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Research on finite element-based heat transfer optimization design method in air conditioner heat exchanger performance analysis

Yan Hou[1,✉], Yan Xiang[1], Xin Xiao[2]

[1] *School of Intelligent Construction and Environmental Engineering, Chengdu Textile College, Chengdu, Sichuan, 611731, China*

[2] *Minmetals Land Limited (Chengdu), Chengdu, Sichuan, 610039, China*

ABSTRACT

People's performance requirements for air conditioning along with people's requirements for indoor air quality also continue to improve, air conditioning heat exchanger as an important part of the refrigeration system in the air-conditioning products in the largest proportion of space. Therefore, this paper is based on finite element analysis of air conditioning heat exchanger optimization design, oriented to the needs of air conditioning heat exchanger, heat transfer to the mechanism of depth analysis. The finite element analysis is used to study the heat transfer simulation theory of air conditioning heat exchanger, and the heat transfer optimization design method is proposed, and the heat transfer model based on finite element analysis is constructed. Through the physical model and its numerical simulation method for verification, the numerical simulation value and experimental value of the pressure drop and convective heat transfer coefficient error of ± 6.50W/m^2 ℃ and ± 12.7Pa, respectively, which verifies the model of this paper and the feasibility of numerical simulation method for. Comparing the performance of the optimized air conditioning heat exchanger, the optimized heat exchanger in this paper improves the cooling capacity by 0.04~0.50kW and the total pressure drop by 11.19~50.84kPa compared with the comparative models, which proves that the optimized heat exchanger in this paper has better performance and can meet the performance and reliability index requirements of engineering applications.

Keywords: Heat and mass transfer mechanism; finite element analysis; heat transfer model; air conditioning; heat exchanger

1. Introduction

A device that transfers the heat of a certain fluid to other fluids in a certain way of heat transfer is called a heat exchanger. In history, heat exchangers have been used for quite a long time, heat exchangers are the most basic equipment used in various fields such as air conditioning, food, chemical, energy, etc., but as time advances, heat exchangers are also constantly undergoing a variety of

✉ Corresponding author.
E-mail address: houyan0712@163.com (Y. Hou).
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optimization, performance of the old heat exchanger has been unable to meet the demand for heat exchanger heat transfer performance in all walks of life, how to optimize the heat exchanger's heat transfer performance is still a variety of fields so far in the Continuous research content [1-4].

In recent years, with the continuous improvement of people's living standards, people's requirements for the thermal comfort of the living environment have become higher and higher, and the number of air conditioners has also soared, which has brought about the global energy consumption is climbing every year, especially the consumption of electrical energy is rising every year [5-7]. Air conditioner to bring people a comfortable environment at the same time also consumes a lot of electricity, followed by a large number of greenhouse gas emissions, China and foreign societies in recent years have continued to implement emission reduction policies, air conditioner energy consumption standards have also been raised, but also continue to promote this air conditioner energy-saving technology continues to move forward [8-10]. In recent summers, the problem of electricity panic will always continue to appear, and the trend has become more and more frequent, the implementation of power-limiting measures has seriously disrupted social production and living order, and its impact is expanding year by year [11-12].

According to incomplete statistics, at the beginning of the 21st century, the energy consumption of air conditioners accounted for about 30% of the overall energy consumption of the Chinese society, China's main electrical energy is thermal power, summer is often the peak period of air conditioner use, the rising demand for electrical energy in summer will lead to the emergence of two problems, the increase in coal consumption and the intensification of environmental pollution [13-14]. In summer, the electricity consumed by air conditioners accounts for about 40% of the total electricity consumption of the Chinese society, and this figure is still rising. Therefore, how to reduce the power consumption of air-conditioners and improve the operating efficiency of air-conditioners has become a very important topic, which also satisfies the current call for energy saving and emission reduction. Therefore, it is necessary to improve the heat exchange efficiency of the heat exchanger of the air conditioning system and reduce the power consumption of air conditioners [15-17].

Due to the popularity of air-conditioners, the basic performance of air-conditioner components such as heat exchangers and compressors has been greatly improved to meet the diversified needs of the market for saving energy, materials, and space, as well as for realizing a comfortable living space. In addition, with the increasing awareness of environmental protection, volatile oils, which do not need to be cleaned, are used in the manufacturing process of heat exchangers for air conditioners instead of organic solvents [18-19]. And in some places, the problem of acid rain is becoming more and more serious, which requires more and more performance from heat exchangers. Most of the heat exchangers for air conditioning use finned tube type heat exchangers. In response to the above situation, heat exchangers for air conditioning have carried out technological innovations, which are summarized as follows Adoption of internally threaded copper tubes, improvement of structure, optimization of the fin shape, reduction of the sheet spacing, thinning of the thickness of aluminum foil, hydrophilic and corrosion-resistant treatments on the surface of the aluminum foil, and treatment of resistance to acid rain, etc. [20-21]. Copper tube finned heat exchanger for small household air conditioners and air-cooled commercial air conditioners are the most commonly used form of heat exchanger, copper tube finned heat exchanger in the work of the tube to go refrigerant, the tube outside the fin measured to go air. Should be the air side of the heat transfer thermal resistance, low heat transfer efficiency, so the air side of the heat transfer thermal resistance occupies the heat exchanger heat transfer resistance of the vast majority of the heat exchanger, how to improve the air side of the copper tube fin heat exchanger heat transfer efficiency has become the optimization of the copper tube finned heat exchanger of the main research content. In order to reduce the heat transfer thermal resistance of the air side and increase the heat transfer efficiency of the air side, at present, Chinese companies have been optimized for the shape of fin openings, coating materials, fin materials, and heat exchanger forms [22-24].

