iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** I **Month of publication:** January 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Experimental Investigation And Cfd Analysis Of Flat Plate Collector Of Solar Water Heating System – A Review

Mr. Vishal R. Bhadane[1], Prof. Prasad P. Patil[2], Prof.R. Y. Patil[3]
[1]Mechanical Engineering Department, [3]Head of Mechanical Engineering Department
[1,3]North Maharashtra University, Jalgaon.

Abstract :Solar flat collectors are devices used to trap solar thermal energy and use it for heating applications like water heating, room heating and other industrial applications. Analysis of solar collector is complex task, due to high number of parameter affecting its performance .This paper presents the study on different techniques that are employed to enhance the efficiency of flat plate collector .Effect of using enhancement device ,use of propylene glycol, nanofluid, change water flow rate for better capture of radiation and method of heat loss reduction .The problem of flat plate solar energy collector with water flow is simulated and analysed using computational Fluid-Dynamics. Computational Fluid-Dynamics (CFD) approach has become powerful tool o investigate the heat transfer phenomenon. A lot of work have been made to develop the heat transfer mechanism in a solar collector.
keywords: Solar Flat plate collector, propylene glycol , efficiency of solar collector , CFD simulation

I. INTRODUCTION

Energy production, efficiency and saving are key factor for social and economic development of country. Due to wide application of solar energy many engineers and researchers study from last two centuries. Solar thermal energy system, converts the energy of the sun directly into heat, which is stored using water, air as a working fluid. The typical solar heating system consist of a collector, a heat transfer circuit that includes the fluid and the means to circulate it, and a storage system including heat exchanger. Work of Hottel and Woertz [1] in 1942 and by Hottel and Whiller [2] in 1958 can be looked as a first work on solar flat collector. They had developed the collectors consisting of a black flat plate absorber, a transparent cover, heat transfer fluid and an insulating case.
Nan Wang, Shequan Zeng ,Mi Zhou , Shuanfeng Wang [3] numerical study of flat plate solar collector with novel heat collecting components best inlet water mass flow rate for flat plate collector is 0.15 kg/s. Luca A Tagliafico, Federico Scrapa . Mattia De Rosa dynamic thermal models and CFD analysis for flat-plate thermal solar collectors the CFD analysis has demonstrated can be used productively to enhance the solar collector efficiency e.g. searching optimized tube configuration, especially for particular equipment. Computational Fluid-Dynamics has been powerful tool to investigate the heat transfer phenomena. The CFD package is from Computational fluid Dynamics Research Corporation (CFDRC) and has been successfully used to simulate water currents and heat transfer inside a water-intake. software proved to be powerful and flexible in modelling a wide range of practical problem.

II. DEVELOPMENT OF COLLECTOR

As discussed earlier, to effectively trap the heat from sun, new techniques and methodology has to be applied. These technique aims at increasing the thermal efficiency and overall performance of flat plate collector. The technique includes, use of various different material for the construction of collector, changes in absorber plate design employing different heat transfer fluids to absorb heat etc.

A. Innovative heat transfer fluids in solar thermal collectors: Nano fluids

Water or mixture of water and ethylene glycol are heat transfer fluid generally used in flat solar thermal collectors. Their thermal conductivity is a limiting factor, because it is lower than thermal conductivity of heat exchange solid surface. Innovative heat transfer fluids have been proposed to enhance efficiency of energy systems,based on mixing of solid nanoparticles (<100 nm) of metal or metal oxide with traditional heat transfer fluids as water , ethylene glycol, oil. These suspensions are called -nanofluids, word used by Choi[6] for the first time . Thermal conductivity enhancements have been obtained by several authors. Minsta et al.[7]

