Scientific Research

Numerical Simulation Analysis of Triangular Wavy Fins and Sinusoidal Wavy Fins

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ABSTRACT: In this paper, three dimensional simulation were conducted on the air-side flow and heat transsfer for triangular wavy fins and sinusoidal wavy fins by CFD commercial software,Fluent,which were studied under no slotted, one-wavy and two-wavy slotted conditions respectly. the three dimentional simulation of the air-side flow and heat transfer Analysis of the different inlet velocity on the impact of heat transfer and pressure drop loss were analyzed.Models of the above were inspected combining with the three evaluation criteria, and the merits and demerits of the models were obtained.

Keywords: triangular wavy fins; sinusoidal wavy fins; flow and heat transfer; numerical modelling

1. Introduction

Fin is the main heat exchanger element, because it can extend the area of heat transfer, improve the flow conditions of heat transfer, increase the heat transfer coefficient effectively, ensure the stability of operation and can be manufactured relatively easily. Research on it not only help to improve the heat transfer efficiency and overall system performance, but also has an important guide significance for improving the design type of finned heat exchanger, and developing the compact heat exchanger of more energy-saving and more materials-saving [1].

Through numerical calculation and image display, the systems including related physical phenomena such as flow and heat conduction were analyzed [2]. Because it has low cost, short period, can obtain complete data, can estimate the experimental data difficult to measure and has good repeatability(condition is easy to control: you can continue to improve simulation; further improvements, and then simulate calculation) and verisimilitude, which plays an important role in the commercial or laboratory applications such as design, and transformation etc.[3].

The condition of the flow and heat transfer in the channel was studied by Asako and Faghri [4] through the way of coordinate transformation when the wavy channel changed from sharp corners to rounded corners as early as 1987[5]. It was also studied by Yang etc.[6] under the circumstance of turbulence on the basis of them. The wavy channel was simulated by Xin and Tao[7] by combining rectangular coordinates with polar coordinates. The results show that the return flow zone increased over time when Re is gradually increased to 200, but with the further increase of Re the vortex began to appear downstream the channel and then flow began to become unstable.

Because its geometry is a bit complicated for slit fins, the study on it is very limited. The correlation of heat transfer and resistance of the one-way fin was fitted by Wang etc [10].

The experimental correlation of the two-wavy fin was fitted by Du etc [11]. These two correlations were the most accurate correlation as known so far.

In this thesis, the one-wavy and two-wavy slotted performances of triangular fins and corrugated fins were studied by the commercial software of FLUENT.

2. Phisical and mathematical

2.1 The basic model assumptions

a. Radiation heat transfer is ignored. The heat transfer of the end of fin is not considered. Tube's axial heat transfer and the reverse effect between the tube rows are not considered, and only the vertical heat exchange through the fin is considered.

b. If the flow rate and pressure are low, air can be considered as incompressible fluid.

c. Fins along the direction of heat exchange is uniformly distributed.

d. The thermal conductivity of the fin is infinite or efficiency of the fin is 1.

e. The contact resistance of the fins and the tube outer wall is ignored, and the temperature between the roots of fin and the outside of the pipe wall is same.

2.2 Mathematical model

a. mass conservation equation

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

b. momentum conservation equation

$$u_x\frac{\partial(u_i)}{\partial x}+u_y\frac{\partial(u_i)}{\partial y}+u_z\frac{\partial(u_i)}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial i}+\nu\left(\frac{\partial^2 u_i}{\partial x^2}+\frac{\partial^2 u_i}{\partial y^2}+\frac{\partial^2 u_i}{\partial z^2}\right) \tag{2}$$

c. energy conservation equation

$$u_x \frac{\partial(t)}{\partial x} + u_y \frac{\partial(t)}{\partial y} + u_z \frac{\partial(t)}{\partial z} = \alpha\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right) \quad (3)$$

