Thermal Sciences Design, Engineering and Experiments on solar Water Heaters

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ABSTRACT - Solar flat plate collectors are used for producing hot water at an outlet temperature of 80^0 C by absorbing the solar radiation in the flat plate collector and heating a fixed quantity of water circulated by natural or forced circulation in the solar water heater.The research gaps in this experiment are the operating parameters and conditions that affect the Outlet temperature and the Instantaneous efficiency are not clearly defined.The objective of the research is to to determine the technical problem that affects the oultlet temperature and thermal efficiency of the solar water heater and to improve the performance of the solar heater by solving the technical problem.During the testing of the solar water heater it was found that the circulation was not effective and the overall efficiency was less than the expected output. Then the collector tilt angle was set to latitude angle and the velocity,mass flow rate of water was corrected by revising the layout of the solar Water heater. After correction,it was found the water outlet temperature was 75^0C and the thermal efficiency was 81 %.

Keywords: Circulation, Efficiency,Latitude, Radiation, Tilt.

INTRODUCTION

In 2017, India installed 36 new industrial solar process heat systems with a total collector area of 15,313 m^2.The Country now has the sixth largest installed capacity for solar thermal in the global market.

LITERATURE REVIEW AND OBJECTIVE

Prasad, Byregowda and Gangawati[1]conducted an experimental study on a water heater with a flat plate collector and a Solar tracking mechanism increasing the system's thermal efficiency by 21%.Basavanna etal[2] analysed a flat plate collector with triangular pipes obtaining an increase in water outflow temperature by 330K.Shelke and Patil[3] analysed the effect of variation in tube shapes for flat plate solar water heater.They compared the outlet temperature between an elliptical tube and a circular tube concluding that elliptical tube gives the maximum outlet temperature of water for the same heat flux and inlet temperature.Prakash, vishnuprasad etal[4] showed that the use of special surface coatings improves the optical properties of the collector, the operating temperature and the performance of the system.Sopian etal[5]experimentally studied the performance of a new design of solar water heater where the collector and storage tank are integrated in one unit.The temperatures registered in the storage tank oscillated between 60^0C and 63^0C with a radiation of $700w/m^2$ and the efficiency of the system was 75% with an ambient temperature of 31^0C. The ASHRAE standard requires an experimental determination of steady state collector efficiency under prescribed environmental and operating conditions [6] Ozoe etal[7,8] and Alvarado etal[9]among others have shown the changes in flow pattern with the collector inclination with respect to the horizontal postion.Hollands[10] correlation was used to calculate the Nusselt Number for solar water heater.Among theresearch equations, whillier etal have derived an overall heat loss coefficient and experimental generalised correlations as complements to determine the collectors efficiency[11].Cooper etal [12]have given equations to calculate the overall heat transfer coefficient Ut. Prapas[13] underscored the need for optimisation of system performance to the ultimate limit possible and the performance examination from user point of view.Active system whether direct or indirect can be easily retrofitted to already existing Solar water heater because the storage tank can be placed at any place unlike thermosiphon system.Harrison etal[14].The most commonly used method for analysis of solar water heaters is known as tau alpha method which is based on the product of net transmittance and absorptance of absorbing plate of solar water heater. This technique was developed by Holland and Wright in 1983 and described in detail by Duffie and Beckman[15].The correlation for natural convection between plates was given by Holland etal[16].The effect of tilt angle on the solar radiation can be evaluated using the ASHRAE clear sky equation[17].The effect of geometric and operating parameters by CFD method for solar flat plate collectors was given by Malleboyana etal.The effect of nano particles on the performance of solar flat plate collectors was given by Mohammad [18].The effect of volume flow rate on efficiency of solar collector is discussed in shah etal[19]. The flow distribution in flat plate collectors under different conditions were studied by weitbrect v etal[20].The design of absorber plate and the selective coating plays an active role in the performance of solar water heater for absorbing solar radiation, Jyothi etal[21]At present,solar energy utilisation techniques include photovoltaic, photothermal andphotochemical,Liu etal[22].Solar collectors include flat plate ,vacuum type,concentrating type,gao etal[23].Xuan and Li[24] investigated the convective heat transfer and flow features of nano fluids,effect of volume concentration,convective heat transfer coefficient,friction factor and flow features.