measured thermal conductivity of water based nanofluids with CuO nanoparticles with anaverage dimension of 29 nm and Al_2O_3 nanoparticles, with anaverage dimension of 47 nm and 37 nm respectively. An enhancement between 2.0% and 24.0% was observed using CuO nanoparticles at a volume fraction between 1.0% and 14.0%. With Al_2O_3 nanoparticles they obtained an increase of thethermal conductivity upto 30.0%, in a range of volume fraction from 1.0% to 18.0%. Yu et al. [8] obtained an increase of thermal conductivity of 26.5% for 5.0 vol% of ZnO dis- persed in ethylene glycol. Murshed et al .[9] measured ethylene glycol–TiO_2 nanofluids and ethylene glycol–Al nanofluids thermal conductivity. They obtained enhancements of 18% with 5.0 vol% of TiO_2 and 45% with 5.0 vol% of Al, respectively . Colangelo et al.[10] measured thermal conductivity of diathermicoil-based nano- fluids, with Al_2O_3, CuO, ZnO and Cu nanoparticles respectively, in a temperature range between 20°C and 60°C and a volume fraction between 0.1% and 2.0%. They used CuO and Al_2O_3 nanoparticles with a spherical shape and particle size with average diameters of 30 nm and 45 nm, ZnO, with an elongated shape and anaverage dimension of 60 nm, and three types of Cu nanoparticles,with spherical shape and average diameters of 100 nm, 50 nm and 25 nm.They obtained a thermal conductivity enhancement upto 12.9%, 10.7% and 8.29% with ZnO, CuO and Al_2O_3 nanoparticles, respectively .An increase in thermal conductivity up to 21.76 % was obtained with Cu nanoparticles.

B. Use of enhancement device

Inserting a heat enhancement device inside a solar collector pipe is one of the method to improve ther mal performance of the collector without much modification and keeping size compact. These devices increase the turbulence in the flow thus increasing the heat transfer. A comparative study of few of insert devices with a combined effect of inclinationon the efficiency of the collector was carried out by Sandhu et al. [4]. Authors selected different insert devices with varied configuration: 3 types of twisted-tape inserts, 1. twisted tape with shortest pitch, 2. twisted tape with medium pitch 3. Twisted tape with largest pitch 4. Types of wire coils inserts, 1. Simple coil 2. Coil away from the tube wall 3. Concentric coils 4. Conical coil and Mesh insert. The collector was tested over a wide range of Reynold's no. 200–8000 and Prandtl no. Range 5–8, using water as a working fluid. Experiments showed that all the used devices led to an increase in Nusselt no .of the flow. Nusselt no. Showed a heavy increase for transition and tur- bulent region while a little less in the laminar region.Considering the wire family, concentric wire insert showed the best performance and from twisted tapes, one with the smallest pitch ratio was more promising than the other two. Mesh inserts performed best in laminar region, increasing the Nusselt no. By 270%, whereas concentric coils showed best results in turbulent region with a 460% increase in Nusselt no. Mesh inserts showed a better per- formance at laminar level, but it did increase the pumping power requirement of the system due to increased friction. The authors thus recommended concentric coils as a better option with 110% enhancement in laminar region and 460% in turbulent.Test for the inclination showed that there is no significant enhancement of Nusselt no .due to the channel inclination. On the similar grounds, Hobbi and Siddiqui [12] studied the effect of passive heat enhancement devices like twisted strip, coil-spring wire and conical ridges. No significant difference in heat flux was observed to the collector fluid. But a significant increase in Grash of, Richardson and Rayleigh numbers was observed indicating that the heat transfer mode in the collector is of mixed convection type, free convection being predominant. Authors concluded that due to the high damping effect of shear produced turbulence by buoyancy forces, the applied insert were ineffective in enhancing the heat transfer to the collector. To see the effects of wire inserts in a liquid solar collector, Martı´n et al.[13] carried out a TRNSYS based numerical simulations of the collector. Operating parameters such as local losses, friction coefficients, Nusselt number were studied as a function of Reynolds number to observe their effects on thermo hydraulic performance of collector. To take into account, internal heat transfer coefficient and friction factor, a new collector model was developed by authors. All the simulations performed was based on UNE-EN12975-2 standards. To evaluate pressure drop and heat transfer in the tube, authors used their own cor-relations and experimental data. Analysis was done on 2 working fluids : water and propylene glycol/water mixture, with varied mass flow rates. Results showed an increase of 4.5% in efficiency of enhanced collector as compared to the standard collector. Pumping power for water increased for all the flow rates, butforpro- pylene glycol 44%, there was no increase below 80 kg/h. The increase in pumping power is surely due to an increased friction because of the inserts. Overall, wire inserts are better option to enhance the termal performance and make the collector compacts in warm climatic regions or for warm water, or for small applications like house hold water heating where the pump is slight oversized and hence, there is no change in pumping power. Wire-coil insert was experimentally studied by Garcíaetal, to observe its heat transfer enhancementabilities. Experiments were carried out on two collectors with 5 different mass flow rates. Authors found that with the help of wire-coil insert, there was an average increase of efficiency from 14–31% and an increase in useful power collected of upto 8–12%, with no additional pressure losses. The degree of enhancement due to inserts gets deteriorated with the increasing mass flow rates. Metal heat pipes by many researchers was reported as an effective solution to increase the thermal performance of the collectors. However, many of the collectors are heavy, non-versatile, have complex asembly and installation, possess high hydraulic resistance and low thermal efficiency and lack scalability and adaptability for design. To overcome these short comings, Rassamakin et al.[14] applied extruded aluminium alloy heat pipe with wide fins and longitudinal grooves to the solar collector. Number of fins on absorber plate were taken as arbitrary. Opposite sides of the heat pipes had fins serving as a heat sink surface. Several tests were conducted on the new design. Results showed that with the help of this insert, it is possible to reduce the thermal and hydraulic resistance. Thermal efficiency was also found to be high. The new light weight and inexpensive heat pipe showed high thermal performance. Tanaka et al.[15] theoretically analysed the effect to fusing a bottom reflector on the performance of absorber. A gap between a collector and reflector was maintained and were kept front facing to each other at an angle such that the collector receives the reflected radiations from the reflector along with direct and diffused radiation. By a graphical method, the amount of radiation reflected and then absorbed was calculated. It was absorbed that by placing the bottom reflector at some distance, it is possible to increase the amount of solar radiation absorbed. The distance between the two must be maintained such that the gap length is less than the lengths of collector and reflector. With the change in gap in various seasons, optimum inclination of collector remains same while there is slight change in the inclination of reflector. There was a decrease in absorbed radiation with the increasing gap length for optimum inclination, while the decrease was drastic for other inclination.

