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Research Article

Performance investigation of formed tubes of different geometry for a Flat-plate solar collector

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Abstract

A flat plate collector is widely used solar thermal collector which provides moderate heat whenever require. It can increase the temperature of the fluid up to 1000C above ambient temperature. It is also simple in design, have no moving parts and require little maintenance. They are relatively cheap and can be used in variety of applications. This work aims to concentrate on performance improvements of solar flat plate water collector using formed tubes of different shapes so that we can predict the results and improvement in performance of solar flat plate collector with experimentation.

Keywords: *Flat plate collector; Tubes; solar collector.*

1. Introduction

The solar thermal energy which is collected by a device called solar collector. A flat plate collector is such kind of solar thermal collector which is consuming in such place where moderate heat is required. It can increase the temperature of the fluid up to 1000 ^{0}C above ambient temperature. It is also simple in design, have no moving parts and require slight maintenance. They are also relatively cheap and can be used in variety of application. A modest flat plate consists of four components (1) absorber plate (2) tubes fixed to the absorber plate (3) the transparent cover (4) the collector box. The collector plates absorb the extreme possible amount of solar irradiance and transfer this heat to the operational fluid which is flowing in absorber tube. The fluid used for heat transfer mostly flows through a metallic tube, which is linked to the absorber plate. The absorber is generally made of metallic materials such as copper, steel or aluminum and surface is normally black. The collector strongbox can be made of plastic, metal or wood type insulator to prevent heat loss and the transparent front cover need to be sealed so that heat does not escape and the collector itself is protected from grime and humidity. The heat transfer fluid may be both water and water with antifreeze liquid. Still the heat fatalities due to the temperature difference between the absorber and ambient air outcome in convection and radiation losses.

The main advantage of a flat plate collector is that it utilizes both beam and diffuse components of solar radiation. Efficiency of flat plate collector depends on the temperature of the plate, ambient temperature, solar isolation, upper loss coefficient; emissivity of plate, transmittance of cover sheet, number of glass covers etc. The efficiency enhancement for flat-plate solar collector can reduce its size and obtain higher temperature fluid at outlet for broader application. In response to these demands, different highly-effective techniques have been used in the past to improve the thermal performance of solar collectors including the methods of reducing the heat loss from the top surface or increasing the energy advance inside the solar converter.

2. Literature Review

Literature papers are revised to see the effect of different environment, operating, design and material properties on the performance of flat plate solar collector. Different applications of flat plate solar collector are also reviewed.

Ho-Ming Yeh et.al Study the effect of aspect ratio (l/n·w) on collector performance. l is the length of the tube carrying liquid, n is the number of tubes and w is the spacing between the tubes. In this collector area is fixed and aspect ratio is various by the variation in n and l. From the study it is concluded that efficiency increases with decrease in aspect ratio. It is also detected that efficiency decreases with increase in solar intensity when the inlet temperature is little and efficiency increases with increase in intensity when the inlet temperature is high.

Rama Subba Reddy Gorla et.al Developed the 2D finite element model for the flat plate solar collector. The different Features of the system are considered

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and compare with the experimental data for the validation of the model. The parameters evaluated for the validation of model are Fluid temperature increases along the length of the tube, Fluid temperature varies linearly at high flow rates along the length of tube, Fluid outlet temperature decreases with upsurge in mass flow rate, Efficiency decreases with increase in fluid inlet temperature, Efficiency higher with single cover for low inlet temperature range after some temperature efficiency of two glass cover higher than single, Efficiency increases with increase in tube spacing to tube diameter ratio and after some point it decreases with further increase in tube spacing to tube diameter ratio.

N.K. Vejen *et al*. Theoretical and experimental analysis of HT solar collector with different insulation materials, absorber, anti-reflecting layer and number of risers is carried out. There is a 23-37% output improvement using enhanced HT collector. Rock wool (low thermal conductivity) insulation gives better thermal performance than glass wool at temperature between 40^0C-80^0C. Efficiency improves with number of risers but only at low temperatures. Efficiency increase with improve in absorber properties for all temperatures. Effect increases with increase in temperature of the fluid. Efficiency improved with decrease in glass thickness.

