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Research on Heat Transfer Performance and Flow Law Simulation of High Efficiency Plate-Fin Heat Exchanger

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Abstract

Plate-fin heat exchangers are widely used in aerospace, chemical, refrigeration and other industries due to their advantages of light weight, small size, compact structure and high heat transfer efficiency. In order to develop a more efficient plate-fin heat exchanger, the method of numerical simulation and simulation calculation is used to carry out in-depth study on the performance influencing factors and flow resistance optimization method of zigzag plate-fin heat exchanger. Set up the model of zigzag plate-fin heat exchanger with SolidWorks software, divide the grid, carry out numerical simulation and simulation calculation after verifying the grid independence, and verify its reliability. Then, the heat exchange and flow characteristics of plate-fin heat exchangers with three different structural parameters, namely fin thickness, fin spacing and fin height, are compared and analyzed by single variable method to study the effect of the structure parameters of zigzag fins on the heat exchange performance of heat exchangers. The trend of Nussel number Nu, drag coefficient F and comprehensive evaluation index e of fins with Reynolds number Re is calculated. The analysis shows that within a reasonable range, the smaller the fin spacing, the lower the fin height and the thinner the fin thickness, the better the overall performance of the fins.

Keywords

Plate-fin Heat Exchanger; Numerical Simulation; Structural Parameters.

1. Introduction

Heat exchanger is the main component of Rankine cycle. Through the research on heat exchanger, the efficiency of heat exchange can be further improved, and the exhaust gas energy can be recovered, so as to improve the utilization ratio of engine fuel and consequently achieve the purpose of energy saving. At present, the wall-to-wall heat exchanger is generally used in vehicle engines on the market, which can make indirect contact between working fluid and exhaust gas and exchange heat through the wall[1]. The starting point of this process is from the point of view of energy saving and automotive use, but the requirement of the engine for heat exchanger is first to have a high heat exchange efficiency, and at the same time, the heat exchanger is required to have a small volume as far as possible, i.e. to be "compact". Compactness is an important evaluation condition, which refers to the size of the heat exchanger area per unit volume. As one of the compact heat exchangers, the main advantages of plate-fin heat exchanger are its compact structure, small occupancy volume and high heat transfer intensity. Therefore, plate-fin heat exchanger is widely used in the field of engine residual heat recovery. In the 1930s, plate-fin heat exchangers first developed in Western countries. Technicians used plate-fin heat exchangers for engine heat dissipation. By the 1950s, they had a wider range of uses, i.e. opening up new areas of use and starting to use them in deep cooling and air

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separation equipment[2]. With the rapid development of non-ferrous metal technology and the continuous improvement and application of stainless steel anticorrosion treatment technology and brazing process technology, it has been widely applied in many fields, such as petrochemical industry, aerospace industry, vehicle production, electronic information, atomic energy application, weapon industry development, metallurgical and power engineering and machinery, and has achieved remarkable results in utilization of heat energy, saving raw materials, reducing costs and recovering residual heat.

In this paper, numerical simulation and simulation calculation methods are used to study the performance influencing factors and flow resistance optimization method of zigzag plate-fin heat exchanger. The heat exchange and flow characteristics of plate-fin heat exchangers with three different structural parameters, namely fin thickness, fin spacing and fin height, are analyzed and compared by single variable method.

2. Research Method

2.1 Model Introduction

The prototype of the heat exchanger model studied in this paper is a plate fin heat exchanger applied to the engine cooling system. The three-dimensional model of heat exchanger is established by using ANSYS ICEM software, as shown in Figure 1, and the structural parameters are shown in Table 1. Boundary condition setting and meshing [3]. The single variable method is used to study the influence of structural parameters on the performance of heat exchanger. The scheme is shown in Table 1.

