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Heat Transfer Enhancement in Heat Exchanger using Double Sinusoidal Shape Fins

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Abstract: The improvement of heat transmission in compact heat exchangers is a challenging and continuous area of study for heat exchanger applications. Without expanding the heat exchanger's overall volume, the current study takes into consideration a small heat exchanger that is used in the cooler device for the enhancement study. To calculate the potential using CFD, enhancements to the current flat-finned heat exchanger are simulated for pressure loss and fan discharge modeling. The current study's primary goal is to alter the fin profile to enhance heat transmission without increasing a significant pressure drop, which is accomplished via a perforated, wavy fin. Variations in the perforation's pitch and diameter are taken into account during simulation, and the resulting pitch and perforated profile are then experimentally assessed to determine whether the cooling effects improve. By using simulation, it is discovered that the cooling effect is improved by 28% and that the pressure drop caused by the fin's perforation is reduced by 4.5% when compared to the current design.

Keywords— Heat Transfer Enhancement, Fin and Tube Heat Exchanger, Wavy Fins, Variable Pitch, & Perforation.

1. Introduction

In comparison to other exchanger types, compact heat exchangers are distinguished by high heat transfer surface-area to volume ratios and high heat transfer coefficients. They are high area density heat exchangers with a high ratio of heat transfer surface to heat exchanger volume. Even though the technology is not new, continual research is being done to increase its efficacy and provide greater heat exchange for the same volume. It is utilized in systems with gas-gas, gas-liquid, and liquid-liquid working fluids, among other types. Compact heat exchangers (CHEs) are in great demand for heat transfer enhancement, and from a financial and spatial standpoint, the design of such an efficient exchanger is crucial. Heat transfer enhancement can obtain by three methods Active (with external power source), Passive (without external power source) and Compound (combination of both). In the present work passive methods planned introduce to improve the effectiveness of the heat exchanger and reviews related to passive heat transfer enhancement in the compact heat exchanger are carried out. More works are carried out in the compact heat exchanger tube arrangements and fin profile design. Increasing the turbulence with louvered type fins in the compact heat exchanger increases the heat transfer rate. This operation allowed to pass working fluid between heat exchanger sheets, due to this the fluid molecules remains more time in the domain which removes more heat (Diego, 2016). There are different improvement strategies followed to improve the effectiveness of the compact heat exchanger already which includes tube arrangement and different fin profiles (N. Nickolas et al, 2017). Tube arrays such as inline and staggered are known to produce different flow separations and fluid recirculation. This was observed by Zhang et al., where they found that the inline and staggered arrays of tubes have different performances. In the case of multiple tubes arrangement, the reduced gap between adjacent fins increased the velocity and temperature gradients resulting in a significant increase in heat transfer and pressure drop. This is more significant for staggered tubes arrangements as the gap is even smaller. The heat transfer enhancement with different fin materials are analyzed by Allan Harry Richard et al. and found improvement in efficiencies for copper fin due to higher thermal conductivities compared to brass and aluminum. More works are carried out with helical twisted tape inserts in the liquid side tubes to enhance the heat transfer with increase in turbulence due to swirling of flow (Thianpong et al, A. G. Matani et al and Parveen Banu et al) Plain fins are generally used in the compact heat exchanger due to simple, durable and versatile in applications. Wang et al studied on sensible heat and friction characteristics of plate fin-and-tube heat exchangers having plain fins. In the study of Wang et al (1996) noted that the heat transfer is independent of fin pitch for number of tube rows more than or equal to 4 and Reynolds number (Re) higher than 2000, it means for turbulent cases. The effect of fin pitch on the heat transfer of heat exchanger was studied and noted decrease in heat transfer when fin pitch decreases for certain cases due to increase pressure drop. Increasing longitudinal and transverse pitches increases the rate of heat transfer. The fin pitch and density are not holding direct relation on heat exchange as it is also depends on the pressure drop and hence the pumping power. Increasing fin density in the compact heat exchanger leads to increase in the pumping power requirement (Tahseen A, 2015).

