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Design, Optimization and CFD Simulation of Solar Air Heater with Jet Impingement on V-Corrugated Plate

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Abstract - *The modeling methods are vital to predict the performance of a solar air heater. Earlier works exposed that flat plate solar collector with and without jet impingement resulted in a significant increase in the performance. This paper deals with Computational Fluid Dynamics (CFD) based thermal efficiency evaluation to determine heat transfer characteristics of a solar air heater with and without jet impingement on a collector plate. Autodesk inventor professional is used to model the proposed design and CFD software is used to simulate fluid flow and heat transfer. The design parameters considered in the work are solar collectors without and with jet impingement, 6,8,10 mm jet diameters are used for jet impingement, 300 K ambient temperature, 0.02 – 0.05 kg/s mass flow rate, and 500-800 W/m² solar radiation of selected.*

The simulation results reveal that the collector outlet temperature, Nusselt number, and thermal efficiency is more in 6 mm jet diameter for 0.05 mass flow rate and 600 W/m² solar radiation and there is a pressure drop below 6 mm jet diameter which increases pump power consumption. The V-corrugated collector without and with jet plate has a maximum efficiency of 64.3 %, 72.3% respectively. Enhancement in thermal efficiency is observed by using jet impingement on the corrugate plate. The results gained have been validated with experimental results from the literature.

Keywords: CFD Simulation, Heat Transfer, Jet impingement, Solar Air Heater

1. INTRODUCTION

Ethiopia is a country receives abundant solar radiation which could be used for industrial, space heating, and drying application using solar collector devices. Solar air collectors occupy a vital role among solar thermal systems because of availability, minimal cost, and use of air as the working fluid. However, the disadvantage of a solar air collector's system is they can handle relatively large volumes of air with low thermal capacity, and convective heat transfer rate. Several ways have been done to improve the heat transfer rate by increasing the heat-transfer surface area and increasing the turbulence flow inside the collector airflow duct by using extended and corrugated surfaces, obstacles, porous bed materials, and applied the recycle-effect concept in double-pass operations.[1]

The thermal efficiency of solar air heaters is generally less due to their characteristically low heat transfer capacity between the air and absorber plate. To make the solar air heaters feasible, their thermal performance needs to be enhanced by increasing the heat transfer coefficient. A jet impingement method is an effective approach for raising the heat transfer coefficient.

This paper deals with CFD simulation of solar air heater by analyzing heat transfer characteristics for inline arrangements of circular jets on the corrugated absorber plate and compared with conventional solar air heater which is a corrugated absorber plate.

2. LITERATURE REVIEW

The application of the software is crucial in developing and investigating the mathematical models and predicting the performance of several types of the solar air heater. The design can be optimized with the help of software it saves time and cost which spent during experimental works. The CFD simulation studies in recent years reported that the value of the solutions obtained is mostly within the adequate range proving that CFD is a real tool for predicting the heat transfer characteristics and performance of a solar air heater.

Rajeev Ranjan et al [2] proposed heat transfer and friction characteristics in a rectangular duct of a solar air heater having isosceles right triangle rib shape on the absorber plate by using CFD (Computational Fluid Dynamics). The design parameters were chosen for study ware Reynolds number, roughness height, and roughness pitch. The turbulence model used CFD solutions was the Renormalization group (RNG) k-ε. With the roughness height (e) of 0.5mm, 1.0mm and 1.5mm at roughness pitch (P) of 5mm, 10mm, 15mm, and 20mm. The relative roughness pitch (P/e=3.33-40) and relative roughness height (e/D= 0.015-0.045) were taken. The effect of transverse wedge shape on heat transfer and friction factor was investigate covering the range of roughness parameter having Reynolds number varies from 3000 to 18000. The RNG k-ε model yield better results for two-dimensional flow through conventional solar air heaters.

Shailendra N. Singh et al [3] 'Thermo-hydraulic performance analysis of jet plate solar air heater under crossflow condition' a jet impingement concept has been studied. To investigate the effect of geometrical parameters like hole configuration on the jet plate i.e., inline and staggered holes, and operational parameter like the velocity of air impinging out of the holes on to surface of the absorber plate on the performance of jet plate solar air heater, a detailed analysis has been performed on the design for different air mass flow rates. Experiments are performed with air mass flow rates, ṁ1= 0.05-0.105 kg/sec, ṁ2 = 0.033-0.07 kg/sec, Re = 0.59×104-1.15×104, jet hole diameter, D = 0.006 m. Also, a parallel study has been made on a conventional parallel plate solar air heater to have a comparison of air temperature increment and collector efficiency with those of the jet plate solar heater. The results obtained from the present study show that the mass flow rate of air influences heat transfer in the jet plate solar air heater. The performance of cross-flow solar air heater with inline hole jet plate is superior over that with staggered hole jet plate.