Subhra Das *et al*. Study the effect of various parameters on the performance of flat plate solar collector. This gives the tolerable limits for deviation to the input parameters for steady state conditions. Permissible deviation in collector fluid inlet temperature and temperature difference between collector inlet and outlet is 14^0C.

S. Farahat *et al*. Exergetic optimization is developed for the flat plate solar collector to improve and improve the performance of the collector. Absorber plate area, dimension of solar collector pipes, diameter, mass flow rate, fluid inlet, outlet temperature, the inclusive loss coefficient is taken as variables. Energetic efficiency increases with rise in fluid inlet temperature, decrease with increase in ambient temperature, increase with increase in pipe diameter, reduction with wind speed, increase with increase in optimal efficiency, increase with increase in incident energy.

Y. Raja Sekhar *et al*. An experimentation is performed for to evaluate the top loss coefficient considering the aspects like an insolation, emissivity of absorber, ambient temperature, wind loss coefficient, tilt. A theoretical analysis is also done. The results obtained are Efficiency decreases with increase in emissivity of the plate, Efficiency rises with increase in ambient temperature, With increase in wind loss coefficient Efficiency reductions, No significance effect, due to tilt on top loss coefficient.

Y.Y. Nandurkar *et al*. conducted experiments in which decreasing area of liquid flat plate collector by increasing tube diameter and sinking riser length. Solar flat plate collector having increasing diameter of copper tube of flat plate collector with integral fins performances is superior than the ISI flat plate collector. This work is a study on the relative performance analysis of ISI flat plate collector with improved flat plate collector. It is found that the reformed flat plate collector with increase in diameter of test section, Nusselt number and Reynolds number is increased with second power of tube diameter.

Thundil Karuppa R. Raj *et al*. investigates a new solar flat plate collector which is of sandwich kind. The new type of collector is the water sandwich type collector which is made by bracing two corrugated metal sheets on one another. The absorber is made of 2 sheets of GI (1 mm) with incorporated canals, painted silica based black paint. The outer casing which provides mechanical strength to the equipment is separated to reduce the heat losses from back and sides of the collector. The new collector is be different is the absence of heat carrying metallic tubes. The working fluid is made to pass through the channels that are made when two corrugated metal sheets are braced one over another. Efficiency of the flat plate conventional is 24.17 and efficiency of the new collector is 20.19%.

Alireza Hobbi *et al*. An experiment is performed to see the effect of heat improvement devices on the collector performance. Four types of arrangement are analyzed consistent circular tube, regular tube with twisted strip tabulators, regular tube through coil spring wire and regular tube with conical ridges installed in every 152mm. no significant effect on the performance of collector.

There is also an increasing demand for the solar collectors, especially the flat-plate liquid solar collector. Therefore, an extensive research has been done in order to analyze and to enhance the Performance improvement of solar flat plate heat collector using passive techniques are also mentioned above.

Many researches are also carried out numerous experimental and mathematical research on Performance improvement of solar flat plate heat collector. The Enhancement techniques can be applied to flat-plate liquid solar collectors in the direction of more efficient and compact designs. Tube-side enhancement passive techniques can contain of adding additional devices which are also incorporated into a smooth round tube (twisted tapes, wire coils), varying the surface of a smooth tube (corrugated and dimpled tubes) and making special tube geometries. Extensive work has been carried out in order to enhance the performance of the flat plate collector using former inert techniques and still there is very incomplete research literature available on the performance improvement using the tubes of special geometries.

From extensive evaluation on research literature it has been observed that the only parameter which rests unaddressed is the performance of the flat plate collector fluctuating the cross-section of absorber tube. At the similar time its effect on the performance of SFPC with formed tubes once compared with conventional one. Efforts have been made mainly to rise turbulence with insert devices, selective surfaces, numbers of covers, space between covers and absorber plate on the other hand not on the cross-sectional area of the absorber tube. This work trials the performance of the solar collector with formed tubes.

