Vol. 2 Issue 2, Feb.2012, pp.207-213

Solar Flat Plate Collector Analysis

Sunil.K.Amrutkar[1], Satyshree Ghodke[2], Dr. K. N. Patil[3]
[1] Mechanical Department, TIT, R.G.P.V. Bhopal India
[2] Mechanical Department, TIT, R.G.P.V. Bhopal India
[3]Mechanical Department, IIT, Mumbai 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 °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 (thermosyphon 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).

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 resource why solar energy has not been utilized as energy source for generating large power is considered as follows. The energy generated depends too much on time and seams to supply a stable power needed for a secondary energy source. It will require and enormous cost of equipment to effectively take energy at of such a moving energy source as the sun, and the energy cost obtained from the sun is comparatively high at present. However, as a result of increase of prices of fossil and nuclear fuels, a feasibility of solar energy as a new energy source can be increased, when a very high energy conversion efficiency and a reduction of cost of equipment is obtained, due above reasons, solar energy is one of the best possible and easily available energy. For the betterment of mankind, now a day for various applications with solar energy is in use still. Lot of research work is going on to use the available solar energy to maximum extent. One such area is tracking mechanism to obtain maximum energy. Just by keeping the collector fixed; it is not possible to get maximum energy from sun. It is possible to obtain the maximum energy only when it is rotated along the sun direction. In this context, tracking plays an important role. Tracking is desirable for orienting a solar device towards the sun there by collecting maximum solar energy and improving efficiency. This advantageous to water heater collector applications and this mechanism has been found more advantages than fixed flat plate collector.

II. FLAT PLATE COLLECTOR

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:

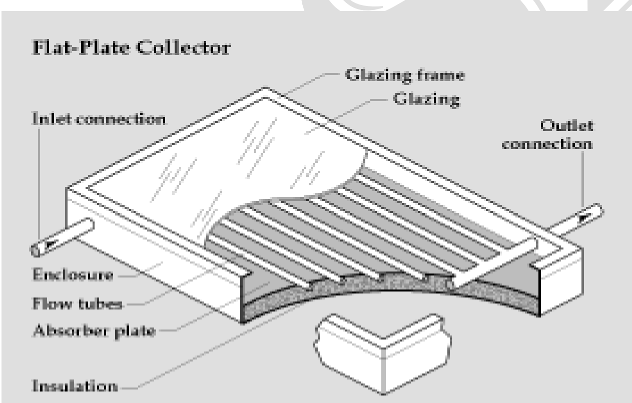

Fig. 1.1 Components of a flat plate solar collector

Absorber plate made of any material, which will rapidly absorb heat from sun's rays and quickly transfer that heat to the tubes or fins attached in some manner, which produces a good thermal bond. Tubes or fins for conducting or directing the heat transfer fluid from the inlet header or duct to the outlet. Glazing, this may be one or more sheets of glass or a diathermanous (radiation transmitting) plastic film or sheet.□ □Thermal insulation, which minimizes downward heat loss from the plate. Cover strip, to hold the other components in position and make it all Watertight.□ □Container or Casing, which surrounds the foregoing components and keeps them free from dust, moisture, etc. Flat plate solar collectors are classified into Water-type (hydronic) collectors, using water as the heat-transfer fluid. Air-type collectors, using air as the heat-transfer fluid. Fig. 1.2 (a) shows a few of the very large number of flat plate solar collectors (hydronic and air type), which are currently used. In this figure, diagrams A (1, 2) show conventional liquid heaters with the tubes soldered or otherwise fastened to upper or lower surfaces of metal sheets. Clips, clamps, twisted wires; thermal cements and many other devices have been tried with varying success.

