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Experimental Investigation of a New Solar Flat Plate Collector

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Abstract

A new and inexpensive solar water heater has been tested. The collector is of sandwich type. The absorber is made of 2 sheets of GI (1 mm) with integrated canals, painted in silica based black paint. Experiments have been carried out to test the performance of both the water heaters under water circulation with a small pump and the results are compared. The results show that the system can reach satisfactory levels of efficiency. Furthermore it proves to be inexpensive and easier to manufacture which makes it a potential technological solution to the domestic water heating problems in rural India.

Keywords: Solar collectors, absorber plate, aperture irradiance, black body.

Introduction

Solar energy has always been a viable option for the energy problems faced by the world. Solar energy is the radiation resulted by nuclear fusion reactions in the sun. The 30% of the solar power actually reaches the Earth, every 20 minutes the sun produces enough power to supply the earth with its needs for an entire year[1]. This solar radiation can be directly converted into heat. Many different kinds of equipment are available for this conversion. These can help lessen the impact of domestic sector on the environment. Flat plate collectors have been in service for a long time without any significant changes in their design and operational principles[2].

A simple flat plate collector consists of an absorber plate in an insulated box covered with transparent sheets. The most important part of a solar collector is the absorber, which usually consists of several narrow metal sheets aligned side-by-side. The fluid used for heat transfer generally flows through a metallic pipe, which is connected to the absorber strip. In plate-type absorbers, two sheets are sandwiched together allowing the medium to flow between the two sheets. The outer casing which provides mechanical strength to the equipment is insulated to reduce the heat losses from back and sides of the collector[3].

The collector can reach temperatures up to 200°C when no liquid flows through it and therefore all the materials used must be able to resist these high temperatures. The absorber is usually made of metallic materials such as copper, steel or aluminum. The collector housing can be made of plastic, metal or wood and the glass front cover must be sealed so that heat does not escape, and the collector itself is protected from dirt, insects or humidity.

The collector housing is highly insulated at the back and sides to reduce the heat losses. Still the heat losses due to the temperature difference between the absorber and ambient air result in convection and radiation losses. The convection losses are caused by the angle of inclination and the spacing between the glass cover and the absorber plate, while the radiation losses are caused by the exchange of heat between the absorber and the environment.

Any absorber plate must perform three functions: absorb the maximum possible amount of solar irradiance, transfer this heat into the working fluid at a minimum temperature loss and lose a minimum amount of heat back to the surroundings.

Solar irradiance passing through the glazing is absorbed directly onto the absorber plate. Surface coatings that have a high absorbtivity value for short-wavelength light are used on the absorber. Paint or plating is used and the resulting black surface will absorb almost over 95% of the incident radiation[4]. The second function of the absorber plate is to transfer the absorbed energy into a heat-transfer fluid at a minimum temperature difference. This is achieved by conducting the absorbed heat to tubes that contain the heat-transfer fluid. The heat-transfer fluid is generally water. Transferring the heat absorbed on the absorber surface into the fluid gives rise to heat losses. Liquid collector absorber plates consist of a flat sheet of metal with tubes spaced 130 mm apart and attached to it. The sheet of metal absorbs most of the solar irradiance and acts as a carrier to bring the absorbed heat into the fluid. In an efficient system the absorber sheet is made of a material with high thermal conductivity. The tubes are not spaced far too apart otherwise a much lower temperature will occur halfway between them.

The new type of collector is the water sandwich type collector which is made by bracing two corrugated metal sheets on one another. The only difference between the earlier collector and this one is the absorber plate. Although it serves the same functions the physics is different from the conventional one. In this collector the heat transfer directly takes place from the absorber plate to the fluid. Whereas in the conventional collector the heat is conducted from the fins to the tube first and then convection to the fluid from the tube takes place.

This work is primarily concerned with the possibility of replacing the conventional collectors with the GI plate sandwiched collectors. So, only the important practical parameters like the steady state outlet temperatures and the efficiencies can be compared.

But the current work deals with a new design form the conventional one. The most striking difference is the absence of heat carrying metallic tubes. The working fluid (water) is made to pass through the channels that are formed when two corrugated metal sheets are braced one over another.

Material and Methods

The absorber plates radiates back small amount of heat because of its higher temperature. This loss mechanism is a function of the emittance of the surface for low-temperature, long-wavelength radiation. Many coatings that enhance the absorption of sunlight (short-wavelength radiation) also enhance the long wavelength radiation loss from the surface. An ideal coating will be a good absorber of short-wavelength solar irradiance and a poor emitter of long-wavelength radiant energy.

