A study on Performance of Flat Plate Solar Collector with Different Absorber

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Abstract— An evacuated flat plate solar thermal collector contains a flat absorber plate containing an evacuated enclosure with a top glass cover. An array of pins supports the glass cover against atmospheric pressure loading. Such collectors can achieve high operational temperatures suitable for many industrial applications and also operate efficiently in low irradiance conditions. Flat thermal solar collectors traditionally use a serpentine tube glued or fixed to a conductive absorption plate with an electrically spectral black coating. Efficiency losses due to temperature changes in the plate can be minimized by using a high conductivity material, such as copper, and making it thick enough to achieve high fin efficiency. The main objective of the present work to enhance heat transfer rate by changing the design of the absorber flat plate and compare the various results obtained from computational fluid dynamics analysis on all designs. In the present work, computational fluid dynamics analysis has been performed for six designs of absorber plate of evacuated flat plate collector to check the temperature distribution and heat generation for better thermal performance, flow variables such as velocity, enthalpy, entropy, etc.

Keywords: enthalpy, entropy, flat plate solar thermal collector, solar collector.

I. INTRODUCTION

Flat-plate collectors are probably the most basic and best-studied technology for solar-powered hot water systems. The general idea behind this technology is quite simple. The sun heats a dark flat surface which collects as much energy as possible, then the energy is transferred to water, air or other liquids for later use. Liquid solar collectors are potential candidates for better heat transfer, but there are few studies addressing the problem. However, improvement techniques can be applied to solar thermal collectors to create more compact and efficient designs. The study of improving heat transfer in a tube-sheet solar panel with metal spiral inserts is presented using TRNSYS as a simulation tool. The numerical simulation method predicts the thermal-hydraulic flow behavior of standard and improved tubular solar collectors and evaluates local losses, friction coefficients and Nusselt numbers as a function of operating parameters. Standard and extended collectors were simulated under the same environmental, radiation and operating conditions. According to the finite volume method, the stationary heat output of the flat plate collector is examined, taking into account the thickness of the absorber plate, the distance of the collector pipes, the length of the collector pipe, the diameter of the collector pipe and the thickness of the insulating layer.

II. LITERATURE REVIEW

ManFan et al. [1] in this study, another V-molded multi-channel layered safeguard is introduced and utilized in the fluid level authority. The safeguard is expelled with aluminum and explicit three-sided channels are straightforwardly framed to improve sun powered retention, lessen warm opposition and diminish pressure drops. For the new gatherer and an ordinary sheet metal authority, optical models and heat move models are created and explores are directed to approve precision.

Shuilian Li et al. [2] The point of this work is to utilize the diverse permeable surfaces of the air generator to cure the poor thermo physical properties of the air. A test study of the engrossing surface of the gatherer was introduced, the state of which was intended to give better heat move surfaces. The study presents four kinds of sun powered air authorities: a sinusoidal ridged plate, a distending plate, a sinusoidal and projecting folded plate and a base plane gatherer. The aftereffects of the trials were assessed at the same time on the days with a similar radiation.

Alsanossi M. Aboghrara et al. [3] this study meant to assess the improvement acquired in the exhibition boundaries of a fly effect HSA on a ridged spongy plate. An energy balance model was created to look at the presentation boundaries of the proposed HSA with the other two HSAs. On a day with clear skies and a mass stream pace of 0.04 kg/s, the hourly outcomes showed that the most extreme fluid outlet temperatures for the proposed HSA, SAH level confronted and SAH plates are 321317. or on the other hand 313 K; the most extreme temperatures of the retentive plates are separately 323.5, 326.5 and 328 K; The greatest temperature contrasts between the permeable plate and the fluid outlet are ~ 3, 9 or 15 K; The most extreme efficiencies are 65.7, 64.8 and 60%.

K. M. Pandey et al. [4] This article gives an outline of the various methods used to improve the effectiveness of late authorities. Impact of utilizing nanofluids as heat move liquid, impact of changing the plan of the spongy plate to more readily catch the radiation, strategies for decreasing heat misfortune, utilizing polymers, utilizing smaller than normal channels for liquid stream, utilizing PCM (stage change materials) to give heat for the time being without the tank and the effect of utilizing upgrade gadgets, for example, additions and reflector were examined in this article.

M. R. Assari et al. [5] The annihilation of the warm delineation of the water stockpiling and the impact on the sun oriented gatherer execution were explored tentatively. The main trial was performed utilizing a customary thermos phonic water stream. On the subsequent endeavor, the endeavor proceeded without depleting the earlier day's high temp water tank. The third and fourth examinations were begun under conditions like those of the principal case. In the third case, during the investigation, be that as it may, the water in the tank was blended in with a dissemination siphon, and in the fourth case the new water was supplanted with similar measure of water in the tank at three unique occasions.

III. Objectives

There are following objective are to be expected from the present work

- The main objective of the present work to enhance heat transfer rate by changing design of absorber flat plate.
- To perform theoretical investigation about absorber tube of flat plate collector.
- To perform computational fluid dynamics analysis on design from base paper as well as different proposed design of absorber plate of flat plate collector.
- To compare the various results obtained from CFD analysis on all designs.

IV. Methodology

Six different design of CAD model of absorber plate of evacuated flat plate collector is created with the help of design modular of ANSYS workbench. For the meshing triangular & rectangular shape elements have been generated with very fine mesh. The quality of the cell including its orthogonal quality, aspect ratio, and skewness has an important effect on the accuracy of the solution. Orthogonal quality is computed for cells using the vector from the cell centroid to each of its faces, corresponding face area vector, and the vector from the cell centroid to centroids of each of the adjacent cells.

