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Studies of Oval Tube and Fin Heat Exchangers

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Fin and Tube Heat Exchanger CFD Research

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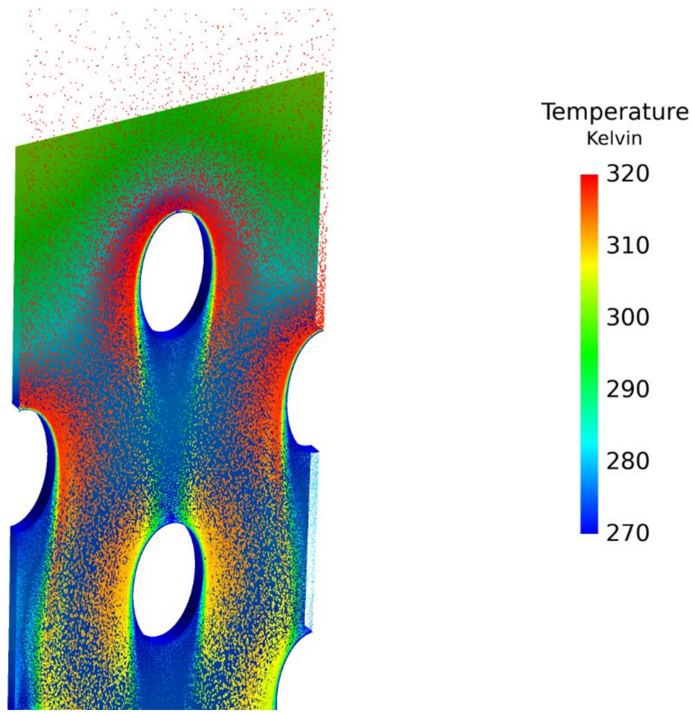

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Introduction

Tube and fin heat exchangers are used in a wide variety of applications because they are inexpensive, lightweight, and relatively easy to manufacture. This type of heat exchanger works by exchanging heat between two fluids. This property of exchanging heat with two closed systems is important because in air conditioning and refrigeration the working fluid can be highly toxic and harmful for the environment. In the U.S., 87 percent of homes have an AC system[1]. This has steadily increased since 2015 which has led to a greater deal of research in this area. There are a lot of different designs of tube and fin heat exchangers with varying fin geometry to improve heat transfer. The downside of any heat exchanger is the pressure drop through the heat exchanger, which could be a problem for high mass flow systems utilizing fans. Changing the geometry of the tube will have an effect on the heat transfer and pressure drop. The purpose of this research is to study the flow of the incoming fluid, in this case atmospheric air at 320K, and how the flow interacts with the different geometries of heat exchangers. The flow will be modeled using computational fluid dynamics (CFD) using ANSYS Fluent as the CFD solver.

TUBE AND FIN HEAT EXCHANGERS

Tube and fin heat exchangers are normally mass produced and good at exchanging heat between two fluids. These types of heat exchangers are most common in the Heating Ventilation and Air Conditioning (HVAC) industry because of the relatively low cost and effectiveness of the system.

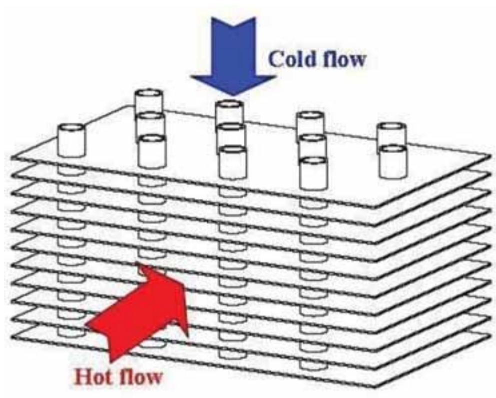

Figure 1: Schematic diagram of tube and fin heat exchanger[2]

Figure 1 demonstrates the most common configuration of tube and fin heat exchangers with circular-shaped tubes. The main interest in this research is to increase mixing in the main flow and reduce the wake/recirculation behind the tubes. The recirculation causes a cold spot due to the lack of interaction with the main flow and therefor decreasing the overall heat transfer of the heat exchanger. There have also been studies on implementing vortex generators which will induce mixing of the flow with different designs. This type of research is still new as one of the latest papers on the use of vortex generators[3] was published in 2018. This research will analyze the different tube geometries with respect to heat transfer and compare it with the pressure drop.