One or more transparent cover sheets are used to reduce convective heat loss. But complete elimination of convective loss cannot be achieved because of the convective current that exists between the absorber and the cover sheet, so transferring heat from the absorber to the cover sheet. External convection then produces a net heat loss from the absorber as it cools the cover sheet.

The collector performance test data is associated with the collector temperature rise above ambient divided by the solar irradiance. The collector temperature used for flat plate collector performance correlation is normally the temperature of the heat transfer fluid entering the collector and not the average fluid temperature.

Every correlation using fluid inlet temperature must specify the fluid flow rate at which the measurements were made. The recommended test flow rate for a liquid collector[2] is 0.02 kg/hr.

Total solar irradiance is used as the basis for flat-plate collector performance calculations. The aperture irradiance is the total solar irradiance measured in the plane which the collector stands. This removes the cosine loss of the beam component as the collector is tilted from the horizontal, as well as some ground reflection[5].

The lack of previous work in this area has been a problem. The experimental work involves tests conducted with two types of solar collector panels under natural insolation. The first type used is similar to the conventional design, whilst the second is the new design.

The conventional collector has two flow paths that are 0.95m long and has attached fins. The tube diameter is about 0.0127m. Both the tube and the plate are made of copper. These flow paths join the header which has a diameter of 0.025m. The entire absorber plate is set in an insulated wooden box. Polystyrene is used as an insulation material. Low iron tempered glass is used as glazing material. The absorber surfaces are coated with silica based black paint and silica gel is used as filling material in case of any unwanted gaps.

Table-1
Material Selection and Design of the two collectors

	Conventional	**New**
Absorber Tube	Copper	GI
Fins	Copper	-
Insulation	Polystyrene	Polystyrene
Casing	Wood	Wood
Selective Coating	Si based black paint	Si based black paint
flow cross section	circular	elliptical
Internal Diameter of the tube	12.7 cm	Major-15cm Minor-12cm
Width of the fins	0.14m	0.14m
Length	0.95m	0.95m
Area	$0.266m^2$	$0.266m^2$

Table-2
Specifications of the two collectors

Specifications	**Conventional Collector**	**New Collector**
Dimensions	1.1mx0.32mx0.22m	1.2mx0.33mx0.22m
Length of the absorber plate	0.93	0.93
Width of the absorber plate	0.26	0.26m
Material of the absorber plate	Copper	GI sheet
Thermal conductivity of the plate material	401W/mK	35W/mK
Density of the plate material	$8960kg/m^3$	$7850kg/m^3$
Plate thickness	0.00005m	0.001m
Tube center to center distance	0.12m	0.12m
Number of flow paths used	2	2
Glass cover emissivity/absorptivity	0.87	0.88
Diameter of header pipes	0.025m	0.025m
Insulating material used	Polystyrene	Polystyrene
Location of collector tray	Vellore	Vellore
flow rate	5l/hr	5 l/hr
Bottom insulation thickness	0.08m	0.08m
Insulation thermal conductivity	0.06W/mk	0.06W/mk

The material selection for the second collector has been a major concern, because of the very small thickness (0.5mm) of the copper plate used. Hence, GI sheet which has more mechanical strength for same thickness is used. Two different GI sheets are pressed in such a way that when they are sandwiched over each other they give a flow path.

Two flat plate collectors were placed with an angle at 18^o to the horizontal towards south facing. Inlet temperature of the water and temperature of the hot water at the outlet were tabulated every five minutes; the efficiencies of both the collectors were calculated.

Results and Discussion

Efficiency Calculation: The steady state efficiency is calculated[6]. All the heat loss coefficients are irrelevant because of the smaller size of the collector area. The actual mathematical modeling is done and the instantaneous efficiency is found to be almost same as that of the steady state value. The experiment has been conducted three different times on both the collectors and the average values have been taken into account for the following calculations.

Average Solar radiation received by earth in terms of energy R = 722 W/m^2/Hr. Mass flow rate of water is 5liters/hour. So, the absorbed energy for one hour is calculated. Solar radiation received by earth in 1 hours in terms of energy R = 722*1 W/m^2/day.

