Numerical simulation research of influencing factors of fin temperature in finned tube heat exchanger

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Abstract. In the using process of the finned tube, the temperature on the top of the windward face of the fin in the first and second row of finned tube is the highest temperature of finned tube. It restricts and determines the high temperature conditions and application fields of finned tube heat exchanger. This paper establishes the research model of the first row and second row finned tube, to carry out the numerical simulation calculation of the fluid flow and heat transfer of high temperature air flowing through the finned tube and exchanging heat with cooled liquid water, and to research the influence of different tube transverse spacing, fin spacing and other factors on the fluid flow and heat transfer characteristics of finned tube and the highest fin temperature. The air outlet temperature, heat exchange capacity, Nu number, pressure drop and maximum fin temperature are obtained in the conditions of different tube transverse spacing and fin spacing, and the variation characteristic, mechanism and law of temperature field and velocity vector for the finned tube are also gained.

1. Introduction
The energy crisis has caused a huge impact on the world's economic development and scientific research, which has greatly promoted the research and development of enhancement heat transfer technology objectively. Finned tube heat exchanger is the earliest and most successful achievement in the process of strengthening tubular heat transfer, and it is widely used in power, chemical industry, petrochemical industry, air conditioning engineering and refrigeration engineering [1].

In recent years, domestic and foreign scholars have carried out many studies on finned tube heat exchanger [2-5]. Romero-Mendez et al. [6] revealed that fin spacing had different influence trends on fluid flow and heat transfer; for certain constraints, fin spacing had an optimal value. Glazar et al. [7] compared and analysed the heat transfer efficiency and pressure drop of microchannel heat exchangers with square and rectangular sections. Ammar et al. [8] experimentally studied the pressure drop characteristics of R134a in microfinned microchannel and smooth microchannel. Al-Neama et al. [9] studied the heat transfer performance of the microchannel with a hydraulic diameter of 1.5mm and a "V" shaped fin. Sarafraz et al. [10] experimentally studied the heat transfer performance of multi-walled carbon nanotubes/water nanofluids, and found that increasing the volume fraction of nanoparticles could enhance the heat transfer effect.

In the process of using the finned tube, the temperature on the top of the windward face of the fin in the first and second row of finned tube is the highest temperature of finned tube. It restricts and determines the high temperature conditions and application fields of finned tube heat exchanger. This paper establishes the research model of the first row and second row finned tube, to carry out the numerical simulation calculation of the fluid flow and heat transfer of high temperature air flowing through the finned tube and exchanging heat with cooled liquid water, and to research the influence of different tube transverse spacing, fin spacing and other factors on the fluid flow and heat transfer characteristics of finned tube and the highest fin temperature.
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2. Research model and related setting

2.1 Research model
In order to simplify the model, the heat transfer and flow field distribution of the front two rows tubes are studied under high temperature air. Calculation models 1: tube transverse spacing 56mm, 60mm, 61mm, 62mm, 63mm, 64mm, 68mm, 74mm, and equilateral triangle arrangement (30°). Take the tube transverse spacing 74mm as an example, as shown in figure 1. Calculation models 2: fin spacing 2.0mm, 2.5mm, 3.0mm, 3.5mm, 6.0mm. Take fin spacing 6.0mm as an example, as shown in figure 2.

![Figure 1. Model of tube transverse spacing 74mm.](image1)

![Figure 2. Model of fin spacing 6.0mm.](image2)

2.2 Related setting
The related settings of fin spacing 6.0mm is taken as an example. Model: length, width and height are 112mm, 648.5mm and 24mm respectively. Round straight tube, the tube Φ25×2mm, tube transverse spacing is 56 mm, equilateral triangle arrangement (30°). The annular fin is 12mm high, 0.5mm thick and 6.0mm apart. The height of 4 fin spacing is calculated here. Extending 500mm for outlet to avoid backflow. The grid is unstructured. Taking the fin spacing 6.0mm as an example, the number of nodes is about 710,000 and the number of grids is about 1.37 million, as shown in figure 3.

![Figure 3. Calculation grid of the model of fin spacing 6.0mm.](image3)

The hot fluid is air; its temperature is 924.75K (651.6℃) and its inlet velocity is 8m/s. The cold fluid is liquid water; its temperature is 332.15K (59℃) and its inlet velocity is 1m/s. The tube and fin are made of stainless steel. Finite volume method is adopted for numerical calculation, second-order
upwind format is adopted for discretization of each equation, SIMPLE algorithm is used for pressure-velocity coupling, and SST k-ω turbulence model is selected [11-12].

3. Calculation results and analysis

3.1 Influence of tube transverse spacing

In order to obtain the influence of different tube transverse spacing on the fluid flow and heat transfer characteristics, numerical calculations are carried out on the models with the transverse spacing 56mm, 60mm, 61mm, 62mm, 63mm, 64mm, 68mm and 74mm respectively. For transverse spacing 56mm and 74mm, the temperature fields in the calculated area are shown in figures 4a to 4b, and the velocity vector diagrams are shown in figures 5a to 5b. It can be found that when the tube spacing is 56mm, the air is disturbed with the largest level, and the vortex formed behind the finned tube is also the largest one. As the spacing of finned tube increases, the air velocity decreases at the narrowest point, which weakens the heat exchange between tube bundle and air. Inside the tube bundle, the air temperature distribution is the most uniform with 56mm tube spacing. With the increase of tube spacing, the influence between adjacent finned tubes on the same tube row position is gradually weakened, and the heat transfer area between hot and cold air is also increased along the air flow direction.