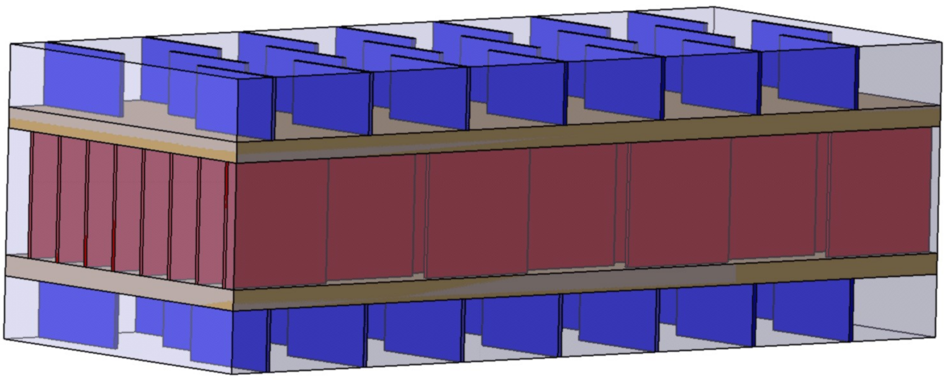

Figure 1. 3D model of plate-fin heat exchanger

Table 1. Basic structural parameters of the model

	length,mm	Width / thickness, mm	height,mm	Wing distance,mm
Integral plate fin heat exchanger model	420	180	140	
A partition	420	180	10	
Cold fluid side fin	60	2	60	56
Heat flux side fin	60	2	60	20

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Table 2. Single variable method simulation scheme

order number	variable	Variable selection / mm	Fixed conditions
1	Wing thickness	1/1.5/2/2.5/3	Fings spacing: 20 mm Height of the fin: 60 mm
2	spacing of fins	18/19/20/21/22	Fings thickness: 2 mm Height of the fin: 60 mm
3	fin height	48/54/60/66/72	Fings thickness: 2 mm Fings spacing: 20 mm

2.2 Model Validation

In the simulation calculation, the simulation model is often verified to ensure the feasibility of numerical simulation. By consulting relevant literature, for the RNG K selected in this paper- ε Turbulence model, the numerical simulation results are compared with the experimental data in the literature to verify the reliability and accuracy of the simulation model. According to the experiment in reference[4], the boundary conditions are set and simulated. The heat exchange calculated by simulation is compared with the experimental results, as shown in Figure 2.

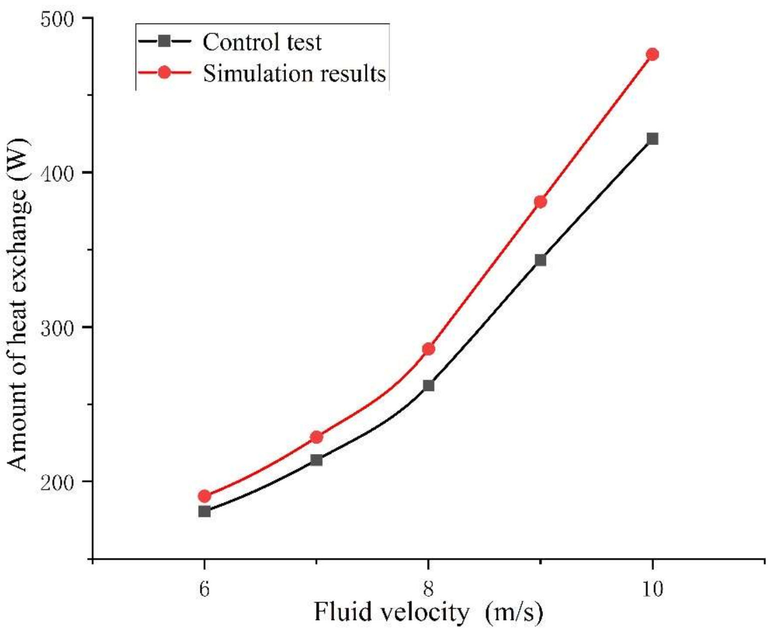

Figure 2. Comparison of heat transfer

It can be seen from Figure 2 that the numerical simulation results are in good agreement with the experimental results in heat exchange under different working conditions. Although there are some differences between the numerical simulation results and the experimental results, generally speaking, the change trend of the two is similar, and the relative error is also within a reasonable range. The relative error of heat exchange is 5.1% ~ 11.45%, It is confirmed that the accuracy and reliability of the plate fin heat exchanger model built in this paper are relatively high, which lays a solid foundation for the accuracy of subsequent simulation analysis.