R = 722 Wh/m^2, R = 1949400 W Sec/m^2, where, A = Area of Flat plate collector in m^2, T1 = Temperature of water at inlet in ºC, T2 = Temperature of water at outlet in ºC, Mass of water taken in the storage tank = 5 liters, Specific heat of water = 4.182 kJ/kg K

Area of the flat plate collector,
A = L*W m^2, = 0.95*0.26, = 0.266 m^2

Radiation received by collector,
R1 = R*A, = 1949400*0.266, = 518540 Joules

Output of the Stationary Collector,
Q = 5*4.187*(44 – 38), = 5*4.187*10^3*(6), =125340

Output of the partially new Collector,
Q = M*Cp*(T2 – T1), = 5*4.187*103*(41 – 36) , = 104675 Joules

Efficiency of Conventional flat plate collector, η = Output of the collector / Input Radiation,
η = M*Cp*(T2 – T1) / R*A, = 125340 Joules / 518540 Joules, = 24.17%

Efficiency of the new Collector, η = Output of the collector / Input Radiation,
η = M*Cp*(T2 – T1) / R*A, = 104675 Joules / 518540 Joules, = 20.19%

Table-3
Efficiencies of the two collectors

Efficiency of the flat plate (conventional)	Efficiency of the new collector
24.17%	20.19%

The first temperature reading recorded always shows a high value. This is because of the heating the plate took while the setup is being arranged. This is only a fleeting value and this should not be considered. The systems took about 15-20minutes before reaching steady states.

Conclusion

Hottel-Whillier Bliss efficiency curves[7] (figure 7) are important in many ways; they demonstrate the effectiveness of a solar collector in absorbing solar radiation[8]. These curves show that the greater the temperature difference between the collector outlet water (T_{out}) and the ambient air (T_a), the lower the operating efficiency due to heat loss.

From the above results, it can be concluded there is little difference between the output temperatures while using these different collectors. Although the use of GI as absorber plate material is widely recognized, copper collectors still dominate everywhere. This particular work proves to be a viable cost cutting solution to domestic water heating. As GI sheet is much cheaper than copper and there is no need of bracing the pate and tube, it further reduces the cost.

The following graphs show the variation of output temperature with time of both the collectors on three different days. The first day is the sunniest day with maximum global levels reaching as high as up to 751W/m^2. The blue line indicates the temperature variance of the conventional collector and the red line of the new collector. Estimation of global solar radiation[9] is carried out using artificial intelligence and neural networks and the numerical analysis of solar flat plate collectors can be carried out using commercial tools similar to[10-12] using CFD tools for better optimization of solar flat plate collectors.

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Table-4
First experimental test results conducted on 12th March 2012

Time (pm)	(W/m^2)	Water Temperature Conventional Collector		Water Temperature New collector	
		Inlet(^OC)	Outlet(^OC)	Inlet (^OC)	Outlet(^OC)
1:00	710	32	41	34	41
1:05	721	33	42	36	42
1:10	730	36	46	36	41.5
1:15	719	35	46	37	43
1:20	748	37	48	37	44
1:25	751	35	48	37	43
1:30	791	34	45	36	45
1:35	741	36	45	35	42
1:40	721	37	49	35	41
1:45	708	35	46	36	41