Diagram A3 shows a bonded sheet design in which the tubes are integral with the sheet, thus guaranteeing a good thermal connection between the absorber plate and the tubes. This process is widely used commercially for producing radiators and other heat exchangers. Diagrams B and D show different ways in which galvanized steel sheets have been fastened together to make watertight containers with individual fluid passages. Diagram C shows the concept of using parallel sheets of copper, aluminum or Galvanized steel, which are dimpled and fastened together at intervals by spot welding or riveting. All of the non-tubular types are limited in the pressure, which they can sustain, and in general they are not suited for use with high line pressures in diagram F, shown is the use of tubing with rectangular or circular cross-section bonded on the plate; rectangular cross-section obtains more contact between the tube and the plate. Mechanical pressure, thermal cement or brazing may be used to make the actual assembly.

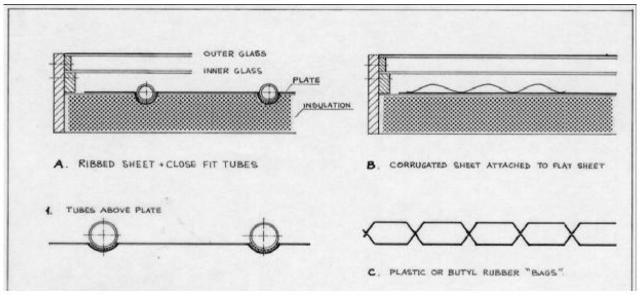

Fig.1.2 (a) Types of flat plate solar collectors (absorber plate sections)

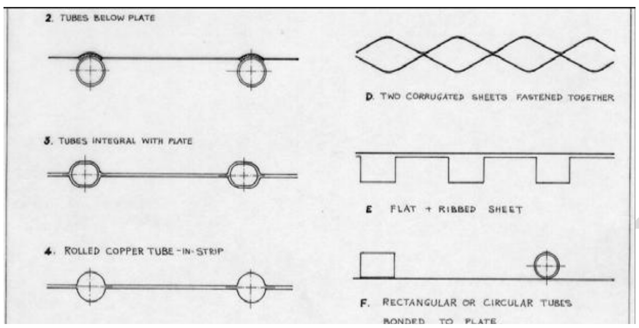

Fig.1.2 (b) Types of air type solar collectors (absorber plate sections)

The heating of air or other gases can be done readily with the flat-plate collector, particularly if some type of extended surface (G) can be used to overcome the low values of the heat transfer coefficient between metal and air. Matrix-type material (H) and many other approaches have been used to provide a means of trapping and absorbing the incoming solar radiation and providing a large contact area between the absorber material and the air Fig. 1.2 (b).

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.

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 short-wave radiation (solar), while virtually none of the long wave radiation emitted by the

Flat plate can escape outward by transmission. Glass of low iron content has a relatively high transmittance (0.85 - 0.90 at normal incidence) for the solar spectrum from 0.30 to 3.0μ, but its transmittance is essentially surfaces (3.0 - 50μ). Plastic films and sheets also posses high short wave transmittance, but, because most of the usable varieties possess transmission bands in the middle of the thermal radiation spectrum, they may have long wave transmittances as high as spectrum, they may have long wave transmittances as high as 0.40. Plastics are also generally limited in the temperatures, which they can sustain without undergoing dimensional changes. Only a few of the varieties now available can withstand the sun's

Ultra-violet radiation for long periods of time. They possess the advantage of being able to withstand hail and other stones, and in the form of thin films, they are completely flexible. The glass that is generally used in solar collectors may be either single-strength

(2.0 to 2.5 mm thick) or double-strength (3.0 - 3.5 mm). The commercially available grades of window or greenhouse will have normal incidence transmittances of about 0.87 and 0.85 respectively. For clear glass such as that used for solar collectors the 4% reflectance from each glass-air interface is the most important factor in reducing transmission, although a gain of about 3% in transmittance can be obtained by the use of water-white glass. Antireflection coatings of the kind used for camera and telescope lenses also can make significant improvement in transmission, but the cost of the process presently available is prohibitively high. The effect of dirt and dust on collector glazing is surprisingly small, and the cleansing effect of occasional rain seems to be adequate to maintain the transmittance within 2 - 4% of its maximum value. In addition to servicing as a heat trap by admitting short-wave solar radiation and retaining long wave thermal radiation, the glazing also reduces heat loss by convection. The insulating effect of the glazing is enhanced by the use of several sheets of glass or glass plus plastic.

