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A Review on Heat Pipe Assisted Flat Plate Solar Collector

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Abstract: The conventional flat plate collector solar water heater has an average performance in terms of attained temperature and pumping work. The review is focused on heat pipe based flat plate collector, material used for cover plate and absorber plate, design modification and heat transfer fluid. This review suggested that thermal performance of heat pipe based solar water heater is higher than conventional water heater available in market. Heat pipe technology gave higher heat transfer rate, higher efficiency with uninterruptable operation.
Keywords: Heat Pipe, Solar Collector, Radiation, Absorber Plate, Nano fluids

Abbreviations
^{0}C- Degree Celsius
Dia.-diameter
ETC-Evacuated tube collector,
HP-Heat Pipe,
HPFPC-Heat Pipe Flat Plate Collector,
ID-Inner diameter,
J- Joule
K-Kelvin,
mm- millimeter
OD-Outer diameter,
SWH-Solar water heater,
W-Watt

I. INTRODUCTION

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems or for heating swimming pools.

A. The use of solar heat

For solar energy applications that involve the heating of hot water and space heating, extremely high temperature is not required. A liquid (usually treated water) or air heated to 40^{0}C to 60^{0}C will suffice. For these low temperature applications the simple, non-concentrating flat-plate collector can be utilized. With this type of solar energy collection there is no need for the more complicated and expensive steering mechanisms that are required when concentrating devices such as lenses or parabolic reflectors are used. Another important advantage is that heat losses which rise with temperature are also minimized. Also the flat plate collector will collect solar energy from the diffused component of the solar intensity. For these reasons, solar energy systems for space and water heating have usually utilized some type of flat plate collector.

B. Flat-plate Collectors

Most common flat-plate collectors consist of the following key components:
1) Cover plate: This usually consists of one or two layers of glass or plastic.
2) Battern: Serves to hold down the cover plate (or plates) and provide weather –tight seal.

3) Heat transfer element: In the case of a liquid heat exchange fluid, tubes are often attached to the absorber plate. This facilitates the transfer of thermal energy from the absorber plate to the heat transfer medium. Tubes, roll-band plates, open channel flow, corrugated sheets, and finned tubes are some of many different types used. The same diversity is found in air type collectors.
4) Absorber: This is usually a metallic plate coated with a black paint to improve the absorption of solar radiation.
5) Insulation: Sufficient insulation is employed to reduce heat loss through the back of the collector to a small fraction of the total collector heat loss.
6) Enclosure: A container for all of the above components. The assembly is usually weather proof. Preventing dust, wind and water from coming in contact with the absorbed plate, tubes and insulation is necessary for optimum performance.

Above the absorbing surface, space about half an inch apart, are one or more cover plates (usually glass) whose function is to reduce upward heat losses. Most of the sun's rays are transmitted through and are absorbed by the black surface. Typically 92 to 96% of the radiation usually incident upon the blackened plate is absorbed. This energy is then transferred to the water inside the header and riser pipes which causes the water to gain temperature. To prevent heat losses, the sides and the bottom of the collector are insulated.

C. *Evacuated-tube collector*

One way of improving the performance of a liquid flat-plat collector is to reduce or suppress the heat lost by convection from the top. This is done by having a vacuum above the absorber plate. As a consequence, it become essential to use a glass tube as the cover because only a tubular surface is able to withstand the stresses introduced by the pressure difference. A number of evacuated tube collector(ETC) design have been developed. One design consists of a number of long cylindrical flat-plate collector module side-by-side. Each module is evaluated, cylindrical glass tube containing a rectangular metal absorber plate. The absorber plate has a selective surface coating and heat pipe is attached to it. A glass-to-metal scale is provided between the heat pipe and the end cover of the glass tube. The length of the heat pipe inside the evacuated glass tube constitutes the evaporator section in which heat is absorbed and the fluid inside the heat pipe evaporates. The evaporated fluid rises to the condenser section where it condenses. The heat of condensation is conducted to the fluid flowing in the collector header pipe through an aluminum block clamped on the heat pipe.

The design requires a glass-to-metal seal integrity is difficult to maintain. The need for such a seal is eliminated by developing designs using all-glass- double-walled evacuated tubes. Here each module consists of a long Dewar type evacuated tube with the outer surface of the inner wall being the absorber surface. This surface is selectively coated. The absorbed heat is conducted inwards through the inner glass tube wall and is removed by a number of ways. Collectors differ mainly in the way the heat is extracted from the inside. A heat pipe inside the evacuated tube transports the heat. Aluminum spacers are used to provide the thermal contact between the inner glass wall and the heat pipe shows another design in which a U-tube fixed to a flat metal is inserted in the evacuated tube. The metal fin makes good thermal contact with the inner glass wall and helps the transfer of heat to the liquid flowing through the U-tube.

II. REVIEW ON HEAT PIPE BASED SOLAR COLLECTOR:

S. Rittidech et al. [1] experimented with flat plate solar collector working in conjunction with a closed-end oscillating HP, which was based on gravity force and capillary action.