The working fluid is taken as water flowing inside the absorber tube of parabolic trough collector having density of 1000 kg/m3, specific heat = 4182 J/kg-k, thermal conductivity = 0.6 w/m-k and viscosity of water liquid = 0.001003 kg/m-s. For the boundary conditions set fluent launcher options as double precision for 64 bit processor, for thermal aspect enable energy equation on, Pressure based absolute velocity formulation steady state fluent solver is used for this analysis.

Heat transfer by absorber flat plate:

$$Q = mc_p\text{-}\Delta t \quad W$$

A. Computational fluid dynamics analysis for absorber plate of evacuated flat plate collector

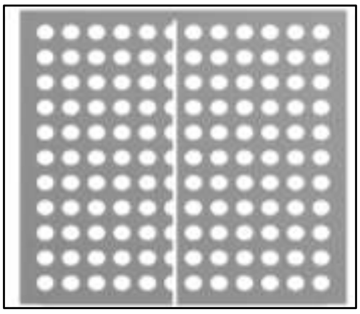

Fig. 1: CAD model of absorber plate of evacuated flat plate collector

In the present work a three dimensional CAD model of absorber plate of evacuated flat plate of design-1 having hole size 10 mm diameter in regular pattern with array spacing 5 mm is created with the help of design modular of ANSYS workbench as shown in figure No.1

Meshing : for the design-1 the total nodes are 476609 and total No. of elements are 467066 which are triangular & rectangular in shape.

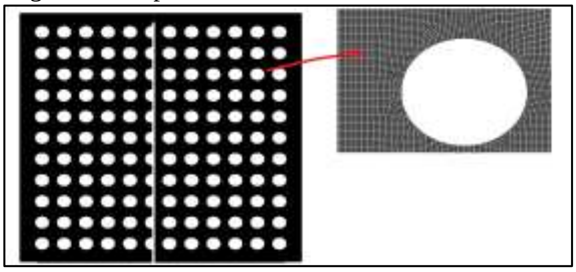

Fig. 2: meshing of absorber plate of evacuated flat plate collector

B. Material properties

The working fluid is taken as water flowing inside the absorber tube of parabolic trough collector having density of 1000 kg/m3,

Specific heat = 4182 J/kg-k,

Thermal conductivity = 0.6 w/m-k and

Viscosity of water liquid = 0.001003 kg/m-s.

C. Boundary conditions of absorber plate of evacuated flat plate collector

(1) To determine the maximum temperature inside the absorber plate of evacuated flat plate collector according to base paper need to on energy equation.

(2) Viscose laminar flow model is used for fluid flow having velocity inlet of 0.025m/sec.

(3) Defining of material property, set fluid as water liquid having density of 1000 kg/m3, specific heat = 4182 J/kg-k, thermal conductivity = 0.6 w/m-k and viscosity of water liquid = 0.001003 kg/m-s.

(4) For the outlet boundary condition the gauge pressure needs to be set as zero because the flow of water inside the absorber plate of evacuated flat plate collector according to base paper is atmospheric.

(5) Water inlet velocity of 0.25 m/sec (R. moss 2018) at 23 oC temperature

(6) Pressure based absolute velocity formulation steady state fluent solver is used for this analysis.

D. CFD Analysis for Design-1

In the present work, a three-dimensional CAD model of an absorbent plate of a vacuum flat plate with a hole size of 10 mm in diameter in a regular model with a distance of 5 mm is created using a modular design by Atelier ANSYS. The dimensions are as follows:

Dimension of plate = 200×200 mm

Diameter of hole =10mm

Pitch diameter = d

Addendum = (a = 1⁄pd)

Dedendum = (b = 1.25⁄pd)

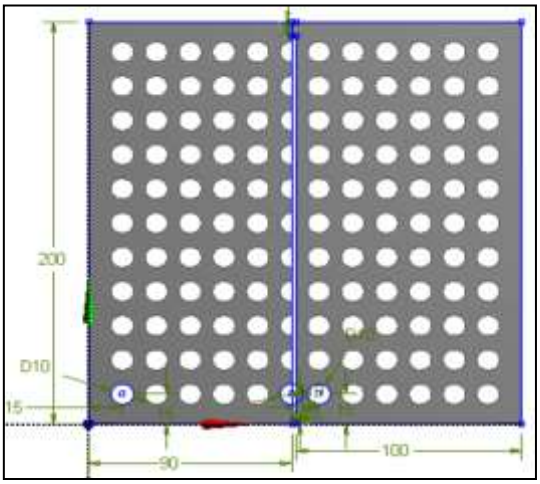

Fig. 3: CAD model of absorber plate of evacuated flat plate collector [Screen shot –ANSYS Software]

1) Meshing

After the CAD geometry is completed, the vacuum plate collector absorber plate is imported into the ANSYS workshop for further computer-aided fluid dynamics analysis. The next step is networking. Meshing is an important operation in finite element analysis in this process. CAD geometry is divided into a large number of small parts called meshes. In the present work it is 476,609 and the total number of elements is 467,066, which are triangular and rectangular.