C. Effect of inlet water mass flow rate: Nan wang et al

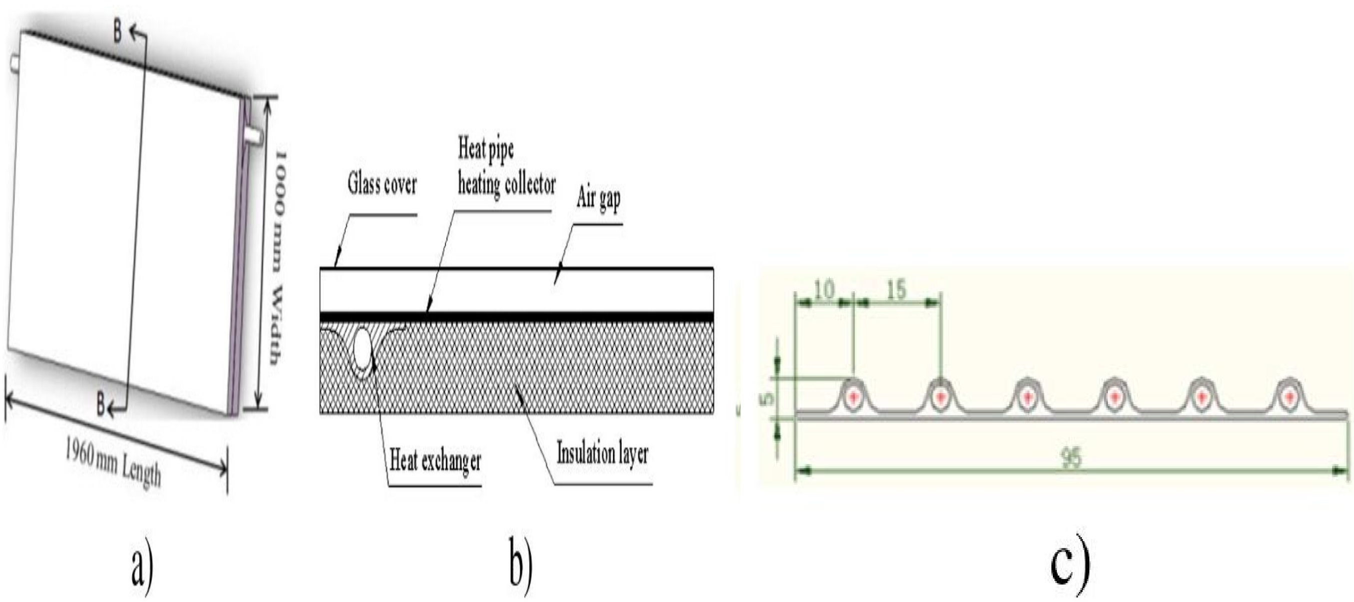


Fig. 1.