The optimized design of heat exchanger has always been the focus of research in the field of heat transfer, and its optimized design mainly involves heat transfer medium, heat transfer fins, heat transfer structure design and coating surface layer, in which the research and analysis and optimized design of heat transfer fins are as follows, the literature [25] systematically reviewed the finned heat exchanger, focusing on the performance of the heat transfer parameter and the mechanism of heat transfer of the new type of fins materials and structural parameters, and finally verified the relevant by characteristic Finally, the related validation was carried out through characteristic calculations. Literature [26] compared the heat transfer performance of perforated wave fins, staggered wave fins and discontinuous wave fins of heat exchangers based on simulation experiments in order to analyze how the key design parameters such as fin waveform aspect ratio, shot hole diameter, staggered ratio and breaking distance affect the heat transfer performance of fins, and the study confirms that the optimized heat transfer performance of the proposed fin is superior to that of the traditional heat exchanger fins. Literature [27] applied a multi-objective optimization algorithm with genetic algorithm, differential evolutionary algorithm and adaptive simulated annealing algorithm as the underlying architecture to optimize the design of the heat exchanger fin parameters, identified the fin offset length, fin height and fin length as the optimization variables, and introduced a multi-criteria decision making method, TOPSIS, to obtain the optimal solution of fin parameters. Literature [28] revealed that the fin thickness and fin spacing of the heat exchanger significantly affect the heat exchange efficiency of the heat exchanger through phase change material melting experiments, and pointed out that the horizontal angle of the heat exchanger also affects the heat exchange efficiency of the heat exchanger to a certain extent. Literature [29] conceived a heat exchanger design methodology to investigate the feasibility of hybrid fins for heat exchangers, in order to fully utilize the characteristics of different fins, combined with the nonlinear programming (NLP) model, enumeration methodology for practical case study analysis, confirming the feasibility of the hybrid fin-matched fin combinations in the heat exchanger design practice.

Based on the research carried out from the perspective of heat exchange system structure optimization and design, literature [30] investigated the impact of folded plate and longitudinal ribbed tube combination structure on the heat exchange performance of the segmented folded plate shell and tube heat exchanger, and compared the data obtained from simulation experiments with the experimental data and the results of the literature, confirming that the folded plate and the longitudinal ribbed tube combination structure design significantly improves the heat exchange performance of the heat exchanger. Literature [31] in-depth introduction to the shell and tube heat exchanger heat exchange design optimization path, focusing on the optimization of the geometric shape structure design of the heat pourer, including the introduction of inserts, optimization of the shell side baffle plate, pointing out that the future focus of the development of the heat exchanger optimization is the direction of the strengthening of the tube structural design, nano-fluid and other ways to strengthen the performance of the heat exchanger.

Optimization analysis from the perspective of heat exchanger media is as follows, literature [32] explored the heat transfer and mobility performance of different nanofluids in solar heat exchanger system, based on the experimental results, it is known that compared to the base fluid, nanofluid has better heat transfer performance and pressure drop, which is the highest heat transfer efficiency when the working fluid is 1.0 wt.% fe3o4 - water nanofluid. Literature [33] combined theoretical analysis and research experiments to analyze the contribution of nanofluids to the heat transfer efficiency improvement of heat exchangers, the study pointed out that the heat exchanger performance is poorer below sixty degrees Celsius, but the use of nanofluids can improve the heat exchanger's thermal efficiency of about 10%, and in the high temperature case (70 degrees Celsius) nanofluids can improve the performance of the heat exchanger of about 1%, in which the SiO2/water nanofluid performs better than Cu/water nanofluid at high temperatures. Literature [34] discussed in detail the cases and related studies on the application of nanofluids in heat exchangers, and simulated and analyzed their working journeys, and pointed out that the nanofluids improved the heat transfer effect, enhanced the heat transfer efficiency, and reduced the energy consumption of heat exchangers in most of the cases.

Literature related to heat exchanger coating layers include, literature [35] reviewed the advantages of polymer materials for heat exchanger material design, including low cost, low density and corrosion resistance properties, but the mechanical and thermal properties of the ware are poor, and analyzed the physical parameters that determine the thermal conductivity of polymers and composites, which contributed positively to the design of polymers and composites for adapted heat exchangers. Literature [36] introduced porous metal-organic framework (mof) as an advanced adsorbent to coat the evaporator and condenser surfaces to control the humidity in the heat exchanger system, which can effectively reduce the potential cold load of the heat exchanger, and save energy while improving the efficiency of heat exchange. Literature [37] elaborated that desiccant coated heat exchangers can effectively solve the problems of low energy efficiency as well as low heat transfer efficiency of vapor compression air conditioning, and listed the dryer coating coating methods, and looked forward to the future research trend of heat exchanger drying coating. Literature [38] carried out research experiments to evaluate the metal-organic skeleton coating material (fused polysiloxane fused microporous aluminum fumarate) with high potential for heat adsorption applications applied to heat exchange systems and evaluated it to support the positive role played by the coating material in improving heat transfer efficiency.

The heat exchanger is an important part of the operation that affects the energy consumption and airflow of the air conditioning system, this paper proposes the heat transfer simulation theory based on finite element analysis through the in-depth study of air conditioning heat transfer and mass transfer mechanism, and elaborates the application method of finite element analysis. On this basis, this paper is oriented to the needs of the air conditioning heat exchanger, puts forward the heat transfer optimization design method, and then constructs the heat transfer model based on finite element analysis. This paper verifies the validity of this paper's model through data simulation results, which provides a guarantee for the subsequent optimization performance analysis of air conditioning heat exchangers. Finally, the heat transfer optimized heat exchanger in this paper is simulated according to the simulation model, and the cooling capacity and total pressure drop of the heat exchanger are compared with those of the comparison model to further assess the advantages of the optimized design method of the heat exchanger in this paper.