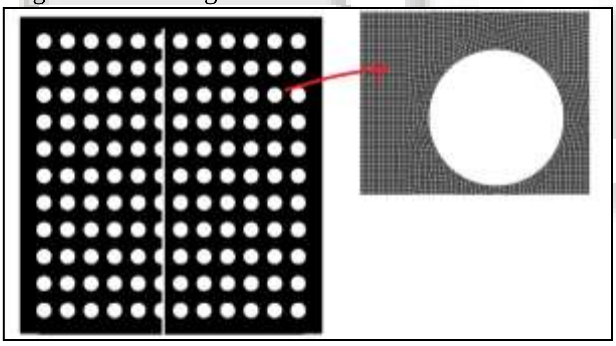

Fig. 4: Meshing of absorber plate of evacuated flat plate collector according to base paper [Screen shot –ANSYS Software]

2) Orthogonal Mesh Quality

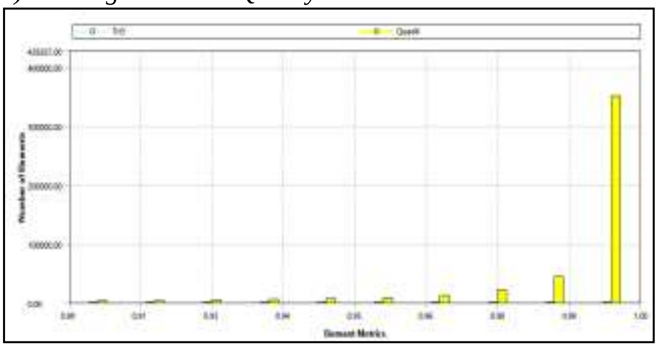

Fig. 5: Orthogonal mesh quality for absorber plate of evacuated flat plate collector

The orthogonal quality is calculated for cells using the vector from the cell's centroid to each of their areas, the vector from the corresponding face area, and the vector from the cell's centroid to the centroids of each of the adjacent cells. The worst cells have an orthogonal quality closer to 0, the best cells closer to 1. In this case, the minimum value is 0.9 and the maximum value is 1 and the average value is 0.98872, which means that the quality of the mesh is acceptable and very good.

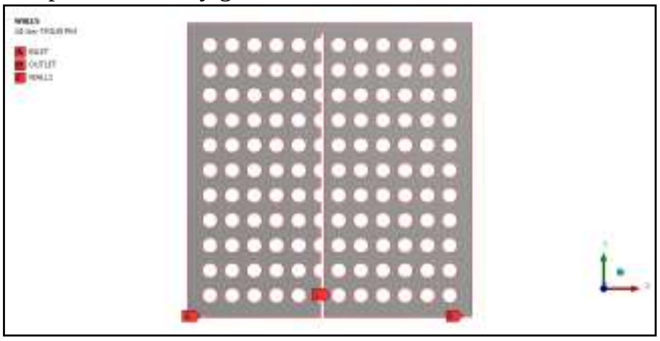

Fig. 6: Boundary conditions of absorber plate of evacuated flat plate [Screen shot –ANSYS Software]

3) Computational fluid dynamic analysis of absorber plate of evacuated flat plate collector:

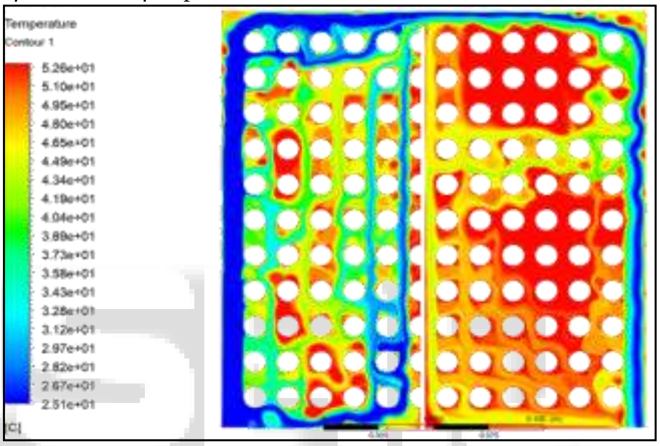

Fig. 7: Temperature distribution over the absorber plate of evacuated flat plate collector [Screen shot –ANSYS Software]

The computational analysis of fluid dynamics was performed on an absorbent plate of a vacuum flat collector according to the base paper in order to obtain a temperature distribution on the flat collector. The maximum temperature was recorded and is 52.818°C.

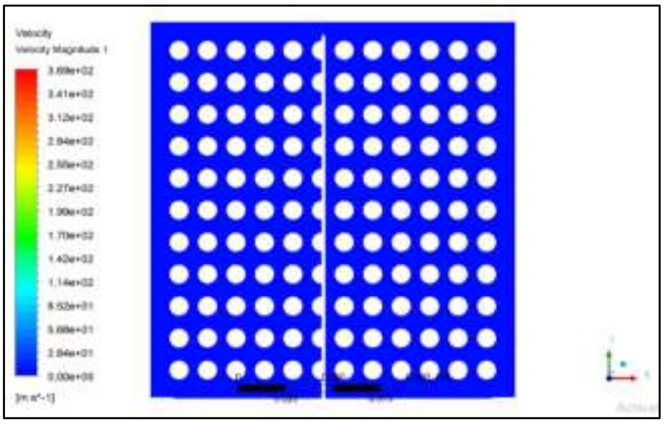

Fig. 8: Velocity distribution over the absorber plate of evacuated flat plate collector [Screen shot–ANSYS Software]

The computational analysis of the fluid dynamics was performed on an absorbent plate of a flat collector evacuated according to the base paper in order to obtain a velocity distribution on the flat collector. The maximum recorded speed is 0.369 m/s.

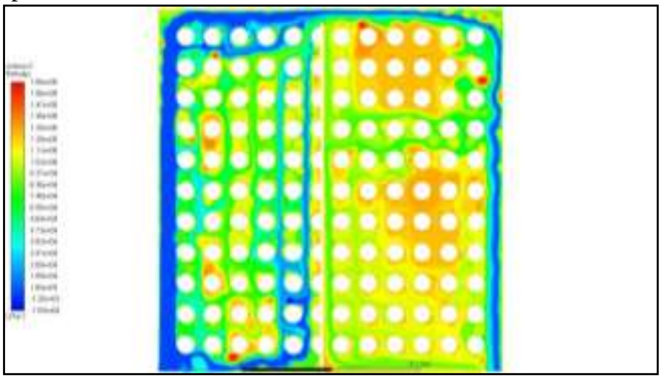

Fig. 9: Enthalpy of the absorber plate of evacuated flat plate collector [Screen shot –ANSYS Software]

Computerized fluid dynamics analysis was performed on an absorber plate of a vacuum flat collector to obtain the enthalpy of the flat collector. The maximum enthalpy of 1.65 x 105 J/kg was recorded.

