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A review on analysis and development of solar flat plate collector

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ABSTRACT

Solar flat plate collectors are devices used to trap solar thermal energy and use it for heating applications like water heating, room heating and other industrial applications. Flat plate collectors are popular for low and medium heating applications and there are undergoing constant development in terms of size reduction and enhanced efficiency. This paper presents an overview on the different techniques that are employed to enhance the efficiency of flat late collectors. Effect of using nanofluids as heat transfer fluid, effect of altering absorber plate design for better capture of radiation, methods of heat loss reduction, use of polymer, employing mini channels for fluid flow, using PCM (phase changing materials) to provide heat during night without tank and effect of use of enhancement devices like inserts and reflector have been discussed in this paper. A brief insight on various techniques used to analyse the effects and various designs has also been presented with the development methodology. Some analytical studies and CFD models have also been mentioned. This review paper also deals with the suggestions for the research work which can be carried out in the direction of heat transfer from solar flat plate collectors.

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1. Introduction

Solar collector is a kind of heat exchanger wherein heat exchange takes between a distance source and a heat transfer fluid flowing in the collector [35]. Solar radiation from sun hits the absorber plate of the collector and the thermal energy is then transferred to the fluid. Based on their design, solar collectors can be classified as concentrating and non-concentrating type. Non-concentrating type can be further divided in flat plate collector and evacuated tube collectors. Flat plate collectors are the most common type of collectors and the most primitive too. Work of Hottel and Woertz [36] in 1942 and by Hottel and Whiller [37] in 1958 can be looked as a first work on solar flat plate collector. They had developed the collectors consisting of a black flat plate absorber, a transparent cover, heat transfer fluid and an insulating case. Tabor [38] in 1955, employed selective black surfaces to increase collector efficiency. His experiments on optical concentration revealed the ability of optical concentration to produce high pressure steam. Many studies have been done after that to analyse

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and improve the thermal efficiency of the collector.

Due to growing energy problems, solar energy is been looked at as source of infinite energy. Solar collector have been greatly studied in this matter. Many of the new designs have been developed after 1990. Various research works are being carried out over the world to improve the thermal performance of flat plate collectors. Polymers are used to build novel collectors so as to reduce the weight. Use of nanofluids make the collectors compact by giving the same output as that of big collectors but in a comparatively smaller sizes [33]. Absorber plates have undergone many modifications with the help of new and better techniques in manufacturing and material science [9,25]. Studies are also focused to find the optimum spacing between the glass covers in multi-glazed collector. Indoor and outdoor tests are carried out based on the operating and design parameters to obtain the best possible design for desired working conditions. To increase the efficiency, it is very much important to decrease the heat loss from the collector. Many studies are oriented in this direction to study and reduce heat loss, with increased glazing, honey comb maze based absorber plate, considering wind velocity in analysis of collector etc.

Analysing the performance of collector is equally important as it helps to further develop and improve the design. In fact, development and analysis always go hand in hand. Experimental analysis of all the different collectors developed is not feasible. Hence analytical and numerical methods have been employed, to approximately analyse the behaviour of collector in different conditions. CFD codes have helped researchers to a great extent. Ability to reduce lead time, to study system under hazardous condition and study of controlled experiments of systems which are difficult or impossible to perform practically are some of the unique advantages of CFD [39].

In the present study, authors have made an overview of different development and analysis techniques that have been employed by the researchers to increase the overall performance of collector. Studies include designing and analysis of novel absorber plate designs, analysing the effect of nanofluids (as heat transfer fluid) on the efficiency of collector, ways to reduce heat loss to surrounding, analysis of collectors made up of polymers and effect of add-ons like reflectors and inserts have been discussed here.