A.E. Kabeel et al[4] presents a review of the literature dealing with improvement methods, design configurations and applications of different types of solar air heaters (SAHs). Different investigations have been made on SAHs either experimental or theoretical to improve their performance. Different modifications on an absorber the plate has been made. One of the important improving theories is using fins to increase the heat transfer area. Various types of fins achieved enhancement in the performance such as longitudinal fins, corrugated fins and fins attached with baffles. The recycling process also enhanced the performance of SAHs. Also, it is found that to improve both the heat transfer and thermo-hydraulic performance of SAH, artificially roughened absorbers are used. Using artificial roughness, the results showed good enhancement of both Nusselt number and friction the coefficient for a wide range of Reynolds numbers. Also in the view of using heat storage materials, especially phase change materials (PCMs), various types of packing bed and selectively coated absorbers give good improvement of the efficiency of SAHs.

Alsanossi M. Aboghrara et al [5] deals with the experimental investigation outlet temperature and efficiency, of Solar Air heater. The experimental test set up designed and fabricated to study the effect of jet impingement on the corrugated absorber plate, through circular jets in a duct flow of solar air heater and compared with conventional solar air heater on flat plat absorber. Under the effect of the mass flow rate of air and solar radiation on outlet air temperature, and efficiency, are analyzed. Results show the flow jet impingement on corrugated plat absorber is a strong function of heat transfer enhancement. The present investigation concludes that the mass flow rate of air substantially influences the heat transfer on solar air heaters. And the thermal efficiency of the proposed design duct is observed almost 14% more as compared to the smooth duct. At solar radiation 500-1000 (W/M2), 308K ambient temperature, and 0.01-0.03(Kg/S) mass flow rate. The thermal efficiency is increased by increasing the value of the mass flow rate.

❖ Components of Solar Air Heaters

(i) **Absorber Plate**: The material should have good thermal conductivity, adequate tensile, and compressive strength and be corrosion resistant. In most cases, Copper is preferred because of its preferred property for the absorber plate.

(ii) Cover Plate: as the name implies it covers the absorber plate and must transmit the incoming solar radiation. The purposes of the cover plate are to:

(a) Transmit the maximum amount of incoming solar radiation to the absorber plate.

(b) Reduce the heat loss from the absorber plate to the environment.

(c) Protect the absorber plate from direct contact to weathering.

(iii) Insulation: are provided to reduce heat loss from the absorber plate because of conduction and convection. In most cases, glass wool is used as insulating material. A significant requirement of an insulator is that it should be heat resistant.

❖ Classification of Solar Air Heater

There are different types of solar air heaters used with different sizes and designs, that depend on the application and requirements. Usually, solar air heaters are classified according to many factors.

✓Air movement method, [active, passive or hybrid]
✓Air movement direction, [parallel, counter flow]

3. METHODOLOGY AND MATERIALS

The area selected for a present research study is Limu coffee plantation located in the Oromia Regional State is geographically found in the most ideal coffee-producing area of Ethiopia. The region situated at a latitude of 8.06°N and longitude 36.57°E with an **elevation** of 1773 meters above sea level[6].

1. Solar Radiation

The important meteorological parameters which influence the collector performance are global solar irradiation, ambient temperatures, and wind speed. Solar Irradiance is the amount of solar power available at the selected location. This irradiance variable for a different season of the year and also varies time of the day, along with the position of the sun, and the weather condition. MATLAB models are used to establish a mathematic model of hourly solar radiation on the tilted surface at limmu, Ethiopia.

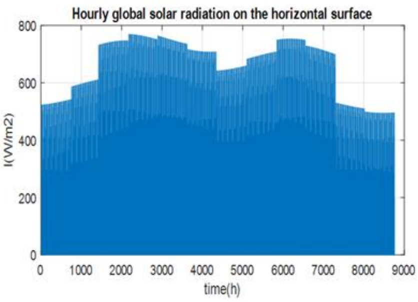


Figure 1. Global solar radiation on a horizontal surface

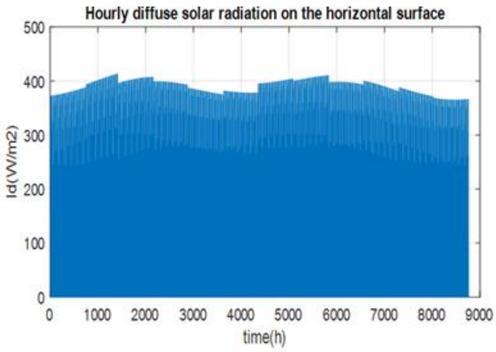


Figure 2. Diffuse solar radiation on the horizontal surface

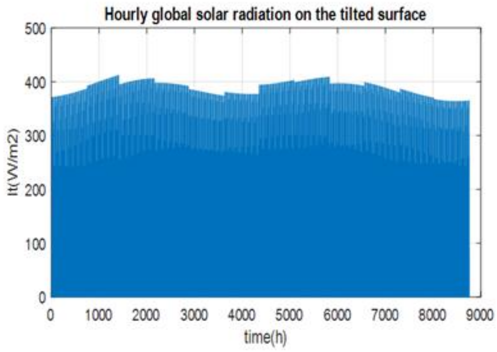


Figure 3. Global solar radiation on the tilted surface

2. Proposed Design

The collector has a rectangular cross-section frame, with a glass cover at the top, an absorber plate below the glass cover, a circular jet plate below the absorber plate. The absorber is a V-corrugated plate painted with black. Therefore, the jets of air are impinged on the lower surface of the corrugated absorber plate to give an effective heat transfer between the air and absorber plate which enhances the performance of the collector by increasing the heat transfer coefficient.

