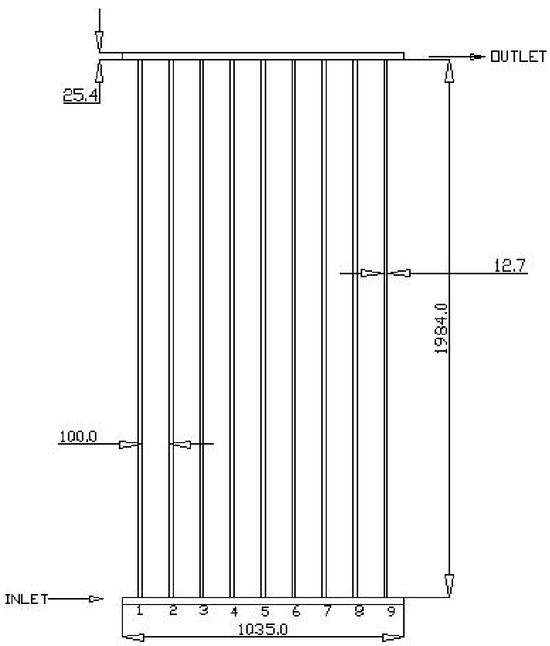

Figure-2. Sectional view of 9 riser tubes flat plate collector.

Case-2: Experimental setup with 12 riser tubes

The schematic diagram of fluid flow pattern is shown in Figure-3. Dimensions of tubes of new flat collector are reduced but area of collector remains the same as conventional one. Header tube diameter is 15.87 mm, riser tube diameter is 8 mm and thickness of both tubes is 1mm. The spacing between the centre to centre distances is 75 mm. The number of riser tubes is increased from 9 to 12. The design of flat plate collector consists of increased number of riser tubes of reduced dimensions [2].

Fluid flow pattern is a parallel one. Fluid flows from inlet to outlet at the same flow rate. Experiments are conducted to improve efficiency of system by considering theoretical facts of reducing diameter of tube.

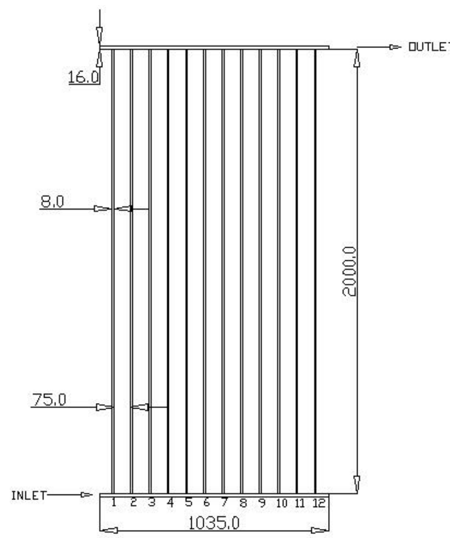

Figure-3. Sectional view of 12 numbers riser tubes flat plate collector.

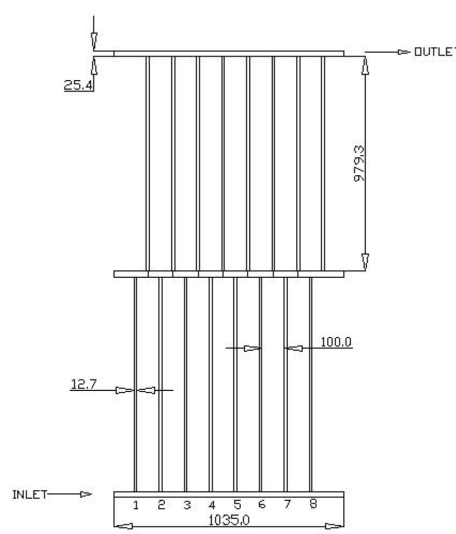

Figure-4. Sectional view of Zig-Zag arrangement of riser tubes.

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Case-3: Experimental set up for Zig-Zag arrangement of the riser tubes.

The schematic diagram of fluid flow pattern is shown in Figure-4. Dimensions of tubes in flat collector are reduced but area of collector remains the same. Header tube diameter is 25.4 mm, riser tube diameter is 12.74 mm and thickness of both tubes is 1mm. The spacing between the centre to centre distances is 100 mm.

In order to improve efficiency of collector, the fluid flow velocity from inlet to outlet is slightly reduced but mass flow rate remains the same. For the above stated improvement an additional header tube is introduced at the centre of the system. In this system fluid flow pattern is a parallel in both bottom and top of the riser tube. However the path of fluids is in zig-zag at the centre of the tube.

RESULTS AND DISCUSSIONS

The Natural circulation solar water heater was tested in the month of March, 2011 at intervals of one hour between 9.00 hours and 17.00 hours.

The incident solar radiation intensity was measured using pyranometer. The water inlet and outlet temperatures for the collector as well as ambient air were measured by thermometer with a precision of 0.5˚C. The mass flow rate of the system was measured by rotometer with the accuracy of 0.005 liters. The collector efficiency of the system was calculated using Eq. (1) to Eq. (8).