2. Design Parameters & Compact Heat Exchanger

The fin and tube compact heat exchangers are critical components used to dissipate heat in many engineering applications. Innovative advances in designing and manufacturing of fin and tube heat exchanger can provide significant benefit in heat loss, weight and cost. However the further most challenge to select optimized heat exchanger with balance between heat transfer and pressure drop. The main objective of the work is to enhance the performance of the heat transfer in a given heat exchanger for different fin profile. Also the fins are designed with holes in different pitches which give good reduction in weight and pressure drop. The performance of fin pattern and perforations are studied well and described detail in this paper. The fig.1 shows the studied profile parameters.

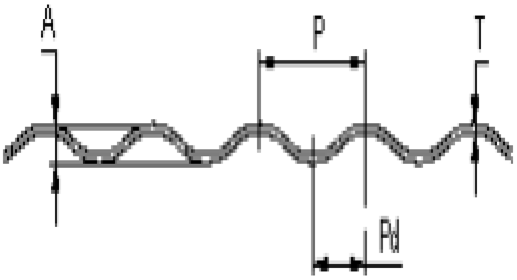


Fig 1: Fin Profile Descriptions, (A-Amplitude, P-Pitch, Pd-PITCH/2, T- Thickness)

3. Boundary Conditions And Computational Model

Computational domain considered for the conjugate heat transfer analysis and pressure drop evaluations is shown in Fig.2 which consists of heat exchanger with copper tubes, aluminium fins and axial fan along with louvered enclosure.

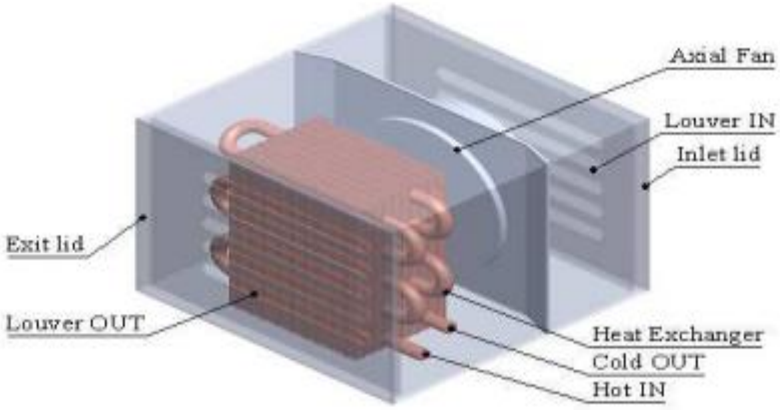


Fig 2: Computational Domains and Lids

The fillets and other chambers are eliminated in the simulation model in order to reduce the computational time. The computational domain is extended 10 mm from in and outside of the enclosure to estimate the pressure drop properly by avoiding the turbulence effects from the louver The model is simulated with solid works flow simulation package with both air and liquid side boundary conditions. In the present analysis the inlet condition of the heat exchanger is considered as 1.67X10-5 m3 /s and the corresponding temperature of 65^{o}C. The exit of the exchanger boundary is considered as outflow. The air side boundary conditions are inlet and outlet air static pressure and the fan is modeled and linked with selected axial fan curve of 200 CFM at atmospheric pressure.

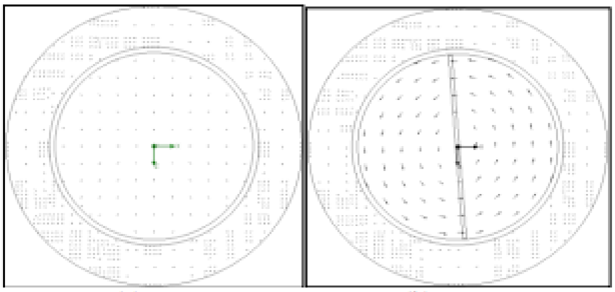
4. Numerical Modeling

The software programs package SOLIDWORKS PREMIUM 2016 was used for the numerical analysis to predict the hydraulic and heat transfer performance. The 3D model of heat exchanger parts shown in figure (1). For swirling flows and boundary layer, the available finite difference procedures in the software are employed for solving the governing partial equations. To simplify these equations it's required to apply some assumptions for flow and energy equations to model the process. The assumptions are: 1-Steady state conditions. 2-No heat loses (adiabatic process). 3- No heat generation. 4-No phase change (every fluid has single phase). 5-The heat exchanger was held vertically, therefore the effect of the gravity is considered. 6-Counter flow heat exchanger is considered. 7- The radiation effects are neglected.