![Figure 4a. Temperature field for $S_{tube}=56mm$.](image)

![Figure 4b. Temperature field for $S_{tube}=74mm$.](image)

![Figure 5a. Velocity vector for $S_{tube}=56mm$.](image)

![Figure 5b. Velocity vector for $S_{tube}=74mm$.](image)

The influence of different tube spacing on some thermodynamic parameters are shown in figures 6a to 6e. As the tube spacing increases, the Nusselt number decreases, the total heat transfer power decreases, and the Nusselt number decreases slowly. This is because when the tube spacing increases, the flow cross-sectional area between the transverse bundles increases, and the air velocity decreases slower and slower at the same inlet air mass flow rate, so the heat transfer coefficient decreases slowly. In addition, with the increase of tube spacing, the pressure drop decreases gradually. When the tube spacing increased from 54mm to 74mm, the Nusselt number decreases by 21.43% and the pressure drop decreases by 66.67%. Tube spacing has a greater effect on the pressure drop. Therefore, the decrease of tube spacing will reduce the size of tube bundle, while the increase of pressure drop will require a higher height of duct. Therefore, the size of tube bundle and the height of duct should be considered comprehensively in practical engineering.

At the same time, it can be found that the maximum temperature of the fin in the first row of finned tube decreases gradually, and the maximum temperature of the fin in the second row of finned tube increases first and then decreases. This because with the increase of the tube spacing, the heat load...
received by the second row of tubes is more and more large, and the heat transfer capacity is gradually slowing down. Therefore, there is an optimal tube spacing, and the heat exchange between hot air outside the tube and cooling water inside the tube is the most sufficient.

![Graphs showing Nu, Qtr, Tair,out, and Tfin,max as functions of S_tube/mm](image)

Figure 6a. Tube spacing influence on Nu. Figure 6b. Tube spacing influence on Qtr.

Figure 6c. Tube spacing influence on T_{air,out}. Figure 6d. Tube spacing influence on T_{fin,max}.

Figure 6e. Tube spacing influence on Δp.

### 3.2 Influence of fin spacing

Here, the tube bundle models with fin spacing 2.0mm, 2.5mm, 3.5mm and 6.0mm are respectively calculated. For fin spacing 2mm and 6mm, the temperature fields in the calculated area are shown in figures 7a to 7b, the velocity vector diagrams are shown in figures 8a to 8b, and figures 9a to 9d are the diagrams of the influences of different fin spacing on some thermodynamic parameters.

![Temperature fields for S_{fin}=2mm and S_{fin}=6mm](image)

Figure 7a. Temperature field for S_{fin}=2mm. Figure 7b. Temperature field for S_{fin}=6mm.
Based on the above results, when the fin spacing increases, the heat exchange between the air outside the tube and the cooling water inside the tube is more complete. When the fin spacing reaches 6mm, the thermal boundary layer of the adjacent fins has been separated, and the middle region is filled with high-temperature air whose temperature is about equal to the air inlet temperature, then full heat exchange is achieved. After the thermal boundary layer is completely separated, the influence of fin spacing on heat transfer power is mainly achieved by increasing the surface area of the base tube between fins, so the increase of the heat transfer power in the calculation area gradually becomes slow. As the fin spacing increases, the air flow velocity decreases. When the fin spacing increases, the fin disturbance intensity is enhanced, which can reduce the thickness of boundary layer and enhance the heat transfer. Nusselt number respectively increases by 3.66%, 0.59%, 0.58%, 1.75%, so the influence of fin spacing on heat transfer coefficient is decreasing.

In addition, with the increase of fin spacing, fin ratio of fin tube decreases, which give rise to the decrease of heat exchange area of finned tube per unit length. In order to obtain the same heat exchange effect, the required equipment size increases, so that the whole machine volume increases. Therefore, for extreme conditions with high air velocity, the influence of spacing on heat transfer coefficient and heat transfer area should be considered comprehensively, so as to select the fin spacing that is most conducive to heat transfer.
4. Conclusions

In this paper, the heat transfer characteristics of finned tube bundles are researched by numerical simulation method, the calculation model of finned tube bundles is established and the influence of tube transverse spacing and fin spacing on heat transfer characteristics of finned tube bundles is analysed. The research results show that:

1) For the arrangement of fork and row, the reduction of tube spacing will reduce the size of the tube bundle and increase the heat transfer power of the tube bundle, but the air pressure drop will increase in a higher proportion. Therefore, the size of tube bundle and the height of air duct should be considered comprehensively in practical engineering application.

2) The average Nusselt number of fin bundle increases with the increase of fin spacing, and the increase rate gradually decreases in this process. Because the increase of fin spacing will reduce the total surface area of finned tube per unit length. So, the increase of fin spacing and the size of equipment should be considered comprehensively in practical engineering applications.

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