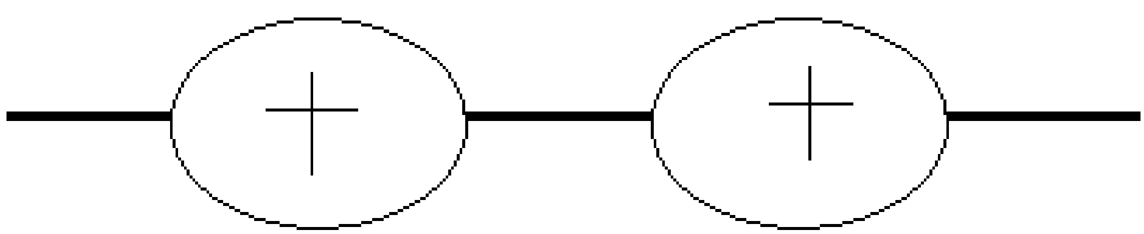

Figure-1
Cross section of sandwich type solar flat plate collectors

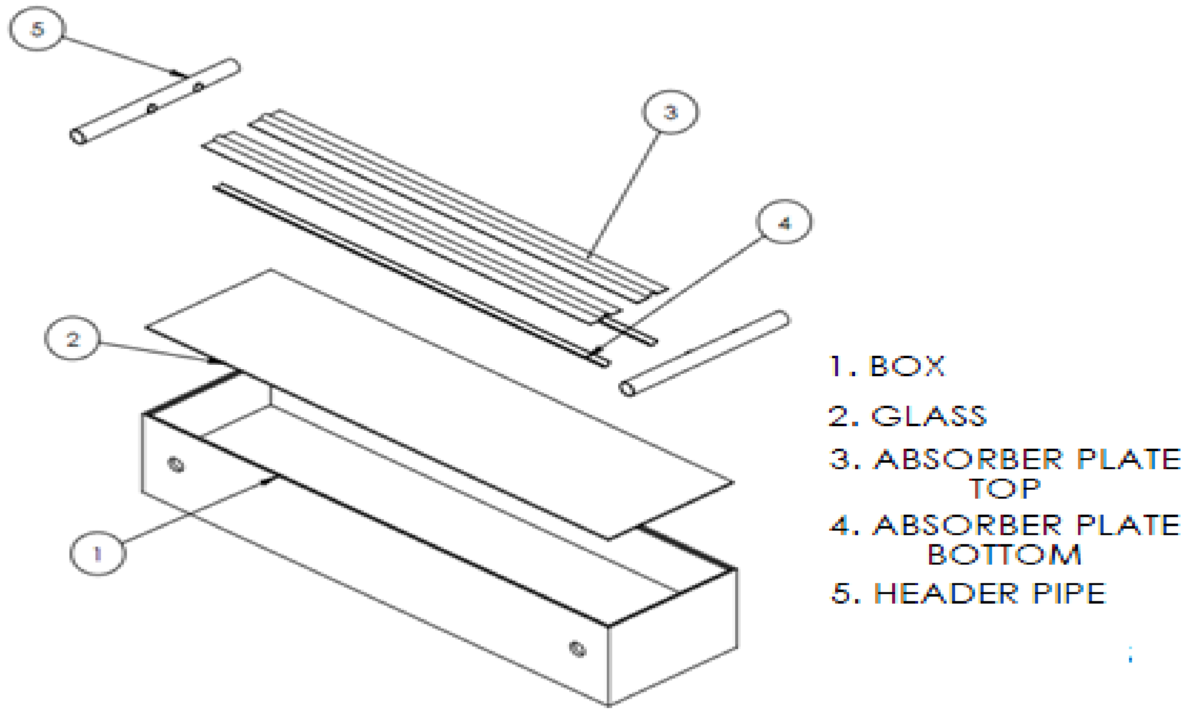

Figure-2
Model of the modified collector

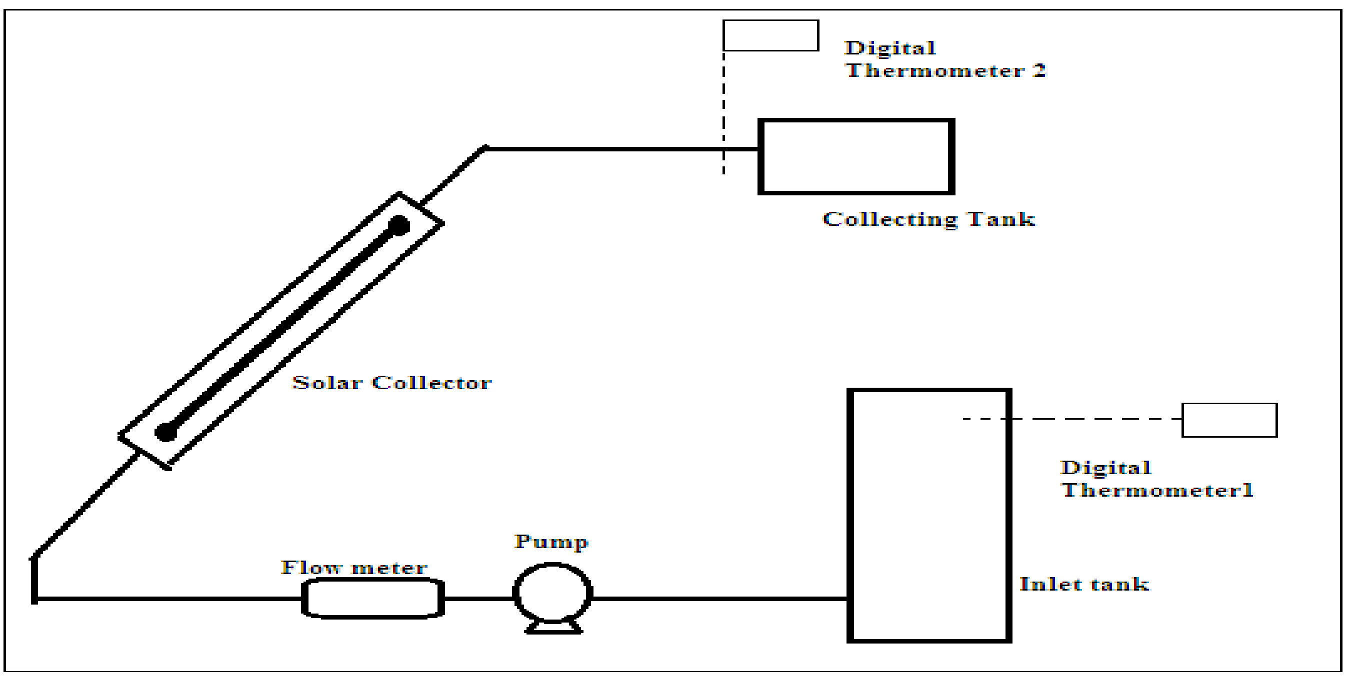