This work aims to concentrate on performance improvements of solar flat plate water collector using formed tubes of different shapes so that we can predict the results and improvement in performance of solar flat plate collector with experimentation.

A large number of geometrical parameters effect the performance of a flat plate collector as selective surfaces, numbers of covers, spacing between covers and absorber plate etc. In this study, shape of tube is considered. Following are some of the conclusions of the research work in connection with thermal enhancement of flat plate solar collector

1. Reduction in the area of the flat plate collector with increasing the tube diameter and reducing the riser length increases the thermal performance of flat plate solar collector matched with the ISI collector.
2. Sandwich type collector can reach adequate levels of efficiency. Also it proves to be inexpensive and easier to manufacture.
3. Trapezoidal profile for absorber plate gives optimal efficiency. The trapezoidal profile is a better choice for transferring energy of a solar collector.
4. Solar Flat plate by using Semi- Circular Cross Sectional Tube increases the area of intimate interaction between the fluid and absorber plate and decreases the resistance due to adhesive and thus performance of solar flat plate collector increases.

From the literature surveys it is detected that performance of solar flat plate collector can be enhanced by using passive techniques i.e. growing surface area of the absorber tube with different tube geometry.

3. Design and Development of Experimental Setup

This work concentrates on the experimental investigation on the performance of solar flat plate collector with formed tubes and its comparison with the conventional solar collector with circular absorber tube. Following are the objectives to be selected for experimental work.

1. To prepare solar collector with **circular, triangular elliptical and square** shape formed tubes **of Copper (Cu)** with same collector area and number of tubes.
2. To manufacture experimental setup in order to test the performance of above mentioned solar flat plate collectors as per ISO 12933 Part-V.
3. Comparison in performance of solar flat plate collector using formed tube and conventional circular absorber tube collector for variable mass flow rate.

The block diagram of the experimental system to be developed and shape of formed tubes for absorber tubes of the collector as given below,

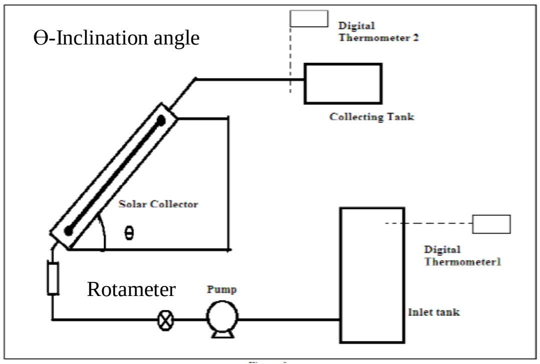

Fig 1 Schematic layout of experimental system

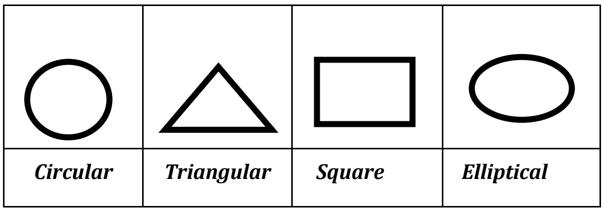

Fig 2 Schematic drawing of the proposed formed tubes to be used in FPC

Fig 3 Actual setup of solar water heater

3.1Solar Collectors

The selection of collector is firm by the heating requirements and the environmental conditions in which it is employed. There are mostly three types of solar collectors like flat plate solar collector, evacuated tube solar collector, concentrated solar collector.

3.2 Storage Tank

Best commercially available solar water heaters require a well-insulated storage tank. Thermal storing tank is made of maximum pressure resisted stainless steel protected with the insulated fibre and aluminium foil. Some solar water heaters use pumps to recirculate deep water from storage tanks through collectors and wide-open piping. This is generally to protect the pipes from icing when outside temperatures drop to freezing or below.

3.3 Heat Transfer Fluid

A heat transfer fluid is used to accumulate the heat from collector and transfer to the storage tank both directly or with the help of heat exchanger. In demand to have an efficient SHW formation, the fluid should have high specific heat capacity, high thermal conductivity, low viscosity, and less thermal expansion coefficient, anti-corrosive property and above all small cost. Among the common heat transfer fluids such as water, glycol, silicon oils and hydrocarbon oils, the water turns out to be the best amongst the fluids. Water is the inexpensive, most readily available and thermally efficient fluid but does freeze and can cause corrosion.