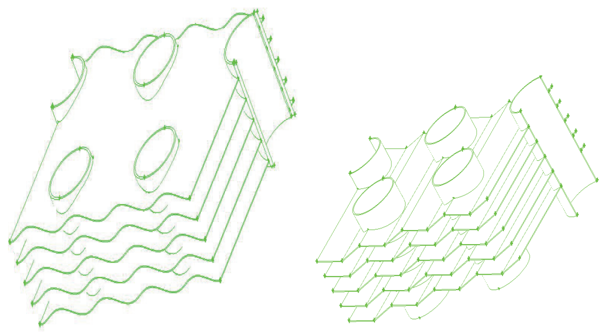
where: ui is ux, uy, uz respectively; xi is the selected coordinates.。

2.3 Computational domain and grid systum

The computational domain is the space between the neighbor fins. Tube outside diameter is 7.5 mm, transverse tube pitch is 10.5mm, longitudinal tube pitch is 15mm, longitudinal fin length is 30mm, fin pitch is2.0mm and fin thickness is 0.1mm.(In this thesis, hexahedral mesh is used in the slotted fin, and the rest using triangle mesh. The details are shown in Figure 2. (Only one model grid is list, and other models are similar to this one.)

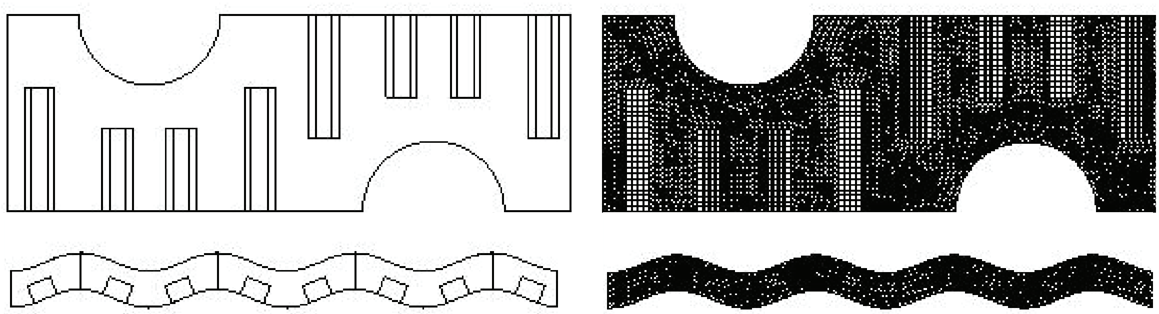
2.4 The boundary conditions of computational domain

Inlet flow rate and temperature are uniform. Both sides of the capacity except the outside of the finned tube wall are symmetric boundary conditions. The upper and lower surfaces, tube outer wall of fin and the small surface slotted out of fin are constant wall temperature [8]. The vertical direction of fin is defined as periodic boundary conditions. The surface of slotted fin is defined as fluid. Since the goal defined as the periodic boundary conditions is required to be paired and mesh generation must be completely uniform, it firstly requires the definition of target link faces for mesh in the GAMBIT, mesh generation, define, then read into FLUENT.



(a) sinusoidal fins **(b)triangular fins**

Figure 1. model of fin



(a) computational domain **(b) fin Grid**

Figure 2. compuatational domain and fin grid

3. Results and analysis

The parameters are defined as follows:

heat transfer rate for the air-side

$$\Phi_h = \dot{m} C_p (T_{out} - T_{in}) \quad (4)$$

Reynolds number $\mathrm{Re} = \frac{\rho u_{\max} D_c}{\eta}$ (5)

heat transfer coefficient $h = \frac{\Phi}{A \Delta T}$ (6)

Nusselt number $Nu = \frac{h D_c}{\lambda}$ (7)

Pressure drop across heat exchanger

$$\Delta p = p_{in} - p_{out} \quad (8)$$

drag coefficient $f = \frac{\Delta p}{\frac{1}{2}\rho u_m^2} \bullet \frac{D_c}{L}$ (9)

logarithmic mean temperature difference

$$\Delta T = \frac{T_{\max} - T_{\min}}{\log\left(T_{\max} / T_{\min}\right)} \quad (10)$$

Where: $T_{\max} = \max(T_{in} - T_w, T_{out} - T_w)$ $T_{\min} = \min(T_{in} - T_w, T_{out} - T_w)$,h is the air side heat transfer coefficient; Dc is the root diameter of fin; $u_{\max}$ is the air velocity of the minimum transverse area;L is the fin length along the flow direction.

