A REVIEW ON THE RECENT ADVANCEMENTS IN IMPROVING THE PERFORMANCE OF THE FLAT PLATE COLLECTOR

[1] Dr. Nilesh. P. Salunke, [2] J.S. Khatik,
[1]HOD, [2]Assistant Professor
Mechanical Enginnering Department,
[1]R.C.Patel Institute of Technology, Shirpur, India

Abstract: The solar collector is the key component in solar energy systems. It absorbs the solar radiation and converts it into a useful form of energy that can be applied to meet a demand. Out of various types of solar collectors, the flat-plate collectors are most economical and popular, since they are fixed permanently in position, involve simple construction and require little maintenance. Flat plate solar collectors used in modern domestic hot water systems have not changed significantly in the past few years. These types of absorbers typically have high heat losses through convective and radiative heat transfer. This paper has a review on number of design investigated which explores the recent advancements and efforts made in improving the performance of the flat plate collector.

***Key Words* - Flat plate collectors, bifacial absorber collector, flat solar radiation reflectors, design advancements in flat plate collectors**

I. INTRODUCTION

Flat plate solar collector is used for low temperature heating applications. Domestic solar water heater is one of the popular examples of its use. These collectors are more reliable, simple in operation and low maintenance required. These collectors are extensively used all over the world. The further applications of this collector are pool heating, laundry, space heating, drying agriculture products etc.

The principles involve in flat plate collector is to gain the radiation energy from the sun by heat absorption. The energy which has been collected is transferred through flow tubes by water which are integrated with heat absorber plate. [1]

In flat plate collector, the ability to absorb more energy is most important in its thermal performance. The heat absorber plate is one of the important components of the flat plate collector. When the absorber plate absorbs more heat from the Sun, the outlet temperature should have higher value from inlet temperature. Thus, from the temperature values, efficiency of the flat plate collector can be obtained.

The ability of the heat absorber plate to absorb more heat from the sun and maintain the heat is the main key in flat plate collector performance. The efficiency of the flat plate collector 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. Flat plate collectors generally have high heat losses and low efficiency since only the upper side of the absorber plate is exposed to the sun. The reverse side of the absorber plate must be insulated to prevent heat loss through the back of the collector. Losses through the top of the collector are influenced strongly by the collector design and orientation. Back losses are primarily related to insulation performance. Also due to moving nature of the sun during entire day the efficiency of the flat plate collector decreases.[2]

The aim of this paper is to present a review on studies of the research carried out on the improving the performance of the flat plate collector.

II. ADVANCEMENTS IN DESIGN OF FLAT PLATE COLLECTORS

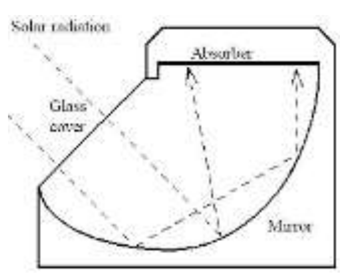

Fig. 1: Schematic of the Reverse Flat Plate Collector

The reverse flat plate collector as shown in fig. 1 was introduced independently by **Rabl** et al [3, 4&5]. The reverse flat plate collector had an inverted absorber plate with a stationary concentrating reflector underneath. Providing the absorber is mounted horizontally the collector cavity becomes thermally stratified and convection is suppressed. Whilst this design significantly reduces the convective heat losses, there are still heat loss paths through the insulation above the collector and conduction through the air cavity.

This design allows the collector to be given a seasonal bias by modifying the shape of the concentrating mirror. The disadvantage from a commercial aspect is that the collector is bulky and would be difficult to mount on a typical roof.

A further development of the reverse flat plat collector is the bifacial collector shown in fig. 2 [6]. This design has been shown to achieve higher efficiencies than other flat plate collectors under low irradiation conditions. The design consists of two identical stationary concentrators with a flat plate absorber above them. The plate receives solar energy on both sides and hence the heat loss path through the thermal insulation on the rear of the absorber plate is eliminated. The back side of the stationary concentrators is insulated to reduce heat losses through the back of the collector system.

