Analysis of Solar Flat Plate Collector

B. K. Gond[1], S. Mittal[2], P. Prajapati[3], R. Khare[4]

[1]*Mechanical Engineering Department*

[1-4]*University Institute of Technology, Barkatullah University, Bhopal, India*

Abstract: **- Flat Plate Collector (FPC) is widely used for domestic hot-water, space heating/drying and for applications requiring fluid temperature less than 100^{o}C. Three main components associated with FPC namely, absorber plate, top covers and heating pipes. The absorber plate is selective coated to have high absorptivity. It receives heat by solar radiation and by conduction; heat is transferred to the flowing liquid through the heating pipes. The fluid flow through the collector pipes is by natural (thermo syphon effect) or by forced circulation (pump flow). For small water heating systems natural circulation is used for fluid flow. Conventionally, absorbers of all flat plate collectors are straight copper/aluminum sheets however, which limits on the heat collection surface transfer area. Thus, higher heat collection surface area is optimized by changing its geometry with the same space of conventional FPC. The objective of present study is to evaluate the performance of FPC with different geometric absorber configuration. It is expected that with the same collector space higher thermal efficiency or higher water temperature can be obtained. Thus, cost of the FPC can be further bring down by enhancing the collector efficiency. A test setup is fabricated and experiments conduct to study these aspects under laboratory conditions (as per IS standard available for the flat plate collector testing).**

The experimental results revealed that the performance of the solar water heater by using all the materials produced the maximum efficiency of around 40 % to 47 % respectively. And the maximum outlet water temperature reached is below 70^{0}C respectively. The order of material priority for better efficiency is copper, aluminium, than stainless steel.

Keywords **- Absorber plate emissivity, Flat plate collector, efficiency of collector, solar water heating.**

I. INTRODUCTION

In the solar- In the solar-energy industry great emphasis has been placed on the development of "passive" solar energy systems, which involve the integration of several subsystems: Flat Plate collectors, heat-storage containers, fluid transport and distribution systems, and control systems. The major component unique to passive systems is the Flat plate collector. This device absorbs the incoming solar radiation, converting it into heat at the absorbing surface, and transfers this heat to a fluid (water) flowing through the Flat plate collector. The warmed fluid carries the heat either directly to the hot water or to a storage subsystem from which can be drawn for use at night and on cloudy days. Since 1900, a large number of solar collector designs have been shown to be functional; these have fallen into two general classes: Flat plate collectors: in which absorbing surface is approximately as large as the overall collector area that intercepts the sun's rays. Concentrating collectors in which large areas of mirrors or lenses focus the Sun light onto a smaller absorber. Since of energy crisis, there has been effort to develop new energy sources as a way to solve energy problem and at of there, solar energy has received special attention. The energy generated depends too much on time and seams to supply a stable power needed for a secondary energy source [1], [2].

1.1 Flat Plate Collector

Flat-plate collectors consist of (1) a dark flat-plate absorber, (2) a transparent cover that reduces heat losses, (3) a heat-transport fluid (air, antifreeze or water) to remove heat from the absorber, and (4) a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or 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. Flat Plate Collectors Of the many solar collector concepts presently being developed, the relatively simple flat plate solar collector has found the widest application so far. Its characteristics are known, and compared with other collector types, it is the easiest and least expensive to fabricate, install, and maintain. Moreover, it is capable of using both the diffuse and the direct beam solar radiation. For residential and commercial use, flat plate collectors can produce heat at sufficiently high temperatures to heat swimming pools, domestic hot water, and buildings; they also can operate a cooling unit, particularly if the incident sunlight is increased by the use of a reflector. Flat plate collectors easily attain temperatures of 40 to 70ºC. With very careful engineering using special surfaces, reflectors to increase the incident radiation, and heat-resistant materials, higher operating temperatures are feasible. The main components of a flat plate solar collector [3], [4].

1.2 Types of Flat Plate Collector

1.2.1 Unglazed Solar Flat Plate Collectors

The term "unglazed water collector" refers to a solar water heating system that consists of a metal absorber without any glass or glazing over top. The most common type of unglazed collector on the market is the transpired solar collector. The technology has been extensively monitored by these government agencies, and Natural Resources Canada developed the feasibility tool RET Screen to model the energy savings from transpired solar collectors. Since that time, several thousand transpired solar collector systems have been installed in a variety of commercial, industrial, institutional, agricultural, and process applications in countries around the world. The technology was originally used primarily in industrial applications such as manufacturing and assembly plants where there were high ventilation requirements, stratified ceiling heat, and often negative pressure in the building [7].

1.2.2 Flat Plate Solar Thermal Systems

Another common type of solar collector which have been in use since the 1950s.The main components of a flat plate panel are a dark colored flat plate absorber with an insulated cover, a heat transferring liquid containing antifreeze to transfer heat from the absorber to the water tank, and an insulated backing. The flat plate feature of the solar panel increases the surface area for heat absorption. The heat transfer liquid is circulated through copper or silicon tubes contained within the flat surface plate.