Figure-3
Schematic of the experimental Setup

Figure-4
a) Conventional Collector b) Sandwich type collector

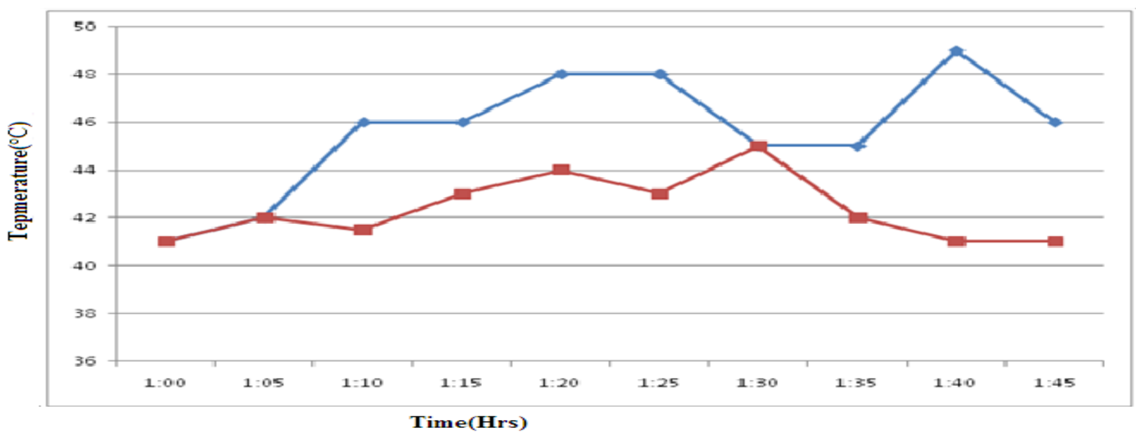

Figure-5
Water outlet temperature Vs Time graph on 12th March 2012