The proposed design is modeled and simulated for the different flow and geometry parameters in the solar collector.

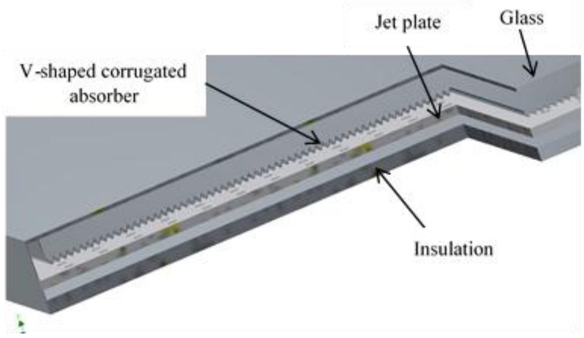


Figure 4 Propose design of the solar air heater

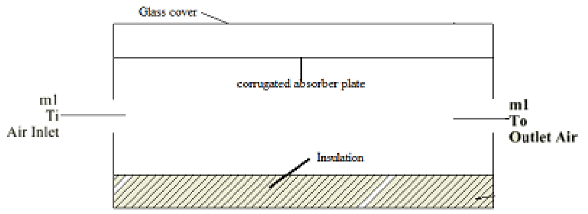


Figure 5. Parallel flow solar collector without jet plate

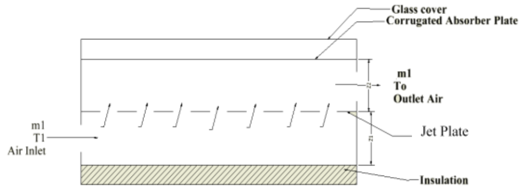


Figure 6. Solar collector with a jet plane

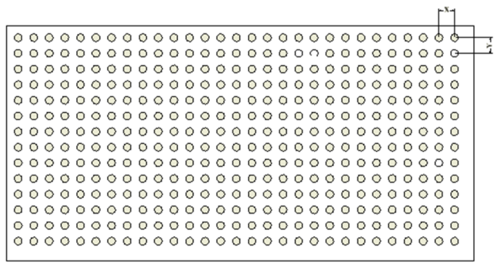


Figure 7. Jet plate with an inline configuration

Table I. Operating and Design parameters used in the simulation.

1	Collector length	L = 2.0 m
2	Jet diameters	6,8,10 mm
3	Collector width	W = 1.0 m
4	Stream and Spanwise pitch [X, Y]	15mm
5	Jet-to-absorber plate spacing [Z_1]	30 mm
6	The spacing between the bottom and a jet plate[Z_2]	30 mm
7	Absorber thickness	t= 1.0 mm, ε_p= 0.95

8	Jet plate thickness	thickness = 4.0 mm, aluminum
9	Glass cover	t = 4.0 mm, ε_g = 0.88
10	Absorber Plate-to-cover spacing	20 mm
11	Insulation thickness	t = 20 mm
12	Mass flow rate	$\dot{m}1$= 0.02-0.05 kg/s
13	Tilt angle	θ= 18.06^0
14	Solar radiation i	500-800 W/m²
15	Wind velocity	2.1 m/s
16	Ambient temperature	300

4. CFD SIMULATION

The computational fluid dynamics simulation is done by ANSYS FLUENT 19.2 which has three main stages as

- ✓ Pre-processing
- ✓ Solver and
- ✓ Post-processing.

A. Geometry Generation

The half geometry is generated with symmetry to minimize computation time and storage.

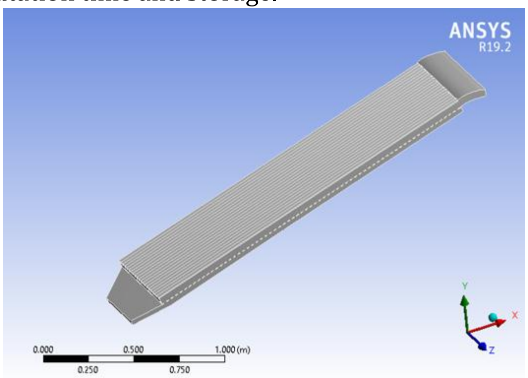
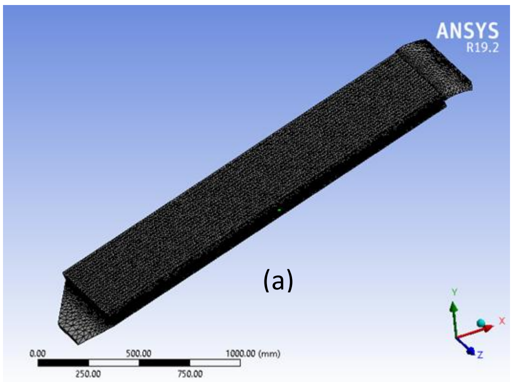


Figure 8. 3D Model of Solar Collector'

B. Mesh Generation

A good meshing has a direct effect on the rate of convergence, the accuracy of the solution, file size, and time of computation. At the meshing stage, appropriate boundary conditions are specified. The fine quadrilateral grids cells are generated for all numerical simulations.