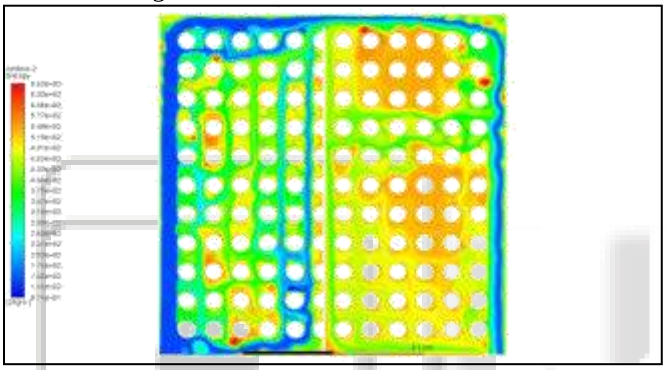

Fig. 10: Entropy of the absorber plate of evacuated flat plate collector [Screen shot –ANSYS Software]

Computerized fluid dynamics analysis was performed on an absorber plate of a vacuum flat collector to obtain the entropy of the flat collector. The maximum entropy of 6.63 x 102 J/kg-K was recorded.

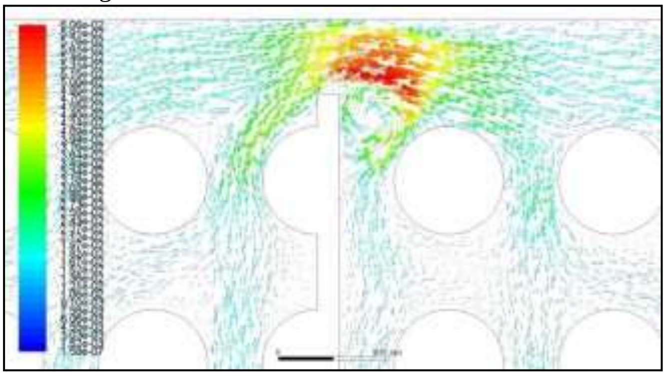

Fig. 11: Vector flow diagram for absorber plate of evacuated flat plate collector [Screen shot –ANSYS Software]

The vector flow chart shows the trend of the water flow in the liquid vector line above the absorber plate of the flat plate collector.

E. CFD Analysis for Design-2

CAD model of absorber plate of evacuated flat plate of design-2 having hole size 10 mm in zig-zag pattern with array spacing 5 mm. as shown in figure No. 12.

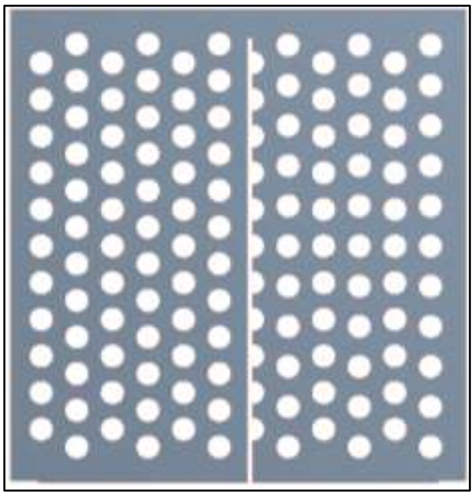

Fig. 12: CAD model of absorber plate of evacuated flat plate collector design-2

1) Meshing

For the design-2 the total nodes are 476609 and total No. of Elements is 467066 which are triangular & rectangular in shape.

Note: All the boundary conditions remain same as previous analysis hence no needs to explain again

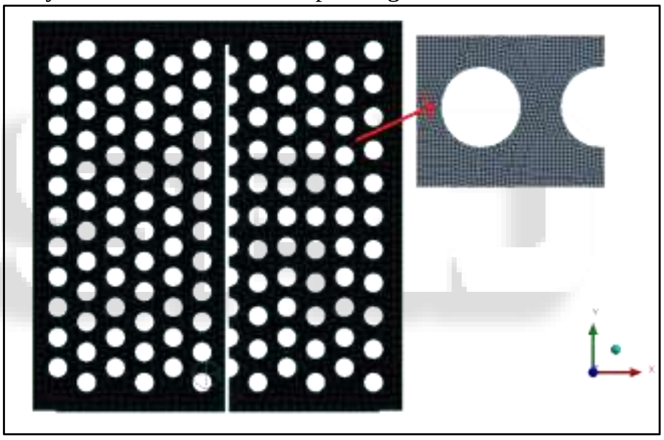

Fig. 13: meshing of absorber plate of evacuated flat plate collector design-2

Note: material properties and boundary conditions are remaining same as previous design.

