International Journal of Research Publication and Reviews, Vol (5), Issue (11), November (2024), Page – 5668-5680

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

ANALYSIS OF SOLAR AIR HEATER IN INDIRECT SOLAR DRYER WITH MODIFIED COLLECTOR USING CFD

V. GOPI SANTH[1], V. PRUDHVI RAJ[2], R. SIVA[3], P. ANANDA RAO[4], R. SANDEEP[5], DR.U. SUDHAKAR[6], DR.K. SIVA PRASAD[7]

[1 2 3 4 5 6 7] Department of Mechanical Engineering, GMRIT Rajam, Andhra Pradesh, India,532127.

ABSTRACT :

The solar dryer is equipment that collects the sun's energy and utilizes it for drying agricultural produce. The project deals with the design and fabrication of an Indirect Solar dryer equipped with modified air collector designs. Due to the formation of the laminar sub-layer which is a thermal resistant layer over the collector surface the heat transfer rate from the collector to air is reduced. So, the study deals with the six types of collectors with different designs, these are tested with an indirect drying unit directly under the sun. Flat plate, Chevron pattern Plate, Plate with Cylindrical Baffles, V-type Plate, Plate with circular holes on cylindrical baffles, and Plate with alternative wing structures are selected, designed, and fabricated for the following study. Turbulent dissipation rate, air outlet temperature, Convective heat transfer coefficient, and collector efficiency are the factors that determine which one of them is the most effective design. The efficient pattern over the collectors was analyzed in CFD (Computational Fluid Dynamics) in Ansys. This study helps to select the best design suitable for definite application under certain atmospheric conditions.

INTRODUCTION :

Although many conventional SAHs are efficient in solar energy conversion, their thermal efficiency is still limited by the poor heat transfer characteristics of the absorber plates and unsatisfactory fluid flow patterns. Over the last few decades, significant concern has been given to upgrading the performance of these systems, especially through the application of passive techniques that improve the heat and fluid dynamics without consuming additional amounts of energy. A number of geometries have been studied, including rectangular ribs and diamond-shaped fins; some of these geometries have exhibited excellent performance and demonstrated great promise in the improvement of efficiency in heat transfer. CFD is utilized in simulation and study of fluid flow, heat transfer, and mass transfer process, and researchers are able to carry out extensive studies on various modifications and configurations in detail before performing the experiments. Further, various studies are performed using CFD by simulating different turbulence models to investigate the impact of roughness of the absorber plate and optimize the shapes of the ducts for better thermal-hydraulic performance. Another very interesting focus of the recent work has been associated with the introduction of Phase Change Materials into SAHs, in which latent heat is accumulated and released while in the process of phase transition, so that system performance is improved even more. Hybridizing PCMs with fins or porous medium, such as Raschig Rings, have been promising for enhancements in energy and exergy efficiencies in the operation of solar air heaters. Apart from improving the heat transfer, most of the research is also focused on reducing the pressure drop and fluid flow optimization. Various cross-sections of the duct, flow patterns, and different configurations are tested to optimize between heat transfer and the fluid friction. Thus, research into the design and performance of solar air heaters is bound to be critical with solar energy being at the forefront of sustainable energy production.

LITERATURE SURVEY :

This is a literature review of existing collector plate designs and their performance characteristics in terms of hydraulic diameter, Reynolds number, friction factor, pressure drop, heat transfer coefficient, and Nusselt number. Present study advances the existing study in order to compare the performance of six different collector plate designs, including an alternative wing structure, in enhancing the performance of SAH-based indirect solar dryers.

Hiwa Abdlla Maarof et.al (2023) [1] stated that non-flat plate absorbers have been found to improve the thermal performance significantly. Average thermal efficiency increased from 28.8% to 54.7%. The mass flow rate affects the thermal efficiency and outlet temperatures. The Nusselt number increased by 141.5% for non-flat plates. Optical and thermal properties were examined by making ray tracing and FEM simulations. The distributions of solar fluxes are not uniform on the absorbing surface.

Abbas S. Shareef et.al (2024) [2] defined that modified solar still improved the productivity of distilled water by 20%. The absorber plates were sliced, and W-shaped glass covers were used. Experimental and numerical studies were carried out based on climatic conditions prevailing in Iraq. Two types of glass covers are compared-pyramid and W-shape. Stainless steel absorber plates were utilized for this experiment.

Saïf Ed-Dîn Fertahi et.al (2023) [3] expressed that thin fins significantly accelerate the melting of Gallium, with a time reduction of 89%. Heat transfer coefficient increases by 96% with fins. Nusselt number increases by 91%, enhancing convective heat transfer. Melting rates are increased by about 30% in Case-3. Temperature T1 changes the mode of heat transfer from convection to conduction.

Marroquín-De Jesús Ángel et.al (2012) [4] mentioned that the absorbers used in the study included pipes and rectangular ducts. The water temperature for both absorbers increased up to 62.5°C. Simulation results showed more uniform Reynolds numbers. CFD is the consistence solving method for this research.

Angham Fadil Abed et.al (2024) [5] expressed that the triangular corrugation absorber collector showed the maximum efficiency. The maximum temperature of the water was 51.7°C in July. The maximum temperature difference that was observed was 14.9°C in November. Efficiency was higher under load conditions than under no-load conditions. Numerical simulations compared very well with the experimental results.

A.Boulemtfes-Boukadoum et.al (2014) [6] reported that Numerical analysis, in the form of improved heat transfer, is generated in solar air collectors. Artificial rectangular ribs increase the thermal performance with minimal friction loss. k-w SST turbulence model yields better results. Global thermohydraulic performance parameter indicates the effective use of rib. Flow visualization gives information about the separation and reattachment zones.

Anil Kumar et.al (2023) [7] given that twisted tape inserts considerably enhance the heat transfer rates in the collectors. Maximum Nu Twist achieved at Re no 17,000 and THDh of 0.022. Height inserts larger in value will result in degradation of the heat transfer. Twisted tape enhances turbulence enhancement, and thus the heat transfer rates enhance. Pressure drop favors the twisted tape over smooth surfaces.

Mohamed A. Alnakeeb et.al (2023) [8] notified that vortex generators improve thermal-hydraulic performance of solar air heaters. Rectangular VGs attain the maximum Nusselt number at 45º angle. Trapezoidal vgs attain a peak Nusselt number at 30º angle. Delta VGs attain the highest Nusselt number at 60º angle. Friction factor decreases with increase in angle of attack. Thermal-hydraulic performance is significantly higher with vortex generators.

Sachin Sharma et.al (2021) [9] informed that the six different baffle shapes of solar air heaters are studied. It is found that the highest thermal performance was shown by sine wave baffles. The maximum recorded thermal performance is 2.05 at Re = 15000. The results obtained with CFD are validated with the experimental data. Deviation between numerical and experimental results is +11%. Baffle shape affects heat transfer and friction factor considerably.

Sameer Ali Alsibiani et.al (2023) [10] publicizes That best performances of all others are found in circular jet holes. THPP is found to be maximum for circular jet holes. The diameter ratio of the jet has a significant effect on the thermal performance. Nusselt numbers increase with an increase in Reynolds number, whereas THPP decreases. Nusselt numbers up to 4.5 times higher. THPP increases and then decreased with stream wise pitch. The study proves efficient in optimizing the performance of solar air heaters.

Jitesh Rana, Anshuman Silori et.al (2019) [11] conveyed that V-shaped ribs enhance heat transfer in a solar air heater. Most important value of Nusselt number was obtained for multi V-shaped ribs with gap. A sub-laminar layer has decreased efficiency in transferring heat. The gaps between the ribs are expanded, which increases the flow and heat transfer. The turbulence intensity increases with the vortex generation and heat transfer.

J.L. Bhagoria a, J.S. Saini b et.al (2001) [12] disclosed that Artificial roughness enhances the heat transfer coefficient in a solar air heater. Reynolds number variation from 3000 to 18000 has been taken in this experimentation. Nusselt number and friction factor correlation have been developed statistically. The range of geometric and flow parameter combinations are adequately covered. Equations confirm the accuracy of experimental data.

Atul Lanjewar, J.L. Bhagoria et.al (2011) [13] revealed that W-shaped ribs are for better heat transfer enhancement in solar air heaters. Experiments were conducted to know the thermo-hydraulic characteristics, heat transfer coefficient and friction factor. Parameters The duct: width to height taken as 8.0; pitch of relative roughness 10. Reynolds number: 2300 to 14000.W-shaped is superior to that of the V-shaped ribs in terms of thermo-hydraulic performance.