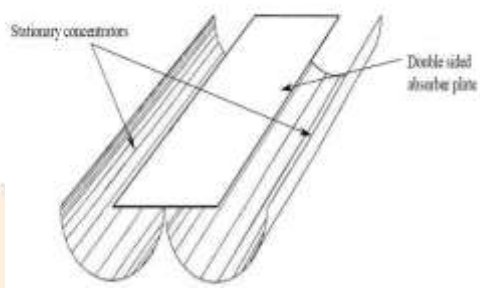

Fig. 2: Bifacial Absorber Collector

In 2002 **N.K. Groenhout**, et al [7], carried out the experiment on advanced solar water heater. The experimental set placed in a temperature-controlled room. Electric heaters had been used to simulate the absorber plate and thermocouples were used to measure the surface temperature on the heater plates as well as the ambient temperature. For the glass cover, low iron, anti-reflective glass was used and the two concentrating reflectors had been modeled using aluminized reflective sheet. Heat loss measurements had been carried out over a range of heater temperatures from 30 to 100^0C. The overall heat transfer co-efficient obtained from the model were 30–70% lower than from conventional flat plate designs.

P.T. Tsilingiris [8] investigate the limitations of the polymer plate absorber design for a wide range of collector loss and convective heat transfer coefficients between heat transfer fluid and absorber plate. His also aimed to calculate the specific collector efficiency factors and conditions under which the associated collector performance parameters should be modified to account for the finite absorber plate conductance.

Balaram Kundu [9] had done 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 fig. 3. The result indicates as shown in fig.4 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.

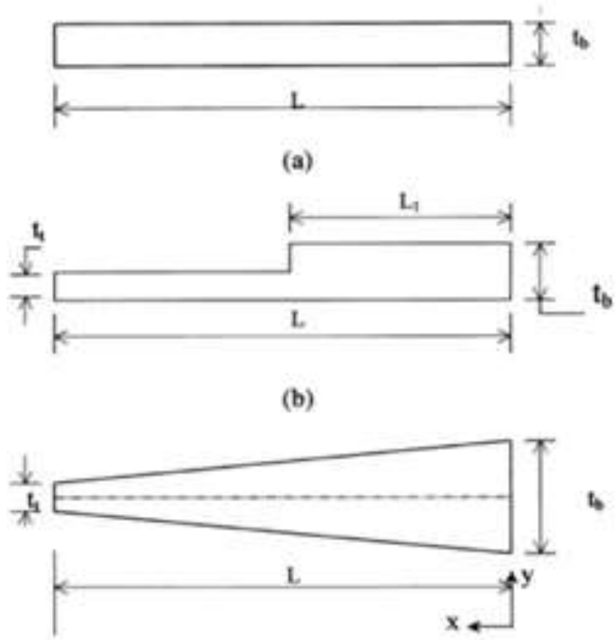

Fig. 3: Schematic Geometry of a Symmetric Heat Transfer Element. a) Rectangular profile, b) RPSLT, c) Trapezoidal profile

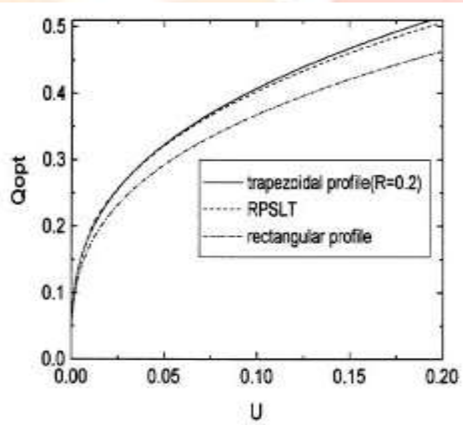

Fig. 4: The Maximum Energy Transfer Rate by Different Profile as a Function of Plate Volume U