The FPC consisted of a 1 mm thick sheet of black zinc covered by a glass enclosure with a collecting area of 2.00 x 0.97 (m x m), an evaporator placed on the collecting plate, and a condenser inserted into a water tank. A 3mm ID copper tubing was bent into multiple turns at critical points along its path and used to channel the working fluid (R134a) throughout the system. The schematic and photograph of experimental set up is shown in Fig.1. In the figure (a), (b) and (c) show HPs, Condenser water tank and wooden frame respectively.

The results approved the expected fluctuation in collector efficiency dependent on the time of day, solar energy irradiation, ambient temperature and flat plate mean temperature. From the experimental analysis, it was concluded that an efficiency of about 62% was achieved which can be compared to that of the solar collector by HP. The system consisted simple construction, corrosion free operation and no winter icing problems, which enhances the features of SWH.

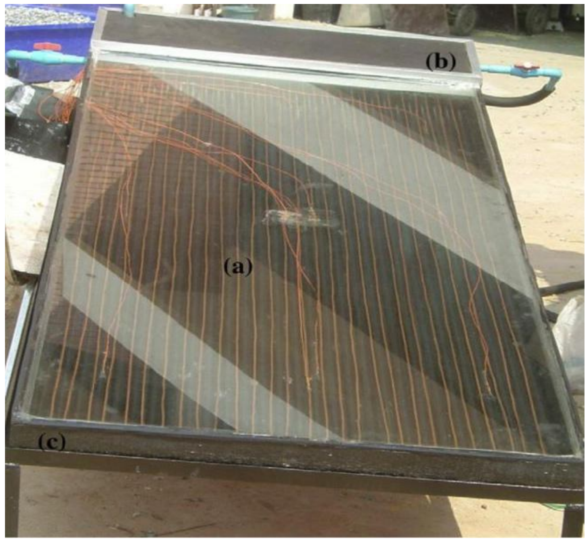
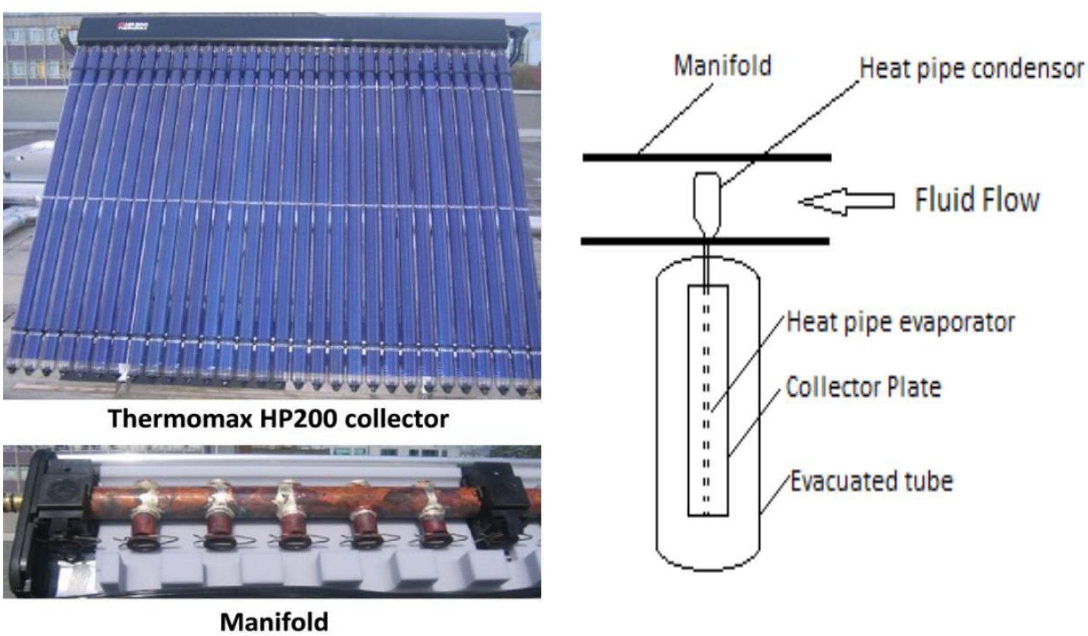


Fig. (1)

Ayompe et al. [2] analyzed the data of the thermal performance of a solar water heating system with HP evacuated tube collector using data obtained from a field trial installation over a year in Dublin, Ireland, which is presented in the paper. The solar circuits comprised of 12mm diameter(outside) copper pipes insulated with 22 mm thick Class O Arma flex. All pipe fittings were insulated to minimize heat losses. The solar circuit pipe length supply and return were 14 m and 15.4 m respectively.Fig.2 shows the schematic and photograph of experimental set up. Thermal analysis revealed that for a yearly global solar insolation on the collector surface of 11,760.3 MJ, a total of 7435.1 MJ was collected while 6121.1 MJ was delivered to the hot water tank. It was also concluded that for 11,973.3 MJ of auxiliary energy supplied to meet the total hot water demand of 18,100.4 MJ, the annual solar fraction was 33.8%. Annual average solar fraction, collector efficiency and system efficiency were 33.8%, 63.2% and 52.0% respectively. The maximum recorded collector fluid outlet temperature was 70.3 °C while the maximum recorded water temperature at the bottom of the hot water tank was 59.5°C. This analysis shows that HP-ETCs are more efficient than their flat plate counterparts when operating as components of a solar water heating system.