Fig. 2 shows the curves of the influence of inlet water mass flow rate on collection efficiency under the condition of different inlet water temperatures, collector tilt 30° and air gap distance 20 mm. As can be seen in the diagram, when the inlet water temperature is given, the collection efficiency increases with the increase of inlet water mass flow rate, and then tends to stay invariant. This phenomenon can be explained by the fact that the increase of the inlet water mass flow rate enhances the convective heat transfer in the heat exchanger with decreasing the thermal resistance on water side and thus improves the collection efficiency. However, when further increasing the inlet water mass flow rate, convective heat transfers increases non-obviously, due to a negligible variation of the thermal resistance on water side. Besides, the collection efficiency tends to be smaller with the increase of inlet water temperature while the inlet water mass flow rate remains constant, which can be illustrated by the fact that the higher inlet water temperature results in an improving average temperature of the flat plate solar collector, leading to more thermal energy losses to ambient by convection. At the same time, Fig. 2 also presents an obvious collection efficiency improvement when the inlet water mass flow rate increases from 0.025 kg/s to 0.15 kg/s. Continuing to increase the inlet water mass flow rate to 0.25 kg/s, the collection efficiency almost remains the same. Therefore, the optimum inlet water mass flow rate of the flat plate solar collector is

0.15 kg

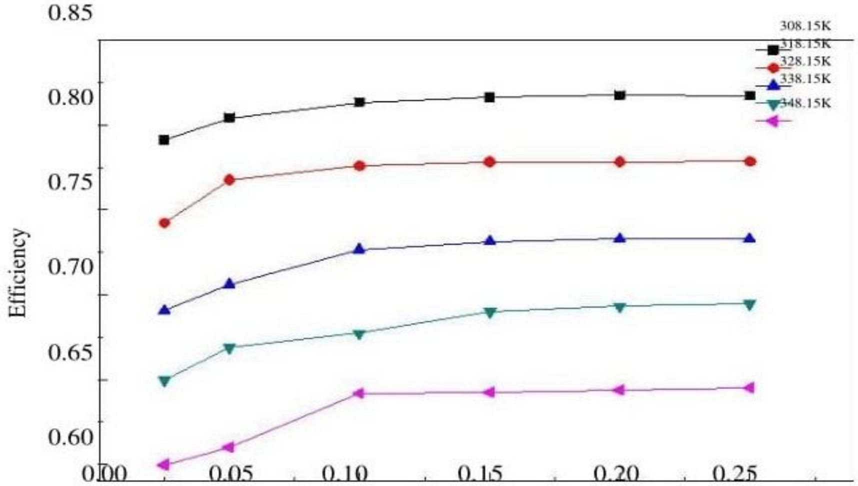
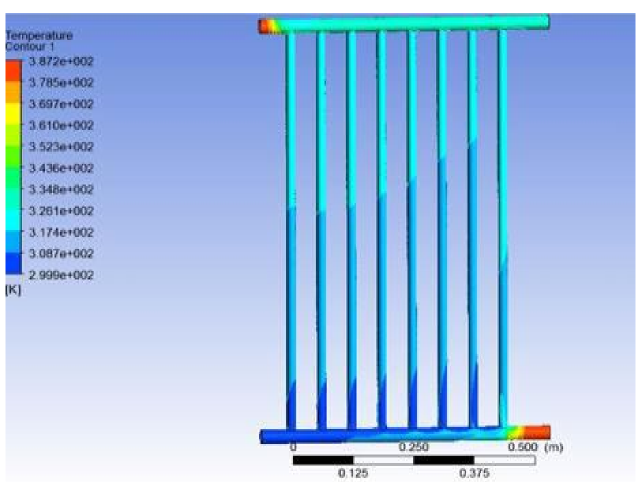