2. Finite element analysis study for air-conditioning heat exchangers

2.1. Heat and mass transfer mechanism analysis

Two streams of air with different temperatures and humidity are exchanged for heat and humidity through an intermediate medium. According to the theory of heat and mass transfer, the driving force for the transfer of heat is the temperature difference, and the driving force for the transfer of mass is the concentration difference. For water vapor transfer, the transfer power can also be said to be the water vapor partial pressure difference. The analysis of the heat and moisture transfer mechanism of the total heat exchanger is to determine the functional relationship between the amount of heat and moisture transfer and its corresponding transfer power. According to the boundary layer theory of fluids, when a fluid with viscosity flows over the surface of an object, a flow boundary layer with a large velocity gradient will be formed. When there is a temperature difference between the wall and the fluid, a temperature boundary layer or thermal boundary layer with a large temperature gradient will also be created. Similarly, when there is a concentration difference, a concentration boundary layer or a mass boundary layer is created.

2.1.1. Analysis of heat transfer mechanism.The conditions of the fluid boundary layer and the thermal boundary layer determine the heat transfer process and the temperature distribution within the boundary layer. The thicknesses of the thermal boundary layer and the flowing boundary layer are not necessarily equal, and the ratio of the two depends on the physical properties of the fluid, and the Nusselt criterion number is usually used to analyze the heat transfer mechanism of the boundary layer.

Nusselt number:

$$Nu=\frac{hd_e}{\lambda_f} \tag{1}$$

Nu characterizes the size of the dimensionless excess temperature gradient in the wall direction, which reflects the strength of convective heat transfer. Where h represents the convective heat transfer coefficient, d_e represents the equivalent diameter, and λ_f represents the thermal conductivity of the fluid.

The magnitude of the heat transfer in the boundary layer is characterized by the three norms Re, Pr and Nu as a function of the geometry of the object. For the paper plate total heat exchanger under study, the heat transfer process between two streams of air through the paper can be viewed as the following three steps:

1) The air on the higher temperature side transfers heat to the intermediate medium paper through convective heat transfer in the boundary layer.

2) Heat in the direction of the thickness of the paper through the form of thermal conductivity to the other side of the air boundary layer.

3) The air on the lower temperature side absorbs heat from the boundary layer through convective heat transfer.

Through these three steps, heat is transferred from the air on the high temperature side to the air on the low temperature side through an intermediate medium. The convective heat transfer process on the air side can be regarded as the convective heat transfer between the fluid flow inside the tube and the tube wall. According to the different fluid flow state, the calculation of the convective heat transfer coefficient of the fluid flow in the tube is divided into the following cases, defining a dimensionless quantity:

$$\mathrm{Pr}\,o = \mathrm{Pr}\,\mathrm{Re}\frac{d_e}{L} \tag{2}$$

For rectangular channels, the equivalent diameter is:

$$d_e = \frac{2bH}{b+H} \tag{3}$$

Where, b, H and L represent the width, height and length of the rectangular channel respectively.

1) When the flow pattern is laminar:

When $\mathrm{Pr}\,o<100$

$$Nu=3.658+\frac{0.085\,\mathrm{Pr}\,o}{1+0.047\,\mathrm{Pr}\,o^{067}}\left(\frac{\mu_b}{\mu_s}\right)^{0.14} \tag{4}$$

When $\mathrm{Pr}\,o>100$

$$Nu=1.86\,\mathrm{Pr}\,o^{033}\left(\frac{\mu_s}{\mu_s}\right)^{014} \tag{5}$$

2) When the flow pattern is turbulent:

$$Nu = 0.023\,\mathrm{Re}^{08}\,\mathrm{Pr}^{n} \tag{6}$$

where $n = 0.4$ if the fluid is heated and $n = 0.3$ if the fluid is cooled.

2.1.2. Analysis of mass transfer mechanisms.When two strands of air with different temperatures and humidity through the plate heat exchanger, due to the existence of water vapor pressure difference between the two strands of air, water vapor will be large by the humidity of the side of the air through the middle of the medium of paper transfer to the humidity of the side of the air is relatively small. In addition to the amount of moisture transfer and water vapor pressure difference between the two streams of air, in addition to the relationship, to a large extent, depends on the intermediate media moisture permeability.

Porous media is a solid material containing numerous internal pores, it is a multi-phase material occupied by the space, which must contain the solid phase. Solid phase is also known as the solid skeleton, there is no solid skeleton of that part of the space is called the pore or void, which is occupied by the liquid, gas or gas-liquid two-phase. Solid skeleton is distributed in the porous medium occupies the entire space, most of the voids are connected to each other called the effective void.

Porous media voids in the fluid if at rest, or transverse across the laminar traces, the mass transfer in the porous medium belongs to the form of molecular diffusion. However, with the size of the void size, this molecular diffusion mass transfer characteristics and laws are different. Now briefly analyzed as follows:

Kn represents the ratio of the pore qualitative diameter to the free range of the fluid molecules and is a dimensionless quantity. Depending on the value of Kn, molecular mass diffusion can be categorized into the following three types.

1) Fick diffusion:

$$\text{Wawn } Kn = \frac{d_0}{\lambda} > 10 \tag{7}$$

Since the pore qualitative diameter d_0 is much larger than the free range λ of the fluid molecules, the mass diffusion is caused exclusively by the irregular motion of the molecules which are not subject to any action of the walls. The mass diffusion of a fluid in a porous medium can be expressed in terms of Fick's law, which is also known as Fick's diffusion.

Fick's law is expressed as a steady-state diffusion condition in which the concentration field does not vary with time, and when there is no overall flow, the diffusive flux of component A in a binary mixture is proportional to its concentration gradient.

Its expression is given by:

$$m_A = -D_{AB} \frac{dC_A}{dx} \tag{8}$$

where m_A is the relative mass diffusive flux of the diffusing substance A, $kg/m^2 s$.

C_A is the mass concentration of component A, kg/m^3;

D_{AB} is the diffusion coefficient of diffusion from substance A to substance B, m^2/s.

2) Knudsen diffusion:

$$\text{Wawn } Kn = \frac{d_0}{\lambda} < 0.1 \tag{9}$$

Therefore, the qualitative diameter of the time gap is smaller than the molecular free range, so the collision frequency of the fluid molecules and the wall is much higher than the collision frequency between them, when the fluid molecules collide with the wall, the wall will produce a transient adsorption, and then irregularly scattered out in all directions. The wall to the impact molecules of this adsorption, making the fluid flow less.