Jose´ M.S. Cruz et al [10] devised a simple, low-cost solar water heater for operation in Mediterranean Europe or regions of similar latitude (40–45_ north). It takes the form of a trapezoidal-shaped water store in direct contact with an inclined flat-plate solar collector assembly. This cross-section induces thermal stratification in the water store, and provides sufficient energy storage to meet typical daily hot-water demand. Then they used a thermal network analysis model to assess the energy-saving potential of the composite system. It indicated that a 30–70% reduction in daily load could be obtained.

B. Hellstrom et al [11] investigated 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, antireflection treatment of the cover glazing, the addition of a teflon film or a teflon honeycomb 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 [12] 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.

A.M. Abu-Zour, et al [13] designed a new solar collector integrated into louvred shading devices. In addition to protecting glazed spaces from excessive solar gain, the collector would be able to supply heat energy to building systems under a range of climatic conditions. This would reduce the buildings primary energy consumption and so its contribution to global CO2 emission.

BAA Yousef et al [14] done 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.

Sunil V. Yeole, et al [15] made an attempt to optimize the performance of flat plate collector by developing a detailed model that includes all of the design features of the collector such as: Geographic location, absorber plate material and size, selective coating, tube diameters and spacing, number of glazing covers and material, back and edge insulation dimensions, material of water storage tank, collector orientation, etc. This well-designed collector can produce hot water at temperature up to the boiling point of water.

M. Jamil Ahmad et al [16] examines the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at ten different stations in the world and makes recommendations on how the collected energy can be increased by varying the tilt angle. For Indian stations, the calculations are based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface. For other stations, the calculations are based upon the data of monthly mean daily global solar radiation and monthly average clearness index on a horizontal surface. It is shown that nearly optimal energy can be collected if the angle of tilt is varied seasonally, four times a year. Annual optimum tilt angle is found to be approximately equal to latitude of the location. It is found that the loss in the amount of collected energy is around 1 % if the angle of tilt is adjusted seasonally instead of using βopt for each month of the year. The loss of energy when using the yearly average fixed angle is around 15 % compared with the monthly optimum tilt.

P. Rhushi Prasad, et al [17] 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 4oC 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.

R. Herrero Martín, et al [18] proposed an enhancement technique applied to flat plate liquid solar collectors for more compact and efficient design. The design consists of tube-side enhancement passive techniques which are incorporated into a smooth round tube (twisted tapes, wire coils). This type of inserted device provides better results in laminar, transitional and low turbulence fluid flow regimes. To test the enhanced solar collector and compare with a standard one, an experimental side-by-side solar collector test bed was designed and constructed. A relevant improvement of the efficiency up to 5% has been reported and quantified through the useful power ratio between enhanced and standard solar collectors.

Hiroshi Tanaka [19] proposed a solar collector with reflector which gives increase in the solar radiation. The reflector was inclined forwards in winter and backwards in summer, and by setting the inclination angle of the reflector at less than 300 throughout the year.

Ljiljana T. Kostic et al [20] proposed an optimum position for the reflectors to improve the thermal efficiency of flat plate collector SWH as shown in fig. 5. For that purpose they were conducted study on thermal collectors with and without flat plate solar radiation reflectors. They made the analytical model for determination of the optimal position of aluminium sheet made flat plate solar reflector for inclination (tilt angle) of thermal collector of 450, during the day time over the whole year period. Then they compare theoretical results obtained by analytical model with experimental data. They also determined the thermal efficiencies of solar thermal collectors without reflectors and with reflectors in optimal position.