Fig, (2)

Hussein et al. [3] presented the paper for optimized design of wickless solar water collector. The theoretical analysis has been carried out with parameters as global solar radiation intensity, inlet cooling water temperature, absorber plate material and thickness, ratio of pitch distance to wickless HP diameter and ratio of condenser section length to total wickless HP length to understand the transient thermal behavior of wickless HP in flat plate solar collectors. This analysis have shown that the effect of the pitch distance ratio on the instantaneous efficiency of the wickless HP flat plate solar collector reduces as the wickless HP diameter decreases and the inlet cooling water temperature rises, it was also suggested that the instantaneous efficiency of the wickless HP flat-plate solar collector is sensitive to the inlet cooling water temperature, the absorber plate material and thickness, the wickless HP pitch and the condenser section length.

Kabeel et al. [4] carried out the experiment for the solar water collector using HP with inner rings to study the effects of the inner rings and their axial distance, in the absorber surface HP on the performance of flat plate solar water collector. Experimental setup comprises of five copper HPs with inner diameter of 11.7 mm, 0.5 mm thickness and a length of 1950mm. The absorber plate made from copper with thickness 0.5 mm the specifications of the different components of the solar water collector. On the other hand, the description of a new design of HPs with inner rings. The ratio between the inner and the outer diameter of the rings equal to 0.5. Three cases of HP with inner rings, in first case the axial distance between the rings are constant and equal to 5 cm, second case the axial distance between the rings are constant and equal to 10 cm, and third case the axial distance between the rings are constant and equal to 20 cm. The schematic of the experimental set up is shown in Fig.4. It was concluded that with water inlet temperature of 308K and solar radiation of 820 W/m^2 the water outlet temperature was 326.7K for the HP without inner rings and it became 338.8K for the HP with inner rings at axial distance of 5 cm. Results revealed that the maximum efficiencies 60% and 82.2% without inner rings and with inner rings respectively.

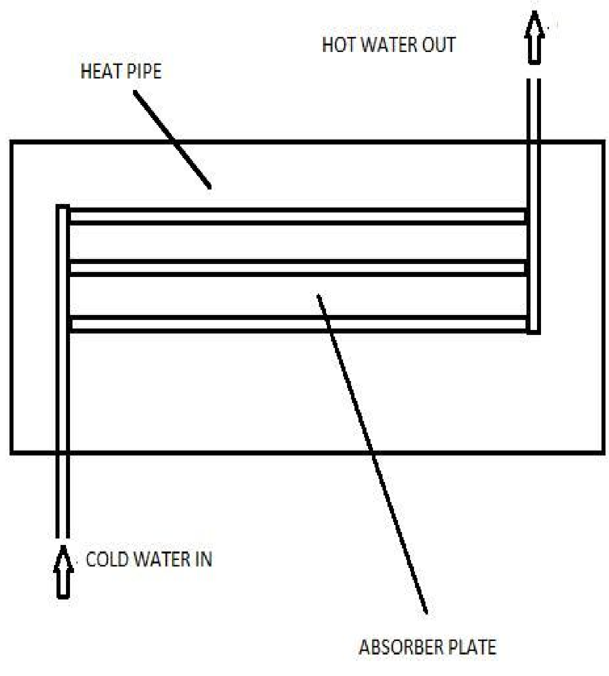


Fig. (3)

Wei et al [5] designed an improved structure of flat plate solar collector that uses one large integrated wickless HP to replace conventional side by side separate HPs. Experiments were performed to test the thermal performance of this new collector. The modification had an integrated HP consisting of 15 vertical pipes and two horizontal connecting pipes on two ends of vertical pipes and one working fluid returning pipe. The HP structure was such designed in a way that condenser section had more area and evaporator section was provided more stability. Experimental set up is shown in Fig.5. From experimental analysis, it was concluded that the maximum efficiency of collector of SWH could reach 66% by employing a new type of solar heat collector. The temperature of 200kg water was also successfully increased by 25°C in the day's work. It was also found that the collector efficiency could be improved by enhancing thermal insulation of collector as well as by keeping vacuum inside the solar collector.