Knudsen diffusion occurs when the pore size is of the same order of magnitude as the mean free range of the diffusing molecules, i.e., Kn is of order $O(10^0)$. Other findings suggest that this

diffusion may also occur when the gas density is very low (i.e., when the void is a very dilute gas.) Knudsen diffusion no longer obeys Fick's law. The Knudsen diffusion relation can be derived from the theory of molecular motion, which shows that the coefficient of proportionality between the mass flux and the concentration gradient is inversely proportional to the pressure in Knudsen diffusion.
3) Transition diffusion:

$$\text{Wawn } 0.1 < Kn = \frac{d_0}{\lambda} < 10 \tag{10}$$

The diffusion of fluid mass in porous media, which neither obeys Fick's law nor the results of Knudsen's diffusion analysis, is called transition diffusion. It is a transitional stage between Fick diffusion and Knudsen diffusion, and its diffusion process should be controlled by both mechanisms.

2.2. Heat Transfer Optimization and Physical Modeling of Air Conditioning Heat Exchangers

2.2.1. Heat transfer simulation theory based on finite element analysis.Currently, the numerical simulation methods commonly used in the field of engineering include finite element method, boundary element method, and finite difference method. Among them, the finite element method is the most widely used and influential. The finite element method is a numerical calculation method for discretization of continuous structures. The cells and nodes form a finite unknown approximate discrete system to approximate an infinite unknown actual continuous system. The finite element method has the advantages of strong adaptability, high computational accuracy, standardized and unified computational format, and has been widely used in civil engineering, in mechanical engineering, aerospace, nuclear engineering, ocean engineering, biomedical and many other fields.

The finite element analysis software ANSYS is a set of structural, fluid, electric, magnetic and acoustic analysis in one of the large-scale general-purpose finite element analysis software.ANSYS thermal analysis based on the energy-saving principle of heat balance equations.ANSYS software can be used to analyze and solve the problems such as heat conduction, heat convection, heat radiation, phase transition, thermal stress and contact thermal resistance.

The basic steps of steady state thermal analysis with ANSYS mainly include building a finite element model, applying loads, solving and post-processing. Modeling is the key part of finite element analysis, because the reasonableness of the model will directly determine whether the calculation can be completed or not.

Formerly a toolbox in Matlab software, Finite Element Analysis is a software package used to simulate a wide range of physical phenomena and perform physical coupling. The software allows easy and convenient creation of models and simulation of physical phenomena by using physical phenomena that can be solved by partial differential equations. It consists of a basic module, 8 specialized modules called Multi-Physics Coupled Finite Element Analysis Software, which covers most of the common physical fields. Whether it is the field of electric fields, the field of chemistry, or various subject areas such as acoustics and mechanics, it has the appropriate module. These physics solutions can be solved widely and easily.

The flow of dealing with the problem is shown in Fig. 1. On the heat transfer module, Comsol sets up heat transfer physics fields such as solid heat transfer, fluid heat transfer, pipe heat transfer, heat transfer at the same time as well as radiant heat transfer, which can largely realize the heat transfer simulation in the fields of scientific research, industry and so on, and it can better play a guiding role in the usual design process. In Comsol finite element analysis software, heat transfer simulation can be realized by editing and defining materials, boundary conditions, selecting appropriate heat transfer equations and a series of settings, using different parameters to obtain the best simulation results.

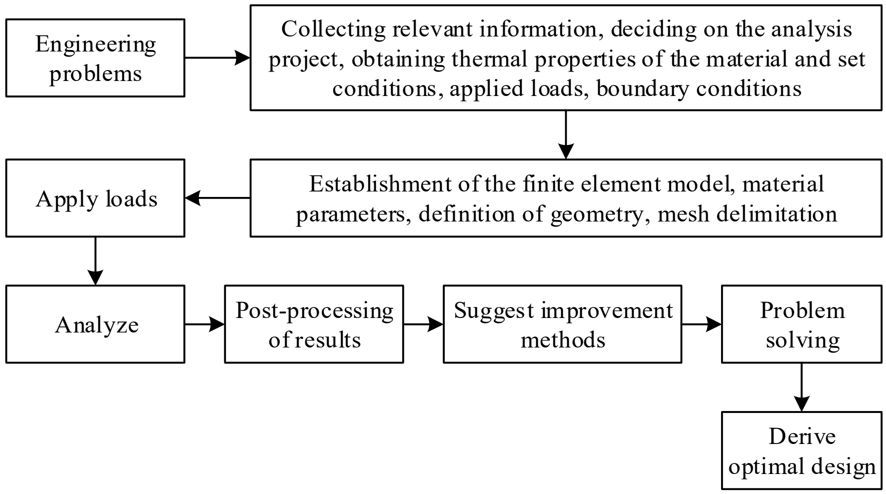

Fig. 1. Comsol process of dealing with problems

2.2.2. Heat Transfer Optimization Design for Air Conditioning Heat Exchangers.An important factor affecting the performance of air-conditioning heat exchangers is the existence of a large vortex region behind the round tube, with poor aerodynamic characteristics and high disturbance resistance. So changing the round tube to elliptical or profiled tube is an effective optimization method, and the transformation of the tube cross section to streamline can significantly reduce the air-side pressure drop.

The pipe cross-section of the shaped tube is obtained by adding two tangents to two circles of different sizes, whose characteristic parameters are the radii of the large circle and the small circle and their centroid distances, and the cross-section of the shaped tube is shown in Fig. 2. By changing the ratio of the radius of the small circle r to the radius of the large circle R, and the ratio of the center distance O to the radius of the large circle R, all shapes of the profiled tube can be obtained. The ratio of r to R is taken from 0 to 1. The ratio of O to R is taken from 1 to 2. Similarly, the relevant parameters for ellipse are the long and short axes, and the minimum ellipticity is taken as 0.5.