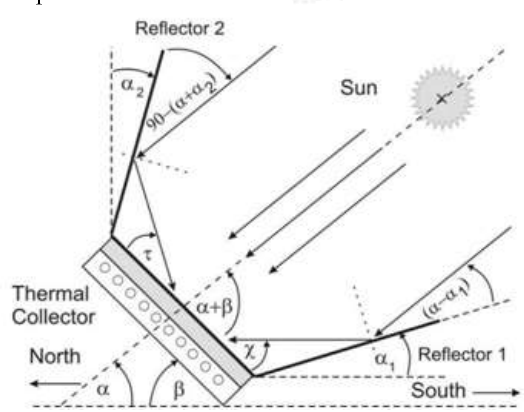

Fig.5: Schematic Diagram of the Thermal Collector with Flat Solar Radiation Reflectors.

The increase of total thermal energy obtained by thermal collector with reflectors in optimal position during the summer period varied in the range 35–44% and it was dependent on the meteorological parameters, such as ambient temperature , wind speed, solar radiation etc.

Manjunath M.S, et al [21] 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 fig.6. A CFD analysis was carried out for the two cases, subjected to a constant heat flux of 600W/m^2 and 1000W/m^2. It can be inferred from the study that the absorber plate temperature shows a rise of average surface temperature of about 5^0C 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 5.5^0C for a dimple solar collector as compared to that of a flat plate solar collector.

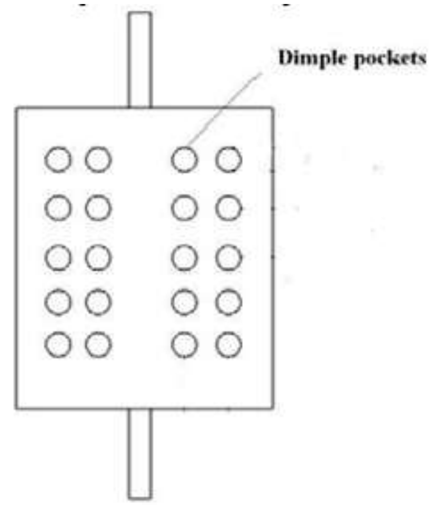

Fig. 6: The Dimple Pockets on Absorber Plate

Raj Thundil Karuppa R. et al [22] tested a new and inexpensive solar water heater. The collector was of sandwich type. The absorber was made of 2 sheets of GI (1 mm) with integrated canals, painted in silica based black paint. They carried out experiments to test the performance of both the water heaters under water circulation with a small pump and compared the results. The results show that the system can reach satisfactory levels of efficiency. It also proves to be inexpensive and easier to manufacture which makes it a potential technological solution to the domestic water heating problems in rural India.

K.E. Amori et al [23] 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 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.

Madhukeshwara. N, et al [24] presented the performance of flat plate collector with three different coatings for solar flat plate collectors where temperatures up to 70°C are easily attained by flat plate collectors. With very careful engineering using special surfaces, reflectors to increase the incident radiation and heat resistant materials, higher operating temperatures are feasible.

K. Sarath kumar et al [25] 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 percent higher than conventional flat plate water heater.

Basavanna S et al [26] 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 rises. 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.

III. CONCLUSIONS

From above literature review, it has been found that the lots of research had been done in the advancements in design configurations to enhance efficiency and performance of flat plate collector. It has been found that flat plate collector enhancement widely investigated both analytically and experimentally. In some design advancement reverse flat plate, bifacial absorber or concentric collectors are used to reduce side and rear losses. Wind barriers are used to reduce losses from top whereas reflectors are used to improve the heat gain. In some papers there is advancement of absorber plate like changing its shape or making concavities on it which results in improvement of efficiency of flat plat collector. Some papers are related with design of riser tubes which include changing the geometry from circular to triangular one or making the exit of riser almost half of the entrance for improvement of the efficiency. Some researchers studied the glazing material and their impact on performance of flat plate collector. In some papers tracking system is studied for the improvement of the efficiency of flat plate collector. Overall, the numerous researchers are trying to improve the performance of the flat plate collector by changing some sort of design of it. The information presented here will be valuable for new research in this area.

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