

A Review of Advancements in Design Configurations for Optimizing Solar Flat Plate Collector Effectiveness

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ABSTRACT: Application of solar energy for domestic and industrial heating purposes has become very popular. Flat plate collector type solar water heater is one of the most widely used solar applications. However the effectiveness of presently used fixed flat plate collectors is low due to the moving nature of the energy source. Recently lot of research has been carried out on the improvement of the thermal efficiency of solar flat plate collector. This paper presents a study of the research conducted on changes in design parameters and its effect on efficiency of solar thermal flat plate collector in recent years. This well design collector can produce hot water at temperature up to the boiling point of water which is used for various domestic and industrial heating purposes.

KEYWORDS: Solar radiation, Collector Efficiency, Reflector, Tracking System, Tilt Angle.

I. INTRODUCTION

The development of the world is going on at the expense of energy consumption. Presently conventional sources are fulfilling the energy needs of the world. But the conventional energy sources like fossil fuels have two main limitations: firstly they are limited in quantity and secondly they produce environmental pollution. It makes the world think for alternative energy sources. Renewable energy sources eliminate the limitations of conventional sources. But because of less knowledge about these sources and high initial cost of the conversion systems limit the use of these resources. Out of the all renewable energy resources, solar energy is the most promising, a very large, clean, inexhaustible and universally available source of energy.

Function of flat plate collector type solar water heater is to transfer the solar radiation into heat to satisfy energy needs. But with some limitations, it is not being used on large extent because of its higher initial cost and lower efficiency. So there is a requirement of enhancement in design parameters of collector and also additions like use of reflectors, tracking system or concentric collector to overcome its limitations.

The purpose of this paper is to presents a study of the research conducted for improvement of thermal efficiency of solar flat plate collector by changes in design parameters in recent years. In the present study, developments in the field of design of solar flat plate collector in recent years have been reviewed thoroughly.

Flat Plate Collector:

It is a metal box with a glass or plastic cover (glazing) on top and a dark-coloured absorber plate on the bottom with insulation at sides and bottom of the collector to minimize heat loss typically mounted on a roof that heats water using the sun's energy. Figure 1 shows the main components of a flat plate solar collector are:

- Absorber plate
- Tubes or fins
- Glazing
- Thermal insulation
- Cover strip

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- Container or Casing

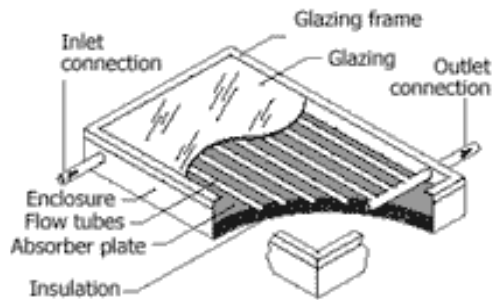


Figure1: Flat Plate Collector Section

Solar collectors are the key component of solar water heating systems. Solar collectors are the devices used to convert solar energy into heat energy. 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.

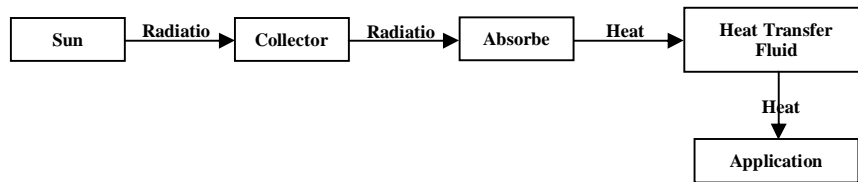


Figure 2: Working Principle of Solar Collector

II. LITERATURE SURVEY

The papers deal with design, analysis and performance of flat plate collector. Number of designs are investigated which explore the recent advancements and efforts made in improving the performance of the flat plate collector. Some papers and reports are given below as a part of literature survey.

Manjunath M.S et al. [1], compared the effect of surface geometry of solar collector having dimple geometry with that of a flat plate solar collector of the same size as shown in Figure 3. A CFD analysis was carried out for the two cases, subjected to a constant heat flux of 600 W/m² and 1000 W/m². It can be inferred from the study that the absorber plate temperature shows a rise of average surface temperature of about 5⁰C for the dimple solar collector when compared to a flat plate solar collector. Most importantly, the average exit water temperature shows a marked improvement of about 5.5⁰C for a dimple solar collector as compared to that of a flat plate solar collector.