1. **Governing Equations**- SOLIDWORKS PREMIUM 2016 CFD package was used to accomplish the numerical investigation. By using The Favre Averaged Navier Stokes (FANS) equations which are conservation equations of mass, momentum and energy for the fluid flows. Additional terms which called Reynolds stresses appear in the (FANS) equations for that must provide extra information, in order to solve this system of equations, the software use for turbulent kinetic energy and its dissipation rate transport equations it called k- model. The software employs one equations system to describe both laminar and turbulent flow, as well as it's suitable for high turbulent flow cases.
2. **Validation** -The validation is done by performing the numerical simulations and then comparing the simulation result of the heat transfer coefficient with the existing correlations for Nusselt number. The difference between the correlation results (which obtained from the experiments) and the simulation analysis results of Nusselt number values are less than 10% difference for the tube side. Figure (2) shows the results and compare between simulation analysis with the three correlations (Dittus Boelter's, Gnielinski's and Petukhov's) in terms of Nusselt number (Nu), Reynolds number (Re) and Prandtl number (Pr).
3. **Mesh independent study**- Finite volume method was used and the mesh cells (the control volumes) are rectangular parallelepipeds. Cut cells approach is used at the intersection area between solids and liquids or near geometry boundaries on the original parallelepiped cells to form polyhedrons cells. In order to check the effect of mesh size on the results, five meshes with total number of cells (210,356), (408,582), (727,750), (1,242,562), (2,568,898) were initially considered, the results of heat transfer rate were compared with the fine mesh and the intermediate mesh with 727,750 cells had been chosen for all simulation cases to save the time required for simulation and giving the same results (0.45% deviation) by comparing it with the finest mesh.

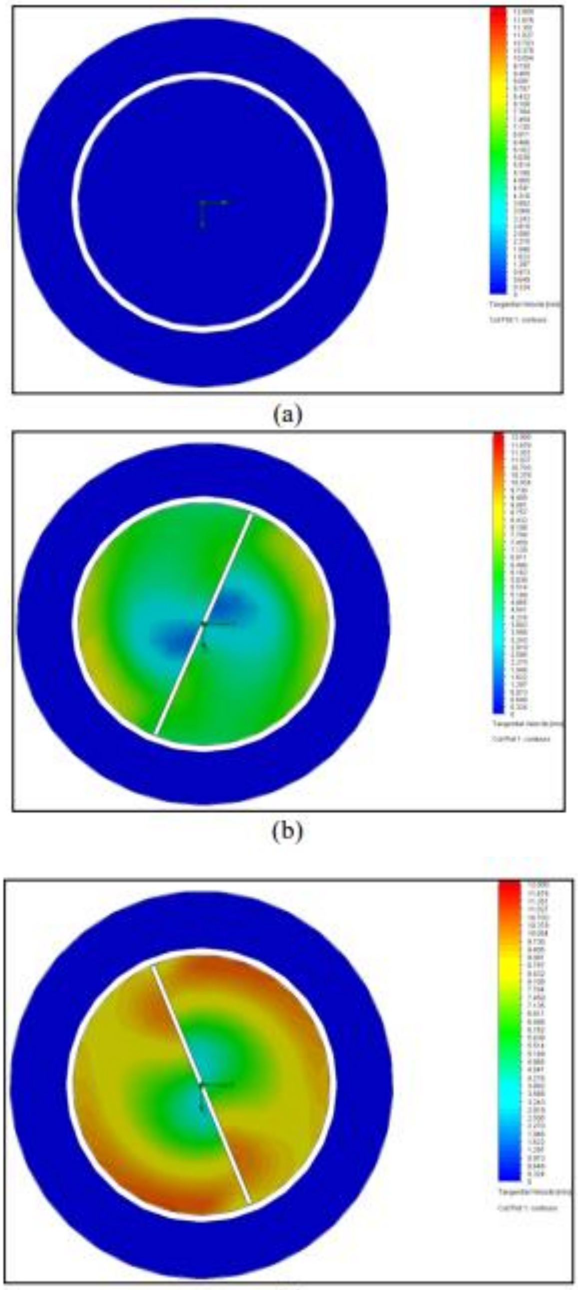
5. Results and Discussion

(i) Velocity and Vectors Contours- The using of twisted tape insert cases an extra swirling flow and increase the tangential velocity especially near the inner wall of the tube. Figure (3) shows the velocity vectors for cross sections from the heat exchanger with and without twisted tape, the dots in plane tube case (figure 3-a) shows that almost no tangential velocity in the inner tube, while the arrows in twisted tape case(figure 3-b) shows that the twisted tape generate tangential velocity and cause additional motion in the flow near the inner wall and along all the flow axis, also it is clear from figure (4) that the tangential velocity increased with the lower twist ratio.