4. Test Methodology

Experimentation was carried out by using different formed tube geometry of solar flat plate collector. Also the inclined angle is 30^0 and flow rate varies with 25LPH.

Table 1 Test parameters

Parameter	Description
Flow rate (Q)	25LPH,50 LPH, 75 LPH,100 LPH
Time	10 AM to 1.30 PM

All the essential components were assembled and experimental set was developed. The necessary instruments were attached at correct configuration and the setup is ready for the experimentation.

4.1 Formulae Used

Heat Gain by Water $= mC_p\,\Delta T$ watt

Energy incident on collector= Area of collector × Intensity of solar radiation

Instantaneous collector effi. $= \frac{\text{Heat gain by water}}{\text{Energy incident on collector}}$

Temp. rise $(\Delta T) = T_{out}\text{-}T_{in}$

5. Results and Discussion

For the logical and systematic comparison, the results are presented in a specific order as described below

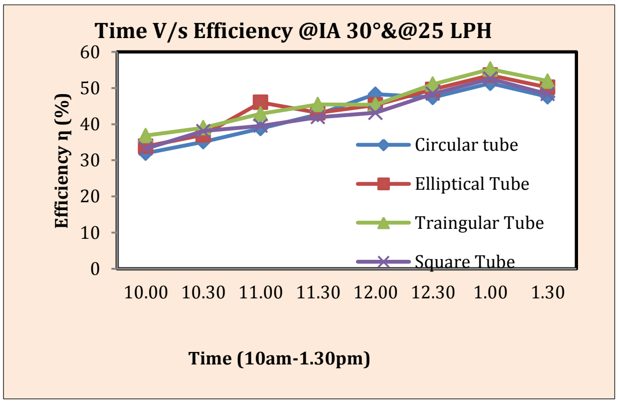

Fig. 4 Comparison in between Time and Efficiency @ IA 30^0 & @ 25 LPH

The above graph shows the relation in between time vs efficiency at inclined angle 30^0 and flow rate is 25 LPH. The efficiency of elliptical tube is maximum at 11.00 am but as the time go on efficiency of triangular tube is maximum at 1.00pm i.e. 55%.

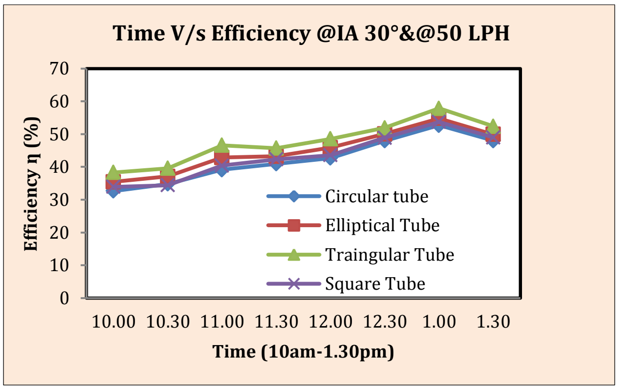

Fig. 5 Comparison in between Time and Efficiency @ IA 30^0 & @ 25 LPH

The above graph shows the relation in between time vs efficiency at inclined angle 30^0 and flow rate is 50 LPH. The efficiency of elliptical tube and triangular tube are maximum at 11.00 am but as the flow rate increases the efficiency also increase. The efficiency of circular tube is minimum at 1.30pm. i.e. 45%.