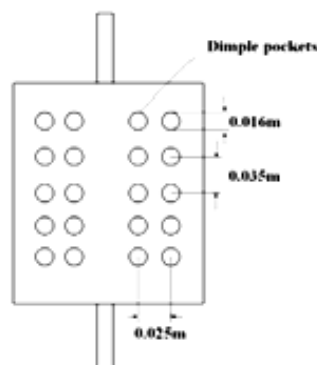


Figure 3: The Dimple Pockets on Absorber Plate [1]

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Rabl et al. [2], introduced about the development of the reverse flat plate collector i.e. bifacial collector shown in Figure 4 [2].

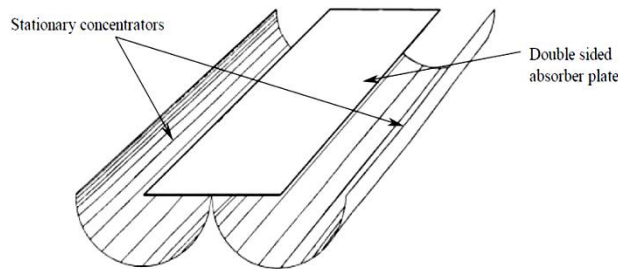


Figure 4: Bifacial Absorber Collector [2]

This design has been shown to achieve higher efficiencies than other flat plate collectors under low irradiation conditions. The design incorporates two identical stationary concentrators with a flat plate absorber mounted above them. The plate is illuminated on both sides and hence the heat loss path through the thermal insulation on the rear of the absorber plate is eliminated. The rear of the stationary concentrators is insulated to reduce heat losses through the back of the collector system.

Sunil K. Amrutkaret al. [3], Figure 5 shows a few of the very large number of flat plate solar collectors 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.

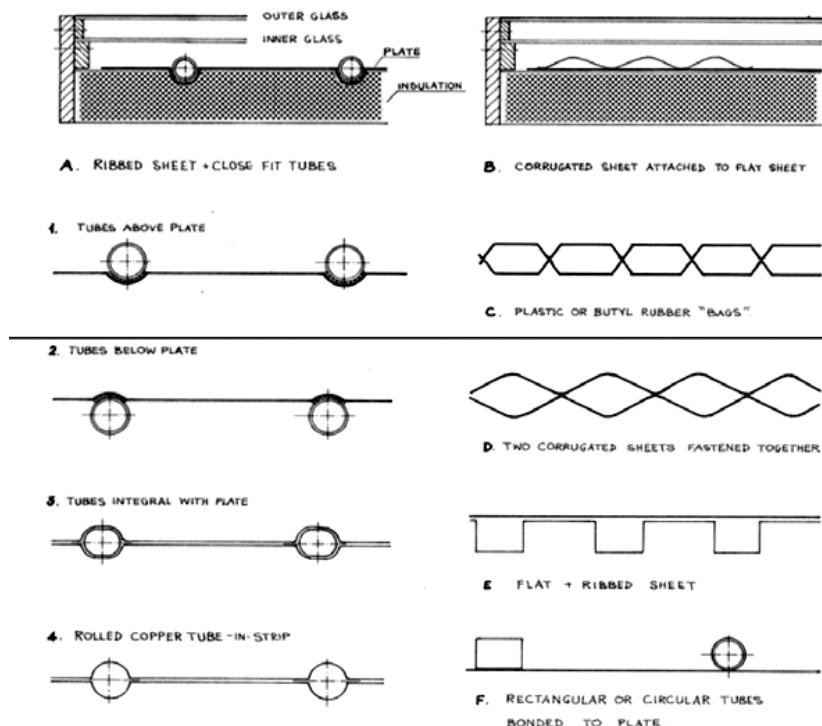


Figure 5: Absorber Plate and Tubes Bonding Sections [3]

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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. 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.

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.

P. Rhushi Prasad et al. [4], conducted experiments for a week during which the atmospheric conditions were almost uniform and data was collected both for fixed and tracked conditions of the flat plate collector. The results show that there is an average increase of 4°C in the outlet temperature. The efficiency of both the conditions was calculated and the comparison shows that there is an increase of about 21% in the percentage of efficiency.