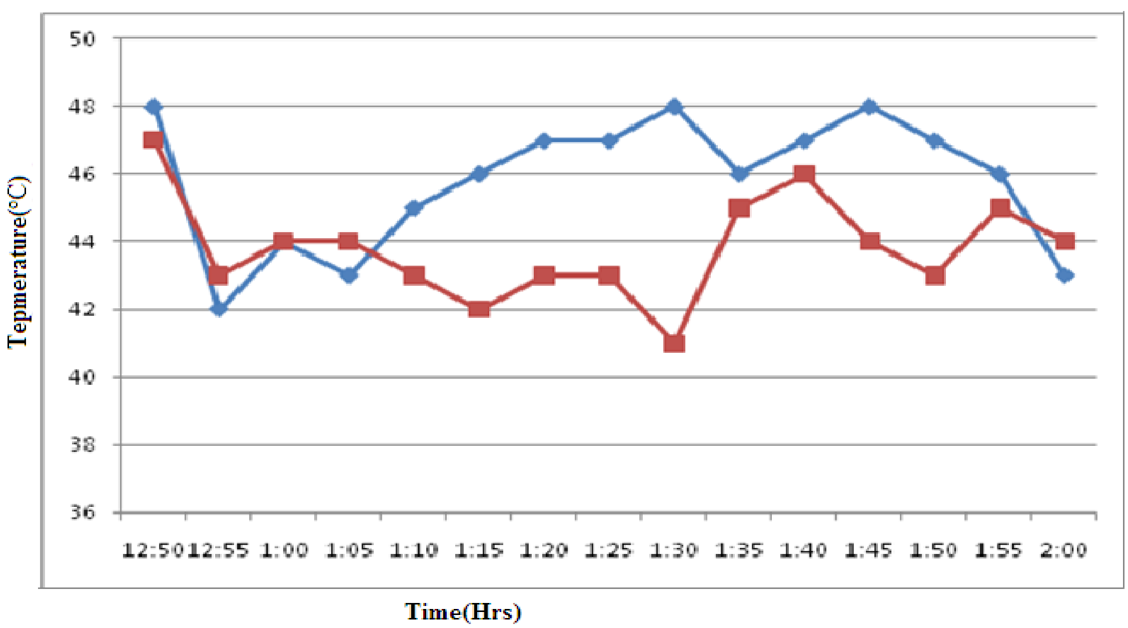

Figure-6
Water outlet temperature Vs Time graph on 29th March, 2012

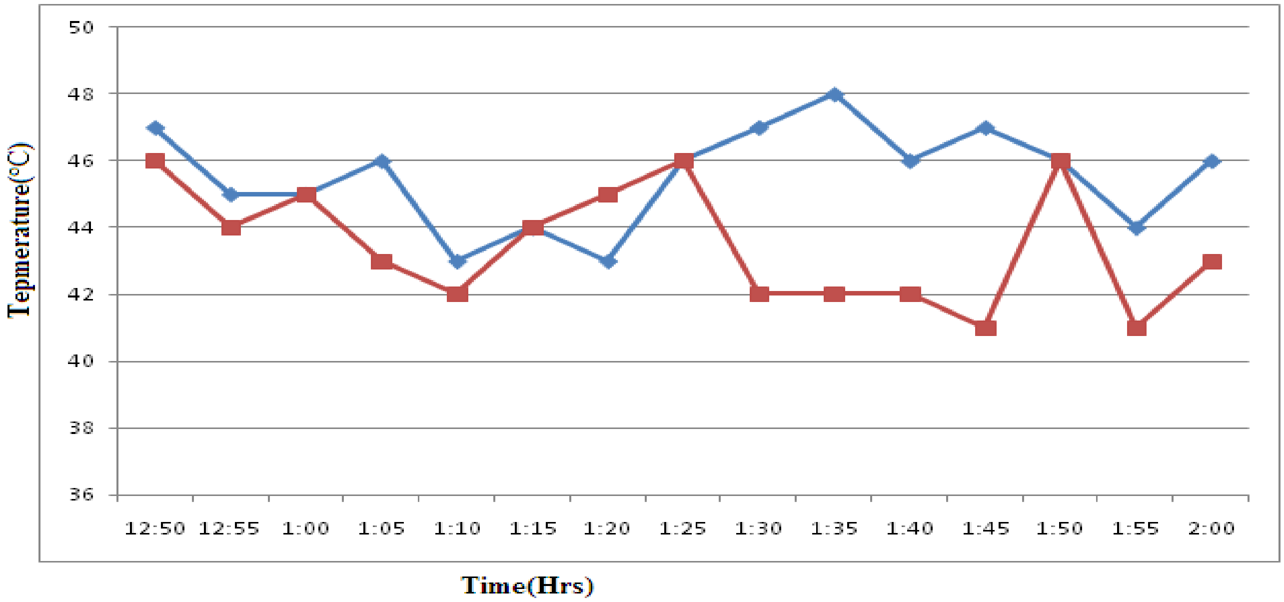

Figure-7
Water outlet temperature Vs Time graph on 2nd April, 2012