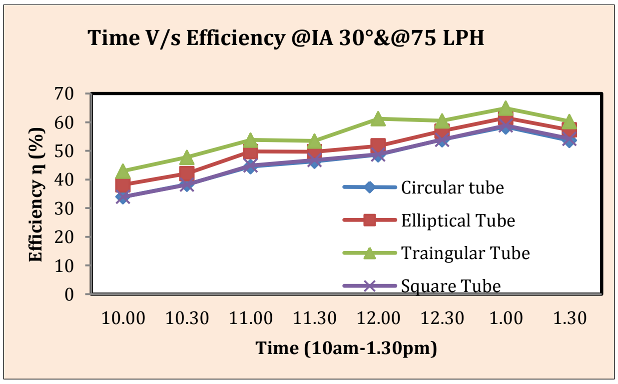

Fig. 6 Comparison in between Time and Efficiency @ IA 30^0 & @ 75 LPH

The above graph shows the relation in between time vs efficiency at inclined angle 30^0 and flow rate is 75 LPH. The efficiency of solar flat plate collector increases as the flow rate of fluid increases. The above graph shows the efficiency of triangular tube is maximum.i.e. 64%

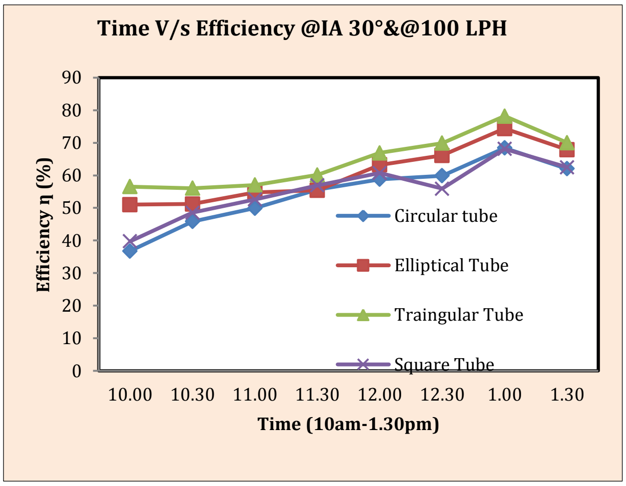

Fig. 7 Comparison in between Time and Efficiency @ IA 30^0 & @100 LPH

The above graph shows the relation in between time vs efficiency at inclined angle 30^0 and flow rate is 100 LPH. The efficiency of solar flat plate collector increases as the flow rate of fluid increases. The above graph shows the efficiency of triangular tube is maximum.i.e. 78% at 1.00 pm similarly the efficiency of square tube also maximum 1.00 pm i.e. 68.12%. Whereas the efficiency of elliptical tube is 74.11% below the range of triangular tube. The efficiency of circular tube is 68.10%.

So from above all graph it shows the relation in between time vs efficiency increase as the flow rate increases similarly the efficiency of all tubes decrease as the time start to increase after 1.00 pm.

Now the another comparison in between the rise of temperature (ΔT) vs time (t) as shown in following graphs.

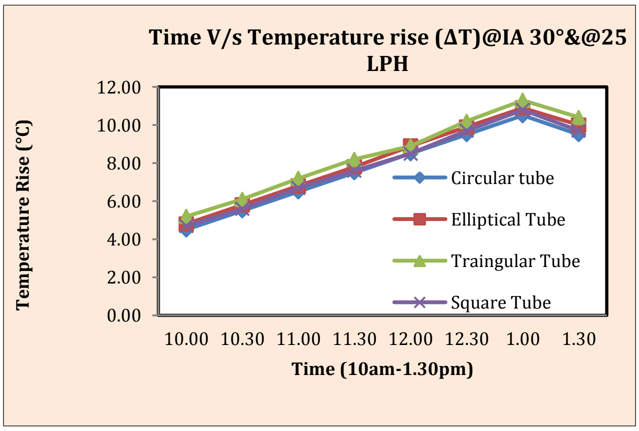

Fig. 8 Comparison in between Time and Temperature rise (ΔT) @ IA 30^0 & @25 LPH

The above graph shows the relation in between time vs temperature rise at inclined angle 30^0 and flow rate is 25 LPH. The above fig 5 shows that temperature rise increases as the time increases. The temperature rise of triangular tube is maximum at 1.00 pm i.e.
11.2° C.