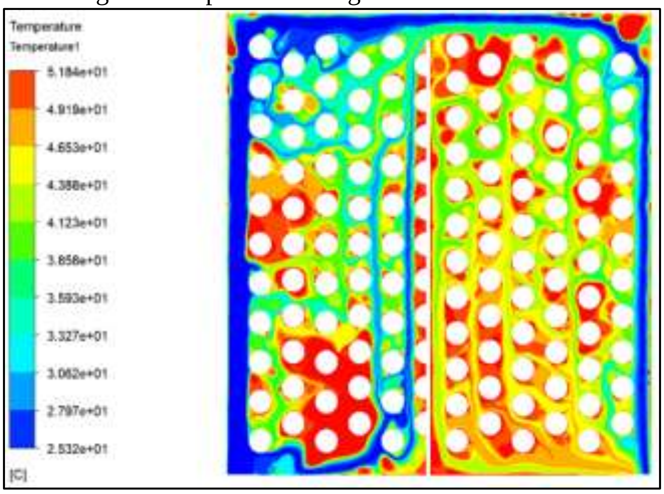

Fig. 14: Temperature distribution over the absorber plate of evacuated flat plate collector for proposed design-2

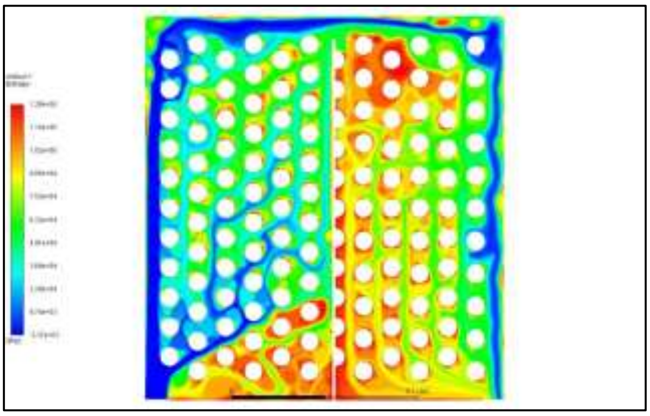

Fig. 15: Enthalpy of the absorber plate of evacuated flat plate collector for proposed design-2

F. CFD Analysis for Design-3

CAD model of absorber plate of evacuated flat plate of design-3 having hole size 5 mm in regular pattern with array spacing 5 mm as shown in figure No.16

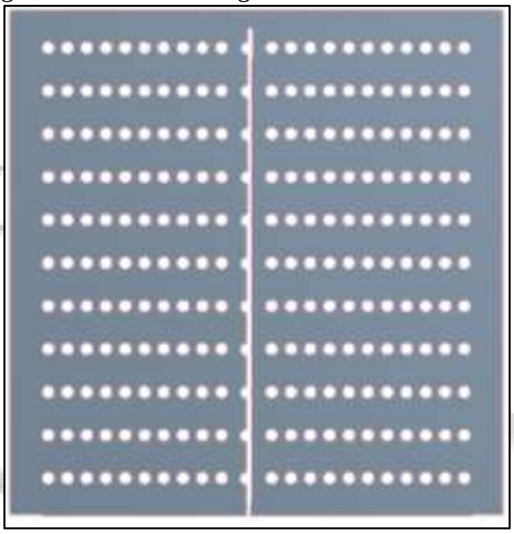

Fig. 16: CAD model of absorber plate of evacuated flat plate collector design-3

Meshing: for the design-3 the total nodes are 543181 and total No. of elements are 534510 which are triangular & rectangular in shape.

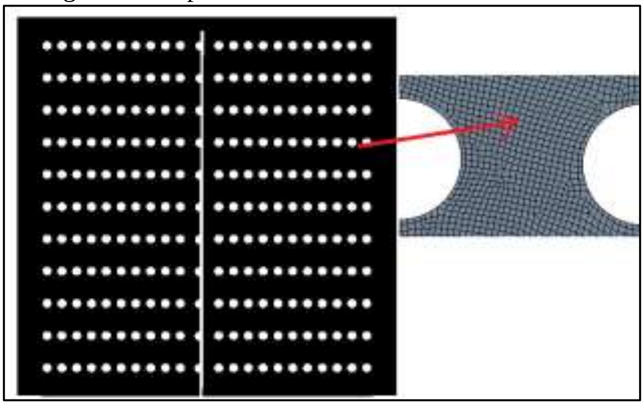

Fig. 17: meshing of absorber plate of evacuated flat plate collector design-3

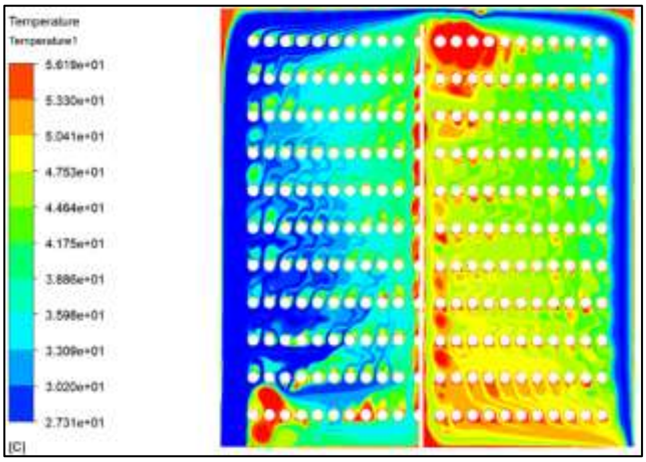

Fig. 18: Temperature distribution over the absorber plate of evacuated flat plate collector for proposed design-3

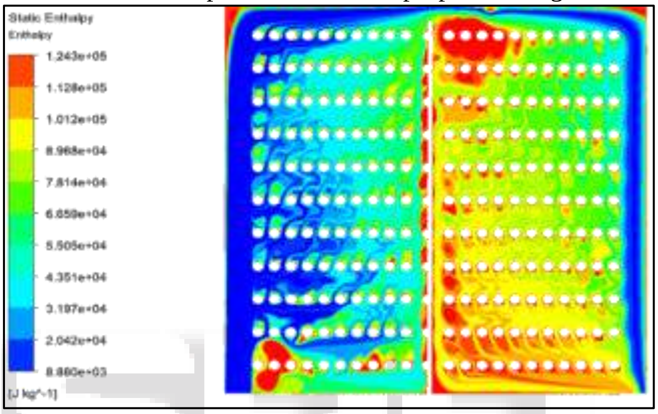

Fig. 19: Enthalpy of the absorber plate of evacuated flat plate collector for proposed design-3