2.3 Evaluation Index of Heat Exchange Performance

When studying the influence of fin structure parameters on the performance of heat exchanger, a reasonable fin evaluation standard is usually required for evaluation. Therefore, the fin comprehensive performance evaluation index e is selected for comparison[5]. The calculation formula of fin comprehensive performance evaluation index e is as follows:

$$e = \frac{Nu / Nu_0}{(f / f_0)^{1/3}} \tag{1}$$

In the formula:

Nu--Nusselt number under new fin structure;

Nu0--Nusselt number under the original fin structure;

f--Resistance factor of new fin structure;

f0--The resistance factor obtained from the original fin structure.

Where: Nusselt number Nu is a dimensionless coefficient, which represents the ratio of heat conduction resistance to heat transfer resistance. The larger the Nusselt number, the better the convective heat transfer effect[6]. Nusselt number Nu is calculated as shown in formula (2):

$$Nu = \frac{hd}{\lambda} \tag{2}$$

The resistance coefficient f indicates the resistance of the fluid along the flow process. The smaller the resistance coefficient, the smaller the resistance friction along the flow[7]. The calculation is shown in formula (3):

$$f = \frac{\Delta p d_e}{2L\rho v^2} \tag{3}$$

Where:Δp--Represents the fluid resistance loss along the way,Pa;

L--Runner length,m;

P--Fluid density,kg/m3;

v--Inlet speed,m/s.

3. Analysis of Simulation Results

3.1 Fin Thickness

The following figure shows the variation curves of Nusselt number Nu, resistance factor F and fin comprehensive performance evaluation index e of plate fin heat exchanger with the increase of Reynolds number under different fin thickness.

