Three Dimensional CFD Simulation on Two Row Plane Fin Heat Exchanger: A Review

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Abstract— Three-dimensional CFD simulations are carried out to investigate heat transfer and fluid flow characteristics of a two-row plain fin-and-tube heat exchanger using ANSYS FLUENT. Heat transfer and pressure drop characteristics of the heat exchanger are investigated for Reynolds numbers ranging from 330 to 7200. Model geometry is created, meshed, calculated, and post-processed using ANSYS Workbench. Fluid flow and heat transfer are simulated and results compared using both laminar and turbulent flow models (k-epsilon, and SST k-omega), with steady-state solvers to calculate pressure drop, flow, and temperature fields. Model validation is carried out by comparing the simulated case friction factor f and Colburn j factor with experimental results from the literature. For friction factor determination, little difference is found between the flow models simulating laminar flow, while in transitional flow, the laminar flow model produced the most accurate results and the k-omega SST turbulence model was more accurate in turbulent flow regimes. The results of simulations for heat transfer in laminar flow using the laminar flow model are found to be in good agreement with the experimental results, while heat transfer in transitional flow is best represented with the SST k-omega turbulence model, and heat transfer in turbulent flow is more accurately simulated with the k-epsilon turbulence model. Reasonable agreement is found between the simulations and experimental data, and the ANSYS FLUENT software has been sufficient for simulating the flow fields in tube-fin heat exchangers.

Keywords: Plate Heat Exchangers, Fin and Tube Exchanger, CFD, Reynold Number, Fanning Friction Factor F, Colburn J-Factor

I. INTRODUCTION

Fin-and-tube heat exchangers are widely-used heat transfer devices in applications like refrigeration and air conditioning systems. It’s easier manufacturing, simpler construction, lower cost, and relatively easy in maintenance makes it one of the most commonly used heat exchangers. A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment.

II. LITERATURE SURVEY

1) Shubham Gupta and Karan Singh Verma (2022) in the research paper, a CFD (computational fluid dynamics) process was investigated using ANSYS fluid fluent. Designing of shell and tube heat exchanger was performed using SOLIDWORKS software which is a CAD modeling software. In the research, 4 different type of shell and tube heat exchanger is designed and analyzed to find out thermal behavior of shell and tube heat exchanger. Three different types of fins are used in the investigation which is spiral fins, baffles and rectangular fins on inner hot fluid pipe. Results were compared in terms of hot and cold fluid throughout the heat exchanger.

   Results stated that the case of rectangular fins provided better results in terms of temperature decrease which is 355.18 K., and the effectiveness of heat exchanger is calculated and the highest effectiveness of 0.3946 is provided in case of having rectangular fins.
2) Abhishek Mishra and Dr. Nitin Tenguria (2020) the research paper experimentally investigated the characteristics of the forced convective heat transfer and pressure drop in both inline and staggered arrangements of circular fin cross flow heat exchanger and and the effect of mass flow rate on parameters such as Nusselt number, overall heat transfer coefficient, and heat transfer was analyzed. The air was blown with the velocities 0.2m/s, 1m/s, and 2.3m/s and the corresponding changes in inlet and outlet temperature of hot and cold air was measured.

   Results stated that Heat transfer (Q), Heat transfer coefficient(h), and Nusselt number (Nu) all increase with the increase in mass flow rate for both the inline and staggered arrangement. The inline arrangement results in better heat transfer, and the value of Heat transfer coefficient(h), and Nusselt number (Nu) is also more. The inline arrangement is resulting in better heat transfer as the number of tubes in inline is taken 6 while in stagger arrangement it is 5.
3) Mladen Bošnjakovi´c and and Simon Muhiˇc (2020) research paper investigated the possibility of enhancing heat transfer through the application of perforation with geometric patterns. The subject of research was star-shaped perforated fins, placed on tubes through which hot water flowed. There was a cold air stream around the tubes and fins. Stainless steel was chosen for the tube and fin material. A numerical method for computational fluid dynamics (CFD) was used to evaluate fluid flow and heat exchange in the modeled heat exchanger. Star-shaped fins, 0.5 mm thick with an outside diameter of 40 mm, were attached to the tube Ø20 as the reference geometry. The fin had 8 perforated holes of circular shape evenly distributed on a diameter of Ø28 mm. The analysis was performed for 3 sizes of perforations: Ø2 mm, Ø3 mm, and Ø4 mm.

   The application of perforation on the fins primarily reduced the mass of heat exchanger, which is very significant in some applications with steel fins. In the areas of perforations, there was greater flow turbulence and an increase in the heat transfer coefficient. There was no significant difference in pressure drop on perforated fins. A higher area goodness factor for perforated fins confirmed the claims. The number and size of perforation holes affected heat exchange, and their importance strengthened with increasing Re number. In the analyzed case of star shaped fins, a decrease in mass of 17.65% (by hole diameter of 4mm) and an enhance in heat flux upto 12% in the observed range was found.

4) Yuzhu Zhou et.al (2020) In order to enhance the cooling efficiency of plate-fin motor cooler, two kinds of plate-fin-tubes were proposed, which named triangle-wing and convex fin-tube. The heat transfer characteristics of fin-tubes are investigated via numerical simulation and experiment.

   The result showed that the k-ε turbulence model is highly accurate in simulation of cooler, and the deviation of average heat transfer coefficient and frictional pressure drop between experiment and simulation is within 10% and 8%, respectively. Both of the triangle-wing and convex fin-tube can increase the heat transfer efficiency of plate-fin cooler. The frictional pressure drop also has an approximate variation trend. In addition, the pressure drop of convex-fin-tube is smaller than triangle-wing-fin-tube on the premise of the same heat transfer coefficient, so the heat transfer performance of convex-fin-tube is the best.

5) M. Shawky Ismail et.al (2019) in the research paper, three dimensional finned-tubes cross flow heat exchanger was examined. The investigation takes into account the outer cold fluid flow (air). The inner hot fluid flow (water) and the conjugated solid domain. The hot water flowing inside the tube is considered laminar while the air flowing outside the tubes inside the fin passages is treated as turbulent. All heat transfer and fluid flow parameters have been studied at different velocities for air in the range between 1-to-6 m/s with fixed Re =1200 for inner water flow. In this study, the heat transfer coefficients and pressure drops on both sides of fluids are calculated numerically for both the conventional size and the selected micro size heat exchangers with plain-tube and finned-tube arrangements.

   The results declare that the micro tube has higher performance with controllable pressure drop as the heat flux ratio is increased by 20% whereas, the heat per unit volume ratio is increased by 800-1200% with the increase of air velocity from the given lower to the higher one. It is found that the effects of using fins are profitable only for the conventional exchanger but not for the micro size exchanger. The most interesting results obtained from this study is the superiority of the micro tube heat exchangers over the typically conventional one in regards of the heat transfer rate per unit volume.

6) Yuvraj Singh Rajput and Abhishek Arya (2019) research paper investigated heat transfer and temperature gradient in a cross flow heat exchanger using different fin thickness. The governing equations was solved using CFD simulation, based on finite volume method The velocity of the inlet air was limited with a values of (1, 2, 3, and 4) m/s, while the volume flow rate of tube side liquid was limited with a values of (2, 3, 4, 5 and 6) L/min and the temperature of inlet air was the room temperature, while the temperature of tube side liquid was limited with a values of (50, 60, 70 and 80) °C.

   Results stated that by changing the dimension of the fin heat transfer would be increase and the temperature of water outlet decrease more. A gradient of temperature distribution along with test tube and the temperature difference are clearly appearing in all cases. The temperature difference increase with increasing the cooling air velocity and increase with decreasing the hot water velocity inside the tube. Temperature gradient of 3 mm finned tube is higher than that of 1.5 mm finned tube and smooth tube. Ansys Fluent is good CFD program to simulate the heat transfer cases. Good agreement is attain between the experimental and numerical results Heat Transfer rate increased by 15% by using 3mm fin instead of 1.5 mm fin.

7) Animesh Kumar et.al (2018) objective of the research was to develop an optimization methodology for the design of a finned tube heat exchanger in a residential air-conditioning unit. Three-dimensional simulations was carried out to investigate heat transfer and fluid flow characteristics of a two-row plain fin-and-tube heat exchanger. Heat transfer and pressure drop characteristics of the heat exchanger are investigated for Reynolds numbers ranging from 330 to 7000. Model geometry is created, meshed, calculated, and post-processed. Fluid flow and heat transfer are simulated and results compared using both laminar and turbulent flow models with steady-state solvers to calculate pressure drop, flow, and temperature fields.

   It was found that the heat transfer rate and flow model accuracy depends on the flow regime and the friction factor. There is a gradual decrease in friction factor as Reynolds number increases and with increase in Reynolds number the turbulence in the flow of fluid increases. The increase in turbulence of the fluid results in the increase in heat transfer rate.

8) A. Y. Adam et.al (2018) research paper aimed to investigate the flow and heat transfer characteristics of laminar cross-flow forced convection in compact fin-and-flat tube heat exchangers. The experiment was performed to explore the influence of the tube inclination angle on the thermal hydraulic performance of the flat tube heat exchanger. Four flat tubes arranged in two aligned rows having the same longitudinal and transverse pitches were examined in the range of Reynolds number between 1768.27 and 2259.46. A constant heat flux of 4169.63 W/m2 was applied at the inner surface of each flat tube. On the other hand, the numerical simulation is solved by ANSYS FLUENT for a two dimensional model with unstructured mesh and the results are compared against the experimental results.

   The numerical simulation results indicate that the average Nusselt number increased by 78.24 % for Reynolds number 1768.27. Besides that, for Reynolds number 1964.75 and 2259.46 the Nusselt numbers were increased by 75.89 % and 54.49%, respectively, compared to experimental results. Moreover, the pressure drop is increased 25 % and 83.38 % for both experimental and numerical simulation with respect to three Reynolds number. It was found that, the tube with 30° degree provides the higher heat transfer with Reynolds number 2259.46. This study could assist engineers in decisions regarding the application of compact fin-and-tube heat exchangers in the automotive field.

9) K. Ranjithkumar et.al (2018) research paper experimentally investigated the effects of fin pitch and fin outside diameter on the characteristics of heat transfer and pressure drop for serrated multi-louvered finned-tube heat exchangers having staggered tube layouts. It was indicated that the fin pitch increased with increasing heat transfer coefficient at the same Reynolds number. The fin outside diameter, however, had an insignificant effect on the heat transfer coefficient. The multi-louvered plate finned tube heat exchangers have better air-side heat transfer Performance than the plate-finned tubes , because of high vortex shedding frequency.

   Results presented the advantage of multi-louvered plate fins in improving the performance of finned tubes or compact fin and tube heat exchanger. This is mainly due to the fact that the interruption of fins in these devices improves the rebuild of the boundary layer close to heat transfer surfaces and increases the level of fluid mixing in the flow domain. The fin Pitches 2.5 to 3.5 gives better performance and also gives more heat transfer rate. The same heat transfer area, the multi-louvered plate fin tubes have better performances than the full fins. The ceramic coating gives better performance in under wet conditions, there is no corrosion on the finned tube when used for a number of days in practical Application.

10) Artur Rubcov et.al (2017) research paper conducted experimental tests of a wavy fin and tube heat exchanger used to heat (cool) air in a ventilation system when the wavy fin of the heat exchanger is dry and wet. The experimental tests, performed in the range of $1000<Re<4500$ of the Reynolds number, determined the dependency of the heat transfer coefficient on the amount of supplied air with the varying geometry of the heat exchanger (the number of tube rows, the distance between fins, the thickness of the fin and the diameter of the tube). The experimental tests were performed on 9 heat exchangers in heating mode (dry fin) and 6 heat exchangers in cooling mode (wet fin). The ratio of heat transfer coefficient values when the fin is dry and wet varies from 0.79 to 1.12.

   Results stated that the heat transfer coefficient in the boundary layer of air drops as the number of tube rows in the heat exchanger increases. The heat transfer coefficient in the boundary layer of air goes up as the distance between fins increases. An empiric equation has been derived that describes the heat transfer coefficient of the heat exchanger with the analysed geometry of the plate with the tolerance of ±10% and in the cooling mode, the thermal resistance coefficient of the boundary layer of air varies in the range from 0.75 to 1.1, depending on the Reynolds number.

11) Ishwar J.Dhangar and Dr. Manojkumar Chopra (2017) in the research paper, the air-side heat transfer of five kinds of fin-and-tube heat exchangers was experimentally investigated with the Reynolds number ranging from 4000 to 10000, and the optimization of heat exchanger with VGs is also addressed. The heat transfer tube was designed and analyzed using commercial CFD software ANSYS Fluent.

   Before optimization, at high Reynolds numbers, the heat exchanger with slit fin offers best heat transfer performance. The larger attack angle, higher length and smaller height of vortex generators will lead to better overall performance of Heat exchangers with VGs. As Reynolds number increases; the pressure drop increases & fluid outlet temperature decreases. That concludes that with increase in Reynolds number the disturbances are increased and the heat transfer reduces.

12) Zena K. Kadhim et.al (2016) in the research paper, CFD investigations was carried out to analyze the temperature difference for cross flow heat exchanger with smooth tube and low integral finned tube. Objective was to simulate the 3D geometry for cross flow smooth and finned tube heat exchanger with hot water inside the tube and cooling air outside the tube by using computational fluid dynamic (ANSYSFLUENT 15). The enhancement of heat transfer has been introduced in many fields of industrial and scientific applications. The study included geometry creation with dimensions (250×500×1200) mm width, height and length, respectively. has a single copper tube with eight passes designed. The low integral finned tube with (19 mm) inner diameter, (21 mm) root diameter and (24 mm) outer diameter and fin height is (1.5 mm). Air is assumed as a cooling fluid passing across the test tube with a range of velocities (1, 2, 3 and 4) m/sec. The inner side flow rates with a range of (2, 3, 4, 5 and 6) L/min. for water. The water temperatures at the inlet of test tube were (50, 60, 70, 80) °C.

   Results stated that the temperature difference increases with increasing the cooling air velocity and increase with decreasing the hot water velocity inside the tube. The temperature gradient of finned tube is higher than that of smooth tube. Good agreement is attain between the experimental and numerical results With maximum deviation of (+9.1%). Ansys Fluent is good CFD program to to simulate the heat transfer cases.

III. CONCLUSION:

The objective of this project is to develop the CFD simulation model for two-row fin-and-tube heat exchanger and verify the results of simulation with the available experimental data from the literature. The purpose of the work was to investigate the possibilities of eventually using CFD calculations for design of heat exchangers instead of expensive experimental testing and prototype production.

To analyse the flow and heat transfer characteristics of the heat exchanger, a model of a two-row fin-and-tube heat exchanger is created using Design modeller and Mesh module to create the geometry and mesh respectively. The resulting mesh (after a grid independence test was carried out) is used for running simulations using a laminar flow model and two turbulence models. Ten different inlet flow velocities ranging from 0.3 m/s to 6.2 m/s and corresponding to Reynolds numbers ranging from 330 to 7200 are simulated in the three different flow models (laminar, k-epsilon turbulence model, and SST k-omega turbulence model). Using the simulation results calculations related to heat flow and pressure loss are carried out to determine the Fanning friction factor f and Colburn j-factor for comparison with the literature values used for the validation.

It is found that the flow model accuracy depended on the flow regime and whether the friction factor f or j-factor is being determined. From the experimental values given in the literature, the laminar flow region for this particular geometry of heat exchanger switched to transitional at around Reynolds number 1300, and moving to turbulent around Reynolds number 2900. The Reynolds number has a characteristic dimension of the tube collar outside diameter.

For friction factor determination, little difference is found between the flow model simulating laminar flow, while in transitional flow, the laminar flow model produced the most accurate results (for friction factor) and the SST k-omega turbulence model is more accurate in turbulent flow regimes. For heat transfer, the laminar flow model calculates the most accurate j-factor, while for transitional flow the SST k-omega turbulence model is more accurate and the k-epsilon turbulence model is best for heat transfer simulations of turbulent flow.

The flow model can be chosen based on what is being studied (heat flow or pressure drop) and the flow regime. It can be concluded that the pressure drop and heat transfer characteristics of a fin-and-tube heat exchanger can be determined with reasonable accuracy using CFD computations carried out in ANSYS Workbench. These results can be used to carry out practical work in the design process of heat exchangers.

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