3.1 Influence of inlet velocity

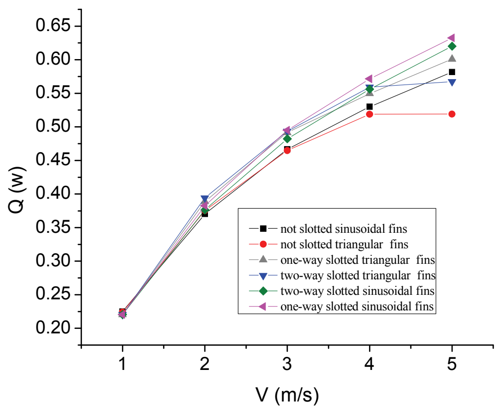


Figure 3. Heat transfer vs. Velocity

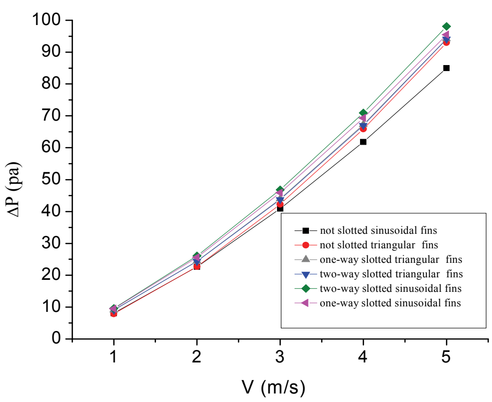


Figure 4. pressure drop vs. Velocity

As shown in Figure 3, heat transfer increases when the air inlet velocity increases. In the same condition, heat transfer of the one-way slotted fin is the best. When velocity is small, heat transfer of the sinusoidal fins is smaller than triangular fins.When the velocity increases to a extent, heat transfer of the sinusoidal fins is larger than triangular fins.

As shown in Figure 4, pressure drop increases when the air inlet velocity increases. In the same condition, increment of pressure drop of the not slotted sinusoidal fin is the smallest. When the air inlet velocity increases, increment of pressure drop of the two-way slotted sinusoidal fin is the largest. Pressure drop of the sinusoidal fins is larger than triangular fins at the same type.

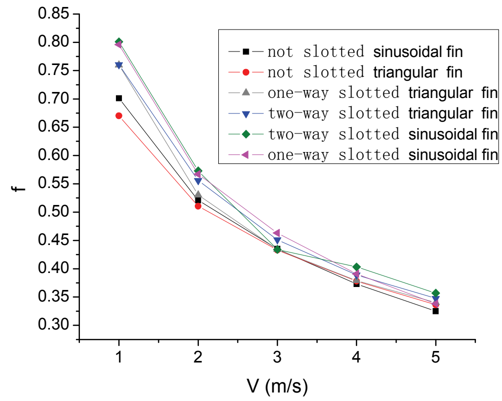


Figure5. velocity vs. drag coefficient

We can see from Figure 5, when the air velocity increases, the drag coefficient gradually decreases for four kinds of fin structure.

When velocity is small, drag coefficient of the triangular fin is smaller than that of the sinusoidal fin. When velocity is larger, drag coefficient of the triangular fin is gradually larger than that of the sinusoidal fin. Drag coefficient of the two-way fins is larger than that of one-way fins at the same type.

3.2 Analysis of three evaluation criteria

The heat transfer enhancement is often associated with the increase of flow resistance of heat transfer medium, which will result in heat transfer enhancement performance decreased. From the perspective of physical performance; we not only take the improvement of the functions into account, but also take the energy savings into account.

From the same perspective of the size of the heat transport under the same pumping power, it is more reasonable that $({Nu}/{Nu_0})/({f}/{f_0})^{1/3}$ should be taken as criteria to evaluate the heat transfer enhancement. From the same perspective of the size of the heat transport under the same pressure drop, then we should take $({Nu}/{Nu_0})/({f}/{f_0})^{1/2}$ as evaluating indicator.