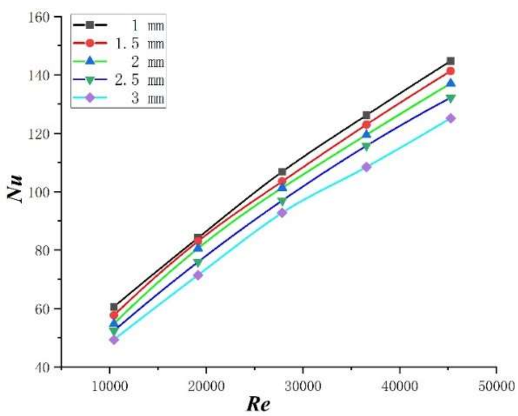

Figure 3. Variation curve of Nu with Re under different fin thickness

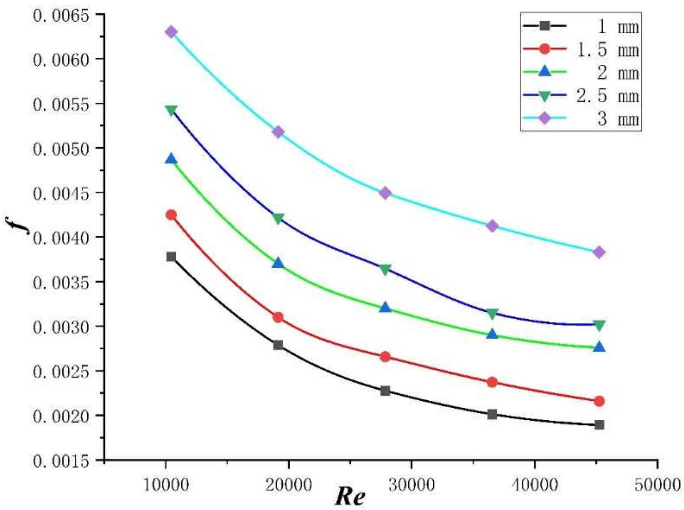

Figure 4. Variation curve of f with Re under different fin thickness

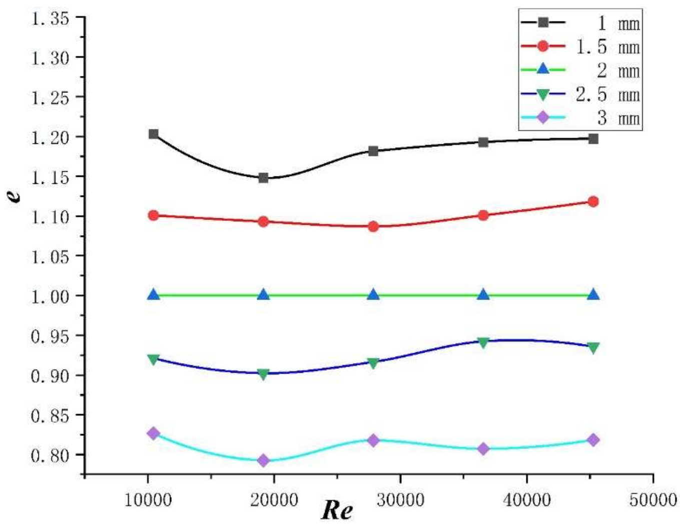

Figure 5. Variation curve of e with Re under different fin thickness

As shown in figures 3, 4 and 5, when the fin spacing and fin height are constant, the Nusselt number Nu at the fluid outlet on the hot side of the heat exchanger increases with the increase of Reynolds number re under different fin thickness; With the increase of the thickness of the serrated fins of the heat exchanger, the resistance coefficient f of the fins of the heat exchanger will also increase. As can be seen from the above broken line diagram, with the decrease of the thickness of the fins, although the comprehensive evaluation index e of the fins gradually increases, the increasing trend is relatively flat.

When the fin thickness is 3mm, the resistance coefficient is larger than other fin thicknesses. The analysis shows that the serrated fins in the channel of the heat exchanger model continuously destroy the fluid boundary layer and increase the flow resistance. Generally speaking, although the comprehensive evaluation index e of heat exchanger fins will increase with the decrease of fin thickness in a certain range, the increase range is very small and will affect the pressure drop to a great extent. Therefore, the change of fin thickness has little impact on the performance of heat exchanger. Therefore, the fin thickness can not be excessively reduced, and the cost will be greatly increased. Various factors should be comprehensively considered when selecting the fin thickness.

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3.2 Fin Spacing

The following figure shows the variation curves of Nusselt number Nu, resistance coefficient f and fin comprehensive performance evaluation index e of plate fin heat exchanger with the increase of Reynolds number under different fin spacing.