Anil Singh Yadav, J. Bhag et.al (2013) [14] announced that present study deals with heat transfer across the case of a roughened solar air heater. The small diameter transverse wire ribs provide major enhancement in heat transfer. An increase in the relative roughness height augments Nusselt number and friction factor. An increase in relative roughness pitch is decreasing the efficiency of heat transfer. Maximum thermal enhancement factor found is 1.65. Artificial roughness increases friction losses in the duct.

Arun Shrivastava1, Dr. Manoj Ayra2 et.al (2020) [15] stated that RNG k-ε model closely follows the experimental values. Average Nusselt number improves when the Reynolds number is increased. Maximum Nusselt number occurs at 43.577 for a Reynolds number of 10,000. Average friction factor decreases with an increasing Reynolds number. Circular as well as square rib roughness enhances the thermal performance. Heat transfer increases energy and cost saving.

Abdullah Alrashidia, Ahmed A. Altohamy et.al (2024) [16] communicated that innovative design in SAH improves the transfer of heat through V-shaped fins. The optimum tilt angle to attain this maximum efficiency is 20°, thus boosting the gain in heat. The proposed SAH can significantly increase air temperature and efficiency. Optimal tilt angle for efficiency is 20°, which enhances heat gain. The proposed SAH can significantly increase air temperature and efficiency.

Anil Kumar et.al (2013) [17] announced that Artificial roughness facilitates improvement in heat transfer with solar air heater ducts. V-shaped and multi v-shaped ribs help enhance heat transfer and friction factor. Among these, multi v-shaped ribs with gap report the maximum thermo-hydraulic performance. CFD analysis is found to be effectively predicting heat transfer as well as the flow characteristics of the ducts. Enhanced parameters are optimal for the performance of roughened solar air heater ducts.

J.L.Bhagoria AnilSinghYadav et.al (2013) [18] declared that the performance of the solar air heater is well predicted by the CFD. The k-e model by the renormalization group gave the best results for simulating the considered problem. Nusselt number increases as the value of the Reynolds number is higher. Chamfered ribs enhance the heat transfer with little friction. The local heat transfer coefficient shows that the turbulence intensity reaches its peak. Two-dimensional models are more efficient than three-dimensional models for simulation purposes.

Dawit Gudeta Gunjo, Pinakeswar Mahanta et.al (2017) [19] revealed that a bent riser tube collector is evaluated with regard to performance in a CFD model. Maximum thermal efficiency was 71% at an outlet temperature of 60°C. Minimal deviation error validates the predictive capability of this model. Exergy efficiency increases as collector heat loss and solar insolation increase. The solar collector heats feedstock for thermophilic microbes very effectively.

Srishti , Paras et.al (2024) [20] disclosed that solar still reached 1.5 kg m−2 at 11:00 h. Steady-state production rate was 8.6 kg m^2 day. To achieve maximum productivity, the optimum angle of inclination was found to be 29 degrees for 1 cm of water depth. The error percentage in the power model calculation was about 12.4% compared with that in the correlation in the literature. CFD is economical and efficient to use for the design of a solar still.

Imran Nazir Unar1 , Ghulamullah Maitlo2 et.al (2020) [21] communicated that 3D-CFD model was developed for solar flat plate collectors. Water exhibited more thermal efficiency than air. The increase in temperature was 79 °C for water, whereas it increased by 73 °C for air. The results were compared to experimental studies to validate the study. Thermal efficiency is strongly dependent on fluids used. Numerical simulations are performed for six different mass flow rates.

Sahand Hosouli a, Nathan Formosa et.al (2024) [22] chronicled that H-pattern PVT collector shows anomalous efficiency values compared with reference collector. Efficiency correlation because the glass cover materials used are identical. The H-pattern collector is more efficient than the reference one as the temperature coefficient increases. Be careful because results are overestimated. A parametric study is performed to determine the effects of heat losses and flow rate variation. An expansion in structural validation for different collectors is also proposed.

Rahul Kumar a, Sujit Kumar Verma et.al (2023) [23] recorded that roughness increases the performance of solar air heaters. V-ribbed enhances more heat transfer with increased friction factors. Heat transfer takes place more efficiently in smooth plates as compared to the rough plates. Maximum thermal efficiency was achieved at the solar intensity of 750 Wm2. Average thermal efficiency came to be higher for the roughened plates as compared to smooth plates.

Ali Ahmadkhani, Gholamabbas Sadeghi et.al (2021) [24] narrated that This study explored the thermal features of double pass solar air heaters. Matrix use enhances the thermal efficiency, but at the expense of the thermohydraulic efficiency. It is shown that the upstream recycling pattern is like the matrix-based systems.The new procedure requires less energy and cost without the involvement of a matrix. The range of varying flow rates, reflux ratios, and solar intensities were covered in the investigations.

Nada Baobaid a, b, Mohamed I. Ali et.al (2022) [25] described that three TPMS-based heat sinks were studied under free convection. Gyroid sheet was found to present very good thermal performance for open surfaces. It was noted that surface temperature is maximum in such a configuration when all sides and top surfaces are open. Compared with conventional heat sinks, the TPMS based heat sinks showed up to 48-61% better performance. Permeability has influence on the flow resistance in the case of porous medium of TPMS. The Nusselt and Rayleigh number correlations were empirically derived from the computational study.

Hossein Ebadi , Antonio Cammi et.al (2023) [26] detailed that three TPMS-based heat sinks were studied under free convection. Gyroid sheet was found to present very good thermal performance for open surfaces. It was noted that surface temperature is maximum in such a configuration when all sides and top surfaces are open. Compared with conventional heat sinks, the TPMS based heat sinks showed up to 48-61% better performance. Permeability has influence on the flow resistance in the case of porous medium of TPMS. The Nusselt and Rayleigh number correlations were empirically derived from the computational study.

Nurul Jannah Yusaidi , Mohd Faizal Fauzan et.al (2024) [27] accounted that three TPMS-based heat sinks were studied under free convection. Gyroid sheet was found to present very good thermal performance for open surfaces. It was noted that surface temperature is maximum in such a configuration when all sides and top surfaces are open. Compared with conventional heat sinks, the TPMS based heat sinks showed up to 48-61% better performance. Permeability has influence on the flow resistance in the case of porous medium of TPMS. The Nusselt and Rayleigh number correlations were empirically derived from the computational study.

Mostafa Esmaeili Shayan a, Farzaneh Ghasemzadeh, et.al (2023) [28] relayed that the use of artificial roughness in the solar air heaters increases heat transfer, and maximum enhancement occurs with a staggered arrangement. The geometry of the roughness has a dominant influence on the thermal performance. Elements of transverse ribs combined with perforations adequately reduce the recirculation effects. Experiments along with CFD analysis validate results concerning convection heat transfer.

Rohit Misra a, Jagbir Singh et.al (2020) [29] transmitted that triangular duct with V-down ribs enhance heat transfer performance.Maximum heat transfer is seen at P/e = 10 and $\alpha = 45°$. The Nusselt number and friction factor rise very sharply with a function of roughness.It reaches its maximum value of 2.064 with the proposed roughness. The model results are comparing well with the experimental data. The triangular cross-section duct minimises the frictional resistance and pumping power.

Mostafa Esmaeili Shayan a, Farzaneh Ghasemzadeh, et.al (2023) [30] broadcased the experiments on a solar air heater were performed to check the impact of heat transfer using two types of S-shaped roughness configurations: staggered and inline. transverse ribs with perforation reduce the recirculation zone formation. The present work presents the staggered S-shaped features used for the promotion of enhancement.

Ji-Long Yao, Hao-Ye Zheng et.al (2023) [31] circulated that solar thermochemical methane dry reforming appears to be a promising route for storing energy. Cylindrical porous foam reactor increases the heat uptake efficiency. Even with improved heat transfer, a slight temperature gradient is insignificant on conversion. The position of the reactor influences the process of reaction and light transmission. In fact, different models of reactor affect transport processes of light as well as heat.

Mohamed Selmi, Mohammed J. Al-Khawaja et.al (2008) [32] disclosed that the CFD model is able to correctly simulate the performance of the flat plate solar collector. The experimentally measured outlet temperatures are validated by the predictions of the CFD model. Water flow has significant influence on temperature distribution in the collector. Maximum temperatures in the absorber plate are set at 370 K with zero-flow conditions. Simulated temperatures highly correspond to experimental readings at several conditions.