1.2.3 Evacuated Tube Solar Thermal Systems

The evacuated tube solar thermalsystem is one of the most popular solar thermal systems in operation. An evacuated solar system is the most efficient and a common means of solar thermal energy generation with a rate of efficiency of 70 per cent. As an example, if the collector generates 3000 kilowatt hours of energy in a year then 2100 kilowatt hours would be utilized in the system for heating water. The rate of efficiency is achieved because of the way in which the evacuated tube systems are constructed, meaning they have excellent insulation and are virtually unaffected by air temperatures. The collector itself is made up of rows of insulated glass tubes that contain copper pipes at their core. Water is heated in the collector and is then sent through the pipes to the water tank. This type of collector is the most efficient, but also the most expensive [5], [6].

1.3 Materials for Solar Energy Collectors

This section describes briefly some of the principal requirements for and the Properties of materials employed in solar collectors used for the transformation of solar energy into thermal energy.

1.3.1 Diathermanous Materials (Glazing)

The term "diathermanous" is applied to materials capable of transmitting radiant energy, including solar energy. From the standpoint of the utilization of solar energy, the important characteristics are reflection (ρ), absorption (α), and transmission (τ). The first two should be as low as possible and the latter as high as possible for maximum efficiency. According to the law of conservation of energy, the relationship between the absorbed, reflected and transmitted energy is: $\alpha + \rho + \tau = 1$ Where, α is the solar absorptance, i.e. the fraction of the incident solar radiation absorbed by a substance. P is the solar reflectance, i.e. the fraction of the incident solar radiation reflected by a surface. τ is the solar transmittance, i.e. the fraction of the incident solar radiation transmitted through a non-opaque substance. The relative magnitudes of α, ρ and τ not only vary with the temperature, the surface characteristics, body geometry, and the material but also vary with wavelength. Solids and liquids are usually opaque in most engineering applications, and transmittance τ for this type of matter is zero. Gases, on the other hand, reflect very little, and ρ can therefore be neglected in a majority of problems. The purpose of the glazing is to admit as much solar radiation as possible and to reduce the upward loss of heat to the lowest attainable value. Glass has been the principal material used to glaze solar collectors because it has the highly desirable property of transmitting as much as 90% of the incoming shortwave radiation (solar), while virtually none of the long wave radiation emitted by the Flat plate can escape outward by transmission [8], [9].

1.3.2 Absorber Plates

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching through the glazing, to lose as little heat as possible upward to the atmosphere and downward through the back of the container, and to transfer the retained heat to the circulating fluid. In general, absorption of solar energy impinging on an absorber plate should be as high as possible, but re-emission (loss) outward from the collector should be minimized [10].

1.3.3 Selective Coating

A surface that has a high absorptance and is a good absorber of solar radiation usually has a high infrared emittance as well and is a good radiator of heat. A flat-black paint that absorbs 96% of the incoming solar energy will also reradiate much of the energy as heat, the exact amount depending on the temperature of the absorber plate and the glazing. Ideally, one would like a surface to be selective, absorbing all the solar wavelengths and emitting none of the heat wavelengths, so that more heat could be transferred to the working fluid; for such a surface, $\alpha = 1$ and $\varepsilon = 0$. Selective absorbers can be manufactured that approach this ideal, and several are available commercially [11], [12].

Fig. 1.1 Absorber Plates

1.1.1 Thermal Insulation

Flat-plate collectors must be insulated to reduce conduction and convection losses through the back and sides of the collector box. The insulation material should be dimensionally and chemically stable at high temperatures, and resistant to weathering and dampness from condensation. Usually, glass-wool insulation 10 cm thick is recommended. It would be between if the insulation also could contribute to the structural rigidity of the collector, but more rigid insulating materials are often less stable than glass wool [13], [14].

Fig. 1.1 Thermal Insulation

II. EXPERIMENTAL SETUP AND TEST PROCEDURE

Analysis is done on the flat plate collector of institution laboratory. It’s having a dimension of 1m wide and 2 m long and its collector plate is tilted at 60^o for the normal incidence of solar irradiation. Tube having an inner diameter of 0.05cm thickness which is connected by 0.5cm thick plate at center to center distance of 10cm.

Two temperature sensors are used one for ambient temperature measurement and other is at outlet water condition. Water is to be circulating in the tube of solar plate collector and hot water comes out from outlet and temperature of which is measured by temperature sensor. The Natural circulation solar water heater was tested in the month of May, 2016 at intervals of between 9.00 am to 3 pm. The incident solar radiation intensity was measured by using pyranometer. The water inlet and outlet temperature for the collector as well as ambient air is with a precision of 0.5^0C. Experimental analysis is done on the three collector plate material namely as copper, aluminium and stainless steel.