2. Analysis methods and techniques

Yasin and Hakan [1] did a comparative analysis of natural convection in flat plate and wavy solar collectors. Analysis was based on Rayleigh number, inclination angle, aspect ratio and wavelength. Laminar flow and thermal field simulation was done with the help of CFDRC commercial software. Mathematical model was developed neglecting the viscous dissipation and assuming constant fluid properties. Vertical walls were considered as adiabatic. Results showed that shape and inclination angle of the collector greatly affected natural convection and heat transfer. Heat transfer in case of wavy collector was more than that of flat plate collector in all the cases. Variation of Nusselt number was found to be linear in case of flat plate collector while wavy in case of wavy collector. With the decrease in wavelength, the mean Nusselt number increased for same aspect ratio. Contrary to flat plate collector, Rayleigh number was found to be highest at the highest inclination angle. Selmi et al. [29] worked to find the usability and validity of CFD models for evaluating solar collector on the basis of their thermal performance. Authors obtained a 3-D temperature distribution over the whole volume of collector and used it to validate the CFD model. An experimental setup was built in order to experimentally calculate the outlet temperature of the fluid which may be used to compare it with CFD model's result. The analysis was done with cover plate and without cover plate, with water flow and without water flow. Solar radiation flux was varied in the CFD model analysis, keeping other parameters constant, so as to make it more realistic as the experiment. Findings of this comparative study showed a good agreement in results from experiments and CFD despite the experimental imperfections. The results showed that CFD can be confidently used to evaluate thermal performance of flat plate collectors. Grine et al. [26] worked with an air solar collector with a view to estimate the local and mean temperature field in the fluid, outlet fluid temperature, wall temperatures, heat flow from air to wall and coefficient of this convective heat transfer. Due to complications in numerical methods, authors developed an analytical model to simulate the thermal behaviour of flat plate solar collector operating in forced convection. A solution for energy equation was developed for a fluid flow inside the collector, based on the Green's function method. With the help of this model, it is possible to estimate the two dimensional air temperature profiles inside and outside the collector and also, we may calculate the local coefficient of heat transfer. Design parameters such as solar collector wall temperature, the flow temperature and the local Nusselt number can also be calculated by this model. According to the results obtained, Nusselt number showed a decreasing trend after 1.2 m from leading edge and hence authors decide to add fins to their model after 1.2 m from the leading edge of the collector in order to increase the performance. The analytical model was confirmed by experimental results.

Flat plate solar collectors are normally used for applications such as water heating, space heating, for providing process heat in industries, etc. In these practical applications, collectors are bound to work under dynamic conditions. For proper analysis of thermal performance of such system, dynamic analysis is thus important. Steady state model derived from steady state test (SST) do not consider dynamic conditions, hence it's necessary to build a dynamic model. Many researchers have worked on this topic to build various models. One such model was built by Deng et al. [13]. Many of the models built earlier, were not so accurate in determining the momentary thermal characteristics of outlet temperature and useful heat gain when the instantaneous solar radiation changed sharply. Authors worked on the issue and built an analytical model in the form of series expansion based on the consideration of effective thermal capacitance, to determine momentary thermal characteristics of the collector. Model introduced a thermal inertia correction along with steady state useful gain to accurately predict the instantaneous useful heat gain. Experiment was performed on air solar collector and the data obtained was used to validate the model. Model was fund to accurately predict the momentary thermal characterises of air solar collector. Also, it could also be used for other collectors provided, they are eligible for SST. Cerón et al. [2] developed a 3-D numerical model for flat plate collector for calculating the efficiency of collector. Different heat interactions like solar radiation absorption, transmission and reflection;natural convection in the air cavity; heat conduction across the tube-absorber welded junction; mixed convection flow in the risers; and heat losses by convection and radiation to the ambient were taken into account and to check model reliability, the heat transfer results inside the risers and in the air cavity were contrasted with well-known experimental correlations. The results obtained from the numerical model was validated from the experimental data. Geometric model was based on the standard flat-plate solar thermal collector and was a reduced to 3 pipe for numerical analysis, maintaining the aspect ratio. A steady-state uniform flow distribution at tube inlet was considered for numerical modelling with three dimensional governing system of equations based on RANS turbulence model. To account for buoyancy effects, Boussinesq approximation had been employed.