Dawit Gudeta Gunjo, Pinakeswar Mahanta et.al (2017) [33] conveyed that a new bent tube solar collector was investigated. The work based on exergy and energy analyses to investigate its performance. Numerical models, validated against experimental results showed good agreement. Peak solar thermal efficiency 71%. Daily average thermal efficiency reached 54%, which is larger than that for straight tube FPC. Inlet and outlet water temperature increases nearly linearly.

Madagonda K. Biradar, Dipal N et.al (2022) [34] publicized that CO2-based systems are more efficient than water. Subcritical vapour CO2 represents 140% greater exergy efficiency than water. High Reynolds and Nusselt numbers were attained with the CO2 system. While using water, there is a fall in efficiency during winter due to freeze risks. Nano-fluids improve performance of a solar water heating system. The study helps design compact solar water heating systems.

Sahand Hosouli a, Nathan Formosa b et.al (2024) [35] announced that a new H-pattern absorber design reduces PV cell cracking. It decreases the thermal expansion by 20%. The efficiency of the proposed design has compared with the reference collector and gives a better value. All efficiency factors such as thermal, electrical, and overall are improved by 10%, 2%, and 8%. The least cavity design has 2 mm. Deviations in efficiency have been found to occur at lower collector performance coefficients.

Rahul Kumar a, Sujit Kumar Verma et.al (2023) [36] recorded that it has been found that roughness can enhance the efficiency of solar air heaters. V-ribbed plates have both improved heat transfer and friction factor. It has a higher heat transfer potential than the roughed plate. Maximum thermal efficiency occurs when the solaire intensity reaches 750 W/m². Its average efficiencies of the plates with surface roughening are greater than those of the smooth plates.

Mostafa Esmaeili Shayan a, Farzaneh Ghasemzadeh et.al (2023) [37] stated that the experiment involved heat transfer in roughened solar air heaters. The two S-shaped arrays of interest were staggered and inline. The geometry of the surface roughness has been found to play a significant role in the thermal behavior and heat transfer. The recirculation zones might be minimized by transverse ribs combined with perforations. In this present study, the aim is to investigate the effects of staggered S-shaped features.

Rohit Misra a, Jagbir Singh et.al (2020) [38] narrated that triangular duct with V-down ribs increases the performance of heat transfer. Maximum heat transfer occurs when $P/e = 10$ and $\alpha = 45°$. Nusselt number increases with a very high value of friction factor due to roughness.THPP obtained at 2.064 using proposed roughness configuration. Triangular cross-section duct possesses low pumping power. The relative pitch of the roughness configuration has a strong influence on the thermal performance.

Dawit Gudeta Gunjo, Pinakeswar Mahanta et.al (2017) [39] transmitted that a new helical tube solar collector was designed and made. Maximum thermal efficiency obtained was 71% at outlet temperature of 60°C. The developed CFD model was validated by the experimental result. Exergy efficiency increases with collector heat loss and solar insolation. Daily average thermal efficiency was 54%, higher than straight tube FPC.

Nurul Jannah Yusaidi*, Mohd Faizal Fauzan et.al (2024) [40] disclosed that Performance of a double pass solar air heater: This paper presents the performance of a double pass solar air heater. The staggered-diamond shape of the fins is chosen for maximizing the convective heat transfer. Maximum thermal efficiency attained is 62.01% at certain specific conditions. Mass flow rates as well as solar radiation have considerable influence on the performance. Tumbling motion caused due to diamond fins increases turbulence and thus enhances the efficiency of heat transfer.

METHODOLOGY :

3D Designing of Collector

The solar air heater collector was designed. The design parameters included collector dimensions, absorber plate material, baffle geometry, and inlet/outlet configurations. The 3D model was created to visualize and optimize the collector's performance. Modifications were made to the design to improve airflow and heat transfer.

CFD Designing

ANSYS Fluent was used for CFD modeling. The 3D geometry was imported, and mesh generation was performed. Boundary conditions such as inlet velocity, temperature, and outlet pressure were defined. Turbulence models (k-ε or k-ω) were selected to simulate fluid flow and heat transfer.

CFD Simulations

Steady-state and transient simulations were run to analyze temperature distribution, airflow patterns, and pressure drop. Parametric studies were conducted to investigate the effects of baffle angle, inlet velocity, and heat flux on system performance. CFD results were visualized using ANSYS Postprocessor.

Procurement of Raw Materials

Raw materials, including absorber plate, insulation, and thermocouples, were procured based on design specifications. Materials were selected for durability, thermal efficiency, and cost-effectiveness.

Fabrication of Collectors

The collector was fabricated using cutting, bending, and welding techniques. Insulation was installed to minimize heat loss. Quality control checks ensured dimensional accuracy and structural integrity.

Fabrication of Inlet and Outlet

Inlet and outlet pipes were fabricated using suitable material and fittings. Connections were made to ensure leak-free operation.

Painting of Collectors

The collector was painted with a black coating to enhance solar radiation absorption. Primer and paint were applied following standard procedures.

Assembly of Fabricated Parts

Fabricated components, including collector, inlet, and outlet, were assembled. Thermocouples, orifice, and manometer were installed.

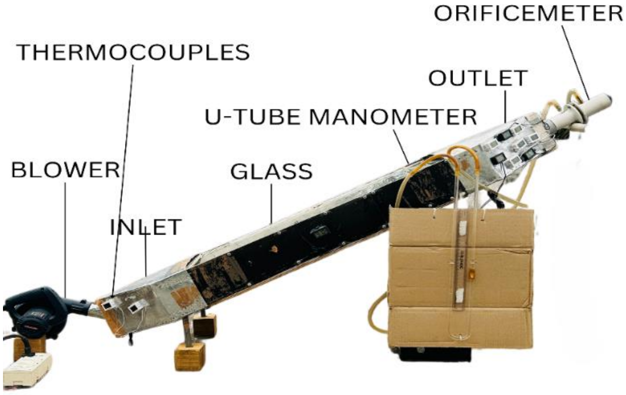
Arrangement of Thermocouples, Orifice, Manometer, Blower

Sensors were strategically placed to measure temperature, flow rate, and pressure drop. The blower was connected to simulate airflow.

Results Evaluation with Experimental Outcomes

Experimental data was compared with CFD results to validate simulation accuracy. Errors were analyzed, and conclusions were drawn. Recommendations for design optimization were provided based on experimental and simulation results.

Setup :



COLLECTOR

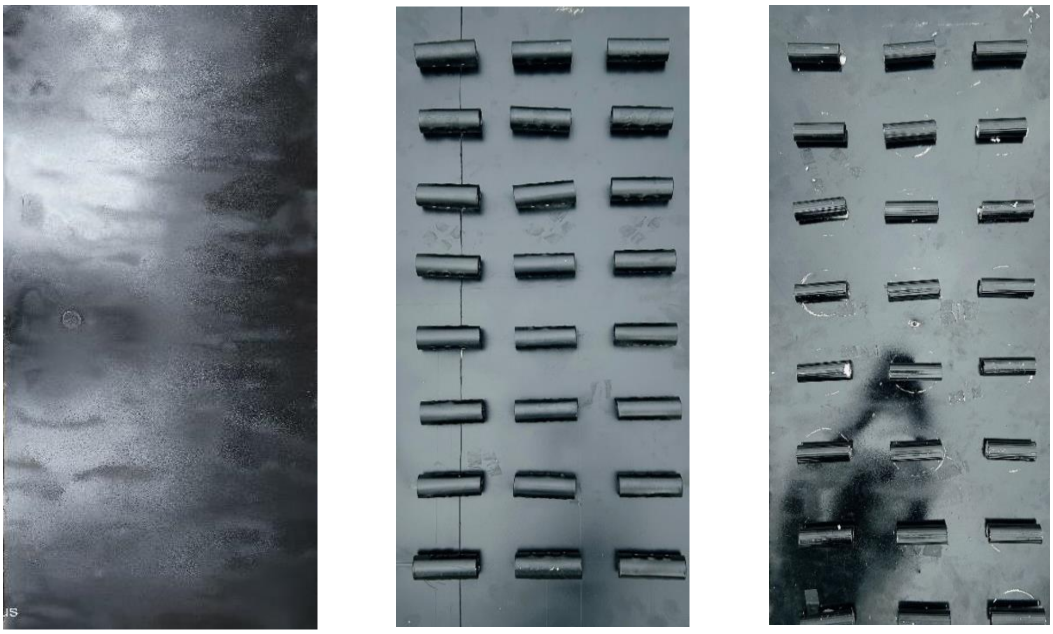


Figure : Flat Plate, Horizontal Baffle plate with holes, Horizontal Baffle plates