The hourly variation of the solar intensity, collector efficiency and collector water outlet temperatures are shown in Figures 5, 6, 7 and 8.

The solar intensity is increasing from 9.00 hours to 13.00 hours, reaching a maximum value of 918 W/m^2 at 13.00 hour in Figure-5. The collector efficiency is also compared with three different cases and it's depicted in Figure-6.

The collector efficiency at 9.00 hour is 36.4% for 9 riser tubes, 39.2% for 12 riser tubes and 42.00% for zig-zag arrangement system. The maximum efficiency is observed at the time 13.00 hour in all the three cases as 53.38%, 59.09%, and 62.90%, respectively.

The collector efficiency decreases after 13.00 hour till 17.00 hour in the same manner. The collector efficiency is shown in Figure-7. The graph reveals that the maximum efficiency is at 13.00 hour in all the three cases.

The collector outlet temperatures are shown in Figure-8. The outlet temperatures at 9.00 hour is 43˚C, 44˚C and 46˚C for 9 riser tubes, 12 riser tubes and zig-zag arrangement respectively. The maximum outlet temperatures were recorded at 13.00 hour for all three cases. The outlet temperature reduced after 13.00 hour until 17.00 hour for all three cases.

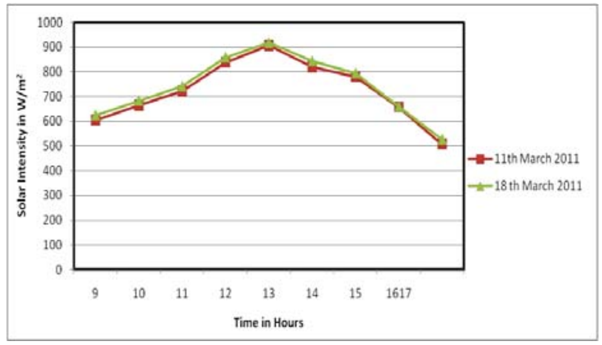

Figure-5. The curve for solar intensity against time.

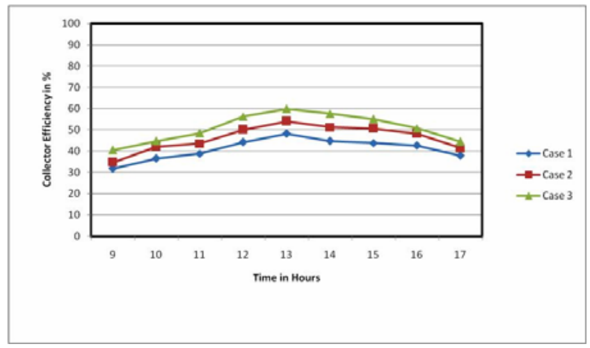

Figure-6. The curve for Collector efficiency against time on 11th March, 2011.

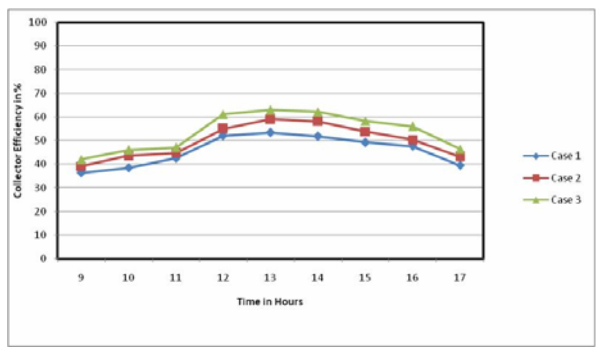

Figure-7. The curve for Collector efficiency against time on 18th March, 2011.

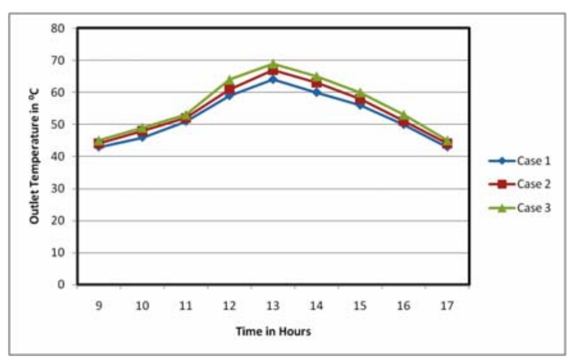

Figure-8. The curve for Hourly variation of fluid outlet temperature by changing the dimensions on 18th March, 2011.

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CONCLUSIONS

Three different experimental set up were made and tested at Tiruchirappalli (longitude 78˚43’, latitude 10˚46’). The result records that the collector outlet temperature is the function of solar irradiance and time. The maximum collector efficiency is at 13.00 hour in all three experiments. The minimum collector efficiency at particular time is obtained at case 1 experiment using 9 riser tubes. The maximum collector efficiency during the day of experiment at any particular time considered is obtained in case 3 experiment using zig-zag arrangement.

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