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Investigation on the Effect of Fin Width on the Heat Transfer Performance of the Condenser Used in the Automotive Air Conditioning System

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The efficiency of the air conditioning system will affect the comfort and the energy consumption. Therefore, study on it can help to reduce the emission reduction. In the system, condenser is a quite important part, which mainly affect the performance of the whole device. In this paper, a new type structure of condenser of automotive air conditioning system has been studied, and some conclusion has been obtained: (1) Unit area heat exchange decreases when the fin width increases. The resistance increases with the fin width increases, and the heat transfer coefficient decreases with the fin width increases; (2) The resistance has a higher decreasing speed and both heat transfer coefficient and the total heat flux increase at a lower speed, which means that the overall heat transfer rate can't be increased just by increase the width of the fin. According to the study of the effect of fin width on the condenser performance, the validity of the computational fluid dynamics (CFD) applied on the air conditioning system has been proven.

1. Introduction

Modern automobile design pays more and more attention on the characteristics, including body shape (Per Mårtensson, Dan Zenkert, Malin Åkermo (2015)), structure lightweight (Åsa Kastensson (2015)), etc. Especially for the shape, the study on it mainly meets the air dynamics requirements to reduce energy consumption (Andrea Rusich, Romeo Danielis (2015)) and achieve the aim of energy-saving and emission reduction. Besides, the air conditioning system of the automobile consumes more energy, and the optimization of the performance of the automobile air conditioner can also help reduce the energy consumption. Therefore, the research on the air conditioner (S.P. Datta, P.K. Das, S. Mukhopadhyay (2014); Alison Subiantoro, Kim Tiow Ooi (2013)) has an important effect on the automobile energy saving.
Automotive air conditioning system study mainly concentrates on the flow structure, heat transfer and resistance characteristics. There are three methods for the research of automobile air conditioning system, including traditional experimental study, computer programming, and computational fluid dynamics (CFD) technology for numerical simulation (M. Abdulkadir, V. Hernandez-Perez, S. Lo, I.S. Lowndes, B.J. Azzopardi. (2015)). Among of all the methods, CFD technology is a powerful tool in the research of heat transfer, mass transfer, momentum transfer, combustion, multiphase flow and chemical reaction. Meanwhile, the optimization design of automobile air conditioning system is one of the important application fields of CFD. Traditional automotive air conditioning system design generally relies on basic theory and experimental analysis to determine the structure of the automotive air conditioning system, which requires a lot of experimental funds as well as a quite long development cycle. For automobile air conditioning system, the flow and heat transfer characteristics of the internal fluid are more complex (S.P. Datta, P.K. Das, S. Mukhopadhyay. (2014)), and performance of the new vehicle air conditioning system can't meet the requirement just by experimental test. Therefore, CFD software, which can quickly, accurately and intuitively reflects the flow of fluid in automobile air conditioning system, has been applied to find out the problems in the design of the flow field analysis to improve the design efficiency.
The application of CFD technology in the automotive air conditioning system is mainly on the design of the duct (Wenxian Zheng, Ying Chen, Nan Hua, et, al (2014)), evaporator (Kyung Hwan Kim, Sun Hwa Kim,

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Young Rim Jung, (2008)), condenser (S.P. Datta, P.K. Das, S. Mukhopadhyay. (2014)), fan, and its vortex shell structure design, frost and defrost analysis and the interior structure design. In the development of automotive air conditioning system, the role of numerical simulation model becomes more and more important (B. Taxis-Reischl, S. Morgenstern, F. Brotz (2001)). For some air conditioning systems, the air duct is very complex, and the flow situation is very difficult to get just by the experimental test. In this case, the simulation tool can get quite accurate results for the numerical simulation of the concrete channel (Gerald Seider, Fabiano Bet, Thomas Heid, et al, (2001)). The optimization and improvement of the system can be obtained by the numerical simulation. In the duct design of automotive air conditioning system, flow control is optimized for the dual air conditioning system, and the expansion temperature is used as the key index to effectively control the maximum cooling rate of the automobile air conditioning system (M.H. KIM, G.Y. Jang, K.W. KIM. (2001).). Except the thermodynamic properties, noise of air conditioning system is another standard of automobile quality. The structure and air duct of the turbine fan have a great effect on the noise. In order to decrease the noise level, the structure of the duct should be optimized to reduce the vibration and resonance.

In air conditioning system, function of the condenser is quite obvious. Research on the structure of the condenser fins and some other heat sink fins has been proposed. For the condenser structure, big automobile factories in the world pay much attention on it, including the width of the louvered fin spacing, angle, border structure and its number, etc. In addition, the CFD technology applied to the research on the development of condenser can effectively modify the design errors, improve the efficiency. In this paper, a new type structure of condenser of automotive air conditioning system has been studied. According to the determination of the fin width, the performance of the condenser has been realized.