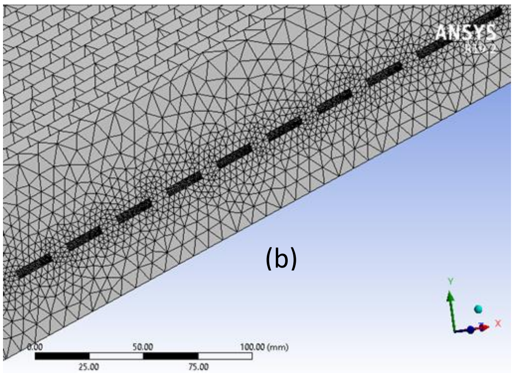


Figure 9. Meshed model for solar collector without (a) and with (b) jet plate.

For the accurate solution, the fluid flow zone is segmented into several zones, and a combination of structured and unstructured mesh was created in the fluid domain. Thus, the mesh system has 2,445,779 elements and 475,695 nodes.

C. Boundary Conditions

At the inlet uniform mass flow rates are taken as $\dot{m}1$= 0.02-0.05 kg/s. The outlet is specified as a pressure outlet with pressure which is equal to atmospheric pressure at the exit. Uniform heat flux 500-800 W/m² imposed on the absorber which is equal to solar insolation, and all other walls are set to adiabatic. The absorber plate material is taken as aluminum. Turbulence parameters at the inlet are defined us turbulence intensity (5%). Ambient temperature for radiation from the top of the glass is taken as 300 K.

Table III Thermo-physical properties of the working fluid & absorber plate

	Material Density (kg/ m³)	Specific heat J/kg K	Thermal Conductivity (W/m²K)	Refractive index
Air	1.225	1006	0.0242	--
Glass	2600	840	1.05	1.5
Aluminum	2719	871	202.4	--

D. Governing Equations

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

X- Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+u\left[\frac{\partial^2 u}{\partial x^2}+v\frac{\partial^2 u}{\partial y^2}+w\frac{\partial^2 u}{\partial z^2}\right] \qquad (2)$$

Y- Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\left[\frac{\partial^2 v}{\partial x^2}+v\frac{\partial^2 v}{\partial y^2}+w\frac{\partial^2 v}{\partial z^2}\right] \qquad (3)$$

Z Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+w\left[\frac{\partial^2 w}{\partial x^2}+v\frac{\partial^2 w}{\partial y^2}+w\frac{\partial^2 w}{\partial z^2}\right] \qquad (4)$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\left[\frac{\partial^2 u}{\partial x^2}+v\frac{\partial^2 u}{\partial y^2}+w\frac{\partial^2 u}{\partial z^2}\right] \quad (5)$$

In the above equations, u, v, and w are the velocity components in x, y, and z directions, p, and T are the pressure and temperature of the flowing air[7].

E. Solver

The CFD analysis is carried out using ANSYS-FLUENT 19.2. Researchers have carried out validation of various turbulence models for CFD analysis of rough surface solar air heater. They have observed that the results obtained by Renormalization-group (RNG) k-ε model show 72.58% absolute percentage deviation in predicted values and the values calculated from Dittus–Boelter correlations[8].

Table II Coefficient of determination (R^2) values of CFD models[8].

Model	(R^2)
Shear Stress Transport (SST) k−ω	0.994
Realizable k−ε	0.995
Standard k−ε	0.996
Renormalization k−ε	0.998

The transport equation for the Realizable *k*-ε model

Turbulent kinetic energy *k* equation [7].

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (6)$$

The rate of energy dissipation $\dot{I}$ equation,

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S_\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon$$

$$Where, C_1=max\left[0.43,\frac{\eta}{\eta+s}\right], \eta=S\frac{k}{\varepsilon}, s=\sqrt{2s_{i,j}^{\;2}} \quad (7)$$

In this equations, G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, G_b is the turbulence kinetic energy generated due to buoyancy represents the contribution of the fluctuating dilatation incompressible turbulence to the overall dissipation rate, C_2 and $C_1\varepsilon$ are the constant, σk and $\sigma\varepsilon$ are the turbulent Prandtl numbers for k and ε respectively. S_k and $S\,\varepsilon$ are user-defined source terms. The eddy viscosity is computed from[7].

$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}$ The model constants are

$$C_{1\varepsilon}=1.44, C_2=1.9, \sigma_\varepsilon=1.2 \quad (8)$$

F. Solution Procedure

In this simulation finite volume method in the steady-state condition, A second-order upwind scheme and double-precision pressure-based are used to solve all governing equations [continuity, momentum, and energy]. To a couple of pressure and velocity SIMPLE algorithm (semi-implicit method for pressure linked equations) is chosen. The convergence criteria of 10^{-6} for the residuals of the continuity equation, 10^{-6} for the residuals of the momentum the equation, 10^{-3} for the residuals of the velocity components and 10^{-6} for the residuals of the energy equation is assumed.

5. RESULTS AND DISCUSSION

3D steady-state CFD simulation of heat transfer and fluid flow features has been carried out at different mass flow rates for v-corrugated solar collectors without and with jet impingement for the jet diameter of 6,8,10 mm in ANSYS FLUENT 19.2. The outlet temperature and efficiency measure the enhancement of thermal performance with different mass flow rates and geometry. Results show the velocity and temperature distribution in the plane parallel to the direction of airflow for all conditions generated using CFD post processors. The flow and temperature distribution are represented by velocity vector and temperature contour respectively.