OBJECTIVE

The objective of the Research is to perform Experiments in Solar Water Heater and plot the variation in Water Outlet Temperature and Instant Efficiency w.r.t the Time of the Day.

Thermal Efficiency of Solar Flat Plate Water Collector is given by

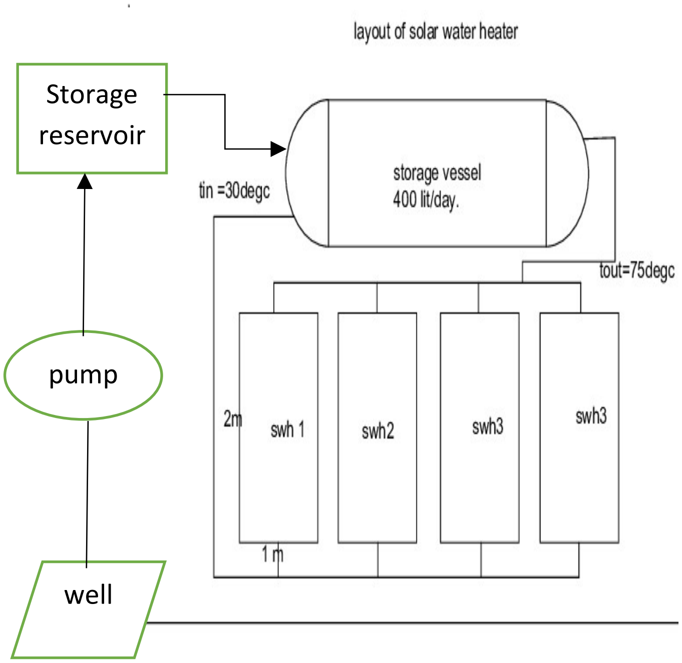
η = output/input x 100 -------- (1.1)

$= qu/G\,.Ac$ G =850w/m^{2}.

$Qu = m.cp\,.[tf1 - tf2]$ ---------(1.2)

1.**MATERIAL AND METHODS**

Solar water heater front view



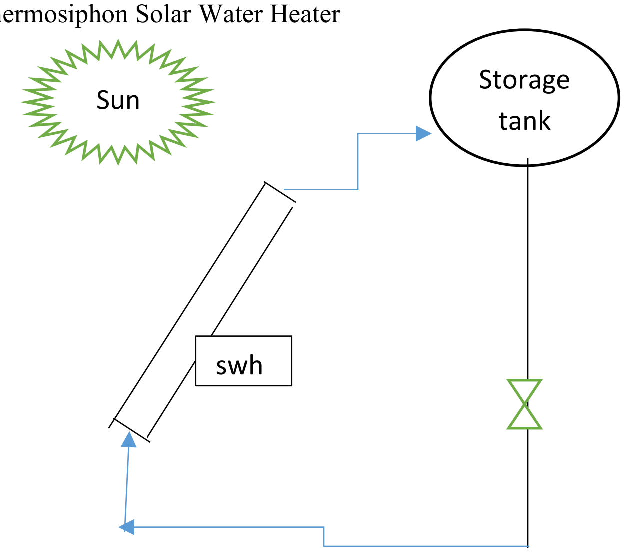
Measurement Equipments;Thermocouple, Pressure gauge,sun shine recorder,pyranometer, Water level Indicator,flow meter,digital thermometer.

The light rays from the sun,as they fall over the flat plate collector penetrate the transparent cover and hit the selectively coated(black body)surface of the Absorber Plate. A part of the Energy falling on the Collector surface is absorbed by the Collector and is then transferred to the Water flowing through the tubes fitted the absorber plate by conduction heat transfer. The remaining part of the radiation is lost to the atmosphere by Convection and Re-radiation. The ratio of the Energy Collected by the Collector Plate to the Energy Incident On the Collector Surface is defined as the Efficiency of the Collector.As the Water gets heated up, the density of the Water gets decreased and the hot water as a result,rises up through the Collector to the header and then to the Insulated Storage Tank.