2. The model and boundary conditions

(1) The calculating model

The three dimensional control equations with incompressible, steady state, and the constant flow can be described as the following:

1) The continuous function:

$$\frac{\partial \rho u_i}{\partial x_i} = 0 \tag{1}$$

2) Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\cdot\mu\frac{\partial u_k}{\partial x_k}\right] - \frac{\partial \overline{p}}{\partial x_i} \tag{2}$$

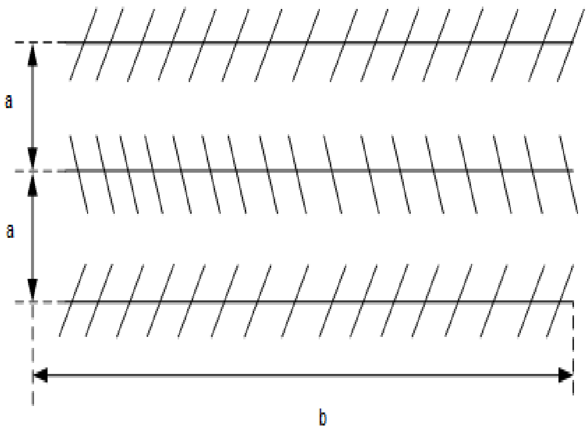
3) Energy equation:

$$\frac{\partial(\rho u_i c_p T)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\lambda\frac{\partial T}{\partial x_i}\right] + \frac{\partial u_i}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\cdot\mu\frac{\partial u_k}{\partial x_k}\right] \tag{3}$$

In the three equations above, ρ is air density; λ is thermal conductivity of the air; c_p is the air specific heat; u_i, u_j, u_k are the velocity of i, j, k direction; x_i, x_j, x_k are the coordinates of i, j, k direction; μ is the dynamic viscosity; $\overline{p}$ is the average pressure.

(2) Geometric model

The structure of the condenser is shown in Figure 1. The thickness of the core part is composed of width of the fin and the tube. The medium flows in the middle of the flat tube, and the heat transfers from the fin and tube to the airflow when the air flows through them. The fin structure is shown in Fig. 2. Here, the width of the fin is defined as the length of the fin along the flow direction of the air. Here, the fin width is adopted as the single parameter to study the heat transfer performance while the other parameters remain unchanged. The width of each piece of the shutter used in the experiment is 0.85 mm, and the width of the fin is set as 12.8 mm, 14.5 mm, 16.2 mm, 17.9 mm, 19.6 mm, 21.3 mm and 23 mm, respectively.



a: distance between two fins; b: fin width

Figure 1: Schematic view of condenser

(3) The basic assumption and the boundary conditions
In the fin width simulation, the main assumption includes: (1) the air can be seen as the incompressible gas; (2) the gravity effect is neglected; (3) the temperature of the fin is kept constant in the process of heat transfer; (4) Airflow in the process is steady flow. The boundary conditions include: (1) the air temperature is 35 ℃; (2) the temperature of fin surface is 60 ℃; (3) The rotating speed of the driving fan is 720 rpm. Distance between two fin is 1.5 mm. Standard k-ε equation is used in the simulation and the second order accuracy is used in the solution process. Both the inlet and the outlet are set with pressure condition. The detailed information is shown in Table. 1.

Table 1: Simulation boundary conditions of different fin width CFD

Boundary condtion	Boundary type	Parameters
Inlet	Pressure	Temperature of the airflow through inlet: 35℃; Airflow velocity: 3.5 m/s
Outlet	Pressure	Outlet pressure: 0 Pa.
Wall	Wall	Material: Aluminum; Wall temperature: 60℃.

3. Verification

In order to verify the validity of the CFD simulation results, the experiment is prepared. The schematic view of the condenser test bench is shown in Figure 2.
In the experiment, the absolute pressure of the cold medium in entries is 1600 + 5 kPa, and degree of superheat of cold medium at inlet is 25 ℃ while that at outlet is 5 ℃. Oil percentage in the circulating refrigerant is 5% in all the conditions. The airflow resistance has been measured and compared. In the experiment, the requirement of resistance value is less than 45 Pa.

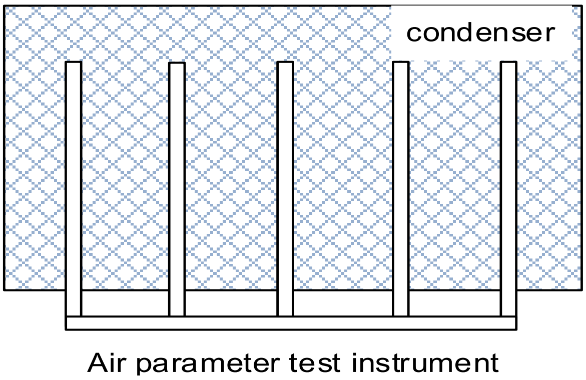


Figure 2: The test bench for the condenser

The experimental results of the condenser experiment are obtained by the method of multiple measurements, while the reliability of the experimental results is verified by multiple experiments. In the process of the experiment, many parameters, including temperature and pressure of air at the inlet and outlet, temperature and pressure of refrigerant at the inlet and outlet, airflow resistance, heat transfer, mass flow rate of the refrigerant, have been monitored and recorded to ensure the correctness of the experimental procedure and results. Some main parameters, such as airflow resistance, heat transfer, et al, have been used to evaluate the performance of the condenser.
The simulation is aiming at part of the fin, therefore, the airflow resistance is adopted as the comparative parameters. Airflow resistance of simulation and experimental results is shown in Tab. 2. As can be seen that both the results are less than 45 Pa. Under the same conditions, the absolute error between the airflow resistance results of simulation and experiment is 2.04 Pa and the relative error is 5.3%, which indicates the simulation results can better reflect the real situation.