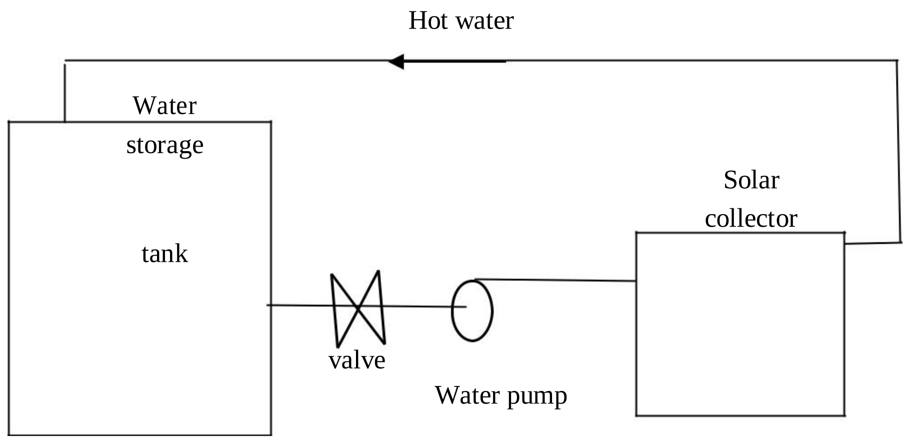


Fig. (4)

Pradhan et al. [6] investigated the thermal Performance of a HP embedded evacuated tube collector, which is a compound parabolic concentrator (CPC). In the research, experiment were performed for different tilt angles. Two stands were provided one for changing height and second for setting different angles. Three thermocouples were used, one to measure the ambient temperature, second at condenser of a HP and the third one at storage water. In this paper, the thermal efficiency of the system for three different tilt angles was calculated for ten minutes interval and different slopes angles were 45°, 25° and 15°. The result shows that the system thermal efficiency was higher for tilt angle 45° and lower for tilt angle 15°, the heat loss factor has been found almost same irrespective of the tilt angle.

Table: 1 Technical specifications of the test set up.

Component	Parameter	Value/description (mm)
Storage tank	Material	Galvanized iron
	Height	140
	Length	200
	Width	120
	Insulation	Asbestos tape
HP	Material	Copper
	Length	1800
	Heat transfer fin	Aluminum
Evacuated tube	Tube length	1780
	Outer Diameter	58
	Inner Diameter	52
FPC	Aperture Area	0.5967 m^2
	Aperture Length	1700
	Aperture Width	351

[Table:1]

Ong et al. [7] carried out the research work for Performance of HP Solar Water Heaters (SWH) by natural convection and forced convection. Between the two natural convection system is cheaper because of no need of a pump. For temperature measurement, nine Cu-con (Type T) thermocouples with an accuracy of + 0.5℃ were inserted and solar radiation was measured with a Kipp&Zonensolari meter and integrator with an accuracy of + 2%. For experiment 30 HPs made of copper were used and HP length was 1.8 m. Evacuated glass tube made of 58 outdoor Día. And 47 indoor Dia. was used solar collector area for natural and forced convection was 3.13 m^2. The schematic diagram of set up is shown in Fig.6.

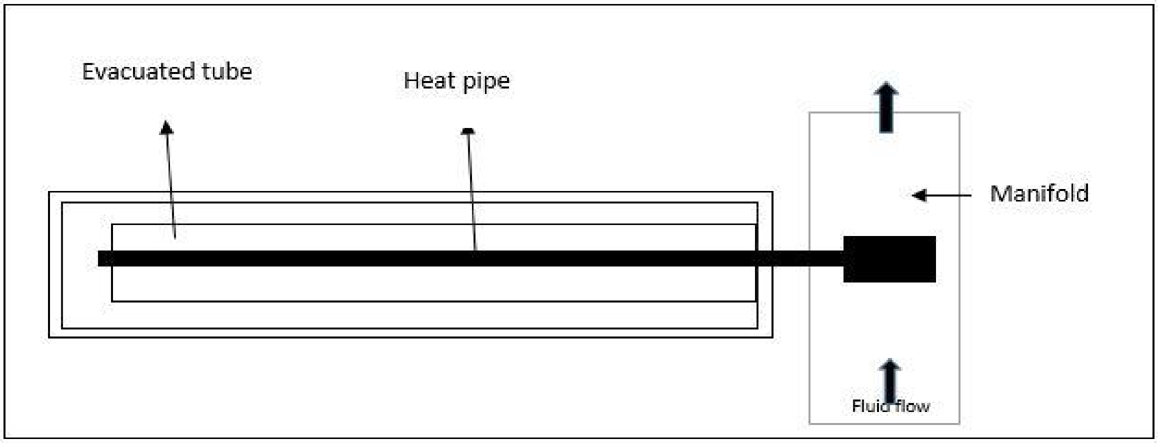


Fig. (5)

From this study it was concluded that the maximum temperature for the natural convection system was nearly 100℃ and for the forced convection system, the maximum temperature was observed to reach 84℃. The experiment shows that the natural convection system performed better than the forced convection system.

Hlaing et al. [8] presented the work on the design calculation, and heat transfer analysis of HP evacuated solar tube collector for water heating. Ethylene glycol was used as working fluid to generate 300L of hot water. Manifold casing dimension was 2.19m length, 0.13m height and 0.14m width with aluminium housing. In this analysis COMSOL Multi physics software was used. The evacuated glass tube material is borosilicate glass with thermal conductivity 1.13W/m K.