Balaram Kundu et al.[5], conducted a comparative study on the performance and optimization of several profile shapes like rectangular, trapezoidal and rectangular profile with a step change in local thickness (RPSLT) as shown in Figure 6. The result indicates as shown in Figure 7 that there is optimum fin efficiency of trapezoidal profile for constant plate volume. The RPSLT profile of absorber plate is superior to other profiles because of higher performance and less difficulties in fabrication.

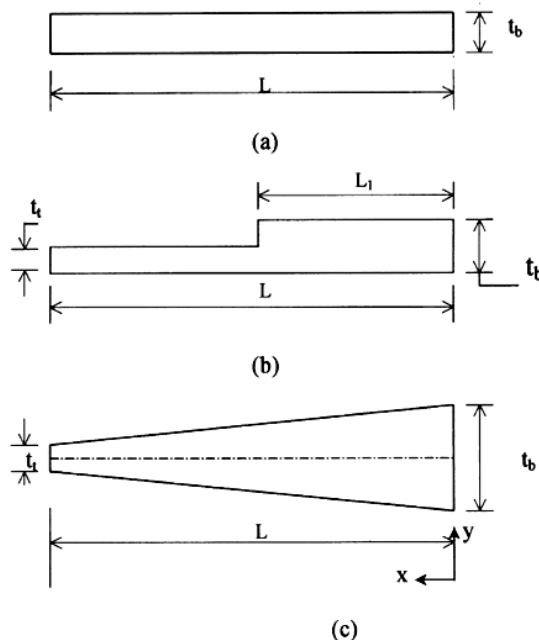


Figure 6: Schematic Geometry of a Symmetric Heat Transfer Element.
Rectangular Profile, B) RPSLT, C) Trapezoidal Profile [5]

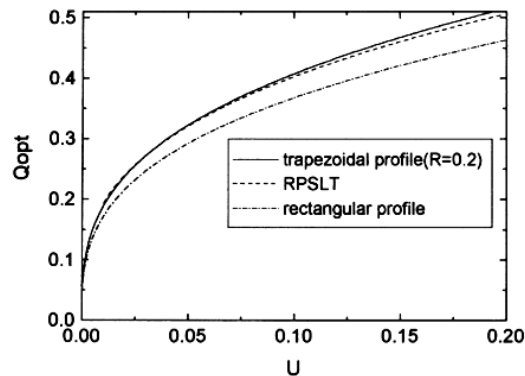


Figure 7: The Maximum Energy Transfer Rate by Different Profile as a Function of Plate Volume U [5]

B. Hellstrom et al. [6], investigate the impact of the optical properties on the annual performance of flat plate collectors in a Swedish climate. The importance of changes in solar absorptance and thermal emittance of the absorber, the addition of a Teflon film or a teflon honeycomb, antireflection treatment of the cover glazing and combinations of these improvements were investigated. A combined increase in absorptance from 0.95 to 0.97 and a decrease in emittance from 0.10 to 0.05, increase the annual performance with 6.7% at 50°C operating temperature. The increase in performance by installing a teflon film as second glazing was estimated to 5.6% at 50°C. Teflon honeycomb gives 12.1%. Antireflection treatment of the cover glazing increases the annual output with 6.5% at 50°C. A combination of absorber improvements together with a teflon honeycomb and an antireflection treated glazing results in a total increase of 24.6% at 50°C. Including external booster reflectors increases the expected annual output at 50°C to 19.9 - 29.4% depending on reflector material.

Dalmo G. Gomes et al. [7], presented a new way of minimize the losses on a flat plate solar energy collector. A wind barrier was added along the collector perimeter in order to modify the flow pattern over it. This barrier creates a region of recirculating separated flow on top of the collector. It was observed a 12% heat-loss reduction in comparison with the traditional double glazing solution.

BAA Yousef et al. [8], carried out a theoretical study to investigate the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium. The analysis of the results at the same configuration and parameters shows that the system thermal efficiency increases by 10-12% in double flow mode than single flow due to the increased of heat removal, and increase by 8% after using porous medium in the lower channel as a result of the increase of heat transfer area. At the same time the pressure drop will be increased. All collectors show improved efficiency obtained when the collector operates at relatively high flow rates, and at relatively low collector temperature rise since the collector losses will be less in low temperature difference.

