

Solar Flat Plate Collector with Baffles: A Review

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Abstract-Given rapid depletion of conventional energy sources and environmental degradation caused by their over exploitation, the renewable energy sources are believed to be the future. Technologies utilizing renewable energy sources differ significantly from one another, not only with regard to technical and economic aspects but also in relation to their reliability, maturity, and operational experience in utility scale conditions. Technologies used to harness solar energy have emerged as the most promising and mature since solar energy is abundant, freely available, and it has commercial potential too. The heat transfer enhancement is very important in many engineering applications to increase the efficiency of solar flat plate collectors. The active techniques require external power like surface vibrations, electrical fields etc. and the passive techniques are those which does not require any external power. Our research involves a solar flat plate collector setup whose risers were designed with two variants namely a riser without inserts and a riser with semicircular baffles. The major aim of the research is to create a turbulent flow of water in the riser so that more efficient heat transfer takes place thereby increasing the efficiency of the entire system.

Keywords- CFD, Solar flat plate collectors, Semicircular baffles, augmentation techniques.

I. INTRODUCTION

It is the age of machines—for either necessity or luxury. Machines need energy to perform tasks. Meeting the ever-increasing demand of energy without degrading the environment has always been concern of scientific community. Generation of energy from limited conventional sources has caused so much environmental degradation that impact is visible in the form of pollution, acid rain, global warming etc.

Thus, there is a crying need for producing green and clean energy from renewable sources. Among all the renewable energy resources, the solar energy has emerged as one of the most promising renewable energy resource since it is abundant, freely available, and it has commercial potential too. The conversion of solar energy into different other forms is evident in nature, as shown in Fig. 1. The solar

energy is converted into chemical energy by the process of photosynthesis in green plants.

The conversion of solar energy into mechanical energy happens during the process of evaporation from water bodies, and change in wind behavior. In addition, there are two broad ways of utilizing the solar energy for the production of energy: (i) solar–electric conversion (converting solar energy directly into electrical energy using photovoltaic solar cell) and (ii) solar–thermal conversion (converting solar energy into thermal energy using solar collector). A lot of research works have been reported in the literature on solar–thermal systems.

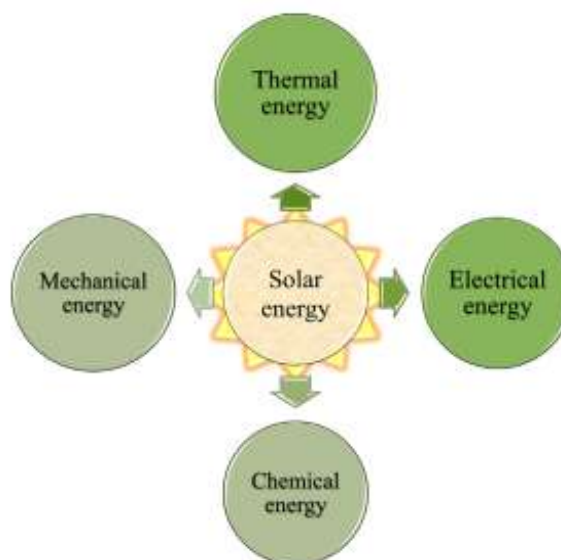


Figure 1: Conversion of solar energy into other forms of energy

In [1] researchers conducted an exhaustive review on different types of solar thermal collectors and their applications. The various types of collectors were discussed and presented with their optical, thermal and thermodynamic analysis. The applications of solar thermal systems in diverse areas of technology were illustrated to emphasize the need of its use whenever possible.

In [2] author presented a review on concentrating collectors, viz. parabolic trough collectors, heliostat field collectors, linear Fresnel reflector, parabolic dish collector etc. They suggested that concentrated solar power (CSP) technology could not only be used for electricity generation, but also for large range of other applications such as desalination of water, industrial heating and cooling, detoxification and disinfection of water etc.