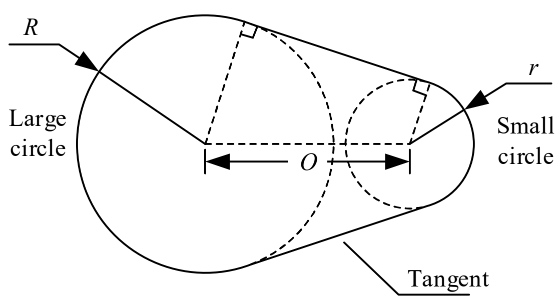

Fig. 2. Special-shaped tube section

In order to ensure that the hydraulic characteristics of the refrigerant side of the heat exchanger are consistent, the tube types designed in this paper are kept to have the same hydraulic radius as that of the round tube a with a diameter of 9 mm, and there are a total of five types of profiled tubes, three types of elliptical tubes, and one type of flat tubes, which are named as b, c, d, e, f, g, h, i, and j, respectively.

Shaped tubes e, f, g, h, and i are the result of five different values of O/R and r/R, e and f are approximated by droplets with different falling speeds $(r/R=0.1)$, h and i are approximated by flat tubes with different degrees of flattening $(r/R=0.9)$, and g are shapes in which both ratios are taken to be the median, while round tubes a and flat tubes j are the extreme cases of the variation of the shape of the tubes.

Because the shape of the shaped pipe is different from that of the round and elliptical pipes in that one end is rounded and the other end is rounded, the effect of the windward direction should be taken into account. For the number of tube rows $N=2$, a total of four rows exist, where the left side is the air inlet and the right side is the outlet.

The air flow and heat exchange outside the tube of the air conditioning heat exchanger are periodic along the tube length direction, so only one periodic unit can be selected as the simulation object. At the same time, there is a symmetry surface of the pipe of the heat exchanger, and there is symmetry in the air flow and heat exchange on both sides of the symmetry surface, so we can choose only the middle region of the symmetry surface of the two longitudinal adjacent pipes for analysis and research. In order to meet the needs of the import and export boundary conditions and the stability of Fluent simulation and calculation, the inlet region is extended by 2 times the fin length distance, and the outlet region is extended by 5 times the fin length distance, which can avoid the inlet effect as well as eliminating the return flow at the outlet. The finalized calculation area is shown in Fig. 3, above and below the fins is half the thickness of the fin spacing of the air flow layer, so that the calculation area can effectively show the flow and heat transfer, but also save computational resources.

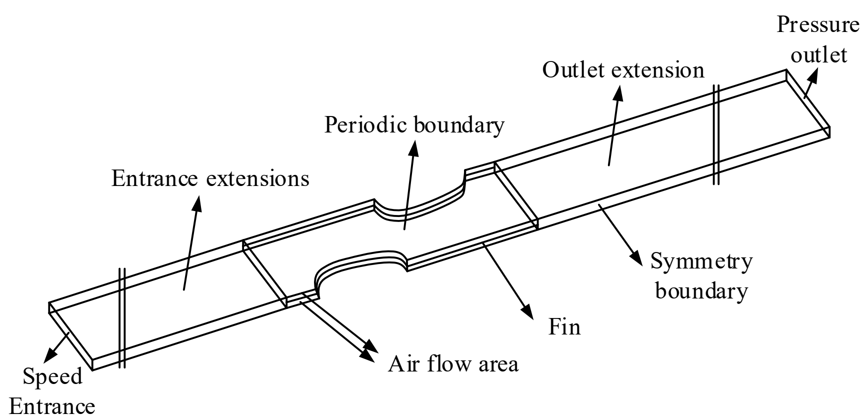

Fig. 3. Schematic diagram of the calculation area

2.2.3. Heat transfer modeling based on finite element analysis.In the process of finite element analysis, the mesh division of the three-dimensional model has a direct impact on the analysis results, the mesh division is finer, it will improve the accuracy and precision of the analysis and calculation, but the amount of calculation is large. On the contrary, it will reduce the accuracy and precision of the analysis and calculation, but the amount of calculation is small. In this paper, the grid is divided into the form of tetrahedron, taking into account the accuracy and precision of the analytical calculations and the size of the calculations, the actual working environment of the air-conditioning exchanger and the requirements of the technical specifications, the division of a reasonable grid structure and the number of the key link in the numerical simulation.

The heat transfer of the heat exchanger of the air conditioner consists of three processes, namely, convective heat transfer between the refrigerant and the copper tubes, heat conduction on the copper tubes and aluminum fins, and convective heat transfer between the air and the copper tubes and aluminum fins. Because the refrigerant and the copper tube to phase change heat mainly, heat transfer coefficient is large, copper and aluminum itself is also a large coefficient of thermal conductivity, so the air side of the heat transfer thermal resistance is the main component of the thermal resistance of the heat exchanger. The air flow and heat transfer outside the tube of the heat exchanger are periodic along the tube length, so only one periodic unit can be selected as the simulation object. At the same time, there is a symmetry surface of the pipe of the heat exchanger, and there is symmetry in the air flow and heat exchange on both sides of the symmetry surface, so it can be analyzed and studied by selecting only the middle area of the symmetry surface of the two longitudinal adjacent pipes. In order to meet the needs of the setting of the import and export boundary conditions and the stability of Fluent simulation calculations, the inlet region is extended by 2 times the fin length distance, and the outlet region is extended by 5 times the fin length distance, which can avoid the inlet effect as well as eliminating the return flow at the outlet.

In order to simplify the calculation, the heat exchanger heat transfer unit model is set as follows:
1) Air is constant physical properties, the flow is incompressible flow.
2) Air on the wall without slip.
3) The heat conductivity of the heat exchanger metal is very large, and it is considered that both the fins and the tube union maintain a constant temperature.
4) The effects of natural convection and radiant heat transfer are not considered.
5) The contact thermal resistance between fins and tubes is not considered.

