PERFORMANCE ANALYSIS OF SOLAR FLAT PLATE COLLECTOR

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Abstract: Now a days the usage of natural resources are highly in progress because artificial resources such as electricity, gasoline, fuel etc are in declination stage and are very expensive. Solar radiation from sun is emitted and falls on earth surface this radiation is collected by using solar collectors. The present work is aimed to predict the performance of flat plate collector tested for 3different days, using an application of water heating. The material used in the work is absorber plate, tube or pipe made of GI, casing and glass. The absorber plate material is mild steel and tube or pipe material is galvanized iron. Mild steel material have absorbility is about 0.8 with black paint coated. The tube material is galvanized iron which is mild steel with coated with zinc for corrosion resistance. For this selection of material the maximum efficiency obtained was 9.75% at temperature 670 c

Keywords: Flat Plate Collector (FPC), Tout(Outlet temperature), Tin(Inlet Temperature), Glazing cover, Glazing frame, absorber plate

1. INTRODUCTION

Solar energy is the energy that sustains life on earth for all plants, animals and people. It provides a compelling solution for society to meet their needs for clean and abundant sources of energy in the future. Energy has played a key role in bringing about our modern civilization. In the era of modern civilization, energy demands are likely to increase for power generation for industrial and domestic usage. Solar radiation is primarily transmitted to the earth and is collected by using collectors. Solar radiation provides enormous amount energy. Solar radiation has been utilized for centuries by peoples for heating and drying. Solar water heating is one of the most successful applications of solar energy.

Solar collectors domestic applications are flat plate, evacuated tube, or concentrating collectors. Flat plate collector (FPC) is a special kind of heat exchanger that transforms solar radiation energy to internal energy which is transferred through a working liquid. This is commonly found in domestic home.

The principles involve in FPC is to gain as much as possible the radiation energy from the sun by heat absorption. The energy which has been collected is transferred through conduit tubes by working fluids (usually water) which are integrated with heat absorber plate. Then, the warm water carries the heat to the hot water system or to storage subsystem which can be used during low sun radiation.

In FPC, the ability to absorb more energy is most important in its thermal performance. The heat absorber plate serves as the central component of the flat plate collector. When the absorber plate absorbs more heat from the Sun, the outlet temperature (T_{out}) should have higher value from inlet temperature (T_{in}) Thus, from the temperature values, efficiency of the FPC can be obtained. For domestic water heating, the FPC can heat the water up to 50°C.

The most common collector types are evacuated tubular collectors (ETC) and flat plate collectors (FPC) without vacuum. Different types of these collectors are described below. Concentrating collectors (Parabolic trough, Fresnel etc.) may also be used, but since a large part of the annual irradiation is diffuse – especially in the northern part Europe – and of these types do not utilize the diffuse part, they are not described further in this fact sheet.

A.   PROBLEM STATEMENT

The ability of the heat absorber plate to absorb more heat from the sun and maintain the heat is the main key in FPC performance. The efficiency of the FPC is defined as the ratio of the useful gain over some specified time period to the incident solar energy over the same period of time .Heat absorbed by FPC depends on thermal properties as well as on the design of the heat absorber plate. Material of the heat absorber plate plays a crucial role in the heat absorbing ability due to the thermal properties. MODELING AND WORKING

B.   COMPONENTS OF A FLAT PLATE COLLECTOR

A flat plate collector is a basic and simple heat absorber which absorbs heat from the sun radiation. Flat plate collector

as known now was developed by Hottel and Whillier in the 1950s.

Basic flat plate collector in Fig 1 consists of few components and their basic function are stated as

(i) **Glazing cover** – transparent cover typically glass which is put on the top of flat plate collector.

(ii) **Glazing frame** – to hold the glazing material.

(iii) **Tubing or fluids pipe** – to facilitate the flow of the working fluid. Water is commonly used as working fluid. Fluid enters at inlet connection and exit at outlet connection.