In the Tank, the top layer of the water will always be hotter than the bottom layer and there will be temperature difference inside the Tank.This Phenomenon is called Stratification,As a result of hot water flow into the Tank,Cold water gets forced to the Collector through the bottom header. Thus the hot Water flows to the storage tank.

Solar water heater side view

Thermosiphon Solar Water Heater



Solar Water Collector Tilt angle;
1.36^{0} before Improvement.
2.22^{0} after Improvement.
Tilt angle = Latitude angle of place.

2.0 CALCULATION OF THE INSTANTANEOUS EFFICIENCY OF SOLAR FLAT PLATE COLLECTORS

Instantaneous Solar Efficiency is given by

$\eta = Qu / G XAc.$ ----(2.1)

$Qu = m.cp.[tf1 - tf2]$ -----(2.2)

m =165Kg/hr
 = 0.046Kg/Sec.

η = 0.046 x 4.186 x(60-30)
------------------------------ x100
0.85 x 2 x 4

Solar constant G=0.850KW/m2

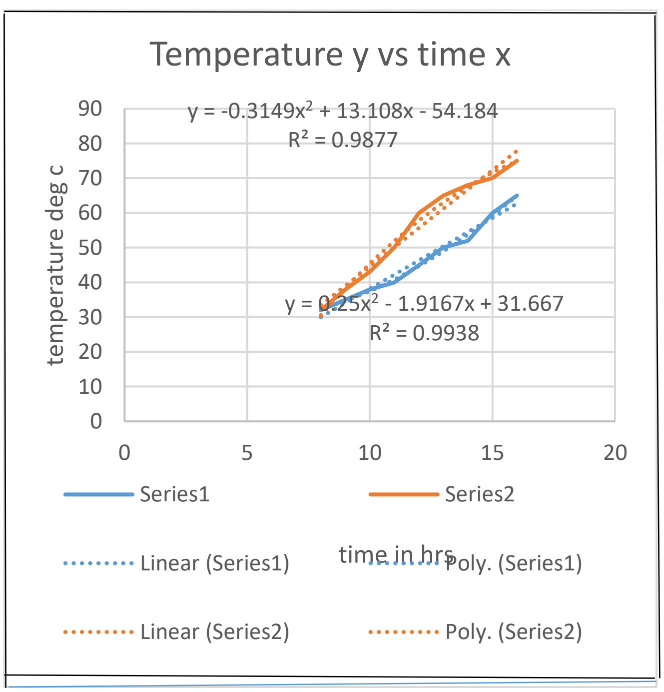
 = 85.0%

3.0 RESULTS AND DISCUSSION

TABLE 3.1
TEMPERATURE VS TIME;

Time(x)	8	9	10	11	12	13.	14	15	16.
T10	31	32	34	49	55	58	60	71	71
T11	31	32	34	50	56	58	62	73	71
T12	32	33	36	52	57	59	64	75	71