Y. Raja Sekhar et al. [9], evaluate top loss coefficient of the flat plate collector both theoretically and experimentally. By performing experiment they concluded that the emissivity of the absorber plate has a significant impact on the top loss coefficient and consequently on the efficiency of the flat plate collector. The efficiency of FPC is found to increase with increasing ambient temperature. There is no significant impact of tilt angle on the top loss coefficient.

K.E. Amori et al. [10], compared the performance of two similar locally-fabricated solar water heaters. One of the collectors features a new design for accelerated absorber; its risers were made of converging ducts whose exit area was half that of the entrance. The other collector was a conventional absorber, with risers of the same cross sectional area along its length. They conducted experiments on the two solar water heaters from January to April of 2009 for different water withdrawal profiles, continuous, interrupted and no load, as well as for horizontal and vertical storage tank

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orientations. Two types of storage tanks were investigated, those with two concentric cylinders, and those with helically-coiled tubes in the cylinder. Results show that a considerable enhancement of thermal performance (approximately 60%) of absorbed heat (useful gain) at solar noon was obtained for the new design, in comparison with the conventional type. The instantaneous efficiency was 31.5% for the accelerated absorbed flat plate at solar noon, while that of conventional absorber was (16.5%). The longitudinal water temperature variations in the risers of accelerated absorber were larger than that of the conventional absorber.

K. Sarath kumar et al. [11], manufactured the model on the concept of advanced solar water heater i.e. conventional solar water heater with concentric collector. They tested the model in two stages. In the first stage the solar water heater was tested without concentrator and in second stage with concentrator. The obtained results show the efficiency of advanced solar water heater is 15.3% higher than conventional flat plate water heater.

Basavanna S et al. [12], has been studied a triangular tube configuration instead of circular tube. The triangular tube raises the outlet temperature due to better contact between tube and plate. As the fluid flows through the tube, the collector fluid gains heat and its temperature rise. In the absorber plate the temperature at the end portion of the plate is high due to the fact that this configuration tube has more surface area of contact between the tube and the plate, resulting in more heat absorption and hence enhanced performance of the collector.

Lot of work was done regarding design and improvement of solar thermal flat plate collector in all over the world. But still there is a vital scope for improvement of thermal efficiency of flat plate collector.

III. MATERIALS FOR FLAT PLATE COLLECTORS

This section describes briefly some of the principal requirements for and the properties of materials employed in solar flat plate collectors used for the transformation of solar energy into thermal energy by review of some research papers as given below.

A. Glazing Materials

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. 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. Tempered glass (4mm thickness) of low- iron content has been the principal material used to glaze solar collectors. Because it has relatively high transmittance as much as 91% of the incoming short-wave radiation as compared to other glazing materials as shown in table 1.

Material	Transmittance (τ)
1 Tempered glass of low- iron content	0.91
2 Window glass	0.85
3 Polymethyl methacrylate(acrylic)	0.89
4 Polycarbonate (Lexan, Merlon)	0.84
5 Polyethylene terephthalate (polyester)	0.84
6 Polyvinyl fluoride (Tedlar)	0.93
7 Polyamide (Kapton)	0.80
8 Fluorinated ethylene propylene (FEP Teflon)	0.96
9 Fiberglass-reinforced polyester	0.87

Table 1: Glazing materials [4]

B. Absorber Plates

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching through

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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. Factors that determine the choice of absorber material are its thermal conductivity, corrosion resistance, withstands the stagnation temperature its durability and ease of handling, its availability and cost, and the energy required to produce it. Of the commonly available materials copper is the best because of its high thermal conductivity as given in table 2.

Material	Thermal conductivity in W/mk
Copper	376
Aluminium	205
Mild steel	50
Stainless steel	24

Table 2: Thermal conductivity of absorber materials

C. 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. For such a surface, $\alpha = 1$ and $\epsilon = 0$. Selective absorbers can be manufactured that approach this ideal, and several are available commercially in Table 3.

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 [4].

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
CuO on nickel	0.81	0.17	4.7
Co ₃ O ₄ on silver	0.90	0.27	3.3
CuO on aluminum	0.93	0.11	8.5
CuO on anodized aluminum	0.85	0.11	7.7

Table 3: Properties of selective coatings [4]

D. Riser and Header Tubes

Riser tubes or fins for conducting or directing the heat transfer fluid from the inlet header to the outlet. While designing, the factors such as choice of materials, inner and outer diameter, volumetric flow rate (m), inlet pressure, number of tubes, spacing of tubes and the thermal conductivity of bond between tube and absorber sheet must be exercised carefully.