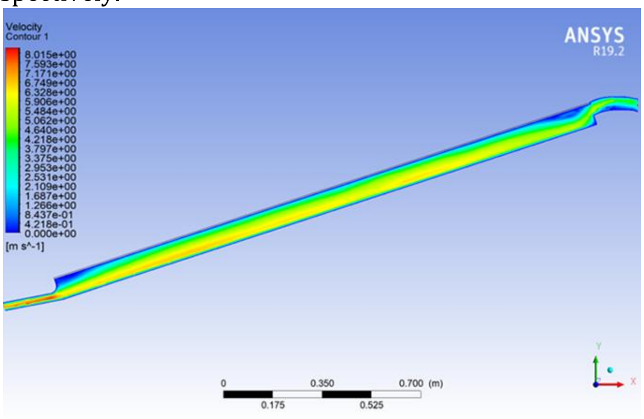


Figure 10. The velocity contour plot without jet for the mass flow rate of 0.05kg/s

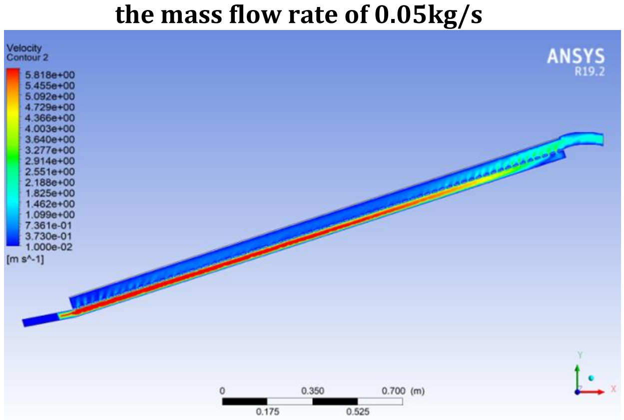


Figure 11. The velocity contour plot of D=8 mm for the mass flow rate of 0.05kg/s

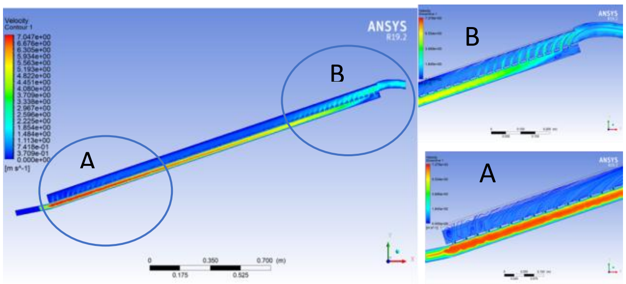


Figure 12. The velocity contour plot of D=6 mm for the mass flow rate of 0.05kg/s

From Fig. 10 to Fig. 12 shows the 2D and 3D contour plot of the velocity of solar collector for without jet plat, D=8 mm, D=6 mm. The velocity of air close to the jet plate is very high and it decreases with far from the inlet wall. Velocity contour as shown in Fig. 11 jet of air impinging on the bottom surface of the absorbing plate this action results in a high cooling effect on the absorber plate and leads to enhanced heat transfer to the air. For D=6 mm, the jet plate creates a high-velocity air jet impinges on the absorber plate and continues to flow at a higher velocity below the absorber plate which results in a high heat transfer coefficient and Nusselt number.

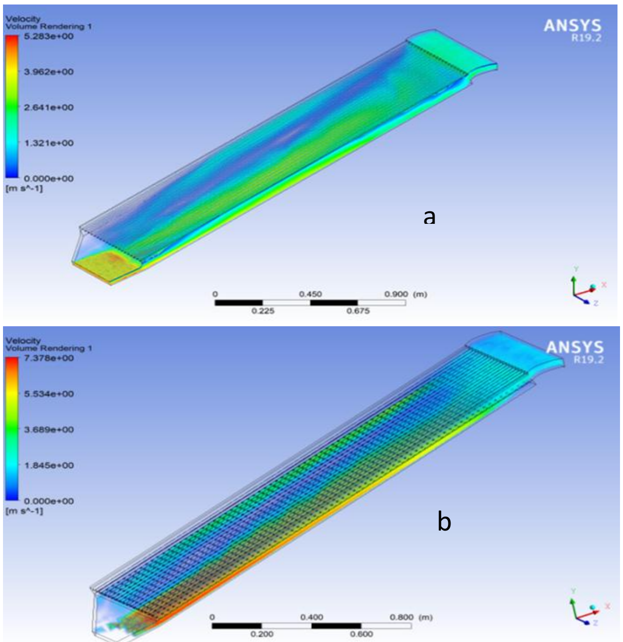


Figure 13. The 3-D contour plot of velocity without jet (a) and with D=6 mm (b) for 0.05kg/s mass flow rate

fig. 13 shows that for the collector with the jet plate as a result of pressure fluctuation and viscous effect flow distribution is not properly uniform throughout the absorber plate. A jet flow is shown near to the absorber through the jet plat which creates turbulence in the jet plate region which able to increase the heat transfer phenomenon with the increasing forced convection heat transfer coefficient. Air velocity passing across the collector is increased with jet plate compare to without jet plate