Fig.2. Water Mass Flow Rate (Kg/s)

D. Use of propylene glycol

LBS College of Engineering, Kasaragod. [16] using a flat-plate solar collector. The solar collector has one (0.6m×0.9m) single glass cover and flat plate of same dimension. The plate consists of 8 tubes and 2 headers made of Copper with tube spacing of 5 inches and a diameter of 0.75 inches. While the absorber made of Red Copper with a black chrome selective surface, the flat-plate has 2 inches Thermocole insulation, and cased by a frame of Aluminum. The flat-plate solar collector was mounted on an iron frame inclined at 26°S. Reagent grade propylene glycol ($C_3H_8O_2$) was used in the experiments without further purification. Propylene glycol–water mixtures were prepared gravimetrically. Various properties of the mixture are obtained from standard which is given below. Thermometers were used to measure the fluid temperature in the inlet and outlet of solar collector. The flow rate is controlled with two metering valves, one at the main flow loop. The flow rates are measured by collecting the fluid for a period of time, 60s, helping a precise measuring container and a stop-watch.

The experimental results include the performance of the Flat plate solar collector using propylene glycol/water as base fluid at various glycol volume concentrations (0%, 25%, 50%, and 75%,) as well as various mass flow rates (0.0167, 0.024, and 0.008 kg/s). The tests of the solar collector are administered for many days with clear sky and moderate wind speed (average wind speed was 2.6 m/s). These tests have performed around solar noon at time 12 pm –2 pm. Figure shown below gives temperature difference between inlet and outlet of the solar collector with various PG concentrations for different testing conductions, in which the inlet temperature is not controlled. According to the graphs shown below with increasing PG concentration, the temperature difference is in increasing manner.



Volume 5 Issue I, January 2017
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

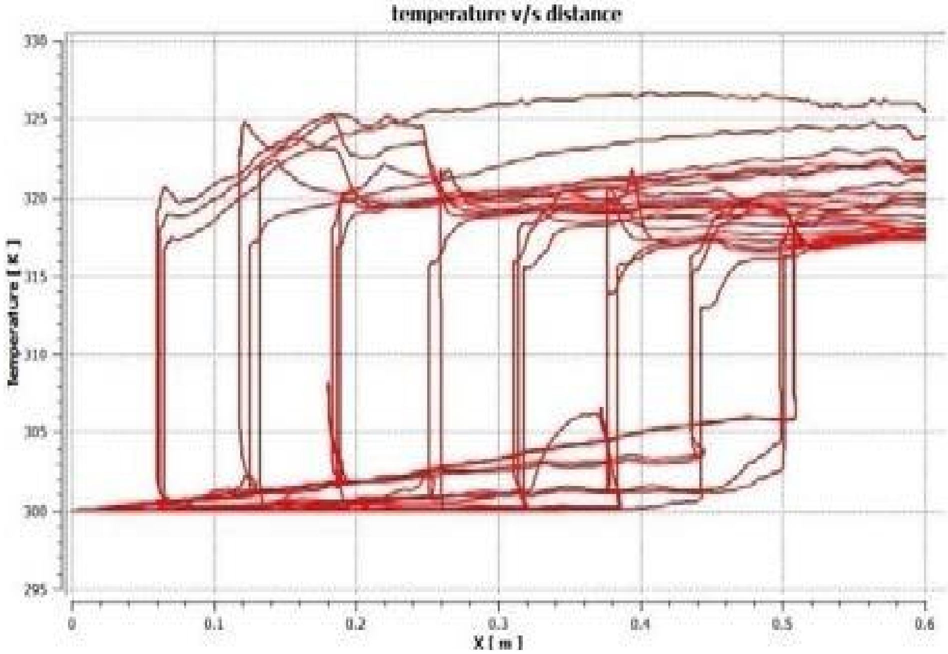


Fig .3. For 0.008 m^3/s and 0% PG concentration: (a) Temperature contour (b) Temperature v/s X axis graph