G. CFD Analysis for Design-4

CAD model of absorber plate of evacuated flat plate of design-4 having hole size 5 mm in zig-zag pattern with array spacing 5 mm as shown in figure No. 20

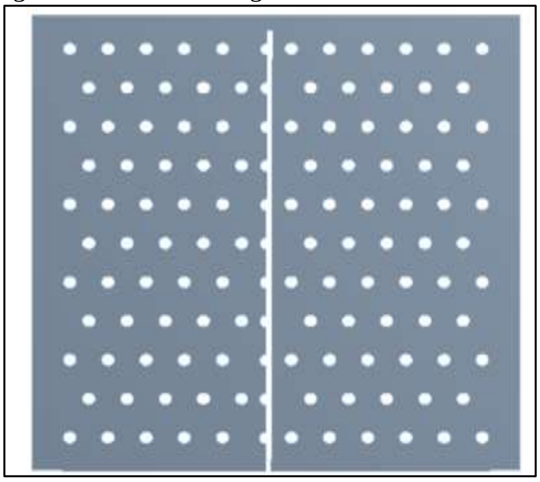

Fig. 20: CAD model of absorber plate of evacuated flat plate collector design-4

1) Meshing:

For the design-4 the total nodes are 568372 and total No. of elements are 563002 which are triangular & rectangular in shape.

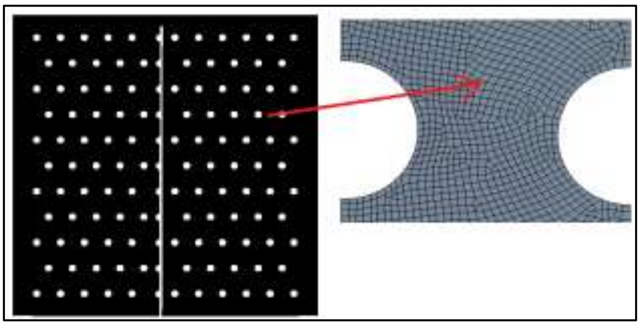

Fig. 21: meshing of absorber plate of evacuated flat plate collector design-4

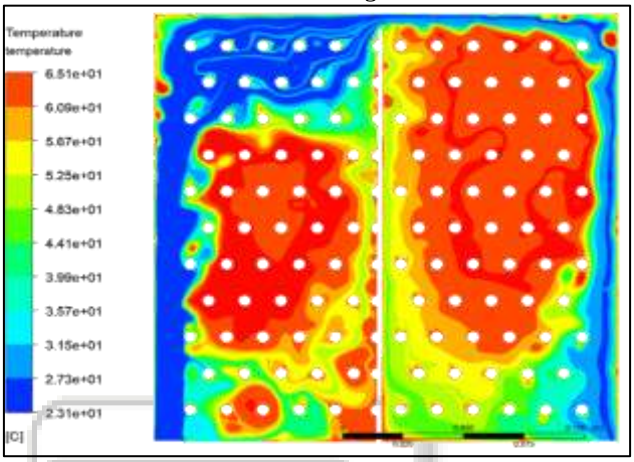

Fig. 22: Temperature distribution over the absorber plate of evacuated flat plate collector for proposed design-4

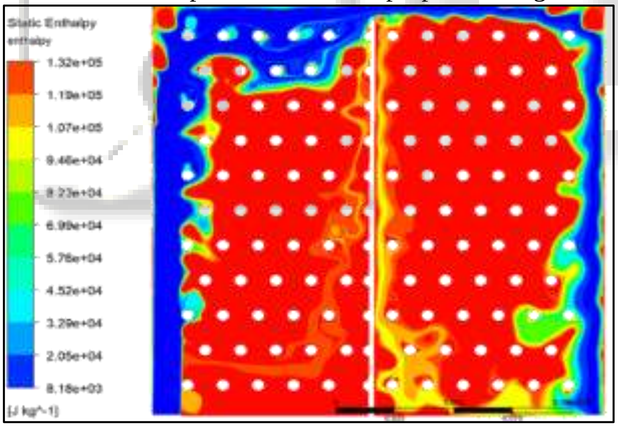

Fig. 23: Enthalpy of the absorber plate of evacuated flat plate collector for proposed design-4

H. CFD Analysis for Design-5

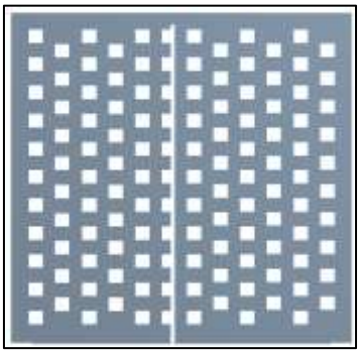

Fig. 24: CAD model of absorber plate of evacuated flat plate collector design-5

1) Meshing:

For the design-5 the total nodes are 32527 and total No. of elements are 30158 which are rectangular in shape.

CAD model of absorber plate of evacuated flat plate of design-5 having square hole size 8 mm in zig-zag pattern with array spacing 7 mm as shown in figure No. 24.