	Parameters	Value (mm) / description
Evacuated glass tube	Length	1800
	Outer Diameter	58
	Inner Diameter	49
	Glass thickness	16
	Number of tubes	30
	Material	Borosilicate glass
HP	Outer Diameter	15
	Inner Diameter	14
	Material	Copper
Heat transfer liquid (ethylene glycol)		0.1 mm^3

Table: 2 Technical specification of setup
[Table: 2]

It was concluded that the maximum hot water temperature is 43℃ at ambient temperature 21℃ and collector efficiency is 72%. It was also observed that the amount of collecting heat will be less when the number of the collector is less.

E. Azad [9] studied theoretical and experimental investigation of HP solar collector. For this experiment 200-liter tank was used and water flow rate set in the range of 0.03–0.032 kg/s. In this study six copper HPs with outside diameter of 12.7 mm and a length of 1850 mm were used. Ethanol was preferred as working fluid because of more efficiency and less prone to freezing. The absorber plate was anodized matt black to enhance its ability to absorb heat. The panel rested on a backing insulation layer of 50 mm thick glass wool, the air gap between the glass cover and the absorber plate was 40 mm. The solar radiation was measured with Kipp & Zonen CM11 pyrometer. The schematic of experimental set up is shown in Fig.8.

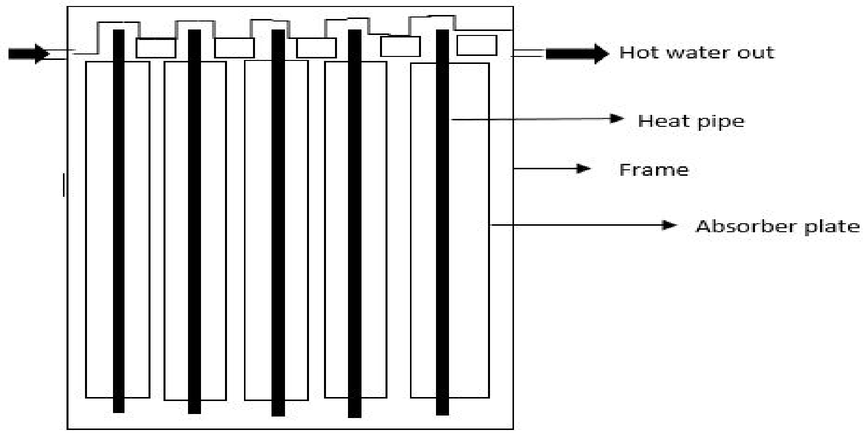
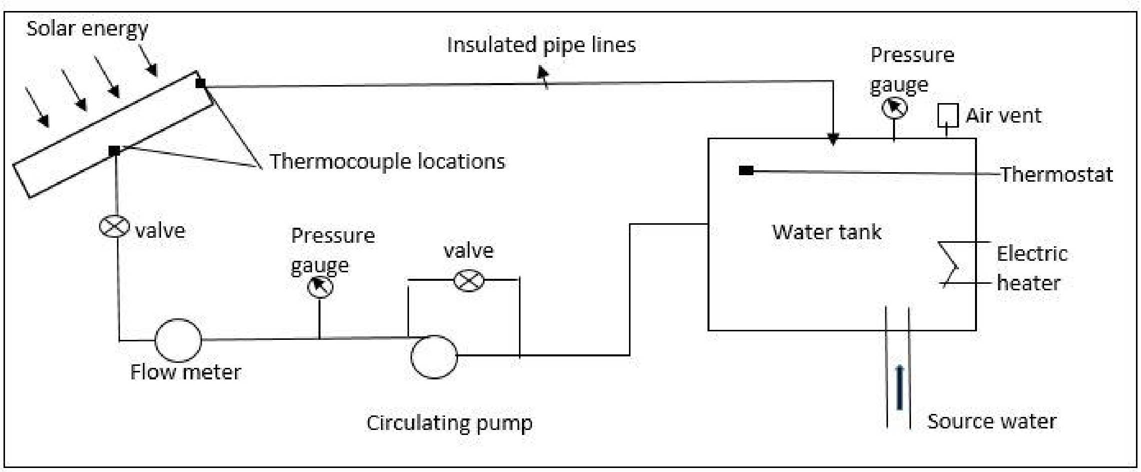


Fig. (6)

From the analysis, the theoretical efficiency was 60.3% while the experimental efficiency was found to be 55.6% and an optimum heated length-cooled length ratio to absorb more heat and increase the overall amount of useful heat.

Hussein et al. [10] researched on performance of wickless HP flat plate solar collectors having different pipes cross sections geometries and filling ratios. Distilled water used as working fluid and different filling ratios of 10%, 20%, and 35%. For study nine copper tubes of 18 mm outside diameters and length of 1.5 m was used. HP welded to an absorber plate made of a copper sheet had 0.4 mm thickness and 0.19 m width. Solar collected was set an angle of 30°. Fig. 9 shows the schematic diagram of experimental set



up. Fig. (7)

Results showed that the performance of wickless HP flat plate solar collectors improves at low water filling ratios and at 20% water filling rate, the semicircular cross section wickless HP solar collector had bad performance compared with the circular and elliptical cross section ones.