(iv) **Absorber plate** – to absorb incident solar radiation to gain heat. Then allowing efficient transfer of heat to a working fluid.

(v) **Insulator** – To minimize heat lost from the bottom and sides of the casing.

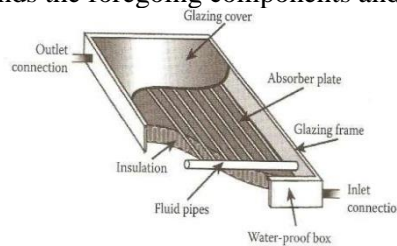(vi) **Casing** – A water-proof box surrounds the foregoing components and keeps them free from dust and moisture.

Figure 1: Model of Flat Plate Collector

C. GLAZING MATERIAL

The purpose of a glazing material is to transmit the shorter wavelength solar radiation and block the longer wavelength reradiating from the absorber plate and reduce the heat loss by convection from the top of the absorber glazing also acts as the cover on the top of the collector casing.

The commercially available window glass will have normal incidence transmittance of about 0.87 to 0.90. Transparent plastic is also generally used as glazing material in FPC. This plastic poses high short wave transmittance but because most of the plastic properties which cannot stand the ultra-violet radiation for a long time period, transparent plastic is unpopular as glazing material in flat plate collector. Table 1 shows transmittance for various glazing material when the direct solar radiation is perpendicular to the glazing material. Crystal clear glass and window glass have highest transmittance of solar radiation. The ability of the glass makes it suitable as heat trap in the collector. Thus, window glass is suitable because it is widely used in local flat plate collector.

Table: 1 Transmittance of various glazing material.

Material	Transmittance (τ)
Crystal glass	0.91
Window glass	0.85
Acrylate, Plexiglass	0.84
Polycarbonate	0.84
Polyester	0.84
Polyamide	0.80

D. TUBING

There are two types of tubing configuration usually found in flat plate collector namely parallel configuration and serpentine configuration.

E. PARALLEL CONFIGURATION

Most flat plate collector has small parallel tubes connected to a larger main carrier pipes as shown in Fig 2. These small parallel tubes are called riser tubes because this is where the working fluids would rise in order to harvest the heat from the sun. The parallel tube is designed to transport working fluid from the bottom of the flat plate collector to the top of the flat plate collector. The fluids pressure is higher at the base of the collector and least at the top. If the top and bottom pipes are large, the pressure difference is moderated and the flow rate in each of the parallel pipes is more uniform. Unfortunately, the flow rate is minimal at the centre where most of the heat is concentrated. Other problems associated with this configuration are the cost and leaking problems. One small leak can cause catastrophic mess in experimentation and calculation.
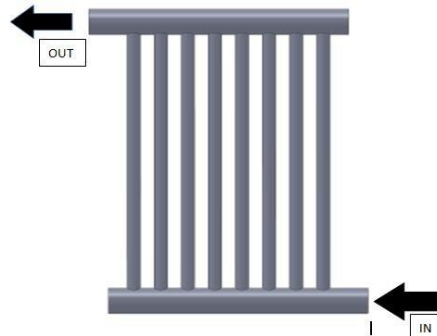
Figure 2: Model of Parallel Tube