MODEL

Three models were made to simulate the different designs of the tube and fin heat exchanger. These models were called base (circular) geometry, oval geometry and oval alternating geometry which were generated in SolidWorks. The base geometry is what the models will be compared to since this is a standard tube geometry used in industry. The three different models of tube geometry are displayed in Figure 2.

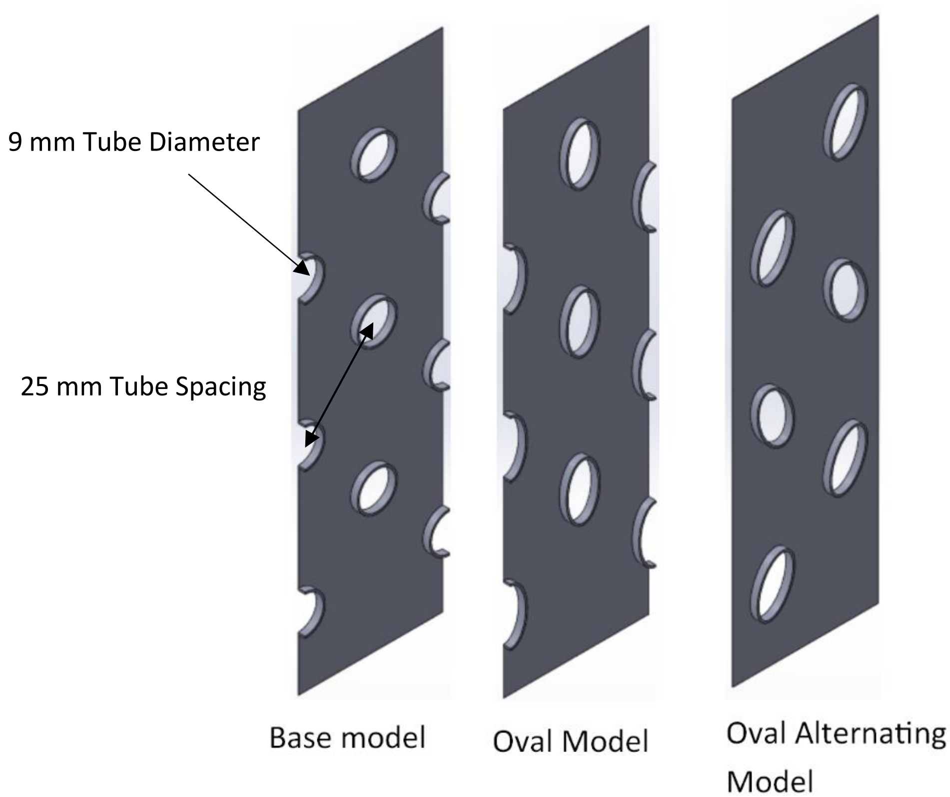

Figure 2: Fin and Tube model types.

The specifications of the base model are tube diameter of 9 mm and fin thickness of 0.16 mm. The tubes are in a staggered arrangement with minimum center distance spacing of 25mm. The dimensions of the oval tube shape are minor axis of 7.5 mm and major axis of 13 mm. These measurements were found by compressing the 9 mm round copper tube to have a minor axis of 7.5 mm. The oval alternating model utilizes the same oval dimensions, with an alternating 20 degrees angle of attack to the direction of the flow.

Mesh (Discretization)

For the computer to simulate the flow the domain must be split up into finite volume elements (discretization) at which the computer then integrates over this finite volume using Finite Volume Method. The mesh is crucial for simulating the flow with promising results. The mesh was generated in Pointwise with skewness and aspect ratio taken in to consideration when making the mesh. The mesh generated are fairly fine when compared with other studies of oval tube and fin heat exchangers, with the same CFD setup for the oval geometry. The mesh for the oval geometry is shown below in Figure 3.