(a) (b)

Fig 3: Velocity vectors in, (a) without twisted tape, (b) with twisted tape



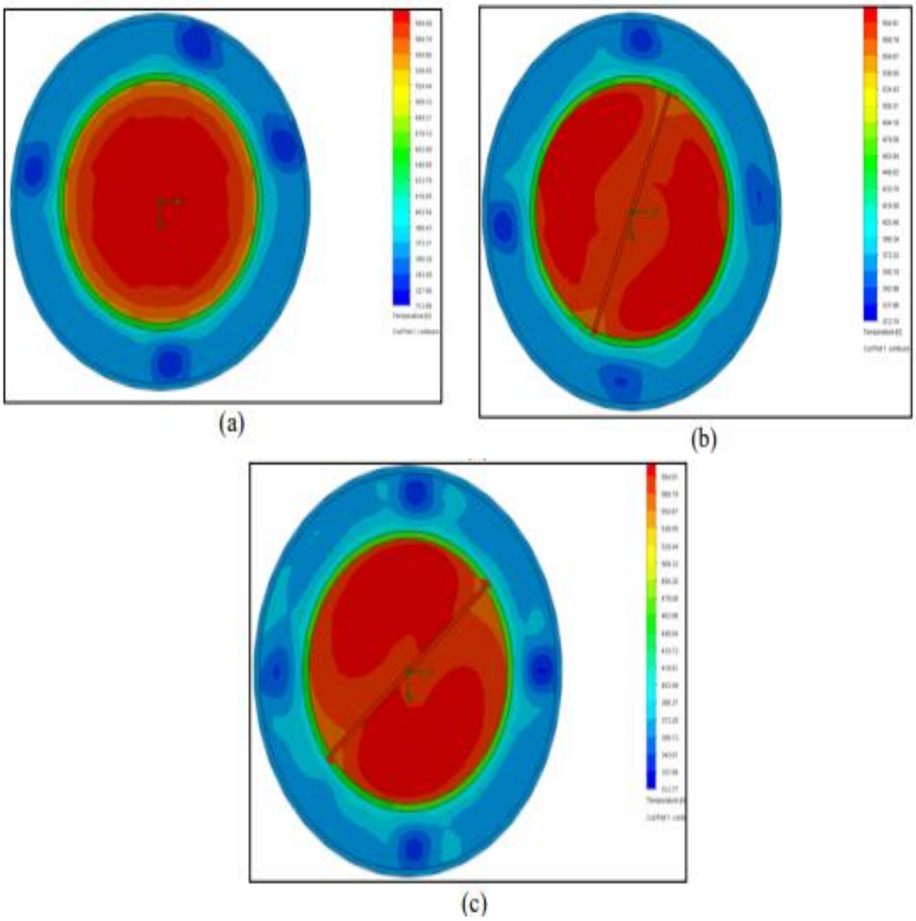
(a)

(b)

(c)

Fig 4: tangential velocity Contours for the heat exchanger with (a) plane tube, (b) twisted tape insert with twist ratio 3.0, (c) twisted tape insert with twist ratio 1.5

(ii) Temperature Contours and flow trajectories- Flow inside the tube can be divided for two parts which is a fluid region near the wall and fluid region in the core. The use of a twisted tape will provide a uniform temperature mixing for the fluid in the core region and near the wall region. This mixing will enhance conduction heat transferred from fluid to the tube wall. On the other side it disturbs boundary flow. For that it is important to analyze temperature profile near the wall and at the core to study the effect of swirling flow on the heat transferred at various cases. Figure (5-a) shows the core region and fluid region near the wall in plane tube case, while figure(5-b,c) shows how the twisted tape mix the fluid at the wall region and fluid at the core region and disturb the thermal boundary layer near the wall and reduce the thermal resistance. From the temperature gradient near the inner tube asfigure(5-a,b,c) shows ,the using of the twisted tape increase the heat transferred , the lower twist ratio lead to more heat transferred to the oil. Figure (6) shows the temperature variation from entrance to exit for the air in the inner tube with respect of temperature scale with and without twisted tape, also it shows the swirling flow causing efficient mixing inside the tube causing uniform temperature for the core and increase the temperature difference between the fluid and the tube wall.