III. CFD ANALYSIS

A lot of authors have performed several numerical CFD simulations using commercial simulation tools, devoting a great effort to the description of the behavior of solar collectors. In order to analyze the flow distribution inside a solar collector with horizontal inner tubes, Integrated Collector Storage Solar Water Heater system, ICSSWH [17,18]. This system integrates the flat-plate thermal solar collector and the hot storage water tank in a unique component. This embodiment can be classified into two basic categories : (i) a direct configuration (Fig 4), in which the service water flows directly in the storage inside of the solar collector, and (ii) an indirect configuration (Fig.4b) in which several tubes are immersed inside the energy storage in the solar collector, with the service water flowing inside them. Both configurations reduce the cost of the entire system (no connection pipes between the collector and the water storage) and require a smaller area for installation . In this context, Gertzos and coworkers [19,20] performed many experimental setups and CFD simulations in order to analyze the thermal behavior and the optimal design for both direct and indirect ICSSWH.The numerical analyses were conducted in 3D complex geometry adopting different CFD model simplemented in the commercial CFD software Fluent 6.3®. Several configurations were analyzed, including the possibility to use water mixing in the storage by means of recirculation pumps. Thecomparison between the temperature profiles of two transient simulations and the relative experimental data showed a good agreement.

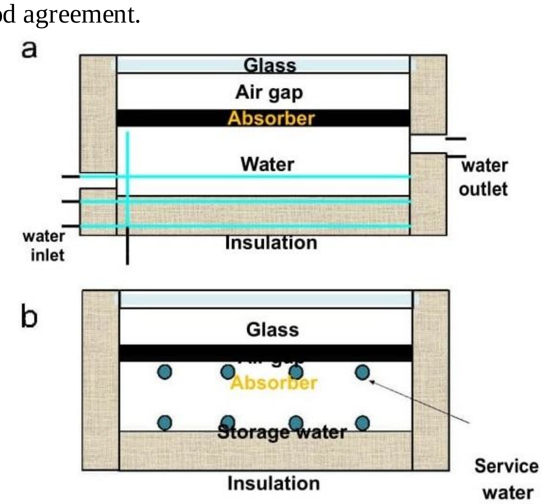


Fig. 4. Direct (a) and indirect (b) ICSSHW systems (adapted from [21]).

Finally, with the aim of increasing the thermal performance of ICSSWHS systems, Mossad and Al-Khaffajy [21] investigated two different configurations (single and double row inside the collector with two different diameters for the configuration b) adopting a steady 3D CFD approach. The results showed that the double row configuration, as shown in Fig.4b, is not a good design because of the high cost and high pumping power required, with no additional benefits if compared to the single row configuration

Table 1: Brief discussion on solar collector development.

Sr. No.	Area of research	Enhancement and Discussion
2.1	Innovative heat transfers fluids in solar thermal collectors: Nano fluids.	Advantages: Improving stability of nanofluids; Improving heat transfer coefficient of nano fluids; Solar thermal systems must be suitable to avoid sedimentation of solid phase inside piping.
2.2	Use of Enhancement Device	Advantages: Improvement in thermal performance without any modification and keeping size compact. Increased turbulence in flow increasing heat transfer in fluid. Desired properties: should be able to increase the turbulence in flow without much increase in pumping power. Output of studies: Insert devices leads to increase in Nu.no. in flow. Twisted tape inserts with small pitch were promising. Mesh inserts are better for laminar flow but increases pumping power. Concentric coils showed enhanced performance in laminar and turbulence flow without any significant improvementin pumping power.
2.3	Effect of inlet water mass flow rate	The collection efficiency increases with the increase of inlet water mass flow rate, and then tends to stay invariant with other variables keeping constant. In this paper, the best inlet water mass flow rate for this flat plate solar collector is 0.15 kg/s.
2.4	Use of Propylene glycol	Propylene glycol–water at 25% PG concentration reduces the maximum efficiency compared to that for 0% PG (pure water) by 5% and 15% experimentally and computationally respectively in mass flow rate of 0.0167 kg/s. By increasing PG volume concentration from 25% to 50%, the efficiency of the Flat-plate solar collector is increased and by increasing volume concentration from 50% to 100% the maximum efficiency of the Flat-plate solar collector decreased by 5% and 14% respectively in mass flow rate of 0.024kg/s.
3	CFD Analysis	CFD analysis has demonstrated can be used productively to enhance the solar collector efficiency, e.g. searching optimized tube config-urations, especially for particular equipment (i.e.,ICCSWHS,PVT, nanofluids, etc.). Despitethat, the main limitations of CFD are due to the slow computational speed and to the complexity of implementation, which also of ten requires commercial software .