Figure: V-Type plate, chevron plate, Alternative wing structured

CFD Simulation in ANSYS

Step 1: Geometry and Mesh Setup

- Some may include designs of your solar air heater and collector plates geometry design in ANSYS Design Modeler or any other CAD software and description of inlet and outlet sections, boundary conditions, and material properties as air fluid and steel for the collector plate.
- Geometries are resolved appropriately so that the results are correct (fine near surfaces, coarse in the bulk flow region).
-

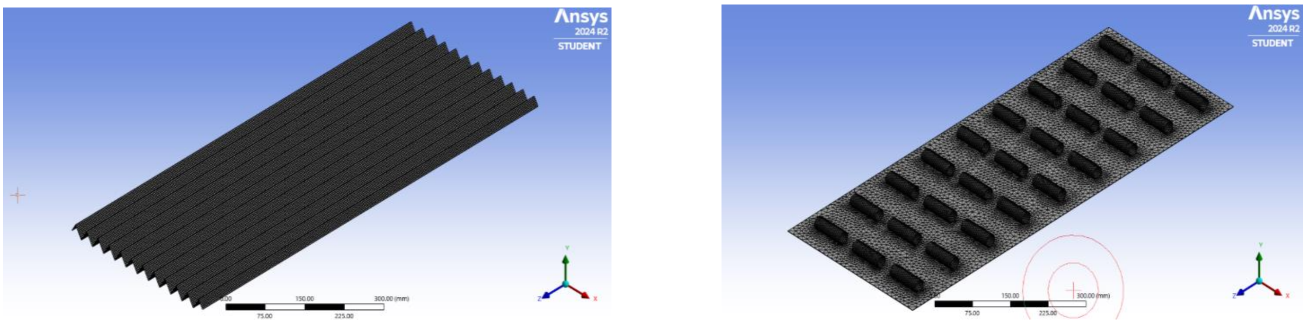


Figure: V-type & Horizontal plate in CFD

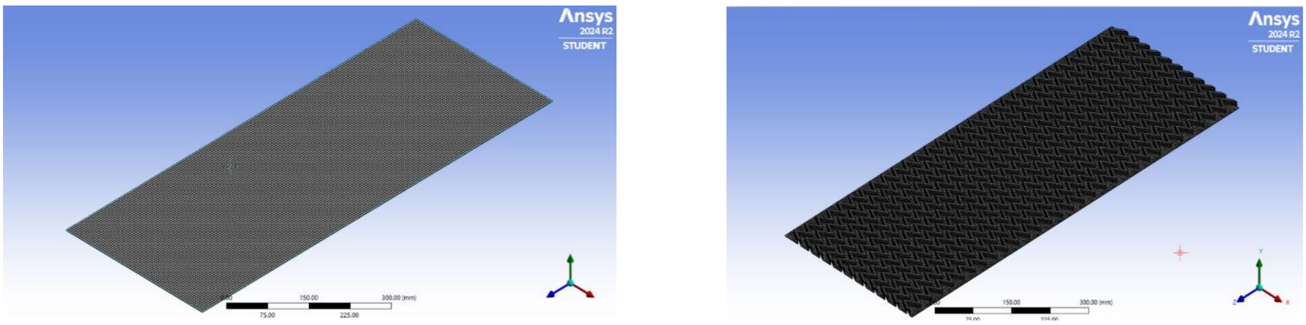


Figure: Flat & Chevron plate in CFD

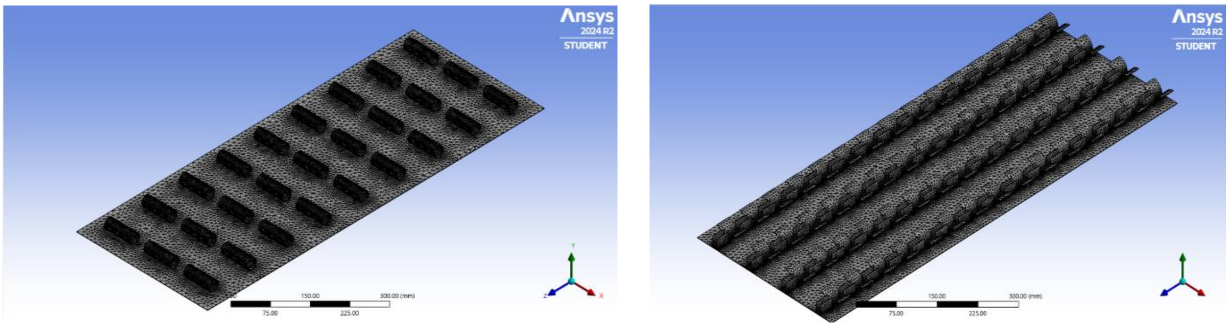


Figure: Horizontal baffles with holes' plate, Alternative wing structure in CFD

Step 2. Boundary Conditions and Solver Setup

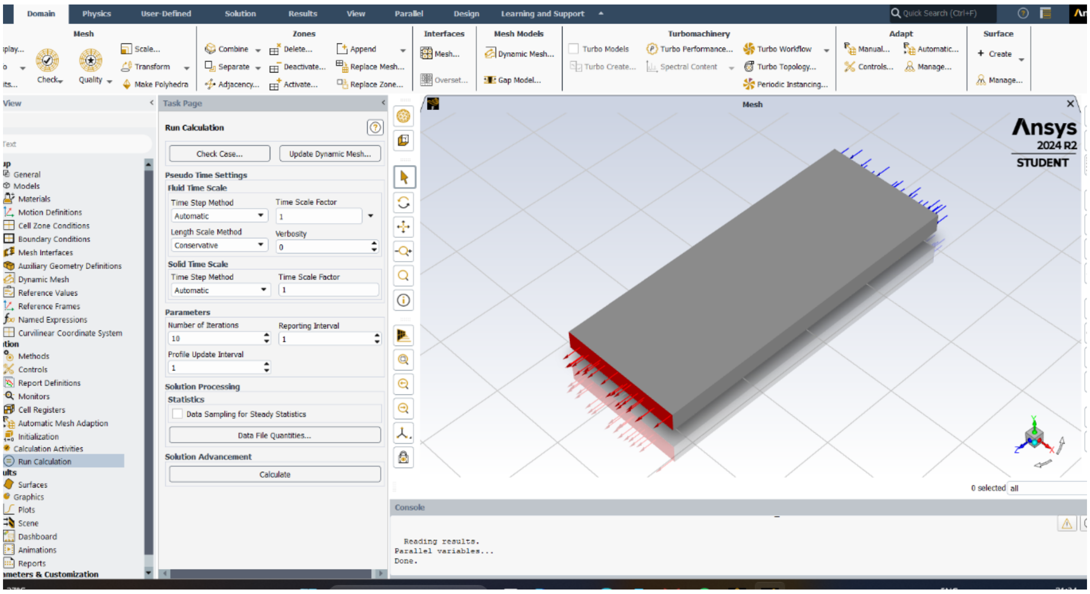


Figure: Boundary Conditions in CFD

- Set the inlet velocity according to the experimental flow rate measured with the orifice meter.
- Specify the thermal boundary conditions, namely the heat transfer coefficient and the solar radiation input on the collector plate surfaces.
- The appropriate wall boundary conditions shall be set, for instance no-slip for the solid surfaces.
- The outlet pressure and pressure boundary condition have to be defined on the basis of the manometer readings.
- The choice of appropriate solver and solution strategy that should be applied for the transient and steady-state simulation.