Jorge Facao and Armando C. Oliveria [11] analyzed the thermal behavior of a plate HP solar collector numerically and experimentally. The numerical model is based on energy balance equations assuming a quasi-steady condition. The temperature in the HP was considered to be uniform and equal to the saturation temperature. The collector analyzed in this work was coated with black paint, with emissivity of 0.96. The plate was encased in a 434mm*325mm*100mm aluminum box with 50 mm of rock wool insulation. The schematic of set up is shown in Fig.10. They observed that collector optical efficiency of 64% and an overall loss coefficient of 5.5W/m^{2}K, which is very near to the theoretical values.

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Nishandar et al [12], developed a Wickless HP flat plate solar collector. Performance at various tilt angles and with different working fluid is analyzed. A FPC with dimensions 940mm*375mm*86mm was used with integrated HP of Copper. Water is used as a working fluid with nano particles. Total 3 HPs are used with outer dia. 12.7mm, inner dia. 11.7mm and total length of 1000mm. Fig.11 shows the photograph of experimental set up. From experiment, it is observed that the thermal performance of wickless HP flat plate solar collector is higher by using water hybrid nanofluid over conventional working fluid water. The heat transfer rate increases between tilt angles 20° to 31.5°, while by further increasing in tilt angle produce adverse effect on heat transfer rate.

Fig. (8)

Ayompe et al [13] investigated comparative field performance study of flat plate and HP evacuated tube collectors (ETCS) for domestic water heating systems in a temperature climate. They presented a year round energy performance monitoring results of two solar water heaters with 4 m^2 flat plate and 3 m^2 HP evacuated tube collectors (ETCS) operating under the same weather conditions. They concluded that the 4 m^2 FPC system compares quite favorably with the 3 m^2 ETC system when connected to a 300 L hot water tank. Flow of water in set up is shown by given flow diagram.

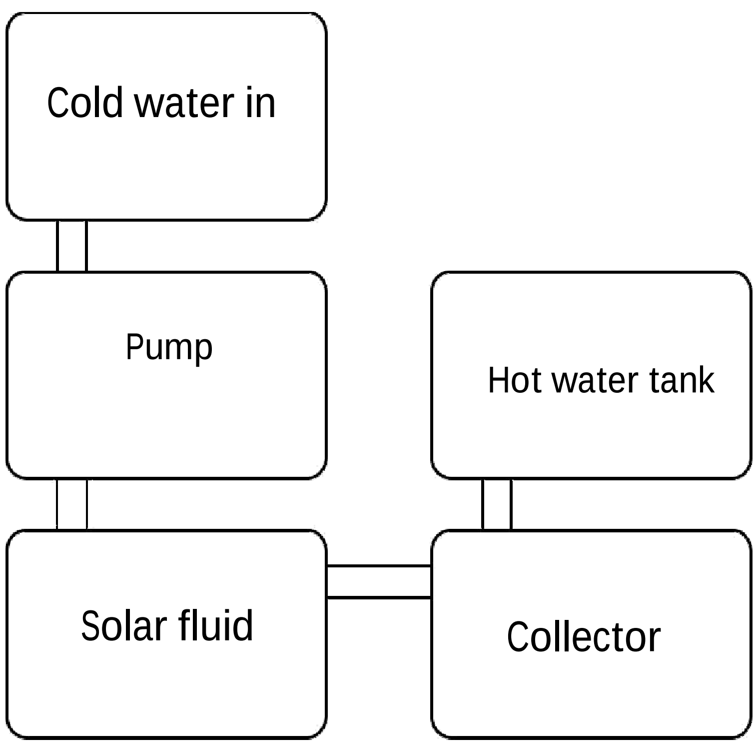

Fig. (9)

E. Azad [14] conducted comparative tests on three different types of HP solar collectors at the same working conditions .The collectors were installed in parallel and the experimental investigation was conducted to measure the thermal efficiency of the three collectors. A closed loop configuration was employed for testing the collectors. The solar collectors were installed and tested under outdoor field conditions in Tehran (latitude 35.7◦N; longitude 52.3◦E altitude 1190 m). The collectors were mounted on the stand, oriented N–S, tilted 35.7◦N towards the south and tested in outdoor conditions. The collectors' efficiencies were determined according to the procedure proposed by ASHRAE standard the hydraulic loop is divided in three lines: the first one goes to the finned tube FPCs (Type I), the second one goes to the collector with double pipe condenser (Type II) and the third one goes to collector with shell and tube condenser. One pump is used to circulate the liquid. Thermocouples were used to measure the water temperature at the inlet and outlet of the condenser. From the experiment, it was concluded that good design of Type II and III collectors have an obvious enhancement over that for the collector Type I in the practical range of reduced temperature parameter. Comparison between the three Types I–III also showed that Type I produces better efficiency over all the reduced temperature parameter range.