Fig. 2.1Aluminium FPC with Polymer tube

Fig. 2.2Stainless steel FPC with Glazing

Fig. 2.3 Copper plate FPC with Polymer tube

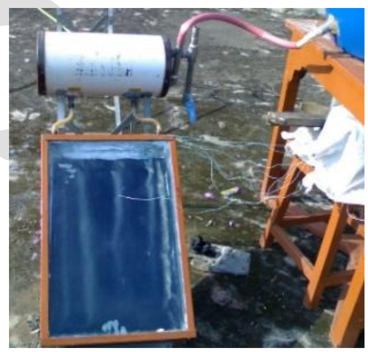


Fig 8.1 Experimental setup of solar flat plate collector

2.1 Observation Table

Inlet water temperature = 26^0C (for all materials)

Table 2.1 Observation table for copper

S. No.	Time	Outlet water temperature(^{0}C)	Ambient temperature (^{0}C)	Irradiation (W/m^2)
1.	9am	52	30	152.58
2.	11am	63	34	363.84
3.	1pm	70	38	575.81
4.	3pm	61	36	380.88

Table 2.2 Observation table for aluminium

S. No.	Time	Outlet water temperature(^{0}C)	Ambient temperature(^{0}C)	Irradiation (W/m^2)
1.	9am	45	31	297.15
2.	11am	56	33	403.18
3.	1pm	66	38	809.56
4.	3pm	58	35	455.37

Table 2.3 Observation table for stainless steel

S. No.	Time	Outlet water temperature (^{0}C)	Ambient temperature (^{0}C)	Irradiation (W/m^2)
1.	9am	41	29	143.18
2.	11am	53	33	376.37
3.	1pm	62	39	829.60
4.	3pm	51	35	509.90

2.2 Equations and Measurement

If I am the intensity of solar radiation, in W/m2, incident on the aperture plane of the solar collector having a collector surface area of A, m2, then the amount of solar radiation received by the collector is:

$$Qi = I.A \qquad (a)$$

However, as it is shown Figure 2, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation. Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed. Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

Thus

$$Qi=I\,(\tau\alpha).A \qquad (b)$$

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation. The rate of heat loss *(Qo)* depends on the collector overall heat transfer coefficient *(UL)* and the collector temperature.

$$Qo=UL.A(Tc-Ta) \qquad (c)$$

Thus, the rate of useful energy extracted by the collector (Qu), expressed as a rate of extraction under steady state conditions, and is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings.

This is expressed as follows:

$$Qu=Qi-Qo=I\tau\alpha.A-UL.A(Tc-Ta) \qquad (d)$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

$$Qu=mCp(To-Ti) \qquad (e)$$

Equation (e) proves to be somewhat inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual useful [15], [16] energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as "the collector heat removal factor (Fr)" and is expressed as:

$$\mathrm{Fr} = \frac{\mathrm{mCp(To-Ti)}}{\mathrm{I\tau\alpha.A - UL.A(Tc-Ta)}}$$

$$\mathrm{Fr} = \frac{\mathrm{mCp}}{\mathrm{AcUL}}\left[1-\exp\left(-\frac{\mathrm{AcUL}}{\mathrm{mCp}}\right)\right] \qquad (f)$$

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain (Qu), is found by multiplying the Collector heat removal factor (FR) by the maximum possible useful energy gain. This allows the rewriting of equation (f)

$$Qu = Fr.\,\mathrm{A[I\tau\alpha - UL(Ti-Ta)]}$$

Equation is a widely used relationship for measuring collector energy gain and is generally known as the **"**Hottel-Whillier-Bliss equation**".**

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ratio of the useful energy gain (Qu) to the incident solar energy over a particular time period

$$\eta = \frac{\int Qu\, dt}{A\int I\, dt}$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Qu}{AI}$$

$$\eta = \frac{\mathrm{Fr.A[I\tau\alpha - UL(Ti-Ta)]}}{\mathrm{AI}}$$

$$\eta = Fr.\tau\alpha - FrUL\left(\frac{Ti-Ta}{I}\right)$$

Fr value 0.845, 0.9707, 0.999 for copper, aluminium and stainless steel plate respectively which is calculated by formula (f)

UL value for copper aluminium and stainless steel are 13.1, 25,47.3 W/m^2-k

It is assumed that FR, τ, α,UL are constants for a given collector and flow rate, then the efficiency is a linear function of the three parameters defining the operating condition: Solar irradiance (I), Fluid inlet temperature (Ti) and Ambient air temperature (Ta). Thus, the performance of a Flat-Plate Collector can be approximated by measuring these three parameters in experiments.

III. RESULT AND DISCUSSION

3.1 Efficiency result for copper

Efficiency of solar plate collector is calculated by above formula and observation is taken by table

Table 3.1 Efficiency of copper plate

S. No.	Time	Efficiency (%)
1.	9am	39.42
2.	11am	44.1
3.	1pm	45.31
4.	3pm	42.0

3.2 Efficiency result for alluminium

Efficiency of solar plate collector is calculated by above formula and observation is taken by table

Table 3.2 Efficiency of alluminium plate

S. No.	Time	Efficiency (%)
1.	9am	31.79
2.	11am	36.5
3.	1pm	42.66
4.	3pm	36.0

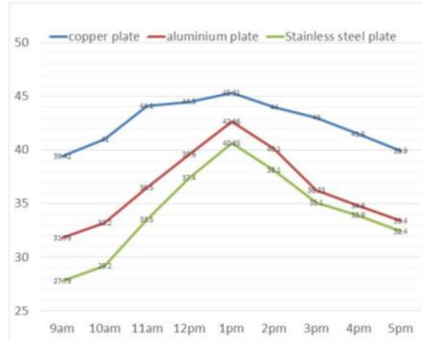
3.3 Efficiency result for stainless steel

Efficiency of solar plate collector is calculated by above formula and observation is taken by table

Taple 3.3 Efficiency of stainless steel plate

S. No.	Time	Efficiency (%)
1.	9am	27.79
2.	11am	33.5
3.	1pm	40.65
4.	3pm	35.8

1. The first is the maximum collection efficiency, called the optical efficiency.This occurs when the fluid inlet temperature equals ambient temperature ($T_i = T_a$). For this condition, the $\Delta T/I$ value is zero and the intercept is $F_R(\tau\,\alpha)$.
2. The other point of interest is the intercept with the $\Delta T/I$ axis. This point of operation can be reached when useful energy is no longer removed from the collector, a condition that can happen if fluid flow through the collector stops (power failure). In this case, the optical energy coming in must equal the heat loss, requiring that the temperature of the absorber increase until this balance occurs. This maximum temperature difference or “stagnation temperature” is defined by this point. For well-insulated collectors or concentrating collectors the stagnation temperature can reach very high levels causing fluid boiling and, in the case of concentrating collectors, the absorber surface can melt.
3. The relationship between efficiency with the time is shown in the below graph for different materials.



Graph: 11.2 Efficiency v/s time graph

The collector efficiency is also compared with three different cases and its depicted fig. The collector efficiency at 9am is 39.42% for copper riser tubes, 31.79 % expected for aluminum tubes riser tubes and 27.79 % for stainless steel riser tubes. The maximum efficiency is observed at the time 1pm in three cases as 45.31%, 42.66% (expected) and 40.65% respectively. The collector efficiency is decreasing after 1pm till 5pm in the same manner. The collector efficiency is shown in graph 10.2. The graph reveals that the maximum efficiency is at 1pm in the three different cases.

4. Temperature range and efficiency of the different materials observed at different temperature are shown in below table.

Table 3.4 Temperature and efficiency range of materials

S No.	Materials	Temperature range (9am – 3pm)	Efficiency range (9am – 3pm)
1.	Copper plate	52^0C - 70^0C	39.42% - 45.31%
2.	Aluminium plate	45^0C - 66^0C	31.79% - 42.66%
3.	Stainless steel	41^0C – 62.5^0C	27.79% - 40.65%

The results shows the maximum temperature of the peak solar irradiation during the test at a maximum water temperature of 70^0C for copper plate ,66^0C for aluminium plate and 62.5^0C in stainless steel plate are obtained. The solar intensity is increasing from 9am to 1pm, reaching amaximum value of 829 W/m2 at 1pm. The outlet temperature measured at 9am is 52 ^{0}C, 45 ^{0} C and 41^0 C for copper riser tubes aluminum tubes coated with copper oxide and stainless steel tubes coated with epoxy-polyether riser tubes respectively. The maximum outlet temperatures were recorded at 2pm for all three cases. The outlet temperature reduced after 2pm until 5pm for all three cases.

IV. CONCLUSION

- The result records that the collector outlet temperature has the function of solar irradiance and time.

- The maximum collector efficiency was obtained at 1pm in the experiments.
- The experimental results revealed that the performance of the solar water heater by using all the materials produced the maximum efficiency of around 40 % to 47 % respectively.
- The maximum outlet water temperature reached is below 70^0C respectively.
- The order of material priority for better efficiency is copper, aluminium, than stainless steel.

V. SCOPE FOR FUTURE WORK

The present study can be extended in the following direction:

1. Experiment can be performed by other different material.
2. Size variation can be done for better efficiency.
3. Optimization can be performed at varied tilt angle of solar flat collector.
4. Cost analysis can also be performed by using other materials.

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