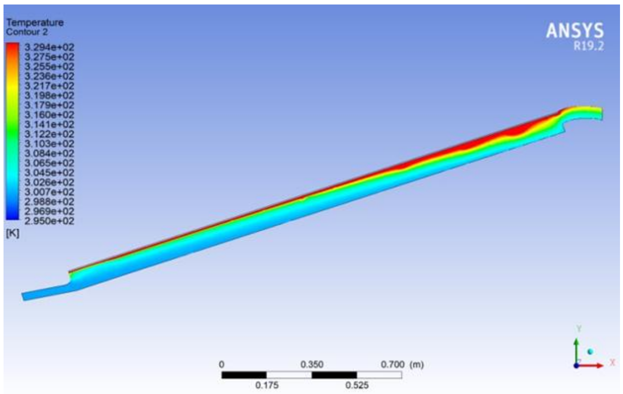


Figure 2. Temperature contour of collector without jet plate

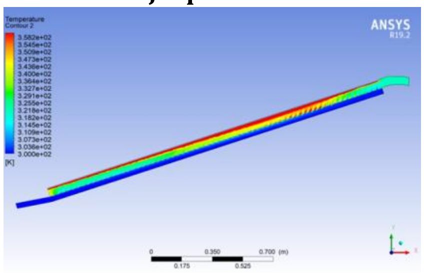


Figure 3 Temperature contour of collector D=10 mm jet plate.

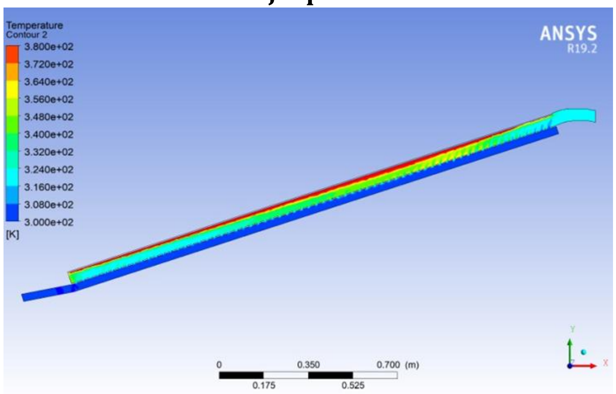


Figure 4 Temperature contour of collector D=8 mm jet plate.

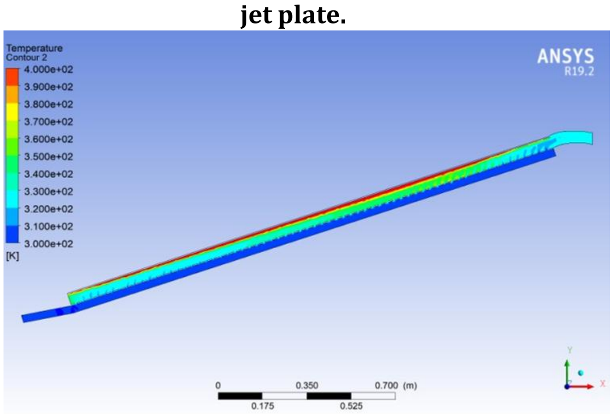


Figure 5 Temperature contour of collector D=6 mm jet plate.

From Figure 2 to Figure 5 the temperature contour inside the solar collector is displayed. The absorber plate has a normal temperature of 300°C at the inlet. Then, the temperature progressively increased to 329,358, 380, and 400 K for the mass flow rate of 0.05 kg/s for without jet plate, 10,8,6 mm diameter of jet plate respectively. The air above the jet plate removes the more amount of heat at the inlet then the air decreases its heat absorption capacity so that the temperature is raised from the entering to the exit point. There is a high heat rejection rate for a 6 mm diameter of the jet plate due to high turbulence created through nozzle flow.

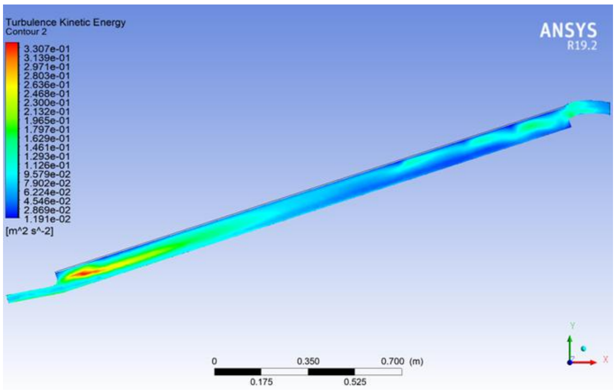


Figure 6 Contour of turbulent kinetic energy for a collector without a jet plate

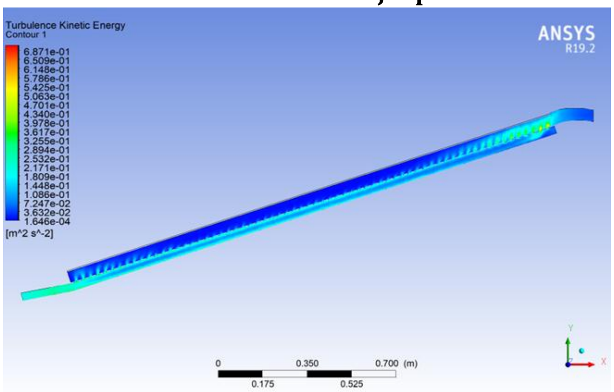


Figure 7 Turbulent kinetic energy contour for collector D=6 mm jet plate.