Chart 3.1



Series 1 -Actual Series 2-Predicted

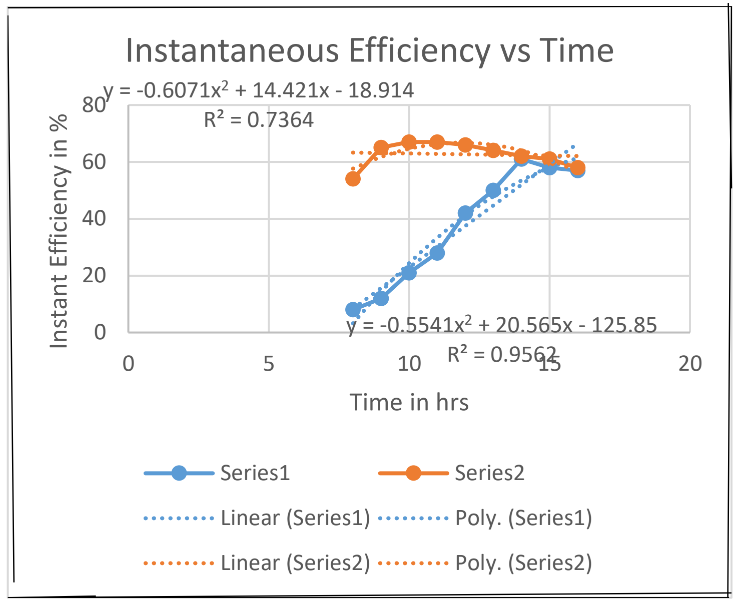


Chart 3.2

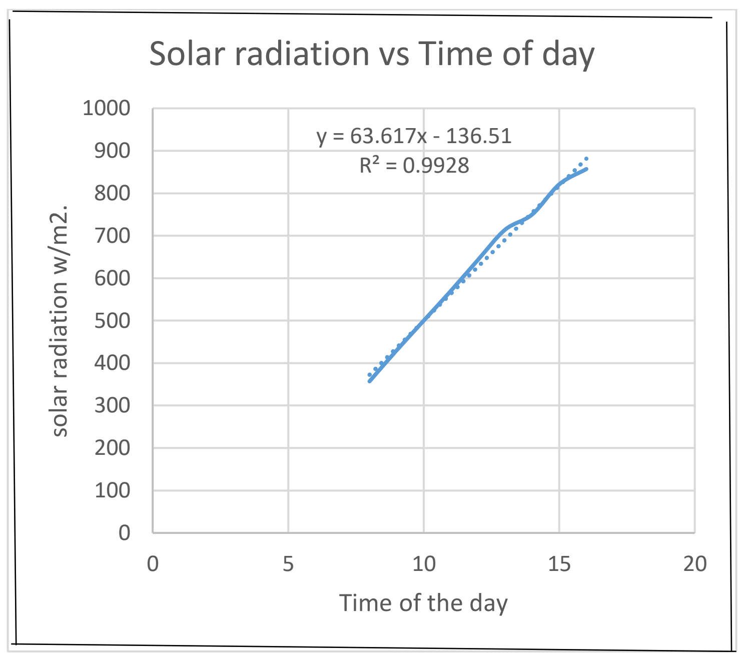
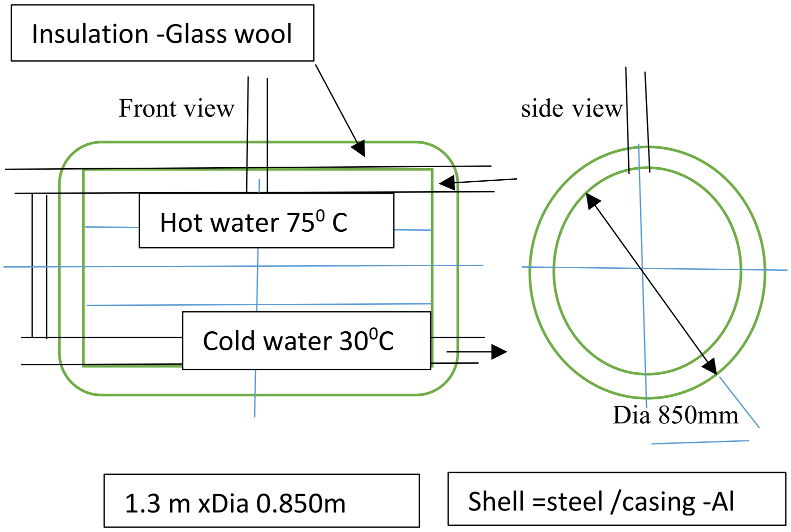


CHART 3.3

Table2.0 Efficiency vs Time.

8	9	10	11	12	13	14	15	16	17
9.34	11.97	16.58	33.4	47.14	53.0	60.5	77.8	79.3	75.0

Cross Section of the Water Storage Tank of Solar Heater.fig1.0



The storage tank is connected to the flat plate collectors through Header pipes at inlet to collector at the bottom and the Outlet of the solar flat plate collectors to connected to the upper Header and connected to the storage vessel. Cold water enter the solar flat plate heater and by density difference and heat Given by the absorber plate gets heated up and rises up to the Upper portion of the tank by thermosyphon technique.