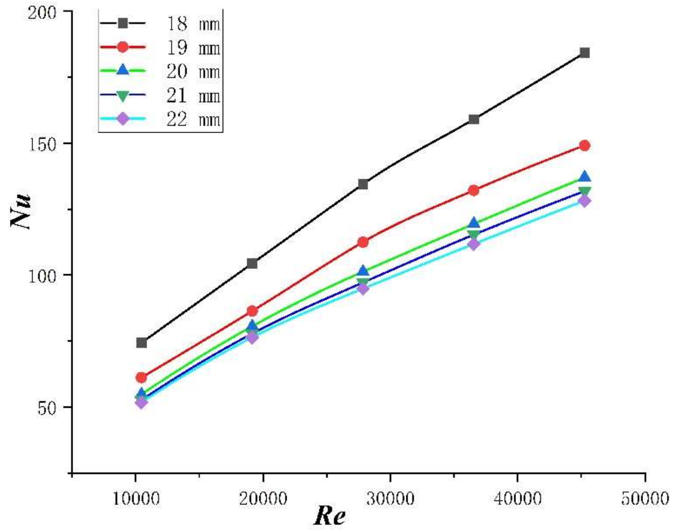

Figure 6. Variation curve of Nu with Re under different fin spacing

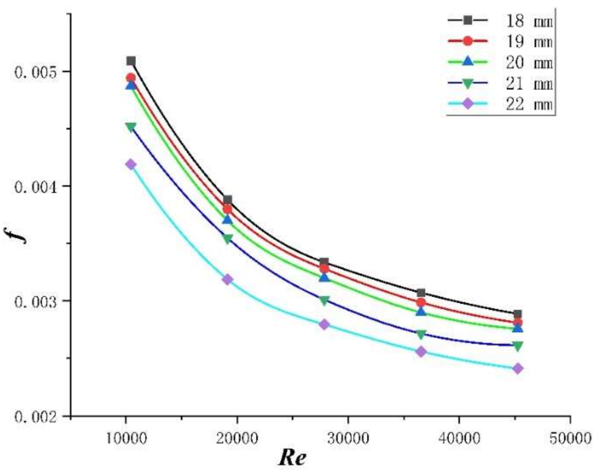

Figure 7. Variation curve of j with Re under different fin spacing

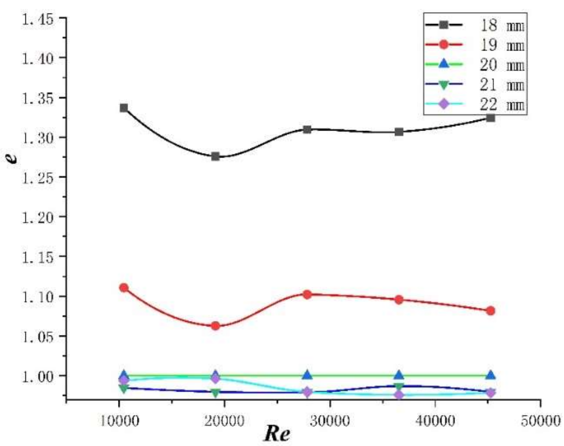

Figure 8. Variation curve of e with Re under different fin spacing

It can be seen from figures 6, 7 and 8 that when the parameters of fin thickness and height remain constant, with the gradual increase of fin spacing, the fin comprehensive evaluation index e with fin spacing of 18mm and 19mm will first decrease and then increase with the increase of fluid inlet velocity. With the increase of fin spacing of heat exchanger, the flow area of cold and hot fluid will also increase, the corresponding flow loss will also decrease, and the influence of boundary layer on fluid flow is also small. When the fin spacing is 18mm, the heat and mass fluid can diffuse to the flow channels on both sides when passing through the serrated fins, and the diffusion range is wide, so that the pressure at the serrated fins changes suddenly, and the flow resistance is less than other parameters. Therefore, in contrast, the fin with the fin spacing of 18mm has the best comprehensive performance.

3.3 Fin Height

The following figure shows the variation curves of Nusselt number Nu, resistance coefficient f and fin comprehensive performance evaluation index e of plate fin heat exchanger with the increase of Reynolds number under different fin heights.