The heat exchange on the air side of the heat exchanger is a constant materiality three-dimensional steady state flow heat exchange problem, and the governing equations for the flow heat transfer are as follows.

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{11}$$

Momentum equation:

$$\rho_f\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x_f}\left[\left(\mu+\mu_z\right)\left(\frac{\partial u}{\partial x_j}+\frac{\partial u_f}{\partial x}\right)\right] \tag{12}$$

$$\rho_l\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x_j}\left[\left(\mu+\mu_r\right)\left(\frac{\partial v}{\partial x_f}+\frac{\partial u_j}{\partial y}\right)\right] \tag{13}$$

$$\rho_i\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x_j}\left[\left(\mu+\mu_z\right)\left(\frac{\partial w}{\partial x_j}+\frac{\partial u_j}{\partial z}\right)\right] \tag{14}$$

Energy Equation:

$$\rho_f C_r\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\frac{\partial}{\partial x_j}\left[\left(\lambda+\frac{\mu_r}{P_r}\right)\frac{\partial T}{\partial x_j}\right] \tag{15}$$

The flow is turbulent, so $k-\omega SST$ turbulence model is used, the coupling of velocity and pressure is done by using SIMPLE algorithm, and the discretization of all equations is done in second order windward format. The inlet is the velocity inlet boundary condition (0.5 to $4m/s$) and the temperature is 308 K. The outlet is the pressure outlet boundary condition. The wall of the tube is used as a constant wall temperature boundary condition (318 K) and the fins are made of aluminum at 318 K. The symmetric surface is used as symmetric boundary condition and the periodic surface is used as periodic boundary condition, and the surface where the fins are in contact with the air is a fluid-solid coupling surface.

The average temperature monitoring of the outlet surface and the average pressure monitoring of the inlet surface are set, and the calculation is considered to be converged when these two values no longer change with the number of iterative steps and the residuals of the energy equation converge to less than 10^{-7} and the other equations converge to less than 10^{-5}.

In order to verify the influence of the grid, five numbers of grids, 340,000, 450,000, 660,000, 840,000 and 1,110,000, were selected for the calculations, and the results of the calculations with different grids are shown in Fig. 4. When the air inlet velocity is 3m/s, the heat exchange calculation results of the grid number of 660,000 compared with the grid number of 840,000, the heat exchange deviation and pressure drop deviation are less than 0.07%, which can be regarded as the accuracy is guaranteed. In order to save the calculation time, the final grid number of 660,000 is adopted.

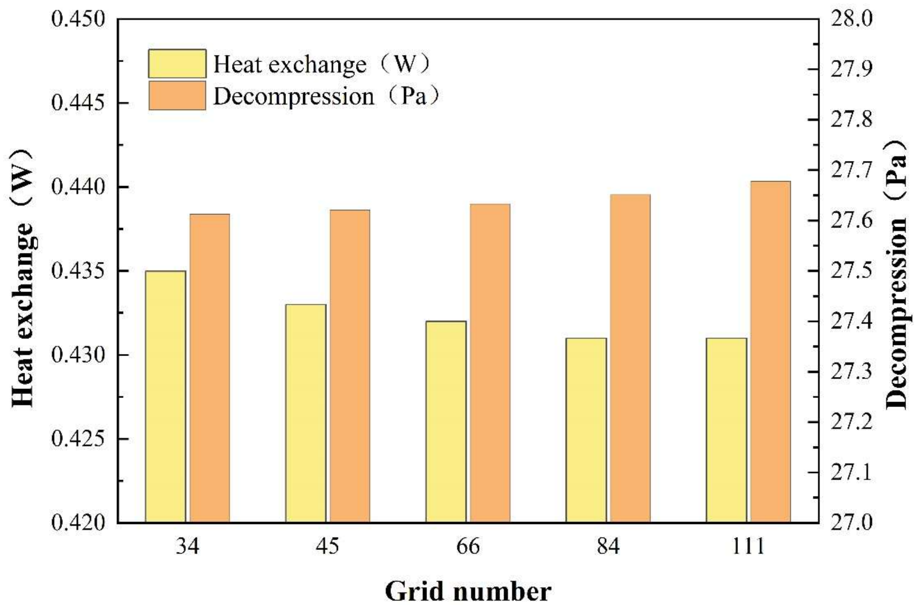

Fig. 4. Calculation results of different grids

3. Finite element based performance analysis of heat transfer optimization of air conditioner heat exchanger

3.1. Experimental validation of numerical simulation results for air-conditioning heat exchangers

3.1.1. Numerical simulation analysis of air-conditioning heat exchangers.Based on the numerical simulation method established through the above process, the numerical simulation values of the flow heat transfer coefficient and pressure drop in the exchanger are obtained when the air velocity v is 3 m/s~10 m/s, and the numerical simulation results are shown in Fig. 5. The simulation results show that with the increase of air flow velocity, the flow heat transfer coefficient of the air conditioning heat exchanger is increased from 60W/m^2°C to 153 W/m^2°C, and the pressure drop value is increased from 38Pa to 467Pa, which indicates that the heat transfer performance is continuously enhanced with the increase of air flow velocity, but the resistance to the flow of air is also increased.