TABLE 1.1 Glazing Materials

Material	Transmittance (τ)
Crystal glass	0.91
Window glass	0.85
Polymethyl methacrylates (acrylic) (Acryl ate, Lucite, Plexiglass)	0.89
Polycarbonate (Lexan, Merlon)	0.84
Polyethylene terephthalate (polyester) Mylar)	0.84
Polyvinyl fluoride (Tedlar)	0.93
Polyamide (Kapton)	0.80
Fluorinated ethylene propylene (FEP Teflon)	0.96
Fiberglass-reinforced polyester (Kalwall)	0.87

Table 1.1 gives transmittances for various glazing materials when the direct solar beam is perpendicular to the glazing because the angle of the direct beam varies a somewhat lower value of τ are usually used. Exact value depends also on the thickness of the glazing

III. ABSORBER PLATES

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching through the glazing, to loose 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. In hydronic collectors the absorber is usually made of copper, aluminium or steel. Factors that determine the choice of absorber material are its thermal conductivity, its durability and ease of handling, its availability and cost, and the energy required to produce it. Absorber plates are usually given a surface coating (which may be a black paint) that increases the fraction of available solar radiation absorbed by the plate (its absorptance α). Black paints, for which α = 0.92 to 0.98, are usually applied by spraying and are then heat-treated to evaporate solvents and improve adherence. These surfaces must be able to withstand repeated and prolonged exposure to high temperatures without appreciable deterioration or out gassing. It is well known that a black body is a perfect absorber of radiant energy and is a perfect radiator; that is, it has an absorptance α and an emittance ε, each equal to unity (emittance is the ratio of the amount of radiation emitted by the surface to the amount of "blackbody" or perfect radiator would emit at the same temperature). Actual surfaces do not behave like perfect absorbers or perfect radiators and have absorptance and emittance less than unity. Parenthetically, it may be pointed out that a black body is not necessarily non-luminous but may be as bright as the sun (which is not quite a black body). The term merely indicates a surface that is a perfect radiator and a perfect absorber. According to Kirchoff's law, at thermal equilibrium the absorptance and emittance of a body are the same. The emittance of a surface varies with its temperature and its roughness. If it is a metal, it depends also on its degree of oxidation. Highly polished metals have low emittance, provided oxidation and surface imperfections are kept to a minimum. The absorptance of a surface depends on the same factors as the emittance and, strictly speaking, on the distribution of wavelengths in the spectrum of incident radiation. If the character of the absorbing surface is such that its absorptance is independent of the distribution of incident wavelengths, it is called grey, and its absorptance and emittance are the same even though thermal equilibrium does not exist - that is, even though the temperatures of the radiator and the receiver are not the same. Evidently, if the difference in temperature between an emitting and an absorbing surface is small, grey body conditions can be assumed with little error. For example, room temperatures and the temperatures attained by solar collectors or by ordinary radiators are nearly enough alike to permit each to be considered "grey". Table 1.2 gives values of absorptance and infrared (IR) emittance for various Materials; it also gives values of reflectance. It is noteworthy that many common building materials have excellent emitting surfaces for long wave radiation.