Step 3: CFD Simulation Running

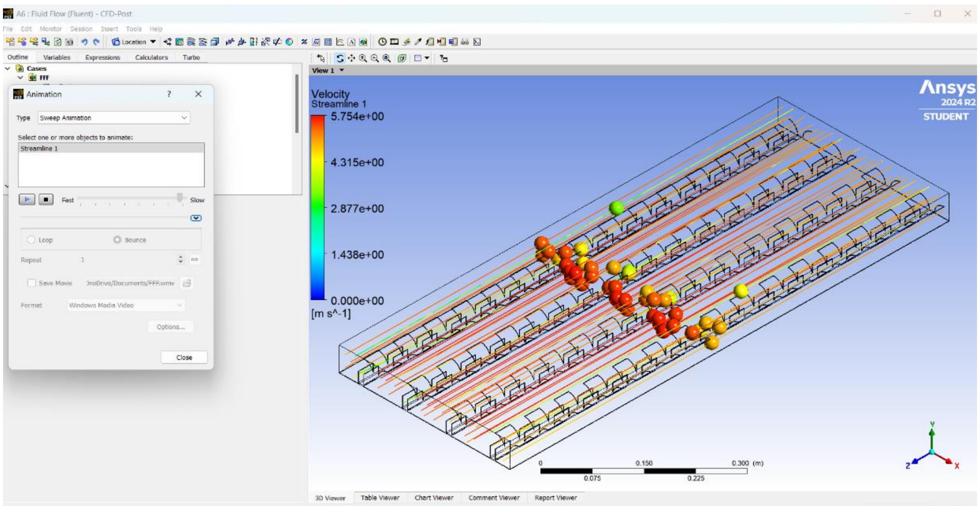


Figure: Streamline particle flow in medium

- For each collector plate configuration, run the CFD simulation.
- Observe the convergence of the solution, making sure that the residuals of the solution are satisfactory.

Step 4: Velocity contours

Such information will be important to understand how collector plate design is impacting the flow pattern and therefore affects the thermal and hydraulic behavior of the system. Uniform flow distribution is ensured and the heat transfer is enhanced for the complete surface area; nonuniform flow (such as stagnation zones or recirculation regions) may cause local ineffectiveness. Contours are an effective way to indicate regions of enhanced turbulence, hence enhancing convective heat transfer by mixing heated air near the plate with cooling air farther away from it. Velocity contours of Horizontal baffles with holes' plate, Alternative wing structure in CFD High-velocity regions typically indicate improved convective heat transfer but may also increase friction losses, leading to higher pressure drops. To make comparisons, velocity contours for different collector designs may be studied to compare the relative ability of the designs in promoting uniform and turbulent airflow. This contour visualization is important in finding the best balance between turbulence enhanced heat transfer and minimum energy loses through pressure drop. The ideas gained from velocity contours will be essential in manipulating the design, hopefully getting the best possible balance of heat transfer performance and energy usage.

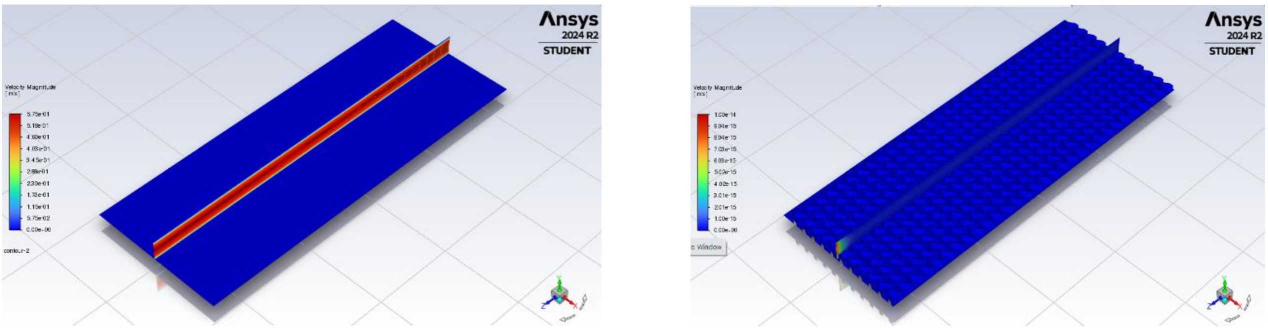


Figure: Velocity contours of Flat & Chevron plate in CFD

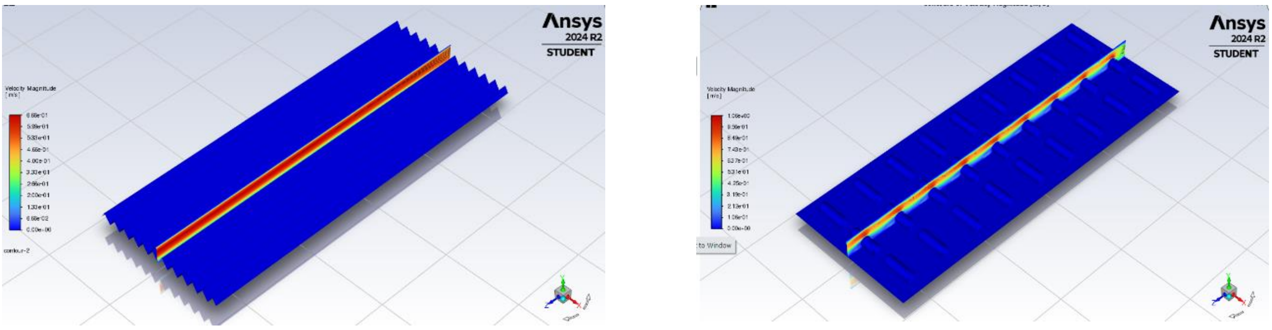


Figure: Velocity contours of V-type & Horizontal plate in CFD

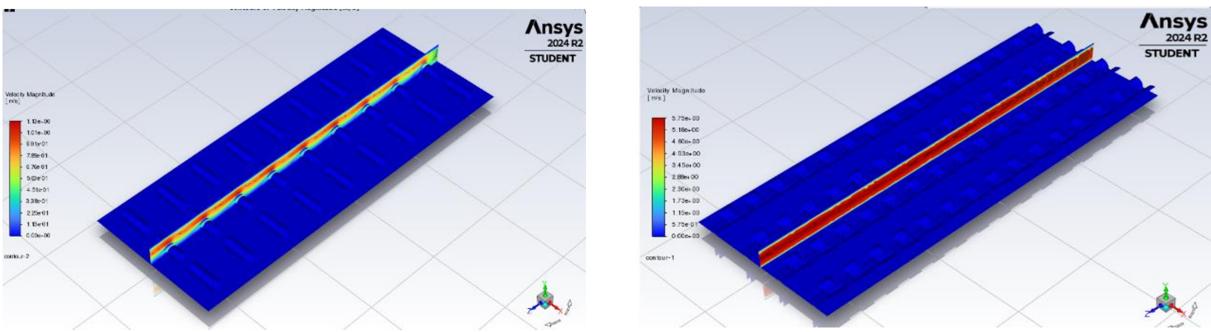


Figure: Velocity contours of Horizontal baffles with holes' plate, Alternative wing structure in CFD