F.   SERPENTINE CONFIGURATION

The serpentine flow in Fig 3 below consists of one long continuous flexible tube so there is no problem with uniform flow rate. The working fluids flow continuously from bottom to the top of the collector. This results in steady heat transfer from the heat absorber to the working fluid. Since the flow rate of the fluid through the serpentine tube is uniform the heat collection process is uniform. The size of this flexible tubing is an important consideration. The common size used for tubing is ½ inches of diameter. Thus, serpentine configuration is used in this investigation due to uniform fluid flow resulting uniform heat transfer from absorber plate to working fluid. Furthermore, serpentine configuration is easier to construct compare to parallel which have many welding joints. The probability of leaking in parallel configuration is high compare to serpentine configuration. galvanized pipe is used in this project because it has anti corrosive and easy to fabricate.
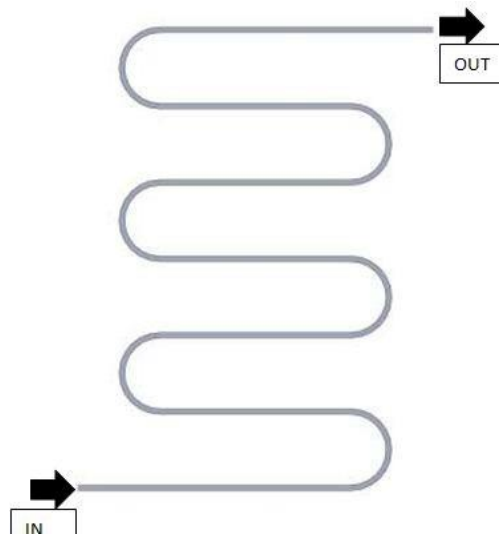

Figure 3: Model of Serpentine Flow

G.   HEAT ABSORBER

The primary function of the heat absorber plate is to absorbed as much as possible of the radiation reaching through the glazing at the same time to lose as little as possible radiation reflecting upward to the atmosphere and downward through the back of the container later transfer the retained heat to the circulating working fluids. Fluid out Fluid in.

In FPC, the heat absorber is usually made of mild steel. In this project, is used for investigation because both of the material has thermal conductivity. Factors that determine the material selection is its thermal conductivity, its durability, easy handling, cost and availability. Heat absorber plate usually given a surface coating, mainly black, that increases the fraction of available solar radiation absorbed by the plate.

H.   PLATE COATING.

Flat black colour has high absorbance value compare to other colour which make it suitable for heat absorber plate coating. The absorbance (α) for black paint is between 0.92 to 0.98. The black paint is applied by spraying on the plate. Some are heat treated to evaporate solvents and improve adherence. These surface must be able withstand repeated and prolonged exposure to the relatively high temperature.

Flat black color is used in this project because it has higher radiation. The flat black colour minimizes the transmission

of outgoing radiation and the FPC can minimize the unwanted reflection. Moreover, material thickness also plays part in heat absorption.

I. INSULATOR

FPC must be insulated to reduce conduction and convection heat losses through the back and side of the collector box insulation material as shown in fig 4 should be the dimensionally and chemically stable at high operating temperature. The thickness of the insulator could contribute to the structural rigidity. This investigation used polystyrene as insulation because it is cheap, easy to find and the most importantly is the polystyrene has good heat insulation characteristic.

Figure 4: Insulation Material.

2. OPERATION FLOW RATE

Suitable flow rate must be used in this investigation. As mass flow rate increase, the operating temperature decrease resulting lower efficiency The suitable flow rate used in this project was set between 0.2 lit/min to 0.25lit/min Working fluids is allowed to flow steady enough to ensure the heat from the absorber plate is transferred uniformly. Temperature difference between the inlet and the outlet are easily measurable when the fluid temperature is already in steady state condition.

3. WORKING

Flat-plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type. They consist of a dark flat-plate absorber a transparent cover that reduces heat losses, a heat- transport fluid (air, antifreeze or water) to remove heat from the absorber, and a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel of copper, to which a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid is usually circulated through tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger Most air heat fabricators and some water heat manufacturers have a completely flooded absorber consisting of two sheets of metal which the fluid passes between. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal— typically copper or aluminum—because the metal is a good heat conductor.