（1）Comparison of the same flow rate

$$Nuf = \frac{Nu/Nu_0}{f/f_0} \tag{11a}$$

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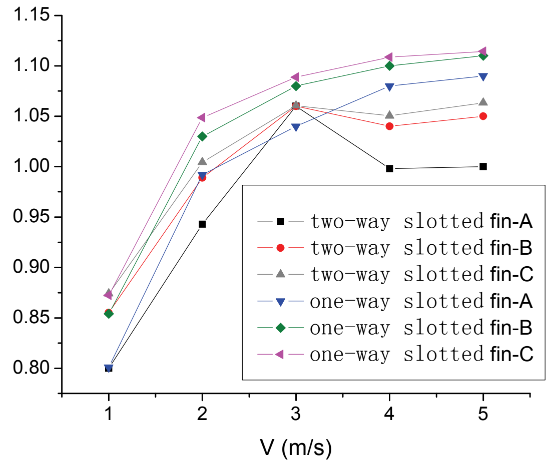
（2）Comparison of the same pressure drop

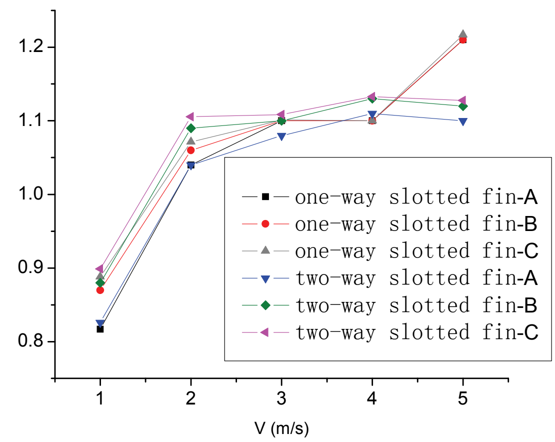
$$Nuf^{1/2} = \frac{Nu/Nu_0}{\left(f/f_0\right)^{1/2}} \tag{11b}$$

（3）Comparison of the same pumping power

$$Nuf^{1/3} = \frac{Nu/Nu_0}{\left(f/f_0\right)^{1/3}} \tag{11c}$$



(a)sinusoidal fins



(b)triangular fins

Figure 6Comparison between slotted fin and not slotted fin under the three standards

In the picture,A —Nuf ratio index,B —Nuf^{1}/Nuf ratio index,C —Nuf$^{1/}$3Nuf ratio index(take not slotted fin as Nu_0 ,f_0 appropriately)

a)For sinusoidal fins,fig(a) shows that when the velocity of two-way slotted fin is 3m/s,the ratio of Nu/Nu_0 to f/f_0 >1,at this point under the same pressure drop and the same pumping power,appropriate value of the slotted fin is also the biggest. For one-way slotted fin,when the velocity increases,the three indexes all increase.When the velocity is small,the three indexes all < 1;When the velocity >2m/s ,the three indexes all > 1.Also,we can see from fig(a) that the overall performance of one-way slotted fin is better than that of two-way slotted fin.

b)For triangular fins,fig(b) shows that when the velocity > 1m/s,both one-way and two-way slotted fin'three indexes all >1.Under the same flow rate,the overall performance of one-way slotted fin is better than that of two-way slotted fin.But Under the same pressure drop and the same pumping power,the overall performance of two-way slotted fin is better than that of one-way slotted fin.

4. Conclusions

In this thesis,three dimentional simulation of the flow and heat transfer of triangular fins and sinusoidal fins was studied under not slotted,one-wavy and two-wavy slotted conditions respectly. The enhanced heat transfer energy-saving mechanism was analyzed preliminarily, and the main conclusions are as follows:

(1) From the perspective of heat transfer perfomance,slotted fin are all better than not slotted fin.however，pressure drop of slotted fin lager than that of not slotted fin,too.

(2) For sinusoidal fins,under the same flow rate, pressure drop and pumping power,one-way slotted fin is better than two-wavy slotted fin.For triangular fins,under the same flow rate,one-wavy slotted fin is better than two-way slotted fin;under the same pressure drop and pumping power,two-wavy slotted fin is better than one-wavy slotted fin.

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