Figure 6 and Figure 7 shows the contour of turbulent kinetic energy for collectors without a jet plate and D=6 mm jet plate. It shows that the highest value of the turbulent intensity is found 0.687 m^2/s^2 near the exit of the collector on the top side of the jet plate for the collector with jet impingement on corrugated absorber plate and 0.33 m^2/s^2 the collector without a jet plate. Thus, it is found that the combined effect of formation of high velocity along with flow impingement effect and flow acceleration near the absorber surface leads to increased heat transfer rate. As a result, the instances of flow impingement, and flow acceleration zones are also higher which leads to improved heat transfer to the flowing air stream.

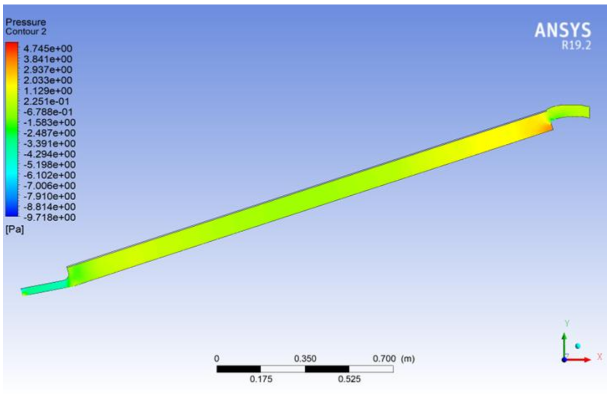


Figure 8 Pressure contour for a collector without a jet plate.

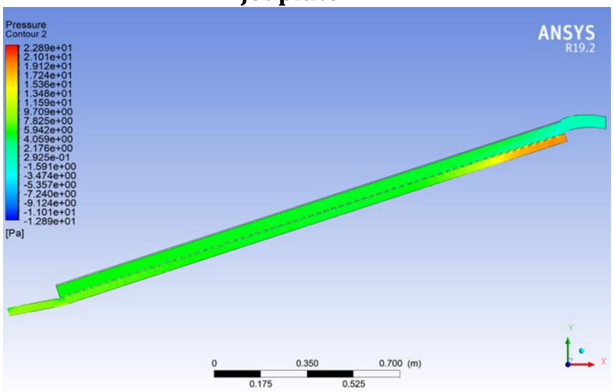


Figure 9 Pressure contour for collector D=6 mm jet plate.

Figure 8 and Figure 9 shows the contour of pressure for collectors without a jet plate and with a D=6 mm jet plate. The pressure distribution across the length of the collector is 4.7 and 22.8 Pa for solar collectors without a jet plate and with a D=6 mm jet plate respectively. So, the pressure drop for the collector with the jet plate is higher. This is due to high turbulence created as a result of the jet plate and high-pressure drop is created at the bottom of the jet plate.

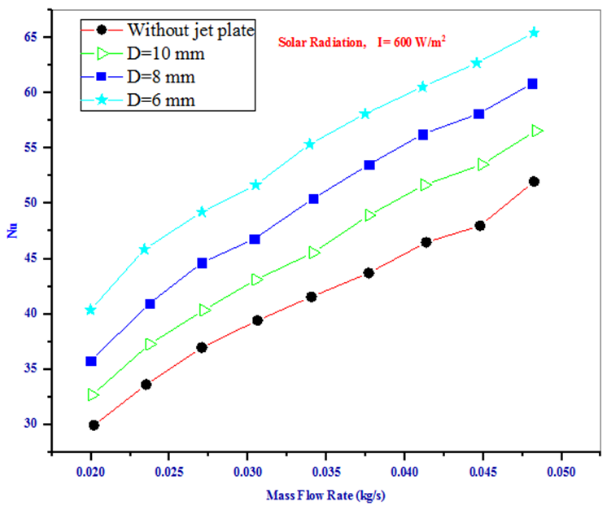


Figure 10 Nusselt number variation with a mass flow rate

Figure 10 shows the Nusselt number variation with mass flow rate for 6,8,10 mm jet diameter and without jet plate V-corrugated absorber plate, Nusselt number increases with increasing mass flow rate. This is because the mass flow rate increases the rate of heat transfer from the absorber plate resulting in higher values of Nusselt number. But it is observed that the value of Nusselt number is more in D=6 mm jet diameter on corrugated absorber plate as compared to others.