TABLE 1.2 Solar absorptance, Infrared emittance and Reflectance for various surfaces

Material	α	P	E	α/ε
White plaster	0.07	0.93	0.91	0.08
Material Fresh snow	0.13	0.87	0.82	0.16
White paint	0.20	0.80	0.91	0.22
White enamel	0.35	0.65	0.90	0.39
Green paint	0.50	0.50	0.90	0.56
Red brick	0.55	0.45	0.90	0.60
Concrete	0.60	0.40	0.92	0.6
Grey paint	0.75	0.25	0.88	0.79
Black tar paper	0.93	0.07	0.93	1.00
Flat black paint	0.96	0.04	0.88	1.09
3M Velvet black paint	0.98	0.02	0.90	1.09
Granite	0.55	0.45	0.44	1.25
Graphite	0.78	0.22	0.41	1.9
Aluminium foil	0.15	0.85	0.05	3.00
Galvanized steel	0.65	0.35	0.13	5.00

IV. SELECTIVE ABSORBER

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 (Table 1.3). Selective absorbers often consist of a very thin black metallic oxide on a bright metal base. The oxide coating is thick enough to act as a good absorber, with $\alpha = 0.95$, but it is essentially transparent to longer wavelength heat radiation, neither absorbing nor emitting much of the 3 to 30 micron radiation. On the other hand, the bright metal base of the absorber surface has a low infrared emittance and radiates very little heat. The combination, in effect, gives a surface that is a good absorber but a poor radiator. As a result, the efficiency of the collector is greater when this type of surface is used. To date, the most successful and stable selective absorber is made by electroplating a layer of nickel onto the absorber plate and then electrodepositing an extremely thin layer of chromium oxide onto the nickel. This combination is more resistant to water damage than the commonly used nickel oxide coating. The manufacturing processes by which selective coatings are applied tend to make selective absorbers expensive. Eventually, innovations in methods and materials may bring the cost down.

V. TABLE 1.3 Properties of Selective Coatings

Selective Coatings	α	ε	α/ε
Black Chrome	0.93	0.10	9.3
Black Nickel on polished nickel	0.92	0.11	8.4
Black Nickel on galvanized iron	0.89	0.12	7.4
Cu on nickel	0.81	0.17	4.7
Co3O4 on silver	0.90	0.27	3.3
Cu on aluminium	0.93	0.11	8.5
Cu on anodized aluminu	0.85	0.11	7.7
Black Chrome	0.93	0.10	9.3
Black Nickel on polished nickel	0.92	0.11	8.4

VI. 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. Temperatures in flat-plate solar collectors can be high enough to melt some foam insulations, such as Styrofoam. And some foam give off corrosive frames at high temperatures, which could damage the absorber plate. In market various solar water heating system manufacturers available as TATA BP solar system, Solarmaxx, Sudarshan Solar, Jain Solar, Jay Solar,AvinSolar, Racold Solar, Digiflic, AtashSolar.Kamal solar.Atash Solar. Air India solar. Sunbeam solar. Each manufacturing of solar water heating system is different with their specification as collector area, absorber area, coating, plate material, thickness, tube diameter, and efficiency. There is huge scope to improve the efficiency of solar water heating system by reducing its area, number of tubes, and cost of collector for same outlet temperature.

VII. RESULTS AND DISCUSSION

From figs. 2(a) it is seen that efficiency of following collector is between ranges of 55% to 71% with their different parameters. In figs.2 (b) it is observed that cost of collector also vary as per their use of material, coating, number of tubes used in assembly. With rupees of 39,000 to 45000.. From figs.2(c) it is seen that storage temperature of different collectors in range of 50^0c to 70^0c which is sufficient for domestic water use. From figs.2(d) it is observed that the collector area having variation $1.9m^2$ to $2.5m^2$ for given collectors, and this important for optimization of area. As reducing the area, minimize the required number of tube for same outlet temperature with reducing its cos