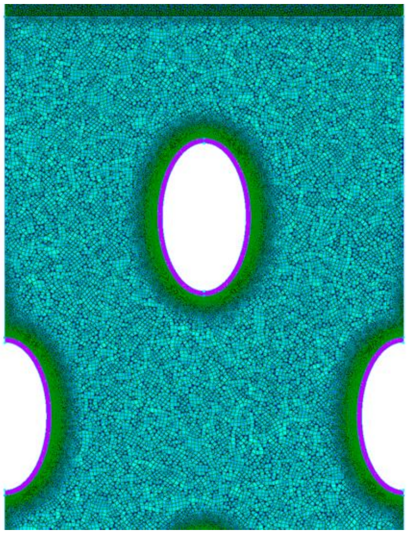

Figure 3: Oval geometry mesh.

CFD Setup

The flow was modeled in ANSYS Fluent using the k-omega turbulence model, and with energy equation on. The main flow was modeled using a velocity inlet and pressure outlet which represents the environment of the heat exchanger. The sides of the model are modeled with periodic boundary condition which corresponds to the geometry of the heat exchanger. The velocity inlet boundary condition was set at a velocity of 2.2 m/s with 320 Kelvin, with the inner tube temperature set to 270 Kelvin. The fluid domain is set to air and the solid domain is set to aluminum. For calculating the steady state heat transfer, a transient model was ran first to get the residuals down and switched over to steady state. For calculation was completed when the energy residuals reached 1E-8 and at which the rest of the residuals have leveled off.

Outcomes

For post-processing, FieldView was used to analyze the data from Ansys Fluent. The first element that was analyzed was the fluid flow and the interaction with the fin and tube geometry. It should be noted that there has not been a mesh convergence study performed due to the situation as of spring 2020, but compared to others results it is found that this mesh is fine and should achieve fair accuracy. The following images display the velocity fields for the flow in each model located halfway between two adjacent fins.

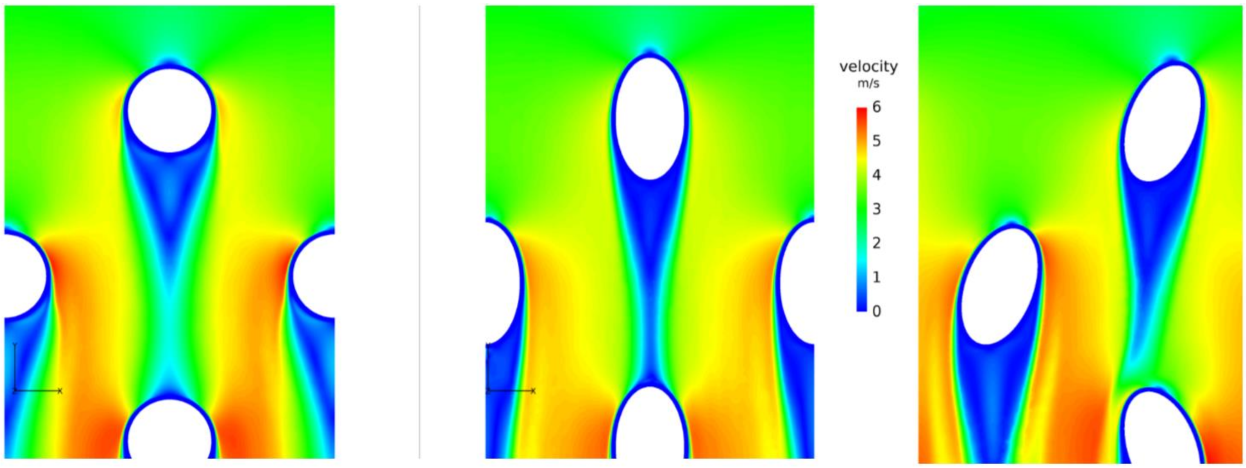

Figure 4: Velocity Field of Different Models

Figure 4 demonstrates that the flow is less constrained when the oval tube is implemented. The wake behind the oval and round tubes is roughly the same area, possibly due to the nearby tubes restraining the size of the recirculation area. The oval alternating model exhibits a more complex flow than the other two models. The complex flow is indicative of mixing flow, which should improve the transport of heat and therefore increase the overall effectiveness of the heat exchanger. The temperature distribution of the flow for each model is shown in Figure 5.