4. DESIGN AND FABRICATION OF FLAT PLATE COLLECTOR

Basically, the FPC is rectangular in shape. The FPC is fixed with wheels at the bottom for easy manoeuvre. A handle has been fabricated and

attached for handling easiness. Measurement instruments like thermometers and flow meter were fixed at the both.
Solar thermal Collector has following basic things for fabrication:

- Outer Cabinet Box
- The Piping Network & Plumbing

J. Outer Cabinet Box

The outer cabinet box of the solar thermal collector is fabricated out of waterproof Plywood. The box has dimension as shown in table 2:

Table 2: Dimensions of outer cabinet box

Units	Size	Thickness
1	0.97m X 0.6m	6 mm
2	0.97m X 0.10m	6 mm
3	0.60m X 0.10m	6 mm

The planks were attached with the help of Steel Nails (2.3 cm) & the Gaps were sealed using Glue and Sealing Materials. The box was cut at the required places to allow Pipes for Inlets and Outlets.

K.   PIPING NETWORK & PLUMBING Galvanized iron pipes were used for the purpose of Heating.
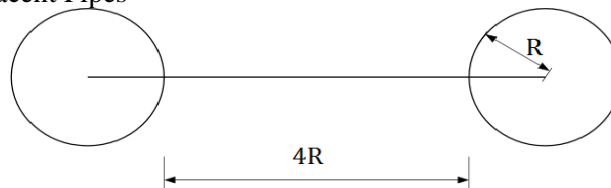
Dimension of the Pipes used (As per market availability):

Outer diameter: 1.8 cm Inner diameter: 1.7 cm Thickness: 1mm

Number of Pipes used: 5

Length of the pipes: 0.650m (Keeping 2.5 cm clearance along the length from the outer Box on both sides)

Minimum Spacing between Adjacent Pipes

The minimum space between adjacent pipes should be kept 4R, where R –Radius of the Pipe. The basic laws of Light and Shadowing Supports the fact. Fig 5shows the Spacing between pipes If pipes are spaced at 4R distance from each other, the possibility of one pipe overshadowing another pipe during any time of the day is eliminated. So the active distance between to adjacent pipes becomes 6R.

6R distance is equivalent to = 6 X 0.9 = 5.40 cm (Minimum Spacing)

Now total number of pipes that can be spread out over the breadth of the Box

= (Box breadth/ Pipe spacing)

But for uniformity and Keeping additional Safety clearances in mind, we take 5 pipes for Fluid Flow. We then assumed the Spacing between pipes to be

6.5 cm & then carryout the necessary Calculations. Then we have 5 inter pipe spacing of 6.5 cm each making the length up to 0.650m & so we divide the rest area into 2. ie; of 7.5 cms each.
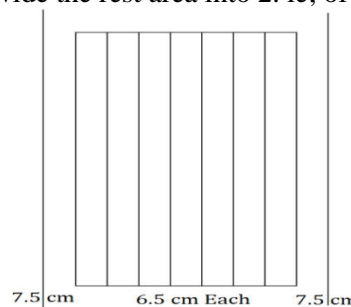

Figure 5 : Piping network and space

L.   Testing of absorber plate:

Take a one liter of container filled with water and dip a absorber plate in the container with a thermometer and do some required insulation on the top of the container placed the container below the sun and wait for 15 to 20 minutes and take the readings on thermometer and note down the readings. After that do the same procedure once again but with a absorber plate coated with black paint and note the readings. Below fig 6 shows the set up of a testing of a absorber plate.

Figure 6: Testing of Absorber Plate

M.   KEY FEATURES IN THE FIN DESIGN Fins are wrapped all over the Tube surface very rigidly. The fins cover the interspace between the adjacent tubes increasing surface area for Heat Collection. The fins are in a definite geometry. ie; They have a fixed curvature having their focus at the pipe center, so as to reflect the unabsorbed light rays on to the Tubes. So, if say absorptivity of the aluminum sheet is 50%, then it conducts the 50% heat to the pipes by means of conduction ,rest 50% heat in form of light rays are concentrated on to the pipes. So ideally the heat losses are assumed to be zero.

Forms of Heat Transfer from Sun's Rays

1- Direct Insolation of Sun's Rays on the Black painted Tube Surface.
2- The direct Conduction of Heat on the Metal Fins from direct Sunlight.
3- Heat in the form of sunrays reflected from the Glossy metal Surface on to the tube.