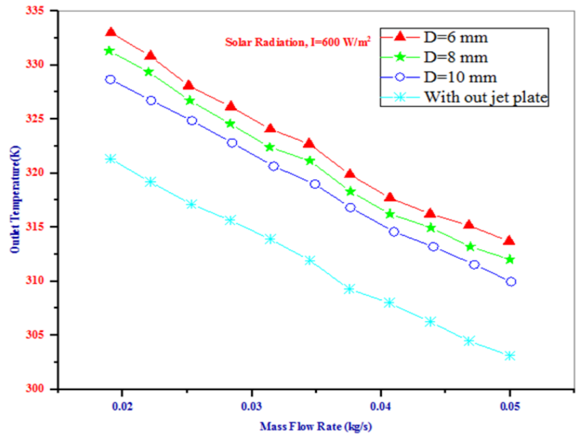


Figure 11 Outlet temperature variation with a mass flow rate

Figure 11 shows the Variation of Outlet temperature with mass flow rate for 6,8,10 mm jet diameter and without jet plate V-corrugated absorber plate, Temperature decreases with increasing mass flow rate. It is realized that at a higher flow rate the output temperature is almost similar for all the collectors. But for the lower flow rate, the D=6 mm collector gives better output with the maximum temperature of 333 K. Another observation is that all jet pate collectors have a better thermal performance with a mass flow rate. This shows better efficiency through the jet plate with a v-groove corrugated absorber plate related to the solar collector without a jet plate.

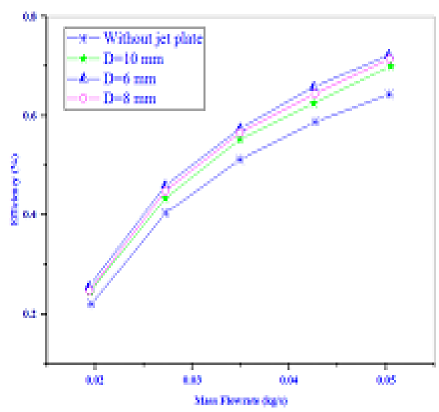


Figure 12 Variation of efficiency with the mass flow rate at a different jet diameter

It is detected from Figure 12 that the variation of thermal efficiency with the mass flow rate for the four types of collectors. It is quite evident from the curve the efficiency is increased with an increase in mass flow rate values for all jet diameters and without the jet. The V-corrugated collector without a jet plate has a maximum efficiency of 64.3 %, and the maximum efficiency of 72.3% is observed at a jet diameter of 6 mm. It is determined from the results that v-groove 6 mm diameter of jet plate collector has the highest efficiency value due to the larger contacting area created by the v-groove absorber and high turbulence created by the jet plate.

CFD Results validation

To validate this CFD simulation model, the results are related to experimental results of different geometries of similar trends for efficiency with Alsanossi M. Aboghrara et.al [5] as shown in Figure 13. It can be seen that there shows good agreement with experimental and CFD work. It has been observed that the proposed model of jet impingement on a corrugated absorber plate predicts the experimental data quite precisely.

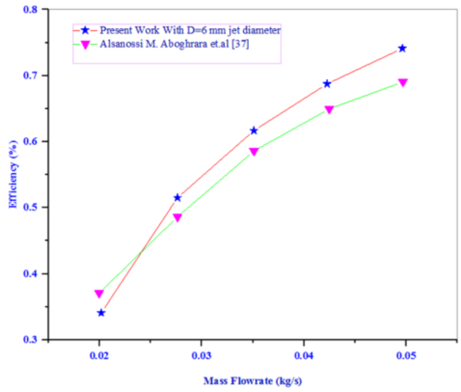


Figure 13 Validation of CFD Results

6. CONCLUSIONS

The 3-D CFD analysis of solar air heater with and without jet impingement on corrugated absorber plate and drying chamber has been carried out. The effect of jet diameter and mass flow rate on heat transfer enhancement and air distribution in the drying chamber is studied. Based on the results obtained the major conclusions are:

- The quality of the solutions gained from CFD simulations is highly within the adequate range as long as that CFD is an effective tool for predicting the behavior and performance of a solar air heater.
- Jet impingement on corrugated absorber plate is a real technique to improve the rate of heat transfer as related to corrugated absorber plate solar air heaters. It has been found that thermal efficiency increases with the increase in the turbulence of the air, which results in higher heat transfer. It was found that by using modified air heater thermal efficiency increased

by 8.0 %.

- Nusselt number enhancement of jet impingements on corrugated absorber plate with an increase in mass flow rate due to an increase in heat transfer surface area and turbulence. It gives Nusselt number of 27-45 for without jet plate and 40-60 for the jet plate.
- The efficiency increases with increasing air mass flow rate. This is because the heat transfer capacity depends directly on the mass flow rate, which induces higher velocities through the jet plate and more heat transfer from the absorber plate to the air.
- The maximum thermal efficiency 72.3 % is achieved on a corrugated absorber plate with a jet diameter of 6 mm and a mass flow rate of 0.05 kg/s.

RECOMMENDATION

- Based on the literature review and discussed in this work, it is recommended that the jet impingement on a corrugated absorber plate which could be used for solar drying and space heating applications. So, these benefits must be studied experimentally.

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CONSULTANCY AND RESEARCH WORKS

Balewgize A. Zeru, Nebiyu Bogale, Henok Mekonnen and A. Venkata Ramayya “Hot Bed Studies in a Biomass Fed Fluidized Bed Power Gasifier for Prototype Development Testing and Evaluation” (Principal investigator), project funded by Ethiopian Ministry of Water and Energy