Step 5: Temperature Contours

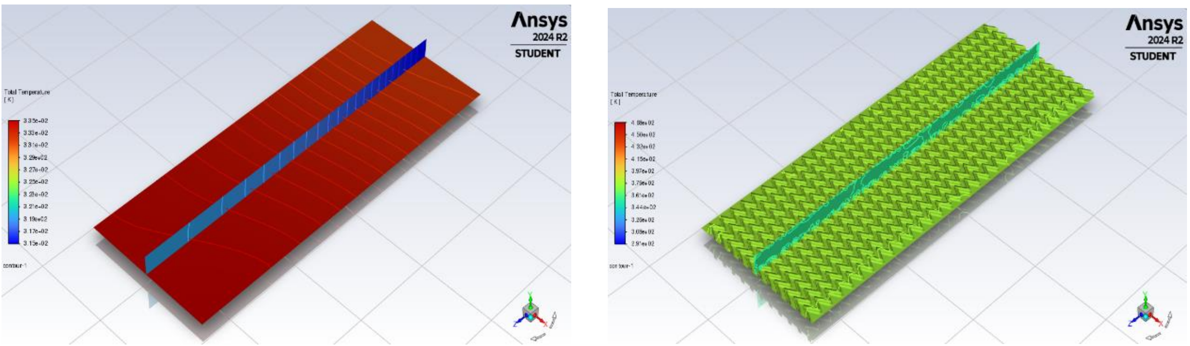


Figure: Temperature contours of Flat & Chevron plate in CFD

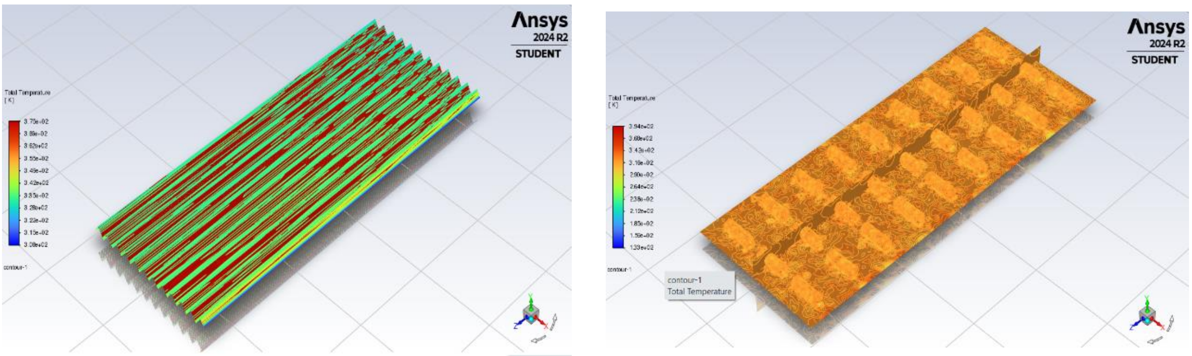


Figure: Temperature contours of V-type & Horizontal plate in CFD

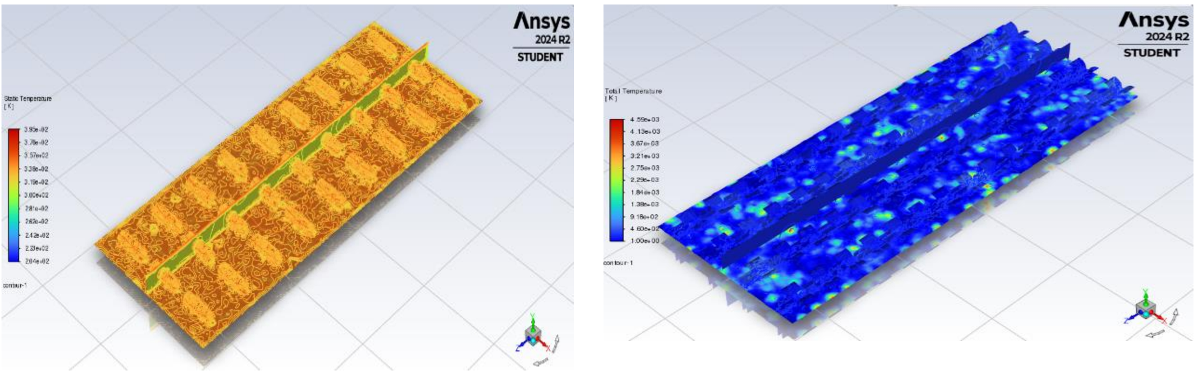


Figure: Temperature contours of Horizontal baffles with holes' plate, Alternative wing structure in CFD

Temperature contours of a CFD simulation give an enhanced visualization of how the thermal energy is distributed along the airflow and onto the collector plate inside the SAH. These contours are important when evaluating the thermal performance of the system, to assess the effective efficiency of heat transfer and point to possible improvements. A uniform temperature gradient along the collector plate implies effective heat transfer from the plate to the airflow. Maximum heat transfer efficiency is accompanied by a sharp rise in the air temperature as it crosses the collector plate. Temperature contours indicate the growth and increase in thickness of the thermal boundary layer over the plate. For roughened or baffled plates, temperature contours show areas where turbulence interferes with the thermal boundary layer and encourages mixing between hot air at the plate surface and bulk cooler air. A higher and flatter the outlet temperature indicates a better plate utilization of thermal energy. Temperature contours provide a clear indication of the thermal performance of the collector design that highlights heat transfer patterns, boundary layer behavior, and outlet air heating.

RESULTS AND DISSCUSIONS :

The collector plate design of a solar air heater (SAH) affects the heat transfer rate, pressure drop, and overall thermal efficiency of the device. This work aims to compare six various configurations of collector plates including conventional and advanced designs to evaluate their effectiveness in enhancing the thermal performance of a SAH used in an indirect solar dryer. The designs selected include a black painted plain plate, transverse cylindrical baffles, baffles with holes, V-shaped folded aluminum sheet, chevron patterned aluminum sheet, and the alternative wing structure.

The hydraulic diameter, Reynolds number, friction factor, pressure drop, heat transfer coefficient, and Nusselt number were determined for each of the configurations under uniform conditions. The experimental results reveal the influence of design parameters like flow turbulence promoters, surface roughness, and flow disruption on enhanced heat transfer and airflow characteristics.

This section provides an in-depth discussion of the results obtained, comparing the performance of each plate. Special focus has been placed on the interplay between improvement in heat transfer and pressure drop, which is critical to efficiency increase without too significant an increase in energy consumption. The discussion also brings out the special characteristics of the alternative wing structure, weighing it against its prospects as a novel and high-performance design.