II. SOLAR FLAT-PLATE COLLECTOR

Solar collector is a device that collects thermal energy of solar insulation by absorbing them. The thermal energy thus stored is carried away by a flowing fluid and utilized for some specific purposes. Fig. 2 shows the classification of solar collectors. The solar collectors are broadly classified as non-tracking and tracking collectors. The non-tracking collectors are kept at rest and also known as fixed or stationary collectors, whereas tracking collectors are designed to track the movement of sun so that the incoming solar radiations always fall perpendicular to them. The tracking solar collectors are further classified as one axis tracking and two axes tracking collectors. Non-tracking collectors are categorized as flat plate, evacuated tube and compound parabolic collectors. Parabolic trough collector, cylindrical trough collector, and linear Fresnel reflector fall under the category of single axis tracking systems, whereas central tower receiver, parabolic dish reflector, and circular Fresnel lens belong to dual axes tracking systems. The collector that uses water as working fluid is termed as solar water heater (SWH), whereas the collector utilizing air as working fluid is called solar air heater (SAH) [3]. A solar water heating (SWH) system comprises of the solar collector as well as the storage tank. The solar water heating systems are further classified as passive SWH systems (do not require external pumping agency and the flow takes place due to thermo-syphonic action) and active SWH systems (require pumping agency to circulate fluid through them). An integrated collector storage system (ICS) has both the collector and storage tank as single unit [4].

A flat plate collector, shown in Fig. 2, consists of a transparent glass cover, an absorber plate with a parallel back plate. Depending upon the type of fluid, that is air or water, the flow passage is designed. For air as a working fluid, the gap between the absorber plate and back plate is made passage for the flow of fluid. When water is used as a working fluid, the copper tubes brazed on the absorber plate are made flow passages [5]. In this case, the back plate is not required. The collector is insulated from the sides as well as from the bottom to further minimize the heat loss. A glass cover at the top helps in reducing the convective as well as radiative heat loss from the absorber plate to the outside air.

During prolonged usage, the dust settles on the glass cover of the collectors that affects their performance adversely.

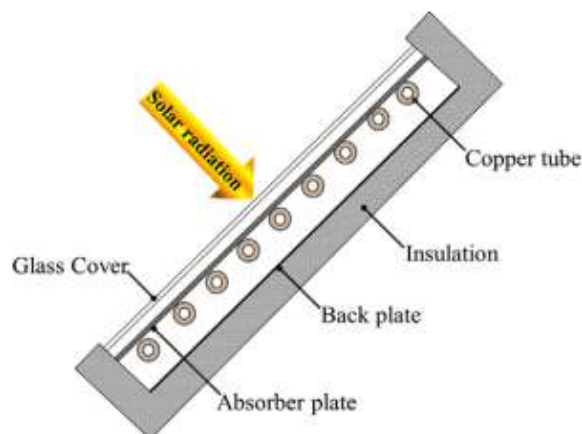


Figure 2: Flat plate collector

In order to increase the heat transfer rate of the system, we can make use of different types of augmentation methods. Augmentation methods include active and passive methods with the latter being the most widely used. In our research we have made use of semicircular baffles which are evenly spaced in the riser tube [6]. These baffles or turbulators convert laminar flow of water to turbulent flow which thereby contributes to an increase in efficiency of the entire system.

III. RELATED WORK

Wijeyesundera [3] developed a 2-point lumped model, in which the solar collector is modeled as two region: (i) the absorber plate and the heat removing fluid, and (ii) the cover plates lumped together in a single equivalent cover. The comparison of this approach with the 1-point lumped model showed that the outlet fluid temperature variation is overestimated by the 1-point model and it is underestimated by the 2-point model. Moreover, analyzing the influence of the thermal capacitance on the long term behavior of the solar collector, the author showed that the steady state approach gives good results in predicting the daily energy collection only when hourly averaged meteorological data is used. If the radiation intensity changes quickly, the dynamic effects become most pronounced and the steady state model overestimates the useful energy collection. In these conditions transient approaches provide better results. The author concluded that the main usefulness of the dynamic approach in modeling the solar collector is detected in the short term study and in predicting the outlet temperature behavior as a consequence of the fluctuations of the climatic data. Morrison and Ranatunga [4] developed a 3-point lumped model separating the thermal capacitance of the fluid and the absorber, realizing a set of three equations:

cover, collector plate and fluid. Moreover, the authors take into account the thermal capacitance of each section of the water loop tubes between the solar collector and the tank, considering the fluid acceleration during the transient heating. The authors used this approach in order to analyze the response of a thermosyphon solar water heater to step changes of insolation. A recent application of this model can be found in [5], who developed a single-capacitance lumped model with the aim of optimizing a solar thermal flat-plate collector. The model showed a good agreement with experimental data. On the same bases, Fraisse et al. [6] proposed a model based on a simplified electrical analogy, taking into account the temperature-dependency of thermo-physical characteristics of the collector. Authors introduced the lumped thermal capacitances for glass cover, absorber and fluid (developing a 3-point lumped model). Three different energy balance equations have been written and solved in transient state. The model was compared to outdoor experimental data set and the results obtained by the well-known software TRNSYSs. Such comparison showed a good agreement between numerical and experimental results, except for the stagnation period. Authors highlighted the importance of the transient approach when the time step is small and the water loop working is intermittent. Taherian et al. [7] adopted a 2-point lumped model taking into account the thermal capacitance of cover and absorber plate for closed thermosyphon water heater. The comparison between simulation results and experimental data confirms that the lumped capacitance approach is capable of predicting the system efficiency accurately only with sunny conditions, while in cloudy days it does not provide accurate results. M. Yahya[8] investigated on the CFD analysis of solar hot water heater with integrated storage system. The performance of flat plate collector with different types insertion in riser tube is analyzed by CFD i.e. $\theta = 5^\circ, 10^\circ$ & 15° . S. Vijayakumar [9] has investigated the results of the heat transfer and has compared it with the available results. The heat transfer rate in the collector has been found to be increased by 18% to 70%. It has been observed that heat losses are reduced consequently increasing the thermal performance about 30% over the plain water. Ravishankar Sathyamurthy et al. [10] designed and evaluated the performance of a novel solar still using a semicircular absorber with baffles under the climatic conditions of Chennai, India is presented. The effect of number baffles and water flow rate on the performance of a solar still is presented. Omara et al. [11] coupled a stepped solar still with internal and external reflectors to enhance energy input and productivity. The result showed that the output of the modified stepped solar still was significantly increased if it was coupled with internal and external (top and bottom)

reflectors. Xiong et al. [12] designed a novel multi-effect solar desalination system with enhanced condensation surface. Experimental and numerical model characterizing of the heat and mass transfer process in the solar still was developed. It was observed that the solar still could generate freshwater about 40% of the total freshwater yield in the night. The overall desalination efficiency and performance ratio of the equipment can reach 0.91 and 1.86, respectively at temperature was relatively high. The effect of the tilt angle of glass cover on productivity was studied by Khalifa [13]. In addition, the value of the optimum tilt angle in different seasons and latitude angles was presented.

IV. AUGMENTATION TECHNIQUES

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers [1]. Existing enhancement techniques can be broadly classified into three different categories i.e. Passive Technique, Active Technique, Compound Technique.

Passive Techniques generally uses surface or geometrical modification to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficient by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop [2].

Following methods are generally used:

- a. Inserts
- b. Extended surface
- c. Surface modification
- d. Use of Additives

Active heat transfer techniques involves some external power input for the enhancement of heat transfer, Some examples of Active heat transfer techniques include pulsation by cams and reciprocating plunger, the use of magnetic field to disturb the seeded light particles in a flowing stream etc.

V. INSERTS

Inserts refers to an additional arrangement made as an obstacle in order to alter the flow pattern in a tube so as to achieve augmented heat transfer. Different types of inserts include:

A. *Twisted Tapes*

Twisted tape increase the heat transfer Coefficient at a cost of rise in pressure drop. The Swirl inserts and tape twister technique are used to create a flow disturbance and the pressure drop losses are much higher as compared to the gain in the heat transfer coefficient [3].



Figure 3: Twisted Tapes

B. Ribs and Baffles

Baffles are used in the riser to direct the fluid stream across the tubes and to increase the fluid velocity and finally improve the rate of transfer. Differently shaped ribs and baffles also create bulk flow disturbance, but unlike tapes or swirls, ribs and baffles are discrete objects.

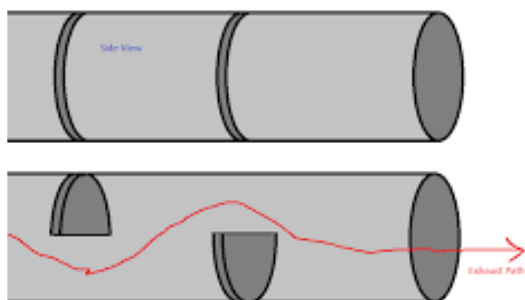


Figure 4: Semi Circular Baffles

VI. CONCLUSION

This paper has comprehensively reviewed the advancements in solar thermal technology with a special focus on performance enhancement methodologies. Flat plate solar collectors have been discussed in a simplistic manner to attract beginners in the sphere of solar thermal conversion technology. Novel approaches have been highlighted in each category to emphasize the use of solar energy for routine activities. It is analyzed that heat transfer for riser tube with baffles is more when compared to riser tube without baffles.

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