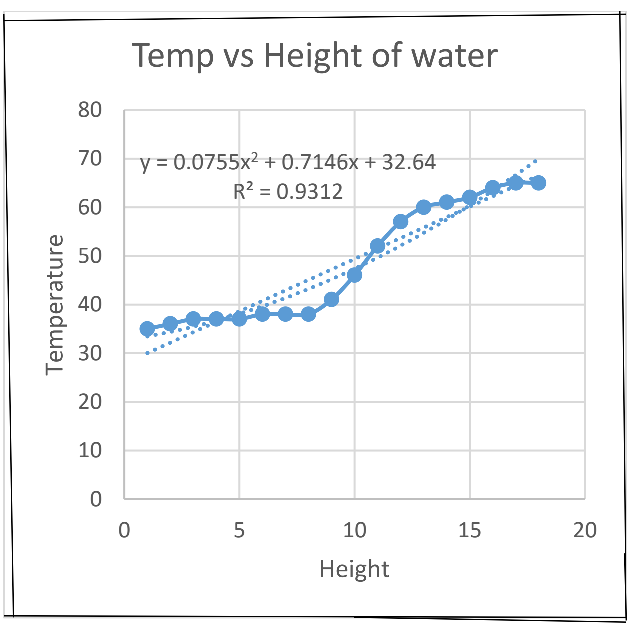


CHART 3.4

Fig 2.0Photograph of the Experimental Set Up.

4.0EXPERIMENTS AND RESULTS

4.1 Water Oultlet Temperature vs Time of the Day.

After measuring the Water Outlet Temperature from the Collector periodically for all the three systems namely 400 LPD,500LPD and 600LPD , It was decided to compare the results obtained with the Theoretical Design Values.Hence in this Chapter, to Start with for each System, the Predicted Water Outlet Temperature and Instantaneous Efficiency are first evaluated before going in the Comparision with the given values.

chart 3.1 and chart 3.5 gives the variation in Water Outlet Temperature with Time of the Day.For 400 LPD System, a Maximum Temperature of 57 deg C will be obtained around noon if the water enters at 32 deg C.

The following observations are made w.r.t to the charts plotted for Temperature Vs Time.

1.A Maximum Temperature Rise is Obtained around Noon.
2.Temperature Rise is Maximum for Lower System Capacity names 400LPD and lower for Higher System Capacity namely 600LPD.
3.The Temperature Rise becomes lesser and lesser as the Inlet Water Temperature to the Collector Increases.This is due to the fact that higher the Temperature, Higher will be the Loss.
4.The variation of solar radiation w.r.t the time of the day Is given in chart 3.3 and the max radiation is 800W/m^2.
4.2 The Formula used for predicting the Instantaneous Efficiencyis given in topic 2.0.

4.2 Instant Efficiency vs Time of the Day.

The variation in Efficiency vs Time is plotted in Chart 3.2.
It is observed from the chart that maximum efficiency occurs around 2 o clock in the afternoon.This can be attributed to the fact that around 2 o clock,the water will be at high temperature Forcing the other liquid to flow.Hence it is possible to achieve a better flow rate during noon hours and inturn a better efficiency.

4.3.Flow Calculations for the Solar Water Heater before Improvement.

Diameter of the riser tubes(mm)=12.7 mm
Material of the riser tubes= Copper.
Density of Water(ρ)= $1000kg/m^3$.
Velocity of Water = 0.12m/sec.
Dynamic Viscosity of Water(μ) =8.9×10^{-4} $N.S/m^2$.

$$Re = (\rho v d)/\mu.$$

Substituting the values,
Re= 2597.
Re> 2000 ,So the Flow is Turbulent.

4.4. Flow Calculations for the Solar Water Heater After Improvement.

Diameter of the riser tubes(mm)=12.7 mm
Material of the riser tubes= Copper.
Density of Water(ρ)= $1000kg/m^3$.
Velocity of Water = 0.15m/sec.
Dynamic Viscosity of Water(μ) =8.9×10^{-4} $N.S/m^2$.

$$Re = (\rho v d)/\mu.$$

Substituting the values,
Re= 2796.
Re> 2000 ,So the Flow is Turbulent.