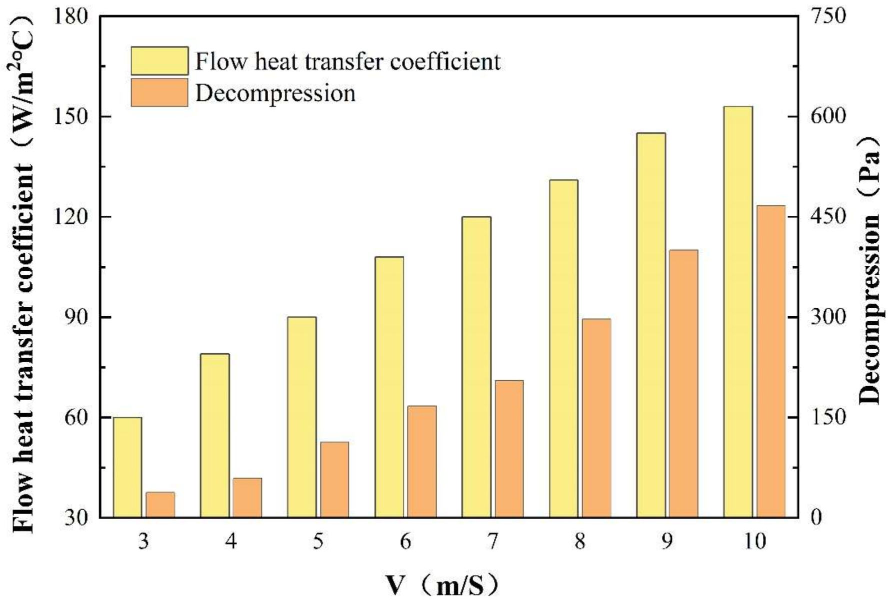

Fig. 5. Numerical simulation

In order to exclude the influence of processing on the flow and heat transfer performance of the air-conditioning heat exchanger, the test was repeated on five new specimens from different production batches, and the test results are shown in Table 1. It was found that the differences in outlet temperature, pressure drop and heat dissipation between different specimens under the same operating conditions were very small. From some of the results extracted from the test report, it can be seen that the heat balance error at different working conditions is less than 5%, indicating that the test equipment currently used has good reliability. At the same time, it is found that the actual values of air flow, temperature and pressure on the hot side and air velocity and temperature on the cold side are slightly different from the set values, but this has little effect on the test results.

Table 1. The test results are taken in part

Serial number	Heat side				Cold side				Thermal balance error(%)
	Mass flow (kg/s)	Entrance temperature (℃)	Exit temperature (℃)	Pressure drop(kPa)	Positive wind speed(m/s)	Entrance temperature (℃)	Exit temperature (℃)	Pressure drop(Pa)	
1	0.21	160.46	40.15	4.91	2.94	24.95	40.88	35.59	4.38
2	0.21	160.39	37.62	4.93	3.91	24.89	37.05	68.6	4.62
3	0.21	160.24	34.87	4.91	5.96	24.98	33.53	169.32	3.90
4	0.21	160.68	33.61	4.91	7.97	25.13	31.78	301.34	3.27
5	0.21	160.46	32.51	4.85	10.1	24.88	30.53	488.15	0.16
6	0.27	160.53	46.17	7.67	2.93	24.98	44.43	33.58	4.16
7	0.26	160.61	42.49	7.47	4.02	24.99	39.86	69.69	2.92
8	0.27	160.89	39.82	7.74	5.94	25.04	35.75	169.32	3.35

3.1.2. Deviation analysis of numerical simulation for air-conditioning heat exchanger simulation. The numerical simulated and experimental values of pressure drop and convective heat transfer coefficient for different air velocities v are compared, and a comparison of the numerical simulation and experimental results is shown in Fig. 6. It is found that they are in good agreement, and the errors of the numerical simulation and experimental values of pressure drop and convective heat transfer coefficient are ±6.50 W/m^2 °C and ±12.7 Pa, respectively, which are due to the existence of errors in the test itself, the existence of errors in the numerical simulation itself, and errors introduced in the process of the numerical simulation and experimental results processing. In summary, the physical model based on finite element analysis and the corresponding numerical simulation method in this paper have good reliability and accuracy, so the model and the numerical simulation method can be used as the basis for subsequent research on the performance of the optimization method of air-conditioning heat exchangers.

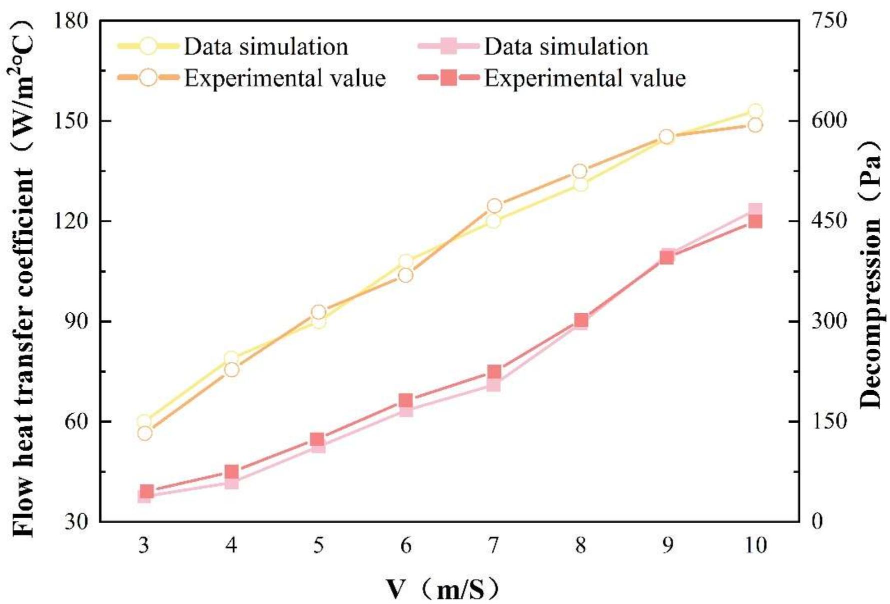

Fig. 6. Numerical simulation and experimental results

3.2. *Performance Analysis of Heat Transfer Optimization of Air Conditioning Heat Exchangers*

In the simulation platform, the calibration of the air conditioner heat exchanger simulation model is realized by adjusting the heat transfer parameters of the heat exchanger reinforced heat transfer tube in the simulation profile. The heat exchanger optimized for heat transfer in this paper is simulated according to the simulation model, and the HP specification of the comparison model is set to 0.8~3.0 HP. Under the consideration of the deviation between the measured results and the simulation results, the cooling capacity and the total pressure drop of the air-conditioning heat exchanger optimized in this paper and the heat exchanger of the comparison model are compared to further assess the heat transfer optimization in this paper relative to the heat exchanger of the comparison model. The advantages of the optimized heat exchanger over the comparative heat exchanger are further evaluated. The results of the comparison of the air conditioner heat exchangers are shown in Table 2, and the cooling capacity and total pressure drop of the optimized heat exchanger are higher than those of the comparative heat exchanger. At 0.8HP, the cooling capacity and total pressure drop of the optimized heat exchanger in this paper are 2.45kW and 23.51kPa respectively, and at 3.0HP, the cooling capacity and total pressure drop of the optimized heat exchanger in this paper are 7.06kW and 160.19kPa respectively.