Table 2: The simulation and experiment results

Item	Precision of the test equipment/Pa	Relative error/%
Experimental resutls	0.4% of the test range	38.28
Simulation results	/	40.32
Relative error	/	5.3%

CFD simulation results of different width of the fins are shown in Table 3. It can be seen that unit area heat exchange decreases when the fin width increases.

Table 3: Effect of fin width on the heat transfer performance

Fin width/mm	Heat transfer of each unit area/ q /W·m^2	Heat transfer area/m2	Total heat transfer quantity/W
12.8 mm	3420	3.9127	13381.43
14.5 mm	3012	4.4467	13393.46
16.2mm	2801	4.9807	13950.94
17.9 mm	2598	5.5147	14327.19
19.6 mm	2440	6.0487	14758.83
21.3 mm	2312	6.5827	15219.2
23 mm	2187	7.1167	15564.22

Variation of heat transfer coefficient h and airflow resistance △ P with different fin width is shown in Fig. 3. It can be seen that the resistance increases with the fin width increases, and the heat transfer coefficient decreases with the fin width increases. With the increasing of the fin width of 1.7 mm, the resistance value will increase 1.5~6 Pa, and the heat transfer coefficient h is reduced from 1.4% to 8%. With the increasing of the fin width, heat transfer coefficient decreases.

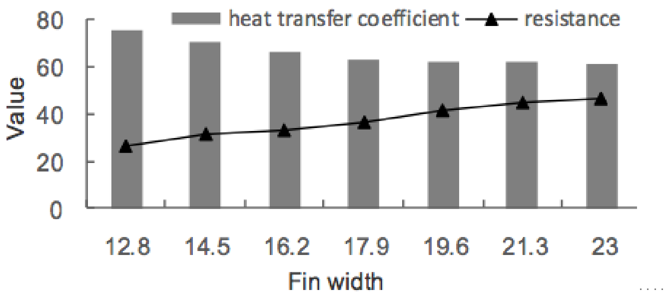


Figure 3: Variation of heat transfer coefficient h and airflow resistance P with fin width

However, heat transfer amount and resistance are increased. In order to convenient comparison, some new parameters have been proposed (Hou Xianjun, Yun Xiang and Liu Zhien (2013)):

$$\alpha = \frac{h \times S}{\Delta P}, \ \beta = \frac{h}{\Delta P}$$

Value of the two parameters of α and β is shown in Fig. 4. Both the two curves have the downward trend, which means the resistance has a higher decreasing speed and both heat transfer coefficient and the total heat flux increase at a lower speed. Then, the overall performance of the fin decreased gradually. It can be seen that the total heat transfer rate can't be increased just by increasing the width of the fin. However, if the resistance requirements can be met, the fin width can be increased to increase the heat transfer rate at some extent.

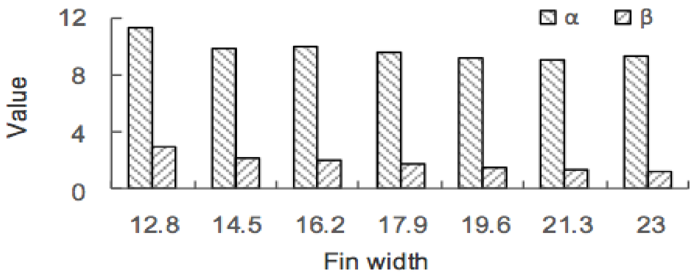


Figure 4: Effect of fin width on α and β

4. Conclusions

Modern automobile design pays more and more attention to the comfort and energy consumption. The efficiency of the air conditioning system should be relatively high, and the optimization of automobile air conditioner is necessary. Automotive air conditioning system study mainly concentrates on the flow structure, heat transfer and resistance characteristics. In various methods, computational fluid dynamics (CFD) technology, which is a powerful tool in the research of heat transfer, mass transfer, and so on, can be applied to the optimization of the air conditioning system performance. In this paper, a new type structure of condenser of automotive air conditioning system has been studied. According to the determination of the fin width, some conclusion has been obtained:

(1) Unit area heat exchange decreases when the fin width increases. The resistance increases with the fin width increases, and the heat transfer coefficient decreases with the fin width increases. With the increasing of the fin width, heat transfer coefficient decreases. However, heat transfer amount and resistance are increased.

(2) The resistance has a higher decreasing speed and both heat transfer coefficient and the total heat flux increase at a lower speed, which means that the overall heat transfer rate can't be increased just by increasing the width of the fin.
(3) The study of the effect of fin width on the condenser performance indicates that the computational fluid dynamics (CFD) can be used in the automotive air conditioning system to modify the structure design.

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