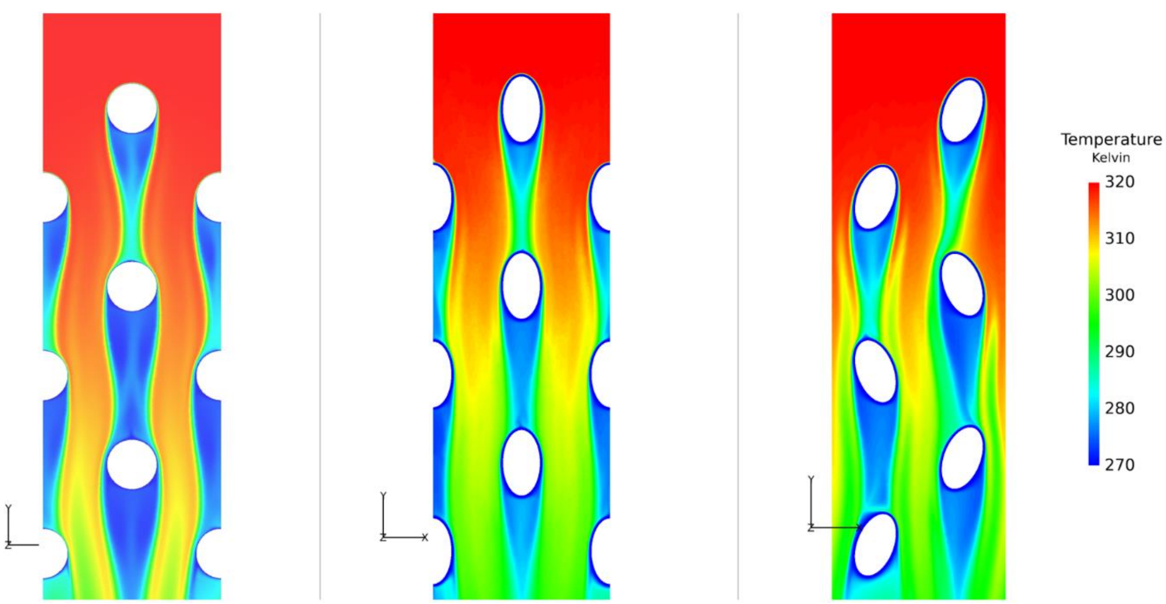

Figure 5: Temperature distribution of the different models

The temperature distributions shown in Figure 4 are the outcome of the energy residual at 1E-8 at steady state. The oval alternating model shows a greater mixing of flow which corresponds to higher temperature difference across the heat exchanger in comparison to the base model. The mixing will also affect the heat exchanger due to the increased pressure drop through the heat exchanger with respect to the oval design. Table 1 shows the pressure drop through each model.

Table 1: Pressure Drop of Different Models at 2.2 m/s

	PRESSURE DROP [Pa]
ORIGINAL	26
OVAL	19
OVAL ALTERNATING	23

As shown in Table 1, both oval designs show lower pressure drop than the baseline design, with the oval design having a lower pressure drop than the oval alternating design. More interestingly, the oval alternating design exhibits greater flow mixing than the original design while also lowering pressure drop. High pressure drop in tube and fin heat exchangers are not desirable since they are used for cooling/heating large volumes of fluid. The heat transfer for each geometry was derived from the heat flux at the tube boundary. Shown in Table 2.

Table 2: Heat Transfer of Different Models at 2.2 m/s

	HEAT TRANSFER [W]
ORIGINAL	4.73
OVAL	4.66
OVAL ALTERNATING	5.01

As shown by these results in Table 2, the original geometry and oval geometry are very similar when comparing the amount of heat they can absorb. The oval alternating geometry has an increased capacity which matches with the theory of increasing mixing of the flow. The interesting part is that with the oval design a lower pressure drop is achieved with almost the same capacity as the original geometry, which could be beneficial for cooling larger volumes of fluid. The oval alternating geometry could be used for more compact heat exchangers due to higher heat transfer and almost same pressure drop as the original design.

Conclusion

In conclusion, the results show that oval design is better for lowering the pressure drop across the heat exchanger while still attaining the same temperature change. The oval alternating model has promising results since the pressure drop was slightly improved compared to the base model and heat transfer was also increased. While these results do not have a mesh convergence study, the oval designs are showing promising results. The future of this research is to complete mesh convergence study and hopefully validate these results with a heat transfer model or using flow visualization.

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