Nusselt Number vs Heater Length

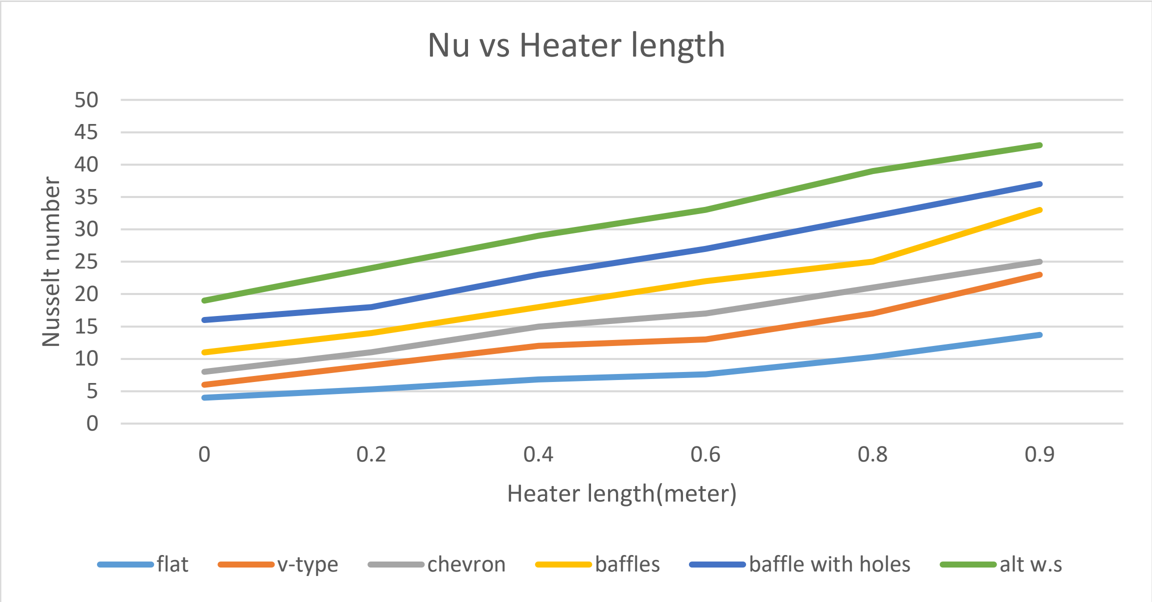


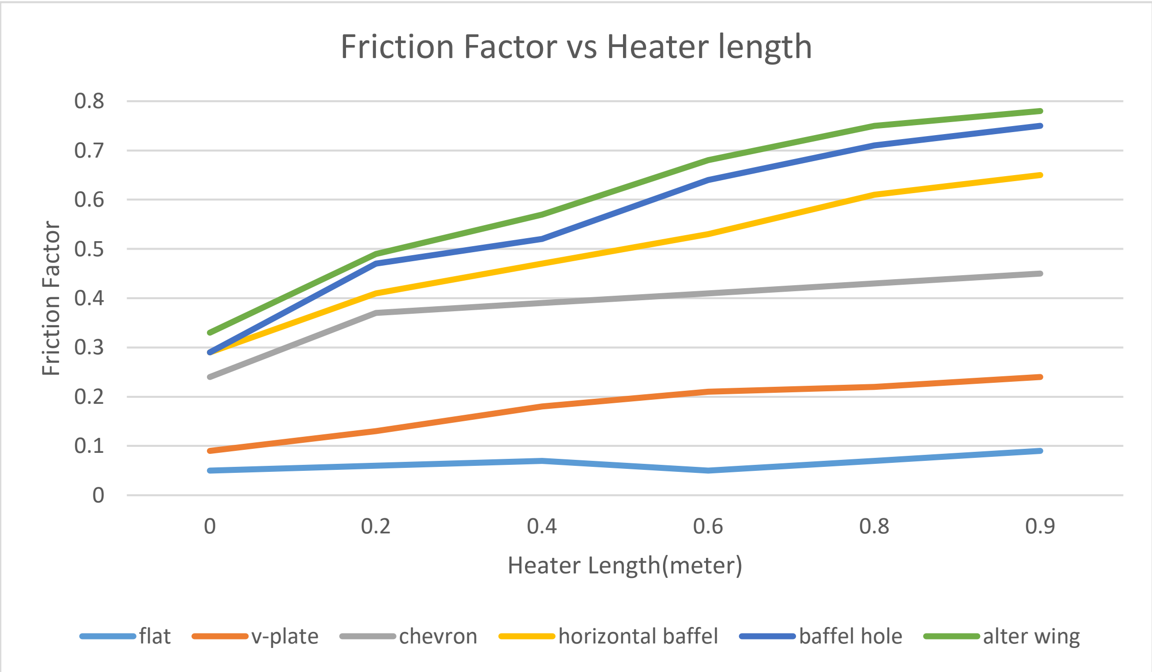
Figure: Variation of Nusselt number through Heater length

Above figure shows that the higher the Nusselt number means that greater heat is transferred to the air, warming it, and the process of drying takes place more rapidly [3].

Surface modifications, flow adjustments, or design changes can dramatically improve Nu, leading to greater system-wide efficiency and performance during drying [15].

Friction Factor vs Heater Length

Figure: Variation of Friction Factor through Heater Length



A higher friction factor usually means a more turbulent flow, which intensifies the convection mechanism or heat transfer (a larger Nu) Ribs demonstrated to enhance both heat transfer and friction factor [17].

Turbulators increase the heat transfer due to increased friction factors [23].

The friction value increases the energy consumption and results in decreasing the system net efficiency [15].

Time vs Outlet Temperature

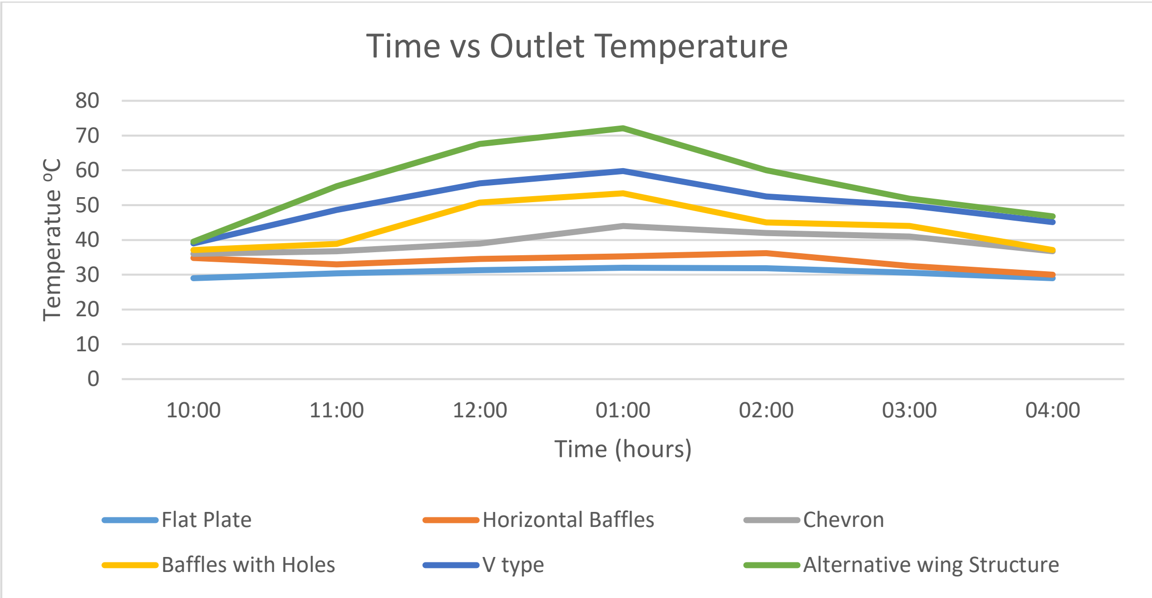


Figure: Variation of outlet temperature thought a day

Gradual increase in the outlet temperature with the increase in solar radiation [13].

Maximum outlet temperature due to high radiation and steady state of the collector.

The outlet temperature keeps on reducing as the intensity of the sun decreases [37].

A lower rate of airflow increases residence time for air in the collector, thereby raising the outlet temperature.

CONCLUSION :

Thermo-hydraulic performance characteristics of solar air heater with black painted plain plate, transverse cylindrical baffles, baffles with holes, V-shaped folded aluminium sheet, chevron patterned aluminium sheet, and alternative wing structure have been investigated and compared based on comprehensive CFD simulations carried out at a constant Reynolds number of 1714. The best performing design has been determined on the basis of average Nusselt number (Nu_b) and average friction factor (f_b) characteristics. The following conclusions are drawn from the present investigation:

1. The use of roughness elements such as baffles, chevron patterns, and alternate wing structures on the absorber plate enhances considerably the thermal performance of a solar air heater by increasing turbulence and heat transfer rates.
2. Local Nusselt number (Nu_{loc}) and local friction factor (f_{loc}) exhibit distinct variations near the leading and trailing edges of the roughness elements. Increased turbulence near the leading edge improves heat transfer, while flow reattachment near the trailing edge results in reduced friction losses.
3. Alternative wing structured aluminium sheet attained maximum Nusselt number 53.82 compared with other designs and gave higher efficiency of heat transfer. Plain black painted plate exhibited the lowest value of Nusselt number of 20.89.
4. The plain black painted plate showed minimum friction factor of 0.0456, whereas the maximum friction factor was of 0.212 for the sheet having alternative wing structure sheet exhibiting a balance between elevated heat transfer enhancement and greater flow resistance.
5. Among these designs, the alternate wing structure was the most efficient design, followed by the chevron-patterned aluminium sheet based on their superiority over other designs with respect to heat transfer characteristics.
6. A study shows that the geometry of the collector plate is a major concern in solar air heaters' thermo-hydraulic performance. At the provided Reynolds number, the highest overall performance is achieved from the alternative wing structure aluminium sheet, and it may be effectively applied to enhance solar-drying systems.

This work gives perspective to optimization of collector plate geometries within solar air heaters, furthering their application with improved energy efficiencies and thermal performances for sustainable drying purposes.

REFERENCES :