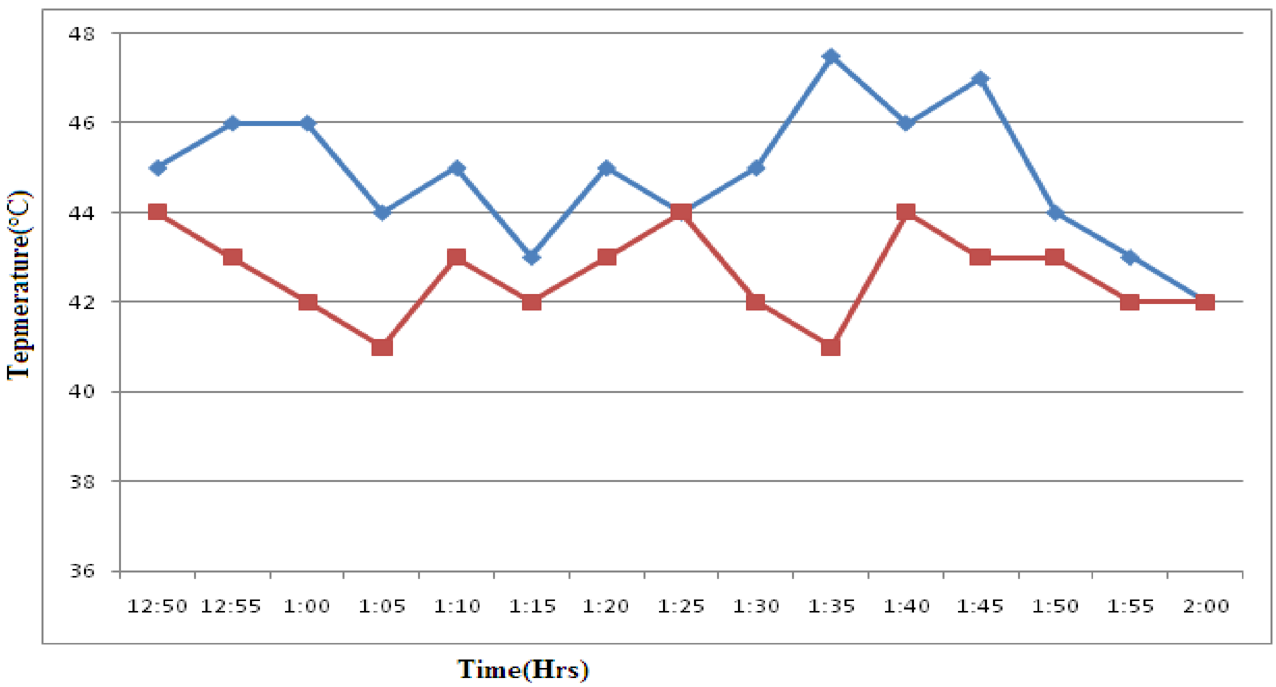

Figure-8
Water outlet temperature Vs Time graph on 4th April 2012

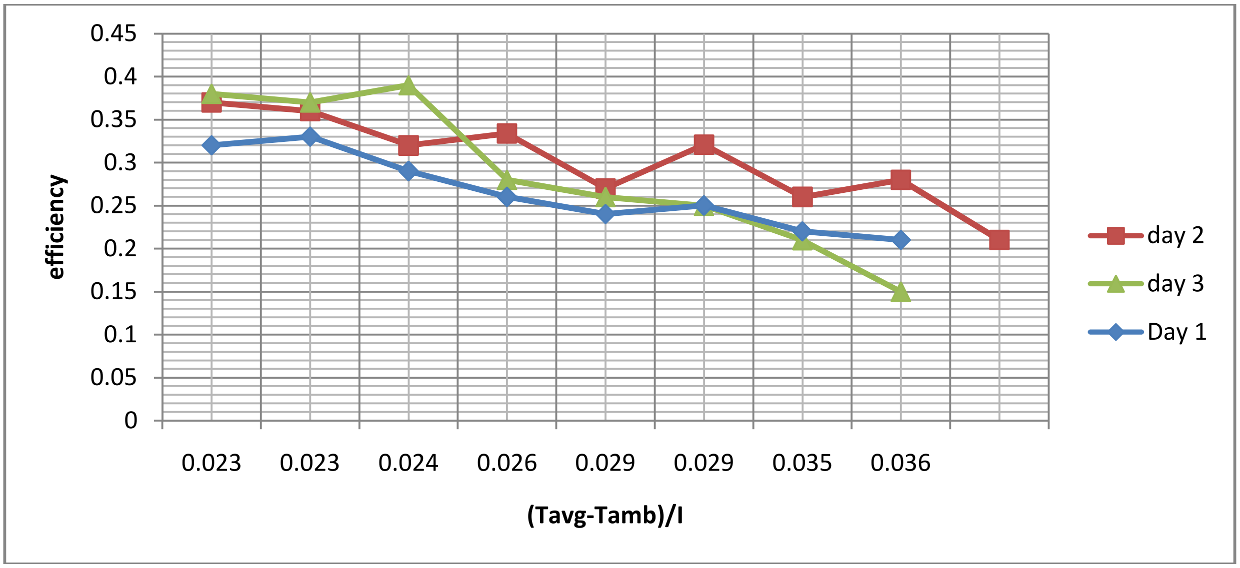

Figure-9
Hottel-Whiller Bliss curve for conventional collector