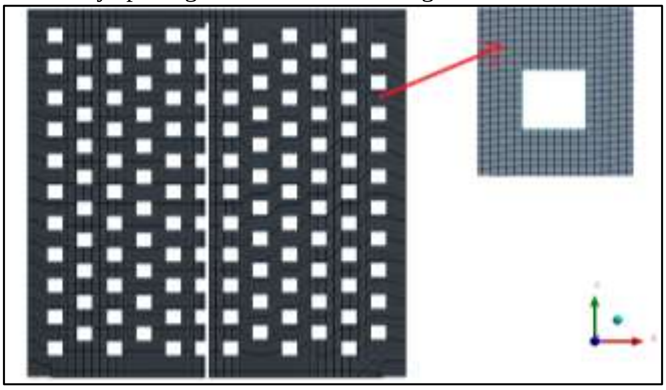

Fig. 25: meshing of absorber plate of evacuated flat plate collector design-5

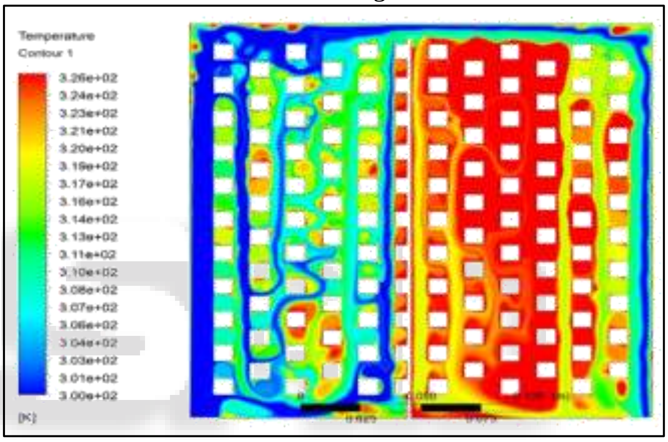

Fig. 26: Temperature distribution over the absorber plate of evacuated flat plate collector for proposed design-5

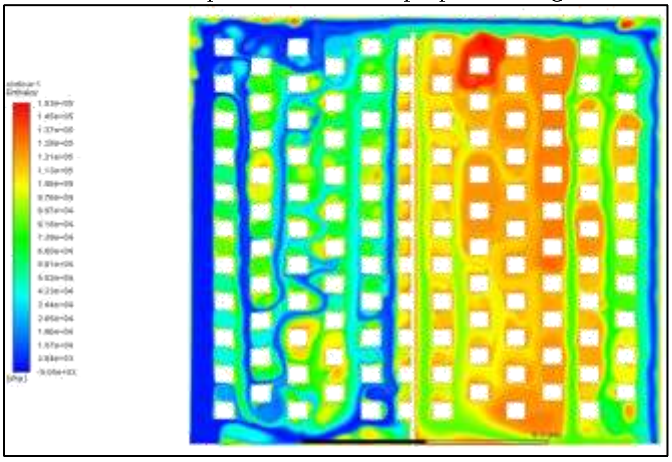

Fig. 27: Enthalpy of the absorber plate of evacuated flat plate collector for proposed design-5

I. CFD Analysis for Design-6

CAD model of absorber plate of evacuated flat plate of design-6 having polygon hole having side of 4 mm in regular and zig-zag pattern with array spacing 5.5 mm as shown in figure No. 28.

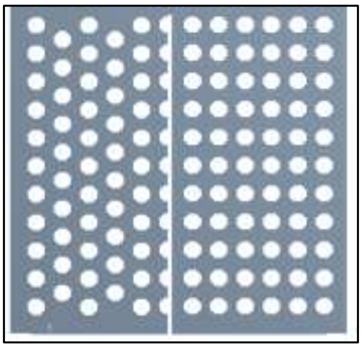

Fig. 28: CAD model of absorber plate of evacuated flat plate collector design-6

1) *Meshing:*

For the design-6 the total nodes are 32729 and total No. of elements are 30537 which are triangular & rectangular in shape.

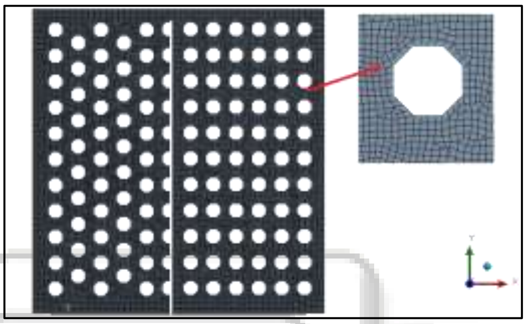

Fig. 29: meshing of absorber plate of evacuated flat plate collector design-6

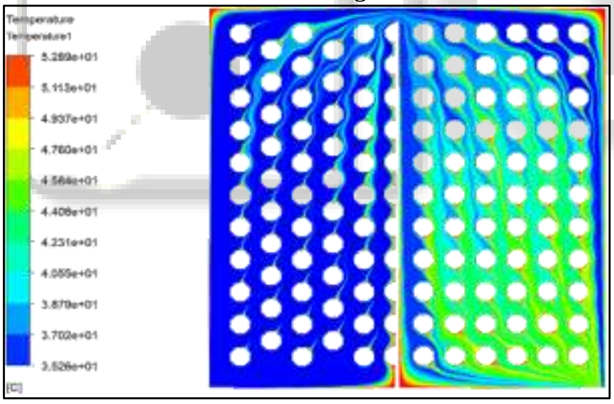

Fig. 30: Temperature distribution over the absorber plate of evacuated flat plate collector for proposed design-6

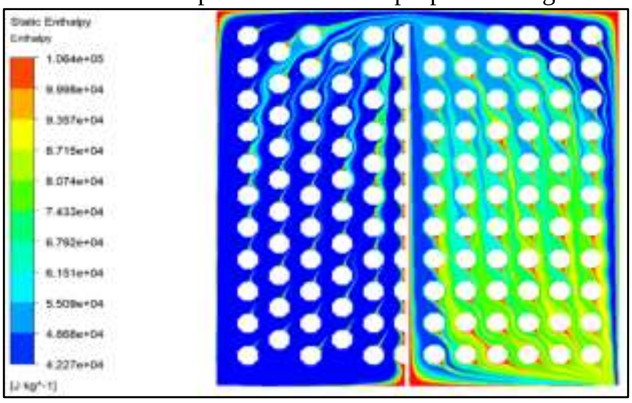

Fig. 31: Enthalpy of the absorber plate of evacuated flat plate collector for proposed design-6