1. Maarof, H.A., Shamsi, M., Younas, M. and Rezakazemi, M., 2023. Hybrid thermal and optical modeling of a solar air heater with a non-flat plate absorber. *Energy Reports*, *9*, pp.6102-6113.
2. Shareef, A.S., Kurji, H.J. and Hamzah, A.H., 2024. Modifying performance of solar still, by using slices absorber plate and new design of glass cover, experimental and numerical study. *Heliyon*, *10*(1).
3. Belhadad, T., Kanna, A., Samaouali, A. and Kadiri, I., 2023. CFD Investigation of Fin Design Influence on Phase Change Material Melting for Solar Thermal Energy Storage. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, *6*, p.100306.
4. De Jesús, Á.M., Ramírez, J.M.O., Sandoval, O.J., Antuñano, M.A.Z. and Oropesa, A.E., 2013. Analysis of Flow and Heat Transfer in a Flat Solar Collector with Rectangular and Cylindrical Geometry Using CFD. *Ingeniería, investigación y tecnología*, *14*(4), p.8.
5. Abed, A.F., Hamad, R.F., Eidan, A.A. and Alshukri, M.J., 2024. Boosting storage collector efficiency with new corrugated absorbers: A numerical simulation approach. *Cleaner Engineering and Technology*, *18*, p.100716.
6. Boulemtafes-Boukadoum, A. and Benzaoui, A.J.E.P., 2014. CFD based analysis of heat transfer enhancement in solar air heater provided with transverse rectangular ribs. *Energy Procedia*, *50*, pp.761-772.
7. Kumar, A., Maithani, R., Ali, M.A., Gupta, N.K., Sharma, S., Alam, T., Majdi, H.S., Khan, T.Y., Yadav, A.S. and Eldin, S.M., 2023. Enhancement of heat transfer utilizing small height twisted tape flat plate solar heat collector: a numerical study. *Case Studies in Thermal Engineering*, *48*, p.103123.
8. Alnakeeb, M.A., Hassan, M.A. and Teamah, M.A., 2024. Thermal performance analysis of corrugated plate solar air heater integrated with vortex generator. *Alexandria Engineering Journal*, *97*, pp.241-255.
9. Sharma, S., Das, R.K. and Kulkarni, K., 2021. Computational and experimental assessment of solar air heater roughened with six different baffles. *Case Studies in Thermal Engineering*, *27*, p.101350.
10. Alsibiani, S.A., 2023. Employment of roughened absorber palate and jet nozzles with different hole shapes for performance boost of solar-air-heaters. *Cleaner Engineering and Technology*, *17*, p.100703.
11. Kumar, A., 2014. Analysis of heat transfer and fluid flow in different shaped roughness elements on the absorber plate solar air heater duct. *Energy Procedia*, *57*, pp.2102-2111.
12. , M.T., Qamar, S.H., Formosa, N. and Gomes, J., 2024. Mitigating PV cell cracking in solar photovoltaic thermal collectors with a novel H-pattern absorber design. *Applied Thermal Engineering*, *242*, p.122516.
13. Abdullah Alrashidi, Ahmed A. Bhagoria, J.L., Saini, J.S. and Solanki, S.C., 2002. Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. *Renewable energy*, *25*(3), pp.341-369.
14. Lanjewar, A., Bhagoria, J.L. and Sarviya, R.M., 2011. Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate. *Energy*, *36*(7), pp.4531-4541.
15. Yadav, A.S. and Bhagoria, J.L., 2013. A CFD (computational fluid dynamics) based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate. *Energy*, *55*, pp.1127-1142.
16. Yadav, A.S. and Bhagoria, J.L., 2013. A CFD (computational fluid dynamics) based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate. *Energy*, *55*, pp.1127-1142.
17. Alrashidi, A., Altohamy, A.A., Abdelrahman, M.A. and Elsemary, I.M., 2024. Energy and exergy experimental analysis for innovative finned plate solar air heater. *Case Studies in Thermal Engineering*, *59*, p.104570.
18. Anil Kumar VS, Saini RP, Saini JS. Performance of artificially roughened solar air heaters e a review. Renewable and Sustainable Energy Reviews 2009; 13:1854e69.
19. Ravigururajan TS, Bergles AE. General correlation for pressure drop and heat transfer for single phase turbulent flow in internally ribbed tubes. Augmentation of heat transfer in energy systems. HTD52. New York: ASME, 1985:9-20.
20. Alrashidi, A., Altohamy, A.A., Abdelrahman, M.A. and Elsemary, I.M., 2024. Energy and exergy experimental analysis for innovative finned plate solar air heater. *Case Studies in Thermal Engineering*, *59*, p.104570.
21. Kumar, A., 2024. ANSYS Fluent-CFD analysis of a continuous single-slope single-basin type solar still. *Green Technologies and Sustainability*, p.100105.
22. Ajeena, A.M., Víg, P. and Farkas, I., 2022. A comprehensive analysis of nanofluids and their practical applications for flat plate solar collectors: Fundamentals, thermophysical properties, stability, and difficulties. *Energy Reports*, *8*, pp.4461-4490.
23. Hosouli, S., Bagde, S., JahangirAltohamy, M.A. Abdelrahman, Ismail M.M. Elsemary,Energy and exergy experimental analysis for innovative finned plate solar air heater,Case Studies in Thermal Engineering,Volume 59,2024,
24. Ahmadkhani, A., Sadeghi, G. and Safarzadeh, H., 2021. An in depth eva luation of matrix, external upstream and downstream recycles on a double pass flat plate solar air heater efficacy. *Thermal Science and Engineering Progress*, *21*, p.100789.
25. Baobaid, N., Ali, M.I., Khan, K.A. and Al-Rub, R.K.A., 2022. Fluid flow and heat transfer of porous TPMS architected heat sinks in free convection environment. *Case Studies in Thermal Engineering*, *33*, p.101944.
26. Ebadi, H., Cammi, A., Difonzo, R., Rodríguez, J. and Savoldi, L., 2023. Experimental investigation on an air tubular absorber enhanced with Raschig Rings porous medium in a solar furnace. *Applied Energy*, *342*, p.121189.
27. Nurul Jannah Yusaidi, Mohd Faizal Fauzan, Ahmad Fazlizan Abdullah, Adnan Ibrahim, Amir Aziat Ishak,,Theoretical and experimental investigations on the effect of double pass solar air heater with staggered-diamond shaped fins arrangement,Case Studies in Thermal Engineering,Volume 60,2024,
28. Shayan, M.E., Ghasemzadeh, F. and Rouhani, S.H., 2023. Energy storage concentrates on solar air heaters with artificial S-shaped irregularity on the absorber plate. *Journal of Energy Storage*, *74*, p.109289.

29. Rohit Misra, Jagbir Singh, Sheetal Kumar Jain, Sachin Faujdar, Muskan Agrawal, Arin Mishra, Pradeep Kumar Goyal,Prediction of behavior of triangular solar air heater duct using V-down rib with multiple gaps and turbulence promoters as artificial roughness: A CFD analysis,International Journal of Heat and Mass Transfer,Volume 162,2020.
30. Mostafa Esmaeili Shayan, Farzaneh Ghasemzadeh, Seyed Hossein Rouhani,Energy storage concentrates on solar air heaters with artificial S-shaped irregularity on the absorber plate,Journal of Energy Storage,Volume 74, Part A,2023,109289,ISSN 2352-152X,https://doi.org/10.1016/j.est.2023.109289.
31. Yao, J.L., Zheng, H.Y., Bai, P.W., Liang, W.P., Zhang, Z.Y., Li, T. and Xie, T., 2023. Design and optimization of solar-dish volumetric reactor for methane dry reforming process with three-dimensional optics-CFD method. *Energy Conversion and Management*, *277*, p.116663.
32. Selmi, M., Al-Khawaja, M.J. and Marafia, A., 2008. Validation of CFD simulation for flat plate solar energy collector. *Renewable energy*, *33*(3), pp.383-387.
33. Gunjo, D.G., Mahanta, P. and Robi, P.S., 2017. Exergy and energy analysis of a novel type solar collector under steady state condition: Experimental and CFD analysis. *Renewable Energy*, *114*, pp.655-669.
34. Biradar, M.K., Parmar, D.N. and Yadav, A.K., 2022. CFD and exergy analysis of subcritical/supercritical CO2 based naturally circulated solar thermal collector. *Renewable Energy*, *189*, pp.865-880.
35. D.G.Gunjo, P.Mahanta, P.S.Robi, CFD and experimental investigation of flat platesolarwaterheatingsystemundersteadystatecondition,Renew.Energy 106(2017)24e36.
36. Kumar, R., Verma, S.K., Gupta, N.K., Mendiburu, A.Z., Sharma, A., Alam, T. and Eldin, S.M., 2023. Experimental assessment and modeling of solar air heater with V shape roughness on absorber plate. *Case Studies in Thermal Engineering*, *43*, p.102784.
37. Misra, R., Singh, J., Jain, S.K., Faujdar, S., Agrawal, M., Mishra, A. and Goyal, P.K., 2020. Prediction of behavior of triangular solar air heater duct using V-down rib with multiple gaps and turbulence promoters as artificial roughness: a CFD analysis. *International Journal of Heat and Mass Transfer*, *162*, p.120376.
38. Misra, R., Singh, J., Jain, S.K., Faujdar, S., Agrawal, M., Mishra, A. and Goyal, P.K., 2020. Prediction of behavior of triangular solar air heater duct using V-down rib with multiple gaps and turbulence promoters as artificial roughness: a CFD analysis. *International Journal of Heat and Mass Transfer*, *162*, p.120376.
39. Gunjo, D.G., Mahanta, P. and Robi, P.S., 2017. Exergy and energy analysis of a novel type solar collector under steady state condition: Experimental and CFD analysis. *Renewable Energy*, *114*, pp.655-669.
40. Yusaidi, N.J., Fauzan, M.F., Abdullah, A.F., Ibrahim, A. and Ishak, A.A., 2024. Theoretical and experimental investigations on the effect of double pass solar air heater with staggered-diamond shaped fins arrangement. *Case Studies in Thermal Engineering*, *60*, p.104619.