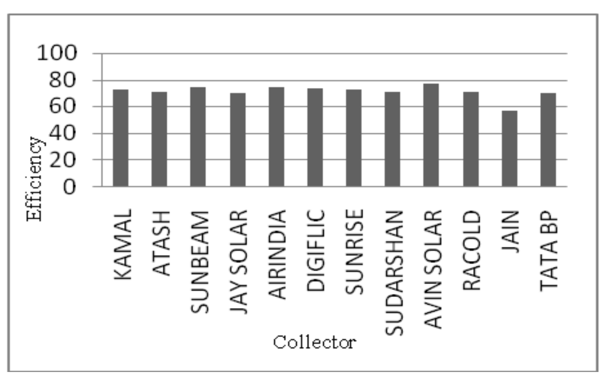

Fig.2 (a) Instantaneous efficiencies of solar collector versus collectors

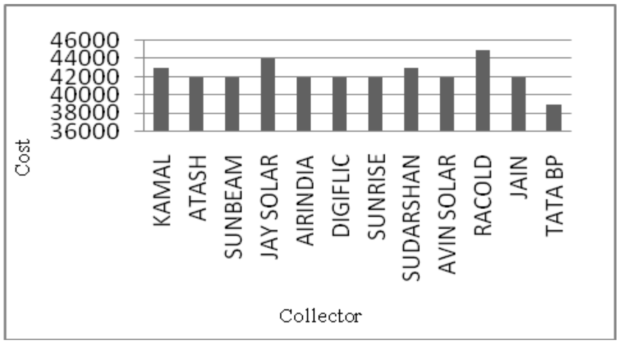

Fig.2 (b) Cost versus type of collectors

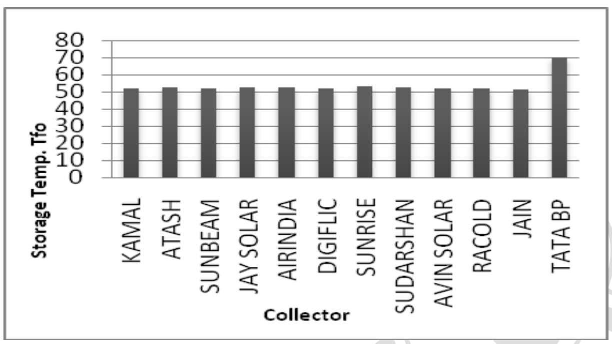

Fig.2 (c) Storage Temp. versus collector

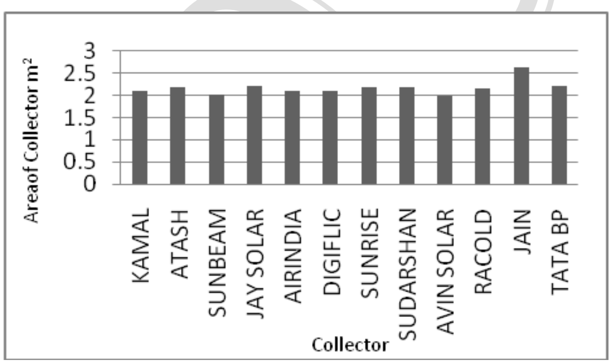

Fig 2(d) Area of collector versus collector

VIII. CONCLUSION

From the above comparison conclude that there are efficiency variation in given collectors with their given parameter, and also in cost, area, and its storage outlet temperature. But there is huge scope to reducing the collector area and minimizing the number of tubes which required for water circulation in collector assembly and its result at same outlet temperature reduce area and cost of collector by changing its geometric shape of flat plat collector.

IX. REFERENCES

[1] J.A. Duffie, W.A. Beckman, *Solar Engineering of Thermal Process*, Wiley Inter science, New York, 1991.

[2] B. Kundu, *Performance analysis and optimization of absorber plates of different geometry for a flat-plate solar collector: A comparative study*, *Applied Thermal* Engineering 22 (2002) 999–1012.

[3] S. P. Sukhatme, *"Solar Energy-Principle of Thermal Collection and Storage*", Tata McGraw Hill Pub, Co., Delhi, 1984.

[4] P. Rhushi Prasad *Experiment Analysis of Flat Plate Collector and Comparison of Performance with Tracking Collector*

[5] Drago.P Solar energy

[6] Carg H. P. *Treatise on solar energy; Volume 1: Fundamentals of solar energy*. John Wiley, New York (1982)