Table 2. Air conditioning heat exchanger contrast results

Specification(HP)	Contrast type heat exchanger		This article optimizes the heat exchanger	
	Refrigerating quantity(kW)	Total pressure drop(kPa)	Refrigerating quantity(kW)	Total pressure drop(kPa)
0.8	2.12	12.32	2.45	23.51
1.0	2.55	16.79	2.89	31.46
1.2	3.57	30.92	3.85	51.67
1.5	3.75	33.94	4.02	55.54
1.8	3.96	37.55	4.00	51.39
2.0	4.72	61.49	4.97	89.25
2.5	5.82	88.70	6.21	130.00
3.0	6.56	109.35	7.06	160.19

The cooling capacity and total pressure drop of the heat exchanger are improved as shown in Fig. 7. From the comparison results of the improvement effect, it can be seen that the cooling capacity of the optimized heat exchanger in this paper has been improved by 0.04~0.50kW compared with that of the comparative heat exchanger, which is about 5.3%~15.6%, and the average improvement of all the specifications is about 8%, and the improvement of the cooling capacity of the specifications is more than 5%, except for the specification of 1.8HP, which is the biggest improvement of 15.6%. The optimized heat exchanger in this paper improves the total pressure drop of the heat exchanger by 11.19~50.84kPa compared with the comparative model, and the larger the specification of the same heat exchanger, the larger the pressure drop improvement, the smallest improvement of the pressure drop of the 0.8HP specification, and the largest improvement of the pressure drop of the 3.0HP specification. In summary, the optimized heat exchanger in this paper has better performance, the cooling capacity is improved obviously, and the total pressure drop is not much improved, the simulation results after considering the deviation are close to the measured results, and the simulation model can meet the requirements of engineering applications.

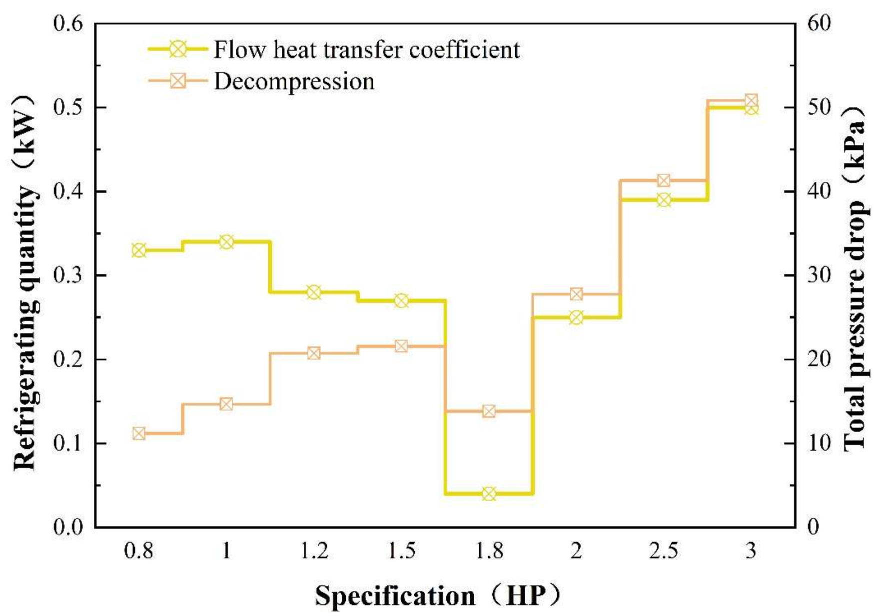

Fig. 7. The refrigerating quantity of the heat exchanger and the overall pressure drop

4. Conclusion

This paper combines the heat and mass transfer mechanism to carry out research on the optimization design of air conditioning heat exchanger, design and development of heat transfer optimization method of the heat exchanger, and based on the finite element analysis to establish a physical model and the corresponding numerical simulation method, through the air conditioning heat exchanger numerical simulation results for the test. Among the simulated values, with the increase of air flow rate, the flow heat transfer coefficient of the air conditioning heat exchanger is enhanced from 60W/m^2°C to 153W/m^2°C, the pressure drop value is enhanced from 38 Pa to 467 Pa, and its heat transfer performance and air flow resistance are continuously enhanced with the increase of air flow rate. The errors of pressure drop and convective heat transfer coefficient of numerical simulation and experimental values are ±6.50 W/m^2°C and ±12.7 Pa, respectively, which verifies that the physical model and numerical simulation method in this paper have good reliability and accuracy, and lays a foundation for the research of air conditioner heat exchanger performance.

The optimized heat exchanger in this paper is in the specification of 0.8HP~3.0HP, the cooling capacity of the heat exchanger is increased from 2.45kW to 7.06kW, and the total pressure drop is increased from 23.51kPa to 160.19kPa. The cooling capacity and total pressure drop of the optimized heat exchanger in this paper are higher than those of the comparative model heat exchanger. From the comparison results, it can be found that the larger the specification of the same heat exchanger, the greater the increase in pressure drop. The optimized heat exchanger in this paper improves the cooling capacity by 0.04-0.50kW and the total pressure drop by 11.19-50.84kPa compared with the heat exchanger of the comparative model, and the average improvement of the cooling capacity of all specifications is about 8%. The optimized heat exchanger in this paper has better performance, with significant improvement in both cooling capacity and pressure drop.

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