N.   FIN FABRICATION

For fabricating the fins the following steps were followed:

- The sheet was cut using scissors at the desired markings
- Then the pipe was then kept on the Sheet at the desired spot & clamped.
-The sheet was then carefully & neatly rolled over the pipe and bent at the right places by applying pressure.
- Holes were drilled at the ends of the sheet, through which wires were put to fasten the sheet to the pipe.
- Then the Fins were curved at the required angle so as to act as solar concentrators.

O.   FINISHING WORK & THE FINAL MODEL

The outer cabinet box was painted pitch black. The piping network was then spread in the box & the Inlet and outlet pipes were taken out at the desired spots. The whole piping network was then supported on wooden stands attached to the cabinet body and then clamped securely to the box. Then the fins were placed on the pipes very carefully, so as to minimize the air gap between the fins and the tubes. Fastening wires were used at the desired spots to make the model robust. Araldite Glue & Adhesives were used wherever sealing was essential, to reduce heat & material losses.

P.   FLAT PLATE COLLECTOR SPECIFICATIONS:

Specifications and the materials used in fabrication of flat plate collector are tabulated in table 3.

Table 3: specifications of the FPC for this project.

Component	Unit
Length of collector	726 mm
Width of collector	457.2 mm
Thickness of collector	101.6 mm
MILD STEEL tube (diameter)	18 mm
MILD STEEL tube (thickness)	1 mm
Tube spacing	60 mm
Tube overall length	3960 mm
Material of absorber	Mild steel
Plate thickness	18 gauge
Insulator material	Polystyrene
Insulation thickness (bottom)	60 mm
Insulation thickness (side)	10 mm

Materials for fabrication process can be easily found in local hardware workshop.

Q.   LOCATION OF EXPERIMENT

This project was conducted at the Muffakham Jah College of Engineering and Technology. The coordinate for the location is 17°39′N; E 78°43 23.378′E.

5. EXPERIMENTAL SETUP

The determination of the flat plate collector and the tilt angle as shown on fig 7 & 8, efficiency must be done in standard operation. ASHRAE 93-77(2003) method is widely use in testing collector efficiency. The test requires a minimum total solar irradiance of

790 W/m 2. The collector is exposed under the Sun while the fluid is circulating under operational flow rate. The collector is set horizontal to the ground.

The principal measurements made in each data set are fluid flow rate, fluids inlet and outlet temperature and solar irradiance. All data are tabulated in a form (Appendix A) for every hour starting from 1000H until 1700H. Data are then plotted in a graph. Data analysis from the graph is essential to obtain the efficiency of the flat plate collector.
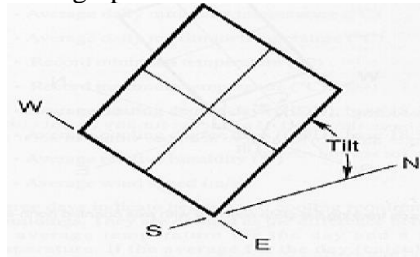

Figure 7: Flat-plate collectors facing south at fixed tilt.

Figure 8: Experimental Setup of flat plate collector

6. FLAT PLATE COLLECTOR EFFICIENCY

The efficiency of flat plate collector can be evaluated by an energy that determines the portion of the incoming radiation delivered as useful energy to the working fluids For flat plate collector, the useful heat gain (Q_U) can be calculated by the formula below.