Table:3 shows specifications of set up.
The collector specifications used in the experiment are:

Type	Condenser	Length (m)	Width(m)	Evaporator length (m)	Condenser length or dia. (m)	Absorber
1	Shell and tube	1.95	1	1.7	0.054 dia.	Extruded aluminum
2	Double pipe	1.85	1	1.55	0.3	Extruded aluminum
3	Shell and tube	1.8	1	1.7	0.054 dia.	Finned tube

[Table: 3]

Harde et al [15] investigated the performance of solar collector with serpentine shape of heat pipe and water-ethanol as a working fluid. The tube was made by bending copper tube in serpentine manner and filled with Water-ethanol as a working fluid with 70% filling ratio. A black painted thick copper plate having dimension was braze from bottom side of HP which worked as absorber plate. At the top section, condenser of rectangular cross-section was made for water heating. Bottom and side wall of setup was insulated with thick glass wool and top side is cover with transparent glass cover to reduce convention heat loss. From the experiment, it was concluded that gravity assist HP shows better performance with having serpentine shape with water-ethanol as working fluid with the performance of collector was found to be varying with angle, as angle increase from 20º to 31.5º average efficiency increases by 30.09% and again decrease when angle further increases up to 60º. It was also observed that solar collector gives maximum efficiency at the angle where maximum solar radiation is obtained.
The collector specifications used are listed below:
HP Inner Diameter=10mm
HP Outer Diameter=12mm
Length of Condenser Section=65mm
Length of Evaporator Section=480mm
Length of Adiabatic Section=50mm
Area of absorber plate=480mm×560mm
Thickness of absorber plate=1mm
Coolant flow rate=4.5kg/hr
Gargee A. Pice et al [16] conducted experiment to investigate the thermal performance of HP based solar collector with nano fluids of varying concentration. They fabricated a thermo siphon loop HP made of copper and an absorber plate made of copper. For different tilt angles, they studied the effect of coolant rate and concentration of nano fluid used on the performance of collector. They came to conclusion that the efficiency increases up to an angle of 50° but after 50° increases in tilt angle reduces the

performance. They also concluded that water source lower performance and 0.5 w/w% shows higher performance at standard tilt angle 33.3° and 50°. Further it was observed that efficiency of the collector is minimum at coolant rate 2kg/hr. There is an increase in efficiency up to 12 kg/hr. But with further increasing in coolant rate the efficiency start decreasing.

Table:4 contains technical specification of experimental set up:

HP (single pipe)	Details	Cover Plate	Details
LHP	675	L*w*t	600*540*3
Le	600	Material	Glass
Lc	75		
Do	12	ABSORBER PLATE	Details
Di	10	L*w*t	600*480*1
Material	Copper	Material	Copper

[Table:4]

Jorge et.al [17] analyzed the thermal behavior of a plate HP solar collector numerically and experimentally to check the closeness of the results. The numerical model was based on energy balance equations assuming a quasi-steady state condition. The major simplification was that the temperature in the HP was considered to be uniform and equal to the saturation temperature since HPs are considered as isothermal devices. A small-scale solar collector, with an aperture area of about 0.1 m2, was experimentally tested during the summer season in Porto. Two types of tests were made: the first was the determination of the instantaneous efficiency curve and the second was the determination of the collector time constant, a measure of its thermal inertia. The schematic and photograph of experimental set up is shown in Fig.12. From the analysis, it was concluded that a collector optical efficiency of 64% and an overall loss coefficient of 5.5 W/ (m^2K), for a non-selective surface coating. There was a good agreement between numerical and experimental results.

Fig. (10)

Ravindra Kohle et al [18] conducted experiments to determine the effect of copper oxide nano fluid (pure water mixed with copper nanoparticle with 30-50nm diameter) on the thermal efficiency enhancement of a HP at different operating conditions. The HP was made of straight copper tube of outer diameter 12 mm and inner diameter 10 mm. The length of condenser evaporator, adiabatic section is 65mm, 480mm, 50mm and respectively. Water and nanofluid was used as working fluid for filling HP. Black painted 0.5mm thick is given to copper plate whose dimension is 480 mm*560 mm. A condenser section used for water heating in this experiment was made rectangular cross-section having dimension 25mm*65mm. 30 mm thick glass wool insulation is used from Bottom and side wall of setup and top side was covered with transparent glass cover to reduce convention heat loss. The experimental solar collector was installed on tilted stand facing south at yeolanashik, India (latitude 20.0420° N, longitude 74. 4890° E) and tested at outdoor condition. By taking Coolant (Water) flow rate 8kg/hr4kg/hr, and 5 different angles of inclination (20°, 31. 5°, 40°, 50°, 60°) of collector the experiment is carried throughout the day. From the experimental analysis, it was concluded that concluded that the solar collector performance depends on coolant flow rate, heat flux at evaporator, working fluid and inclination angle and the thermal performance of HP collector increases as the coolant rate increases up to certain level after that increase in coolant rate has no effect on performance. It was also absorbed that as inclination angle increases from 20° to 50° the heat transfer rate increases while further increase in angle reduces the heat transfer rate. The photograph of experimental set up is shown in Fig.13. Results showed that CuOnanofluid has greater potential to enhance the performance of HP collector than that of water.