V. RESULTS

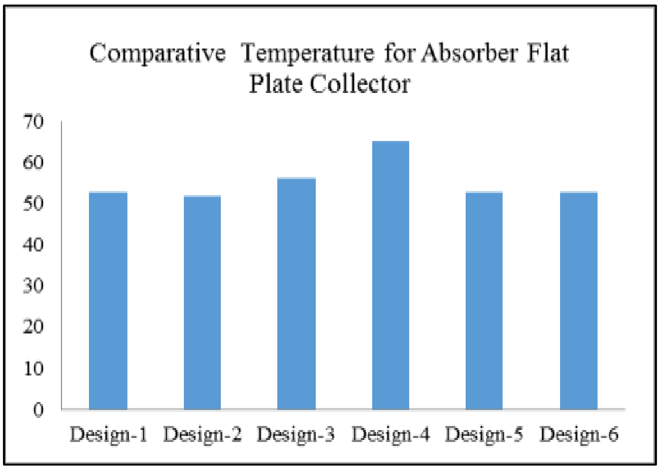

Fig. 32: Comparative result for temperature

It has been observed from above comparative results that Design-4 (absorber plate of evacuated flat plate small hole) gives maximum temperature as compared to other designs.

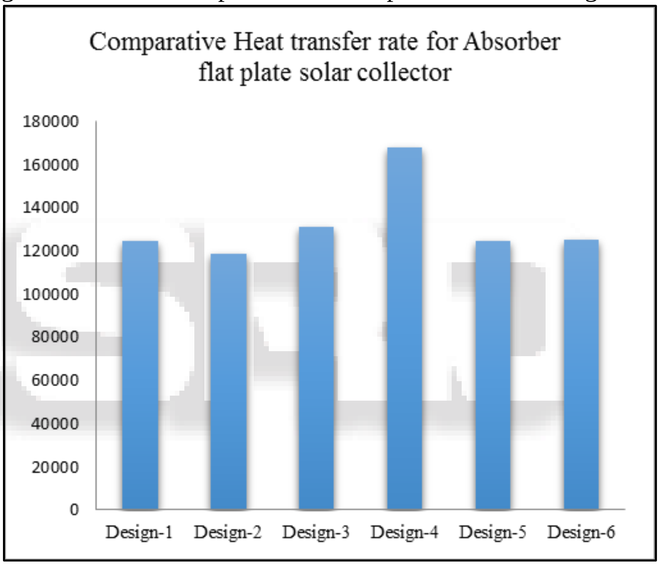

Fig. 33: Comparative result for heat transfer

It has been observed from above comparative results that design-4 (absorber plate of evacuated flat plate small hole) gives better heat transfer as compared to other designs**.**

Computational fluid dynamics analysis have been performed for various designs of absorber plate of evacuated flat plate collector shown in figure no. 32 the Temperature distribution varies from 51.18ºC to 65.15ºC, enthalpy varies from 1.05×10^5J/Kg to 1.31×10^5 J/Kg and the Velocity magnitude varies from 0.364 m/sec to 0.494 m/sec.

VI. CONCLUSION

In the present work, a computerized fluid dynamics analysis was performed for six absorber plate constructions of a vacuum flat collector to verify temperature distribution and heat generation for improved thermal efficiency, flow variables such as velocity, enthalpy, entropy and comparative results. The following concluding points are drawn from this work.

– After performing a computerized fluid dynamics analysis on an absorber plate of a flat vacuum manifold for a maximum design temperature-1 of 52.81 ºC, a velocity of 0.368 m/s, an enthalpy of 1, 09 × 105 J/kg and an entropy of 4.95 × 102 J/kg -K were recorded.

- For the maximum design temperature 2 of 51.8 ºC, velocity amplitude 0.364 m/s, enthalpy 1.06 × 105 J/kg, entropy 4.85 × 102 J/kg -K were recorded.
- For Design 3, maximum temperature 56.18 ºC, velocity amplitude 0.356 m/s, enthalpy 1.24 × 105 J/kg, entropy 5.39 × 102 J/kg -K were recorded.
- For the maximum design temperature 4 of 65.15 °C, velocity values of 0.363 m/s, enthalpy of 1.31 × 105 J/kg and entropy of 5.62 × 102 J/kg -K were recorded.
- For the maximum design temperature 5, 52.832 °C, velocity values of 0.368 m/s, enthalpy of 1.05 × 105 J/kg and entropy of 4.83 × 102 J/kg -K were recorded..
- For the maximum design temperature 6 of 52.892 °C, a velocity of 0.494 m/s, an enthalpy of 1.06 × 105 J/kg and an entropy of 4.84 × 102 J/kg -K were recorded..

From the above conclusion, it was observed that the -4 design is more efficient than other proposed designs, the maximum temperature of 65.157 °C is reached after heating, and the heat transfer rate is 16772.292W, which is higher compared to other models. Therefore, it is recommended that the absorber plate design of the vacuum flat manifold be more suitable for better heating.

VII. FUTURE SCOPE

The present work is concentrated to improve the thermal performance of absorber plate of evacuated flat plate collector by changing its design. Though the study is performed with an utmost care then also there is scope for further improvement. Some of the suggestions for future study might be possible are explained.

1) In the present work material of absorber plate is taken as stainless steel but some other materials can also be used for future improvement.
2) In the present work water is taken as working fluid but some other nano-fluids may also be used.

REFERENCES

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