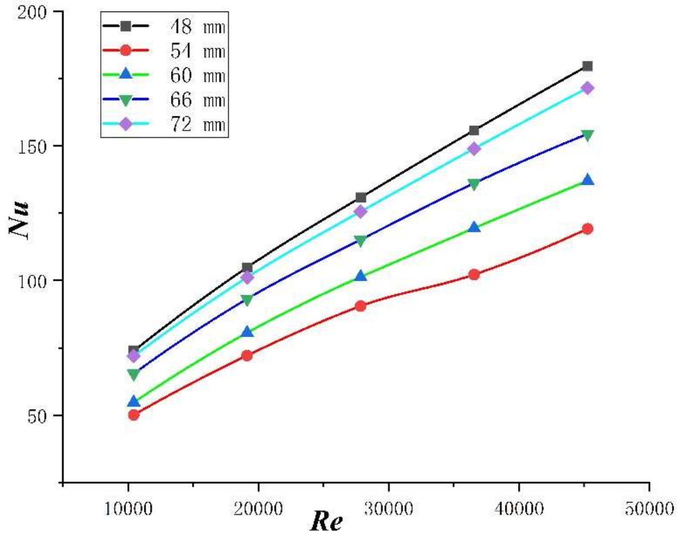

Figure 9. Variation curve of Nu with Re under different fin heights

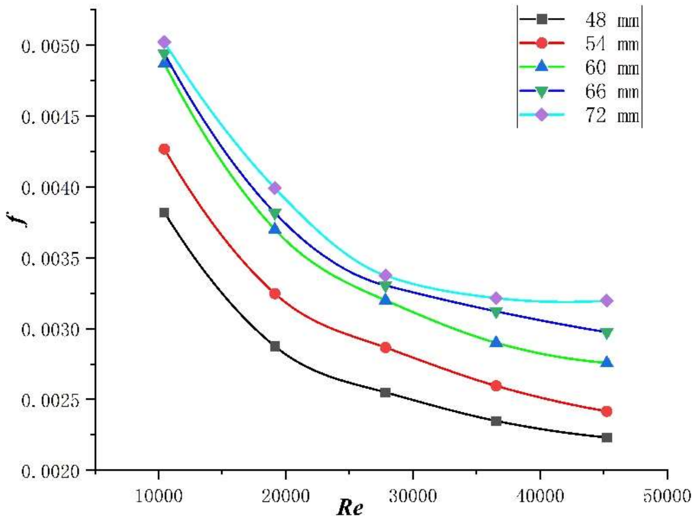

Figure 10. Variation curve of f with Re under different fin heights

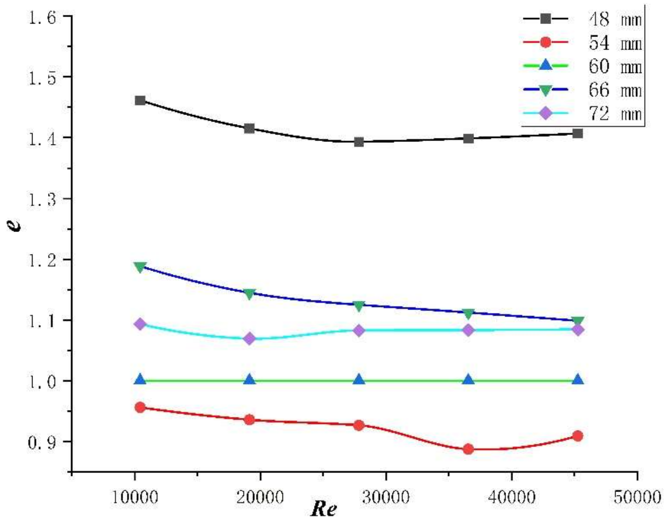

Figure 11. Variation curve of e with Re under different fin heights

According to figures 9, 10 and 11, when the fin height is 48mm, the fin comprehensive evaluation index e is the highest. The reason is analyzed. When the fin height is 48mm, the inlet cross-sectional area is much smaller than other sizes, and the distance between the upper and lower heat exchange surfaces is also greatly reduced compared with other sizes. There is a temperature gradient in the direction of the serrated fin. When the fin height is reduced, the temperature at the center of the fin will increase, the heat exchange temperature difference will also increase, better heat exchange can be carried out, and the heat exchange efficiency will be greatly improved. In addition, the arrangement of serrated fins hinders the forward diffusion of fluid and improves the resistance of the heat exchanger itself. When the fin height decreases, the diffusion range of thermal fluid decreases, and there is a high velocity in the flow direction of the fluid. At this time, it will be reduced by the action of serrated fins. Therefore, under these five fin heights, when the fin height is 48mm, the fin comprehensive performance is better than other sizes.

4. Conclusion

This paper introduces the fin comprehensive performance evaluation index e, and uses the single factor method to analyze the changes of the fin comprehensive performance evaluation index after changing the fin thickness, fin spacing and fin height of the plate fin heat exchanger. By comparing the changes of Nusselt number Nu and resistance factor f respectively, the following conclusions are drawn:

(1) In a certain range, the comprehensive evaluation index e of heat exchanger fins will increase with the decrease of fin thickness, but the increase range is very small, so the change of fin thickness has little impact on the performance of heat exchanger;

(2) In the same heat exchange model, the increase of fin spacing will directly reduce the number of fins in the heat exchanger model, the disturbance caused by the fluid flowing through the serrated fins will also be reduced, and the total heat transfer of the heat exchanger will be reduced accordingly;

(3) As the fin height becomes smaller, the cross-sectional area of the fluid inlet becomes smaller, the diffusion range of the fluid in the channel becomes smaller, the flow velocity in the flow direction will be larger, and the resistance in the channel will also increase. At the same time, the temperature at the center of the temperature gradient in the fin direction increases, the heat exchange temperature difference increases, and the overall heat exchange efficiency of the heat exchanger improves.

In general, the smaller the fin spacing, the lower the fin height and the thinner the fin thickness, the better the comprehensive performance of the fin; That is, when the fin thickness is 1mm, the fin spacing is 18mm and the fin height is 48mm, the comprehensive performance of serrated plate fin heat exchanger is the best. However, relatively speaking, the change of fin thickness has little impact on the overall performance of the heat exchanger, and its resistance characteristics should be considered. In addition, the thinner the fin thickness, the higher the requirements for manufacturing process and economic cost. Therefore, when actually selecting the fin size, it is necessary to make a trade-off and balance between the heat exchange performance and economy of the heat exchanger.

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