Fig, (11)

III. CONCLUSION

The present paper discussed a comprehensive review of the recent advances and developments related with the application of the HP solar collector. Some important conclusions are summarized below: -

A. Use of nano-fluid in HPFC improves the overall performance of the solar water heater in term of rise in efficiency by 10 to 15 %.
B. Improved designs and geometry of collectors reduces size of system with higher performance.
C. Need to work on to size of flat plate solar collector from economical and installation point of view.
D. By tilting mechanism of collector, the system get more exposure of radiation which helps for higher temperature gain for industrial applications.
E. Heat losses due to conduction, re-radiation and convections need to be minimized by improving thermal insulation on the back and the edges.

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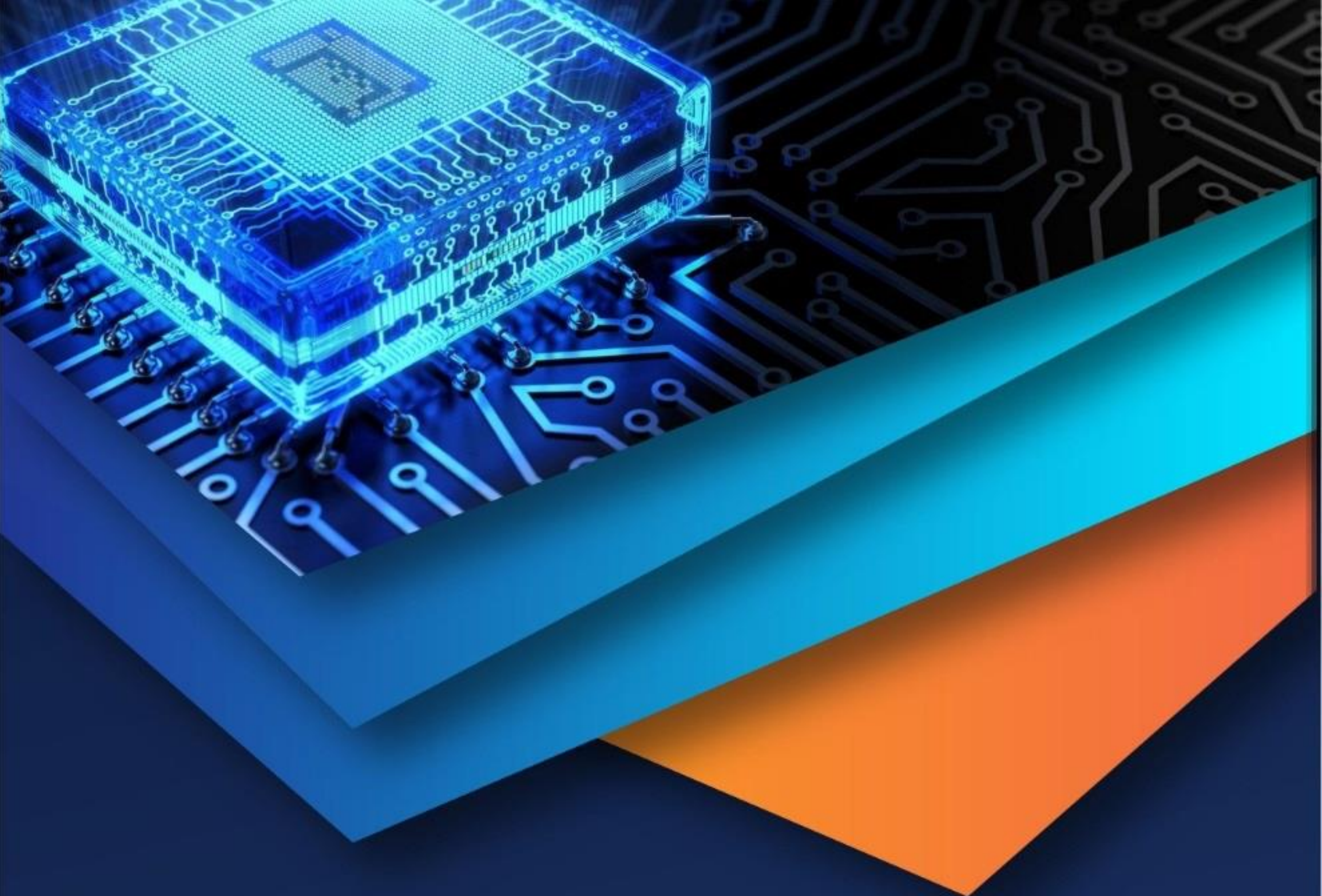

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