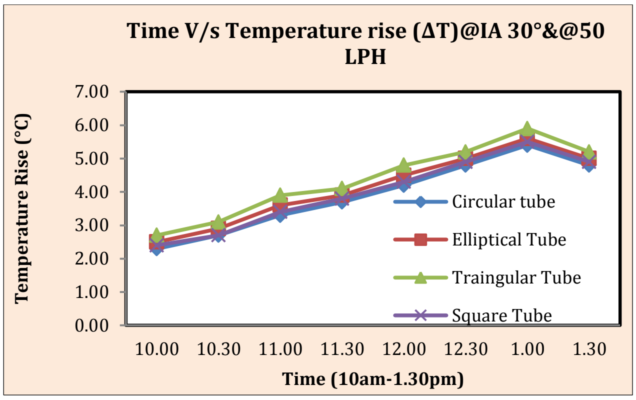

Fig. 8 Comparison in between Time and Temperature rise (ΔT) @ IA 30^0 & @50 LPH

The above graph shows the relation in between time vs temperature rise at inclined angle 30^0 and flow rate is 50 LPH. The above graph shows that temperature rise of elliptical tube is always greater than that of circular tube and square tube. The temperature rise of triangular tube is maximum at 1.00 pm .i.e. 5.90^0 C

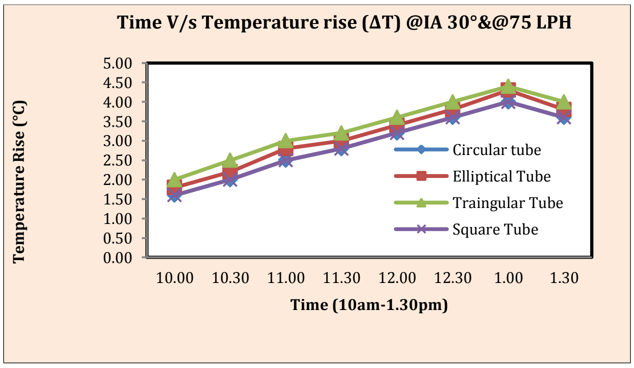

Fig. 9 Comparison in between Time and Temperature rise (ΔT) @ IA 30^0 & @25 LPH

The above graph shows the relation in between time vs temperature rise at inclined angle 30^0 and flow rate is 75 LPH. The temperature rise of the triangular tube is greater than all the formed tube of different shape. The graph shows that the temperature rise decreases as the flow rate increases.

The below graph shows the relation in between time vs temperature rise at inclined angle 300 and flow rate is 100 LPH. The graph shows that the temperature rise of triangular tube is maximum than that of all tube. The graph also indicated that as flow rate increases the temperature rise of the water decreases.

Hence the all the relation shown in graph are indicated that as the flow rate increase then the temperature rise decrease.

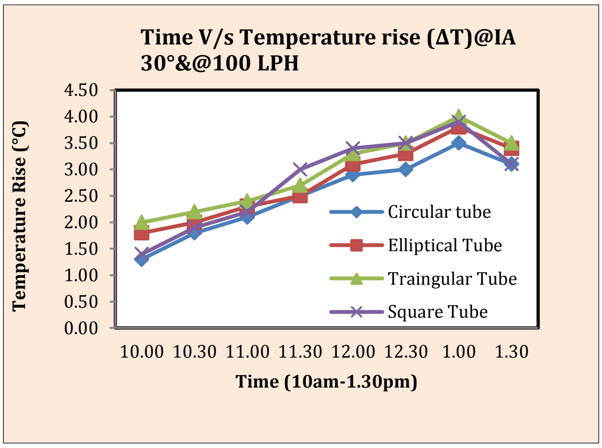

Fig. 10 Comparison in between Time and Temperature rise (ΔT) @ IA 30^0 & @100 LPH

Conclusion

From experimentation result of formed tubes of different geometry for a Flat-plate solar collector, we get different graphs for different geometry of form tube such as triangular, circular, elliptical, and square tube.

In time vs. efficiency graph, it is found that the efficiency of triangular tube is maximum as compared to other tubes. Also it is observed that efficiency is directly proportional to flow rate and it is dependent on the intensity of sun light.

In time vs. temperature rise graph, it is found that temperature rise is inversely proportional to the changing flow rate.

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