A good thermal bonds such as a braze, weld or high temperature solder are required for tube and plate designs, in order to ensure good heat transfer from the absorbing surface into the fluid as shown in figure 8.

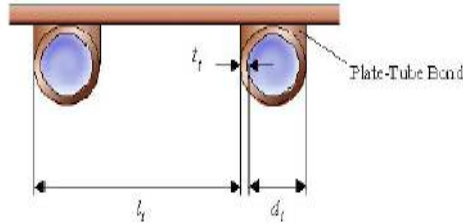


Figure 8: Absorber plate and tube thermal bond

As the number of tubes increases, the tube-to-tube spacing decreases and the collector heat removal factor FR increases. Thus, the instantaneous efficiency improves with the increase of the number of tubes. The effect of the number of tubes on the instantaneous efficiency of the collector is illustrated in Figure 9. The degree of improvement decreases and there exists the optimum number of tubes for the collector considering the manufacturing cost. As shown in this figure the instantaneous efficiency for 11 tubes is almost identical to that for 10 tubes [13].

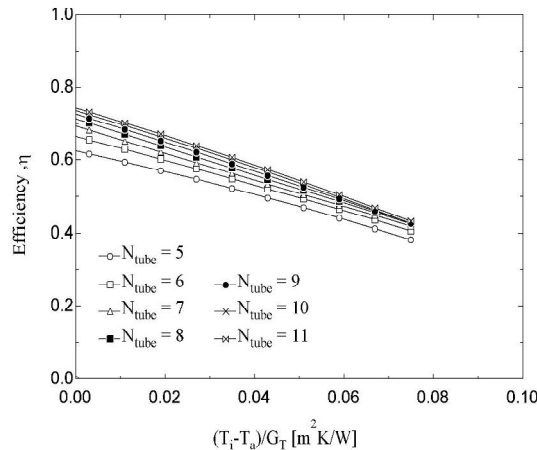


Figure 9: Effect of number of tubes on efficiency [13]

E. Collector Thermal Insulation

Flat-plate collectors must be insulated to reduce conduction and convection losses through the back and sides of the collector box.

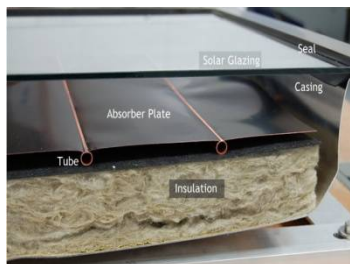


Figure 10: Rock wool thermal insulation

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As the collector may have to operate at temperature as high as 200°C the insulation must not deteriorate, outgas, expand or contract at temperatures between 30°C and 200°C. It must also have structural stability and must not become compact or settle with time. It should not attract moisture and should be fire resistant. It should be light in weight. The section of collector box shows back and side insulation of rock wool in figure 10.

We know, the increase in back and edge thermal conductivity causes an increase in the heat loss from the collector and is equivalent to the increase of thermal leakage from the collector. The efficiency of the collector decreases with increase in thermal conductivity of insulation material. Usually, rock wool or glass-wool is recommended for back and sides insulation of the collector because of its less thermal conductivity

F. Collector Housing

The collector housing is provided to protect the insulation and absorber plate from the environment and also to minimize heat loss. Materials like aluminium, galvanised steel, fibre glass, etc. are used for making the collector housing. It is advisable to use the same material for collector support structure and housing to avoid contact corrosion. Such problems however may not arise with fibre glass or plastic housing.

G. Collector Support

It is advisable to use the same material for collector support structure and housing to avoid contact corrosion. M.S channel or square pipe stand is suitable to withstand the weight of collector and water storage tank. Collector support would be grounded in cement concrete block or faster bolts used of appropriate quality.

IV. CONCLUSION

Based on the review of the literature, it has been concluded that the research is done for the improvement of the thermal efficiency of solar flat plate collector in recent years. A number of studies have been carried out in order to investigate the effect of changes in design parameters, materials and use of additional accessories such as reflectors, tracking or concentric collectors that helpful for the improvement of the thermal efficiency of the solar flat plate collector. But the complete optimization with respect to the design and operating conditions such as mass flow rate is not carried out still today. The information presented here will be valuable for new research in this area.

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