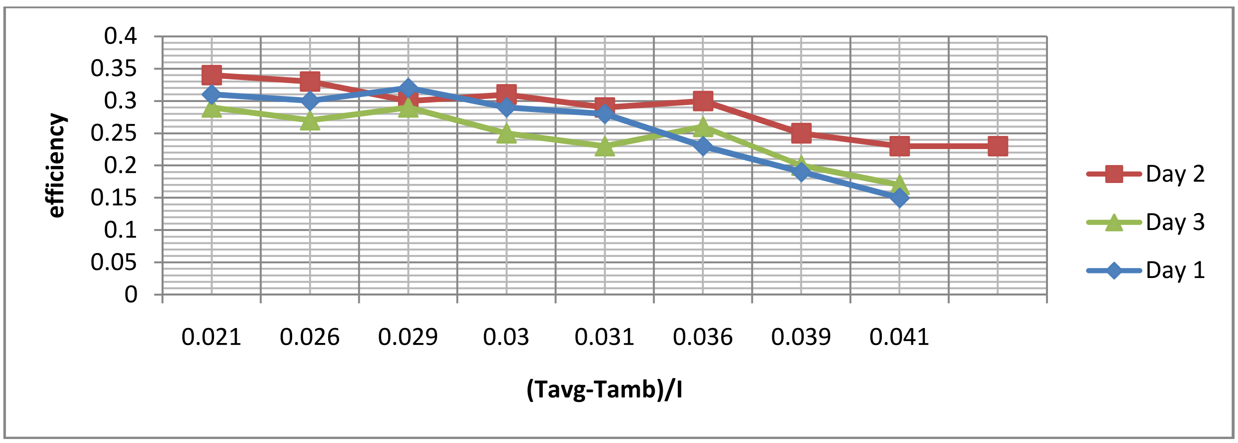

Figure-10
Hottel-Whiller Bliss curve for new collector

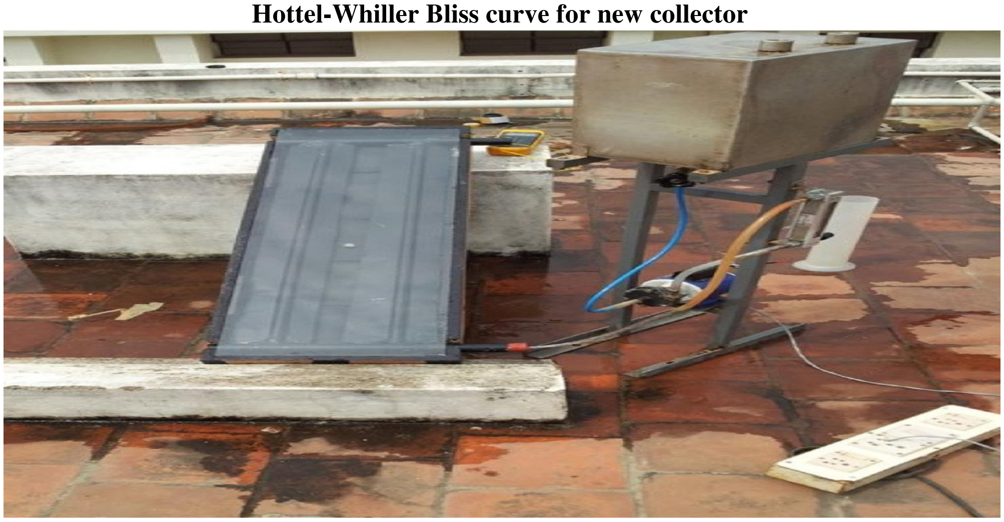

Figure-11
Experimental Setup of the solar collector