REFERENCES

[1] Hottel H, WoertzB.The performance of flate plate solar heat collector. Trans ASME 1942;64:91–104.
[2] Hottel H, Whillier A. Evaluationof flat-plate solar collector performance. In:Transactions of the conference on the use of solar energy thermal processes. Tucson, AZ(USA);1955.p.74–104.
[3] Nan Wang, Shequan Zeng, Mi Zhou, Numerical study of flat collector with novel heat collecting components. Industrial energy conservation center of Shandong academy science, Jinan 250103.china
[4] Huang MJ, Eames PC, Norton B, Hewitt N. Natural convection in an internally finned phase change material heat sink for the thermal management of photovoltaics. SolEnergy Mater Sol Cells 2011; 95(7): 1598–603.
[5] Luca A. Tagliafico, Federico Scarpa, Mattia De Rosa. Dynamic thermalmodelsandCFDanalysisfor flat-platethermalsolar collectors – A review. University of

Genoa, DIME/TEC, Division of Thermal Energy and Environmental Conditioning, Via All' Opera Pia 15A ,16145 Genoa, Italy.

[6] Xuan Y, Li Q. Heat transfer enhancement of nano fluid. Int J Heat Fluid Flow 2000;21:58–64.

[7] Mintsa H-A, Roy G, Nguyen C-T, Doucet D. New temperature dependent thermal conductivity data for water-based nanofluids. Int J Therm Sci 2009;48:363–71.

[8] Yu W, Xie H, Chen L,Li Y. Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid. Thermochim Acta 2009; 544:92–106.

[9] Murshed S-M-S, Leong K-C, Yang C. Investigation of thermal conductivity and viscosity of nanofluids. Int J ThermSci 2008; 47:560–8.

[10] Colangelo G, Favale E, de Risi A, Laforgia D. Results of experimental investi- gations on the heat conductivity of nanofluids based on diathermicoil for high temperature applications. Appl Energy 2012; 97:828–33.

[11] Sandhu G, Siddiqui K, Garcia A. Experimental study on the combined effects of inclination angle and insert devices on the performance of a flat-plate solar collector. Int J Heat Mass Transf 2014; 71:251–63.

[12] Hobbi A, Siddiqui K. Experimental study on the effect of heat transfer en- hancement devicesin flat-plate solar collectors. Int J Heat Mass Transf 2009;52:4650–8

[13] Herrero Martı´n R, Pe´rez-Garcı´a J, Garcı´a A, Garcı´a-Soto FJ, Lo´pez- Galiana E. Simulation of an enhanced flat-plate solar liquid collector with wire-coil insert devices. Sol Energy 2011; 85:455–69.

[14] Rassamakin B, Khairnasov S, Zaripov V, Rassamakin A, Alforova O. Aluminium heat pipes applied in solar collectors. Sol Energy 2013;94: 145–54.

[15] Tanaka H. Theoretical analysis of solar thermal collector and flat plate bot- tomreflector with a gap between them. Energy Rep2015;1:80–8.

[16] Ranjith P. V, Aftab A. Karim. A Comparative Study on the Experimental and Computational Analysis of Solar Flat Plate Collector using an Alternate Working Fluid. Procedia Technology 24 (2016) 546 – 553