(a)

(b)

(c)

Fig 5: Temperature Contours for the heat exchanger for (a) plain tube, (b) twisted tape insert with twist ratio 3.0, (c) twisted tape insert with twist ratio 1.5

(iii) The enhancement of heat transfer rate and Nusselt number The results from simulation show that the enhancement in the heat transfer rate by using twisted tapes increase with the increasing of the number of twist (lower twist ratio) because the lower twist ratio mean extra swirling flow movement, increase the flow path length so this mean giving more time to the heat to transfer, and it generate tangential velocity near the wall to disturb the thermal boundary thickness and reduce the thermal resistance.

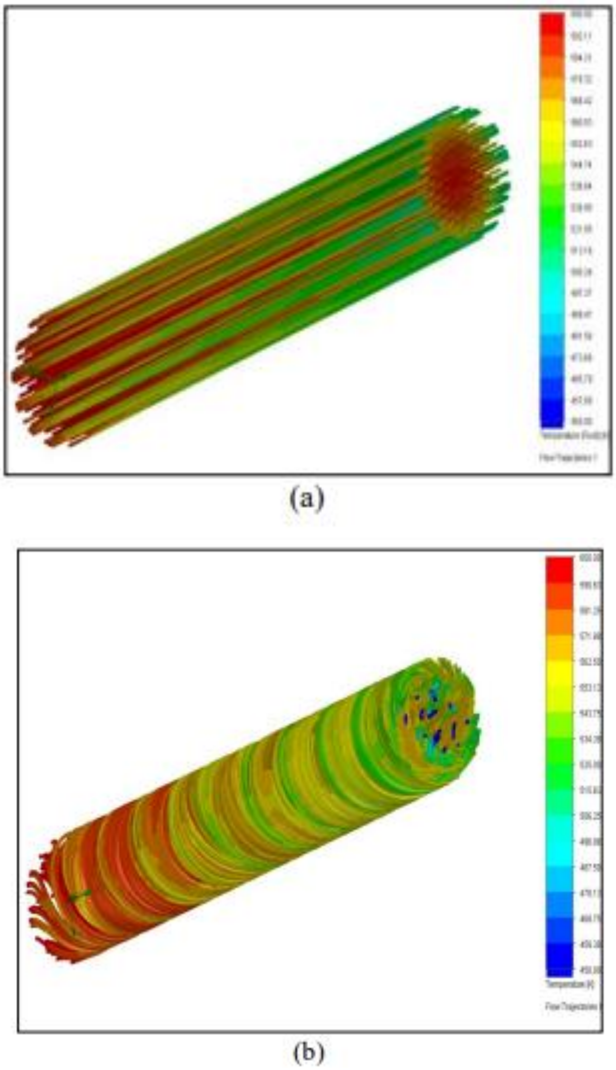


Fig 6: Flow trajectories for inner tube side colored by temperature in case of (a) plain tube, (b) twisted tape insert

6. Conclusion

Plotting the temperature distribution and pressure drop of the compact heat exchanger with a flat fin and various wavy profiles is the result of the computational simulation. The heat exchanger's fin profiles are adjusted in light of the simulation results, and an experimental investigation is carried out. There are barely 6% differences between the simulated and experimental results. When compared to flat fins, the perforated fins improve heat retention by about 28% while increasing weight by only 3.6% and having no significant effect on pressure drop. The purpose of this study can be further expanded by moving the perforation in order to examine pressure variations and enhance heat transfer. The novel asymmetric curve geometry for the wavy shaped heat exchanger channel brought an enhancement of the thermal performance compared to the smooth channel. Furthermore, the in-line arrangement of the shape of protrusions helps to create more efficient mixing of hot and cold air in the channel. Adding the cylindrical vortex generators between the wavy heat exchanger surfaces, a significant enhancement of thermal performance was achieved in comparison with the smooth channel and wavy channel without vortex generators. On the basis of the experimental and numerical results, the investigated configurations were evaluated from the heat transfer and pressure drop point of view with the following main results.

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