4.1 Layout of the Solar Water Heater Before Improvement.

	400 LPD	500LPD	600LPD
Inclination of Solar Flat Plate Collector ɵ	36^0	36^0	36^0
Horizontal Distance of Storage tank from Solar water heater(.mm)	793	696	793
Vertical Distance of Storage tank from Solar water heater.(mm)	576	506	576
Velocity of water flow to Solar water Heater(m/sec)	0.091	0.093	0.094

4.2 Layout of the Solar Water Heater After Improvement.

	400 LPD	500LPD	600LPD
Inclination of Solar Flat Plate Collector ɵ	22^0	22^0	22^0
Horizontal Distance of Storage tank from Solar water heater(.mm)	577	585	585
Vertical Distance of Storage tank from Solar water heater.(mm)	233	236	236
Velocity of water flow to Solar water Heater(m/sec)	0.098	0.097	0.0986

The angle of Inclination of the solar water heater was 36^0 before Improvement and the tilt angle is 22^0 after Improvement.

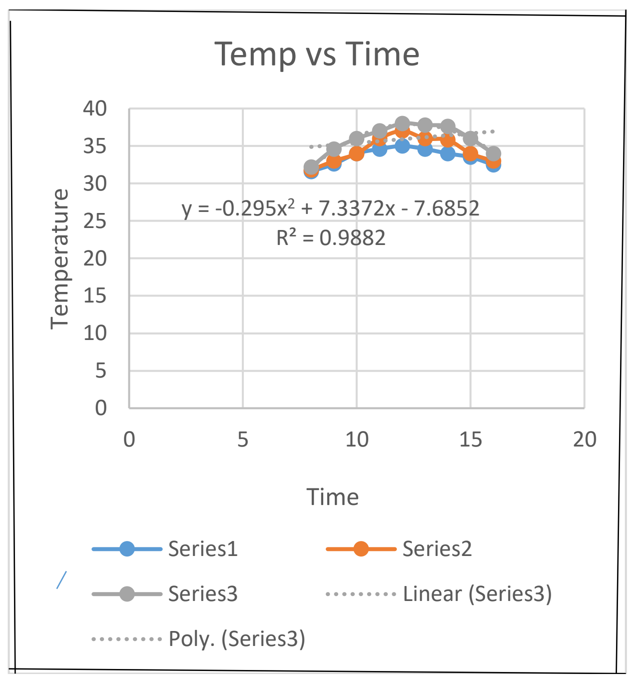


Chart 3.5

. With reference to the chart,the maximum temperature is 38 deg c before improvement and the maximum temperature of 75 degc was achieved after the tilt angle and layout is revised.

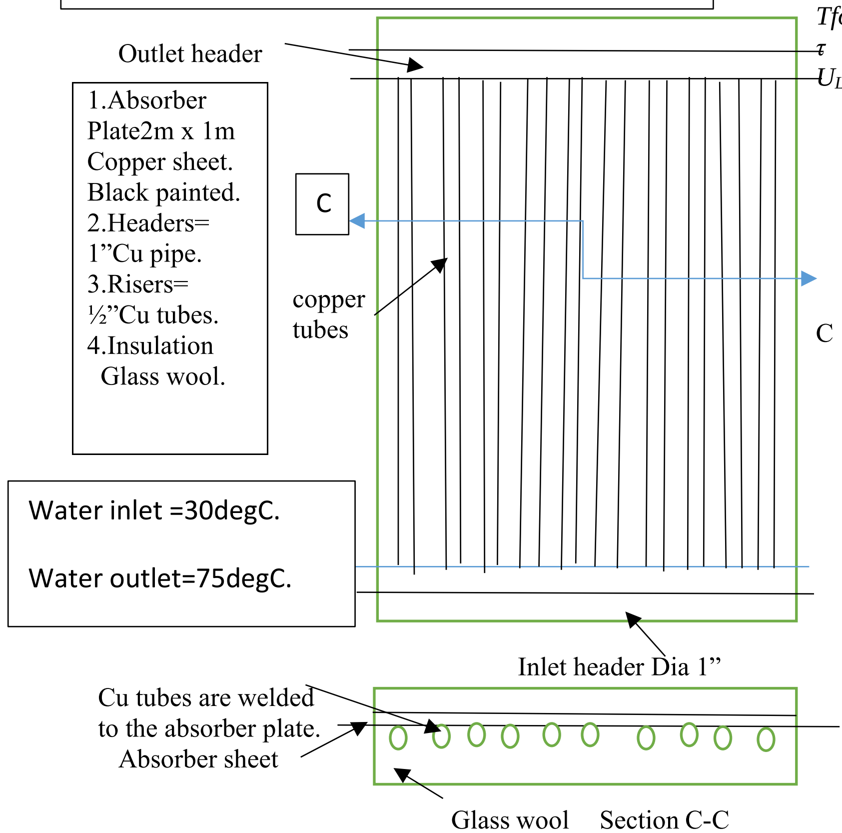
4.3Performance of the Solar Water Heater before Improvement.