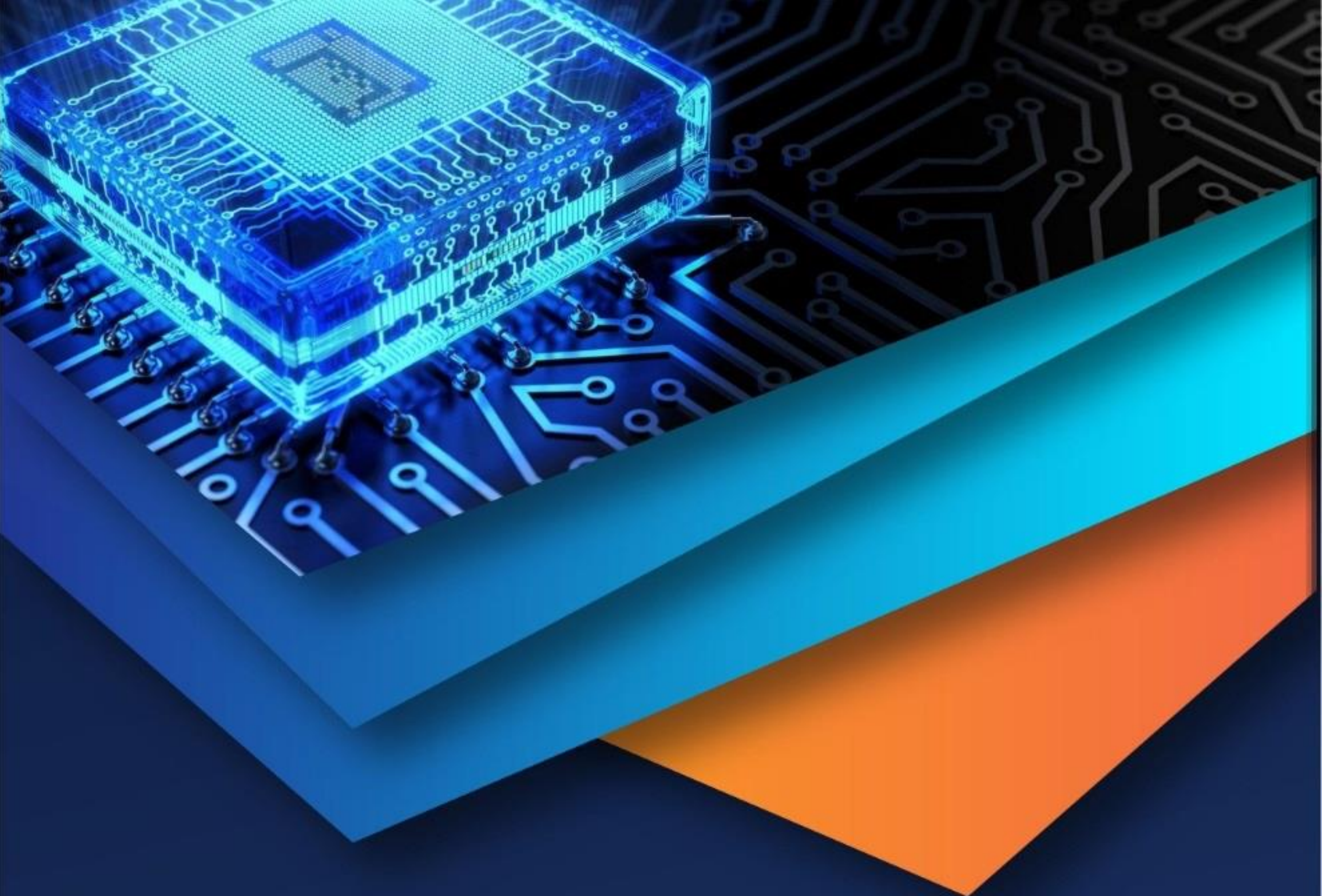
[17] Henderson D, Junaidi H, Muneer T, Grassie T, Currie J. Experimental and CFD investigation of an ICSSWH at various inclinations. Renew Sustain Energ Rev 2007;11:1087–116.

[18] Garnier C, Currie J, Muneer T. Integrated collector storage solar water heater: temperature stratification. ApplEnergy2008;86:1465–9.

[19] Gertzos K, Pnevmatikakis S, Caouris Y. Experimental and numerical study of heat transfer phenomena, inside a flat-plate integrated collector storage solar water heater (ICSSWH), with indirec the at withdrawal. Energy Convers Manage 2008; 49:3104 –15.

[20] Gertzo s K, Caouris Y. Optimal arrangement of structural and functional parts in a flat plate integrated collector storage solar water heater (ICSSWH). Exp Therm Fluid Sci 2008; 32:1105 –17.

[21] Mossad R,Al-Khaffajy M Investigating two configurations of a heat exchan- ger in an indirect heating integrated collector storage solar water heating system (IHICSSWHS). In:Proceedings of the ICREPQ'12. Santiago de Compostela (Spain) ; 2012 .p .1 –6.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY