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Study on heat transfer enhancement of nanofluid in a new type of heat exchangers

Liang Zhang[1*], Pingping Qu[1], Yuyan Jing[1], Wenjie Wang[1], Xinyue Yao[1]

[1]College of Vehicles and Energy, Yanshan University, Qinhuangdao, 066004, China

[1*]E-mail: zhangliang402@ysu.edu.cn

Abstract. As one of the essential equipment in industrial production, improving the efficiency of heat exchangers to slow down energy consumption has become a popular topic. In this paper, the structure of a conventional fixed tube plate heat exchanger is optimized by numerical simulation, replacing the straight tube with a wavy wall tube. The impact of particle size of Cu-water nanofluid on the performance in the new heat exchanger (HEX) is also investigated. The results indicate that using the wavy wall tube enhances the flow field perturbation and improves the working mass's flow state; adding nanoparticles in water can improve the heat transfer capacity of the fluid. It is also found that the shell process pressure drops (ΔP) and the heat transfer effect of the HEX increased with increasing of the fluid volume flow rate; at the same volume flow rate and the volume fraction of 0.5%, the ΔP of the Cu-water nanofluid in the HEX increases with increasing of the particle size. The heat transfer performance decreases gradually with increasing of the particle size. The smaller particle size of Cu nanoparticles can improve the efficiency of enhanced heat transfer to a larger extent.

1. Introduction

Energy tension has become a common concern in the world, while the industrial process has higher requirements for upgrading the heat-transferring effect of a heat exchanger (HEX) due to the gradual increase in the size and power of industrial equipment [1]. In recent years, many researchers have proposed various passive and active technologies to promote the further development of enhanced heat transfer research. A lot of scholars have promoted heat transfer by changing the structure of heat exchanger tubes. Many different shapes of tubes have been proposed, and most of them have been tested and simulated. They have their own advantages and disadvantages, among them, wavy wall tubes have been widely studied and applied because of their excellent performance. Zhou et al. [2] investigated the turbulent heat transfer performance of fluid in a bellows with two amplitude values and found that the larger the amplitude, the greater the wall shear and the better the heat transfer effect. Liao et al. [3] conducted numerical simulations of bellows at different Reynolds numbers and found that the bellows had better flow and heat transfer performance when the ratio of raised to cratered corrugation of the combined corrugation was equal to or less than 1. Meanwhile, due to the development of nanotechnology, researchers have discovered the huge advantages of nanomaterials, which have been widely used in various fields, especially in industrial production, nanofluid-enhanced heat transfer technology has received wide attention due to its low cost, flexibility in manipulation, and diversity of forms [4]. The suspended heat transfer characteristics of copper oxide nanoparticles in fine circular tubes were experimentally investigated by Dai et al. [5]. Wu et al. [6] found that increasing the volume fraction of nanoparticles could lower the average temperature of the fluid-solid heat transfer surface, thus enhancing the heat transfer capacity of the nanofluid, but also significantly increasing the pumping power of the system.

In summary, many researchers have studied both wavy wall tubes and nanofluids separately, and there is a lack of research on the simultaneous application of wavy wall tubes and nanofluids to fixed tube plate heat exchangers. This paper is not only the structure of the heat exchanger optimized by numerical simulation but also the influence of particle size on the strong heat exchange performance of the new HEX, which provides a certain reference to the development of a fixed tube plate HEX.

2. Mathematical model

2.1. Geometric model

To optimize the structure of the heat exchanger, this paper used a wavy wall tube with a wave length of 25 mm and a wave peak value of 3.50 mm to replace the conventional straight tube with a maximum diameter of 16 mm. The geometric model of this new heat exchanger is displayed in Fig. 1. At the same time, we can also see the flow path of the fluid in the HEX, the distribution and number of baffle plates.

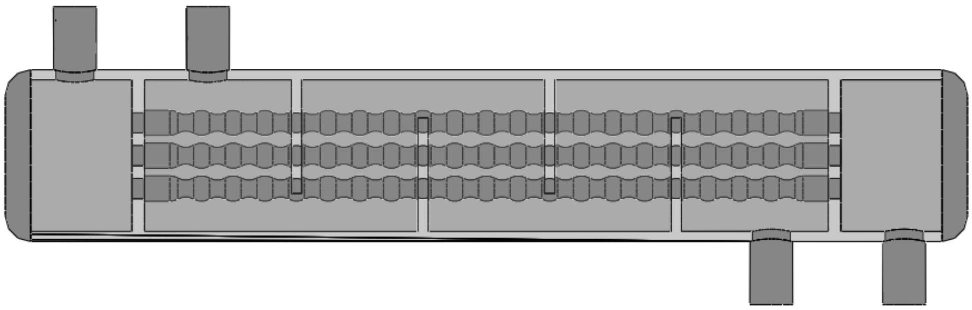

Fig. 1 Geometric model of the new heat exchanger.

2.2. Computational model and boundary conditions

Currently, most researchers numerically analyze nanofluids' flow heat transfer capability as single-phase fluids. The single-phase model only investigates the effect of changes in fluid physical parameters on the results, ignoring the interaction between the underlying fluid and particles. However, some scholars, taking into account the movement of particles, regard nanoparticles as a kind of fluid, which interacts with the base fluid, greatly reducing the error caused by the single-phase model. In this paper, the two-phase mixing model in Fluent was selected. The relevant equations of the mixing model are as follows.

Continuity equation:

$$\nabla\left(\rho_m \cdot \bar{v}_m\right)=0. \tag{1}$$

Where, ρ_m and $\bar{v}_m$ are the density and velocity of the mixture, respectively.

Momentum equation:

$$\nabla\cdot\left(\rho_m \vec{v}_m \vec{v}_m\right)=-\Delta p+\nabla\cdot\left[\mu_m\left(\Delta\vec{v}_m+\Delta\overrightarrow{v_m^T}\right)+\nabla\left(\sum_{k=1}^{n}\varphi_k\rho_k\vec{v}_{dr,k}\vec{v}_{dr,k}\right)\right]+\rho_m g+\vec{F}. \tag{2}$$

Where, μ_m is the viscosity of the mixture, φ_k is the fractional volume of the second phase.

Energy equation:

$$\nabla\cdot\left(\sum_{k=1}^{n}\varphi_k v_k\left(\rho_k E_k+p\right)\right)=\nabla\cdot\left(k_{eff}\Delta T\right)+S_E. \tag{3}$$

Where, E_k is the total system energy, k_{eff} is the effective thermal conductivity of fluids.

The working medium in the new HEX is water and nanofluid, the nanofluid flow in the shell process with an inlet temperature of 300 K. The volume flow rate is used in five groups of 0.5, 1.0, 1.5, 2.0, 2.5 m^3 /h, and the working mass in the tube process is hot water with a velocity inlet of 1.0 m/s and an inlet temperature of 360 K. The pressure outlet is used for both the shell and tube process outlets. The SIMPLE algorithm is used in the solution process. Because the number of grids will affect the results in numerical simulation, in order to reduce the error as much as possible, the models with different number of grids are simulated. The number of meshes for this heat exchanger model was determined to be 4.8 million by verifying the mesh irrelevance.

3. Results and discussions

3.1. Heat exchanger pressure characteristic analysis

Fig. 2 represents the shell process pressure drop (ΔP) variation in the heat exchanger when the working medium is pure water and nanofluids. It can be seen from the figure that due to the folding plate, there is a significant change in the ΔP of the shell process fluid on both sides of the plate, while a significant increase in pressure can be seen at the dead flow zones, such as corners. It is also found that the nanoparticles to the base fluid significantly changes the ΔP of the HEX, but from the comparison of Fig. 2(b) and (c), it is found that the bigger the particle of the nanoparticles, the smaller the pressure drop change under the same conditions. At the same time, the particles not only affect the state of the flow field, but also change the pressure distribution in the HEX. It can be seen from the cloud map that the nanoparticles make the pressure distribution of the flow field more uniform, reduce the local huge pressure, and increase the service life of the heat exchanger to a certain extent.

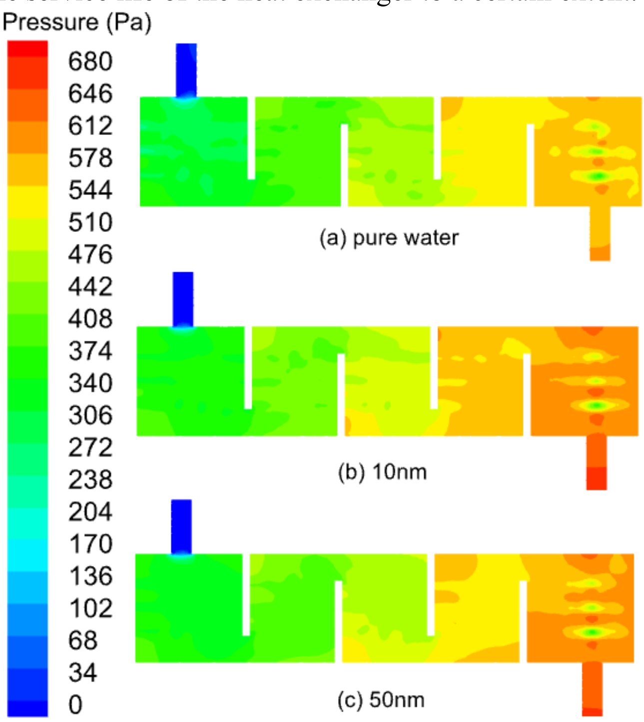

Fig. 2 Heat exchanger shell process pressure cloud.

To show more clearly the impact of nanoparticle size on the ΔP of the HEX, the variation of ΔP with volume flow rate and particle size is obtained, as shown in Fig. 3. From the figure, the ΔP in the shell process higher with the enhancement in volume flow rate at various working masses, while the effect of nanofluids on the ΔP is more significant, but the effect of particle size variation on the pressure drop is relatively insignificant. It is calculated that at a volume flow rate of 1.5m^3 /h, the ΔP increases by 15.0% and 13.1% for nanofluids with the particle size of 10 and 50 nm compared to pure water, which may be because there are more nanoparticles with 10 nm particle size per unit space, and the particle interaction increases, which increases the flow resistance and leads to an increase in pressure drop.

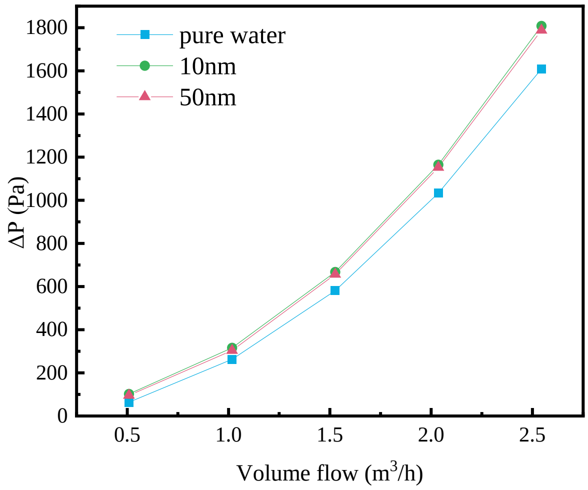

Fig. 3 Variation of pressure drop with particle size and volume flow rate in the HEX.

3.2. Heat exchanger temperature characteristic analysis

The nanofluid is used mainly to improve the efficiency of the device, so the temperature of the heat exchanger with pure water and different particle size nanofluids was analyzed, as shown in Fig. 4. From the figure, the perturbation of the flow field by the wavy wall tube makes the temperature of the HEX shell process fluid undulate near the wavy wall tube and both the folding plate and the wavy wall tube affect the temperature field of the heat exchanger. Also, comparing these three subplots, it can be learned that the highest heat exchanger shell process exit temperature is observed for the 10 nm particle size of nanofluid, followed by 50 nm particle size and the lowest heat exchanger shell process exit temperature using pure water. This expresses that the heat exchange effect of nanofluids is better at small particle sizes.

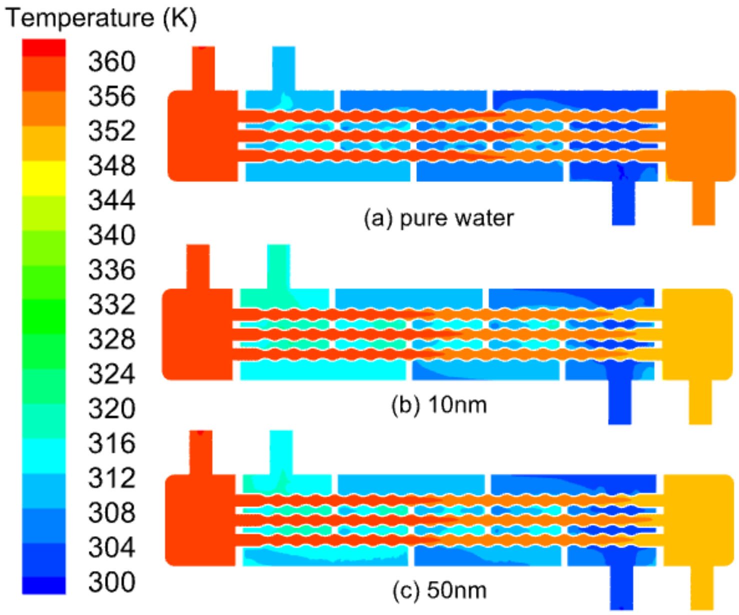

Fig. 4 Heat exchanger temperature cloud.

The variation of the temperature differential (ΔT) of the heat exchanger shell process with particle size and volume flow rate is given in Fig. 5. From the figure, the ΔT of the heat exchanger shell process is gradually decreasing as the volume flow rate increases. It can also be seen that under the same conditions, the nanofluid has a better heat exchange effect than pure water, and the ΔT is the largest value for the 10 nm particle size of the nanofluid. Under the same working conditions. the minim the size in the nanofluid, the more particles per unit volume, and the interaction between the particles and fluid; at the same time, nanoparticles have much higher thermal conductivity than liquids and can accelerate the process of heat exchange, they improve the enhanced heat transfer effect of the HEX.

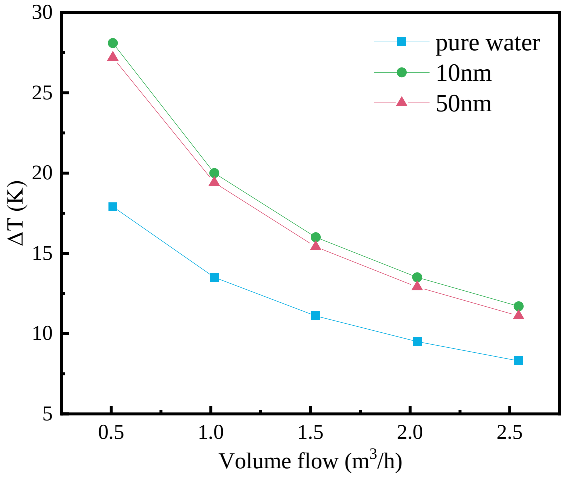

Fig. 5 Variation of ΔT between inlet and outlet of heat exchanger shell process with the volume flow rate.

It can be seen from the above that optimizing the structure of the HEX can improve the effect of the HEX , which is one of the methods of passive strengthening. At the same time, the application of nanofluids to the HEX is a composite strengthening technology to enhance interchange of heat. The purpose of heat transfer enhancement is to affect the flow field and the physical parameters of working fluids in different degrees from two angles. This method can provide a new idea for energy conservation in industrial production, It can slow down the consumption rate of non renewable energy.

4. Conclusions

In this paper, the advanced heat-exchange of nanofluids of two particle sizes in a novel heat exchanger is investigated and the following conclusions are obtained.

(1) The ΔP of the HEX gradually increases as the volume flow rate increases; adding nanoparticles increases the flow resistance of fluid and consumes additional pump work. The ΔP of the heat exchanger was also found to be inversely associated with particle sizes.

(2) The use of wavy wall tubes can destroy the flow boundary layer near the pipe and make the flowing condition of the HEX shell process fluid better to achieve the effect of enhanced heat exchanging. Also nanofluids can accelerate the efficiency of the HEX, and the smaller the particle sizes of the nanoparticles, the better the heat transfer effect.

Acknowledgments

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