$Q_U = mc_p(t_o - t_i)$ Where

Q: the useful heat gain (watts) m: Mass flow rate (kg/s)

c_p: Heat capacity at constant pressure (kJ/kg.K) t_o: Fluid outlet temperature (°C)

t_i: Fluid inlet temperature (°C)

After obtaining the useful heat gain, (Q_u), the efficiency of the flat plate collector can be calculated by using;

$$\eta = Q_U / A * I_T$$

I_t : energy gain from solar radiation (W/m^2)

A_c : collector absorber area (m^2)

Q_u: enegy absorbed by the flat plate collector (W)

II.   EXPERIMENTAL SETUP

The experimental setup as shown in fig 10 consists of:

- The fabricated SWH (Solar water heating System)
- Plastic water pipes
- Flow control valves (1no.s)
- An Insulated Water Storage Tank
- Cardboard Sheets & other Insulation materials.
- Steel/Wooden support for mounting the SWH
- Water & Power Supply

- Thermometer/ Temperature measuring equipment

Figure 9: Experimental Setup

7. PROCEDURE
- The open garden place (without shade) was chosen for the experiment.
- The true South direction was determined with the help of compass & then the SWH was fixed properly on wooden/steel supports facing the South direction while making an angle of 30 degrees with the ground.
- The flow connections were made proper & the pump was switched on.
- The outlet temperature in the insulated box was measured at regular intervals of time, with different flow rates of water.

8. RESULTS AND DISCUSSION
After conducting the experiment for consecutive 3days in the month of April(8th, 9th,&10th-2014), the radiations are tabulated in table 4 and the results obtained from this radiation data are shown in table 5 and the graphs are plotted in fig 11 & 12.

TABLE 4: RADIATION AS ON 8, 9,10th of APRIL 2014.

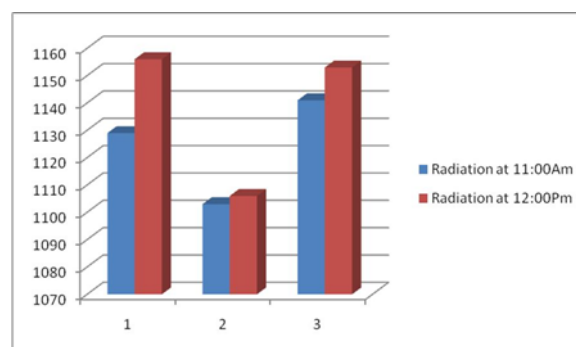| Days	TIME	RADIATION WH/M^2
8th April	11:00	1129
	12:00	1156
9th April	11:00	1103
	12:00	1106
10th April	11:00	1141
	12:00	1153

Figure 10: Radiations Data at 8, 9, 10th April 2014
Table 5: Experimental Data As On 8, 9,10th April 2014

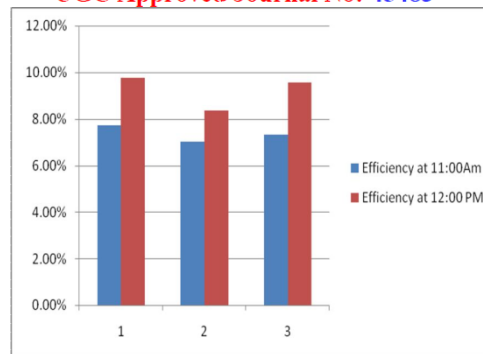|	TIME	T_i	T_o	Flow rate litre/min	Angle	H %
8th April	11:00	28°	61°	0.225	30°	7.71
	12:00	28°	67°	0.225	30°	9.75
9th April	11:00	26°	45°	0.225	30°	7.01
	12:00	26°	49°	0.225	30°	8.35
10th April	11:00	28°	45°	0.225	30°	7.31
	12:00	28°	56°	0.225	30°	9.55

Figure 11: Efficiency graph for 8, 9, 10th April 2014

9. CONCLUSION

The solar heater collector thus fabricated was put to test under the sun while circulating water through it at 0.225 litre/min flow rates. The results obtained were satisfactory and the SWH efficiency went as high as 9.75 % on 8th of April. These types of solar water heaters can easily be used to heat domestic application. A flow rate comparable to that of 15 lph is best for heating. The heaters are to be used intermittently for heating a batch of water till 15-20 minutes until the efficiency drops down and then fresh water be circulated through it.

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