Subject	400LPD	500LPD	600LPD
Water Outlet Temperature (Deg C)	58	62	63
Water Inlet Temperature (Deg C)	32	32	32
Instant Efficiency(%)	25	56	54

4.4Performance of the Solar Water Heater after Improvement.

Subject	400LPD	500LPD	600LPD
Water Outlet Temperature (Deg C)	78	75	72
Water Inlet Temperature (Deg C)	32	32	32
Instant Efficiency(%)	78	77.8	81.64

Fig 3.0Cross section of a solar flat water heater



5.0 CONCLUSION

It can be concluded from the studies conducted that by taking proper care in the Installation of collector tank, collector tilt angle and piping system, it is possible to achieve a high efficiency. Our Experience suggests that though the collector and storage tank are properly designed,due to lack of proper sizing and level of pipes in the system, a poor efficiency was noticed.However this problem was removed when the pipes are sized and located properly.Hence it is suggested that due importance shall be given not only to the basic design of the collector system but also to the Installation.

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NOMENCLATURE

Ac	Area of solar collector	[m^2]
I	Solar constant	[w/m2]
T	Temperature	[Deg C]
α	Absorptivity	
ρ	Density of water	[kg/m^3]
ω	Rotor rotational speed	[rad/s]
Q	Heat Flow	[KW]
G	Solar Constant.	[W/m^2]
Cp	Specific heat of water	[W/m^2 °K]
Tfi	Water inlet temperature.	[Deg C]
Tfo	Water outlet temperature.	[Deg C]
τ	Transmissivity.	
U_L	Overall heat loss Coefficient.	[w/m^2 ^{0}k]

REFERENCES

1.Mauthner,F;Weiss;Spork-Dur,MSolarHeat worldwide; IEA Solar Heating and Cooling Gleisdorf, Austria,2016.
2.https://www.researchgate.net/publication/353549578_A_Review_of_Solar_Flat_Plate_Thermal_Collector.
3.Selmi etal.(2008)Validation of CFD simulation for flat Plate solar energy collector.Renewable Energy 33,383.
4.American Society of Heating,Refrigerating and Air Conditioning Engineers,inc ANSI/ASHRAE 93-2010(RA2014),Methods of Testing to Determine the Thermal Performance of Solar Collectors,ASHRAE,Atlanta,USA 2014.
5.ISO 9806-1 International Standard,Test Methods for Solar Collectors-Part 1;Thermal Performance of Glazed Liquid Heating Collectors Including pressure drop,ISO,Switzerland 1994.
6.https://www.researchgate.net/publication/355184395_NON_CONVENTIONAL_ENERGY_SOURCES_FOR_CONSERVING_THE_NATURAL_RESOURCES_OF_EARTH.
7.Sukatme(2008),'Solar Energy -principles of Thermal Collection and Storage'Mc Graw Hill Education.
8.Energy Conservation in BHEL,R.Rajkumar ME Thesis, Anna University,Chennai 600025.