Experimental Study on Flow Resistance Characteristic of Corrugated Low Finned Tubes

Bin Ren¹²*, Zhe Pu¹, Xiaoying Tang¹², Hongliang Lu¹², Yannan Du¹, Aini He¹²

¹ Shanghai Institute of Special Equipment Inspection and Technical Research, Putuo District, Shanghai, 200062, China
² National Heat exchanger Product Quality Supervision and Inspection Center, Jinshan District, Shanghai, 201518, China

*Corresponding author’s e-mail: renbin_580912@163.com

Abstract. The heat transfer enhancement techniques have been developed to the third generation. The most popular and successful enhancement techniques are the artificial roughness surface and helically corrugated tube. Corrugated low finned tube is a kind of helically corrugated tube with trapezoidal shape groove. In this paper, the flow resistance characteristic of corrugated low finned tubes was studied experimentally. The results showed that all the enhanced tubes had a larger friction factor than the smooth tube due to the turbulence augmentation and rotational flow produced by helical rib. Moreover, the friction factor ratios slightly increased with the raise of Reynolds number and rib height presents more significant effect on flow resistance. Finally, all the experimental data were fitted as the function of Reynolds number, Prandtl number, pitch to diameter ratio and rib height. The research results can provide a foundation for designing heat exchangers using this enhancement technique.

1. Introduction

The heat transfer enhancement techniques are widely used in many applications in order to make possible reduction in weight and size or enhance the performance of heat exchangers [1, 2]. The most popular and successful enhancement techniques are the artificial roughness surface and helically corrugated tube. They are all passive techniques which does not need any external power.

Vicente et al [3] studied the isothermal friction characteristic on a family of 10 corrugated tubes which were manufactured by cold rolling. A unique dimensionless parameter named severity index was used to establish roughness influence on flow. The real benefits offered by corrugated tubes were assessed by calculating one of the performance evaluation criteria. Pethkool et al [4] conducted experiments using helically corrugated tubes over a wide range of Reynolds number from 5500 to 60,000 by employing water as the test fluid. The pressure loss result revealed that the average friction factor of the corrugated tube was in a range between 1.46 and 1.93 times over the smooth tube.

Corrugated low finned tube (CLFT) is a kind of spirally corrugated tube with trapezoidal profile. Ren et al [5] studied the heat transfer performance under the turbulent flow condition. Due to the wider spiral protrusion, its heat transfer performance is better than that of ordinary spirally corrugated tube. In this paper, the flow resistance characteristic of corrugated low finned tubes was studied experimentally. The effects of tube structural parameter and fluid Reynolds number were also analysed. All the experimental values were fitted as the function of Reynolds number, Prandtl number, pitch to diameter ratio and rib height to diameter ratio.
2. Experimental apparatus

2.1. Test loop

The experimental apparatus in this work is the identical system used in Ren’s work [6, 7], which is showed in Figure 1. Valve #1, #2, #3, #6, #7 and #8 were closed while the rest valves remained open. Therefore only the heating water circuit, the test section, the cooling water circuit and the data acquisition system were used during single-phase convective experiments. The heating water circuit consisted of the heating water tank, the heater and the magnetic pump. The test section was a double-pipe, countercurrent flow heat exchanger, in which the heating water flowed through the inner tube and the cooling water flowed through the annular channel. The cooling water circuit was comprised of the cooling water tank, the centrifugal pump and the plate heat exchanger. The data acquisition system consisted of some sensors, the Agilent 34970A Data Logger/Switch Unit and the PC.

![Figure 1. Schematic diagram of experimental loop](image)

During the experiment, the sensors were used to measure the volumetric flow rates, temperatures, pressures and pressure drop of heating and cooling water. The volumetric flow rates could be measured by turbine flowmeter mounted on a straight tube. And the length of straight tube should be twenty times tube diameter in upstream direction and fifteen times tube diameter in downstream direction. The temperatures of fluids were measured by thermocouples inserted into the center of the tube. The distance between temperature sensor and flange sealing surface or screwed nipple should be less than 150 mm. The pressure and pressure drop was measured by pressure transmitter and pressure difference transmitter. The distance between measuring holes and disturbances should be greater than five times tube diameter in upstream direction and two times tube diameter in downstream direction.

2.2. Data reduction

The friction factor for the tube side could be expressed as:

\[ f = \frac{d_i}{L} \cdot \frac{2\Delta p}{\rho_h \cdot u_h^2} \]  

(1)

Here, \( d_i \) and \( L \) were respectively the inner diameter and length of testing tube. \( \Delta p \) was the pressure drop between the inlet and outlet of the testing tube. \( \rho_h \) and \( u_h \) were respectively the density and velocity of heating water.
3. Results and discussion

3.1. Verification of the experimental apparatus

The experiments with the smooth tube were carried out to verify whether the experimental devices and instruments were functioning well. Before data reduction, the testing data with heat balance error greater than 5% must be eliminated. The experimental friction factors were compared with the predicted values calculated from Filonenko correlation described in Eq. (2) [8].

\[ f = (1.82 \lg Re - 1.64)^{-2} \]  

(2)

As it can be seen from Figure 2, the experimental friction factors are only related to Reynolds number and all of the experimental data agree well with the predicted values. The maximum deviation is +8.9% indicating that the experimental system can accurately test the flow resistance performance.

3.2. Flow resistance characteristic

Figure 3 presents the variation of friction factors with Reynolds numbers for the testing tubes. It can be found that the friction factors decrease with the rise of Reynolds numbers both inside enhanced tubes and the smooth tube. And the friction factors are still related to Reynolds number, indicating that the flow has not yet entered the complete hydraulic roughness zone. Moreover, all the enhanced tubes have a larger friction factor than the smooth tube due to the turbulence augmentation and rotational flow produced by helical rib. The increase of rib height and decrease of pitch raise the friction factors.

![Figure 2. Comparison between measured and calculated f](image1)

![Figure 3. Variation of f with Re](image2)
Figure 4 shows the variation of friction factor ratio \( \left( \frac{f_a}{f_s} \right) \) with Reynolds number. It is observed that the variation trend of friction factor is different with that of Nusselt number. The friction factor ratios slightly increase with the raise of Reynolds number, while the Nusselt number ratios show the opposite trend. And the augmentation factor of friction factor is larger than that of Nusselt number, inferring that the adoption of the corrugated low finned tubes cannot save energy under the identical flow rate. Moreover, the gap between different rib heights is larger than that between different tube pitch indicating that the rib height presents more significant effect on flow resistance.

3.3. Correlation for friction factors

By fitting the experimental data, the friction factor can be correlated as the function of Reynolds number, Prandtl Number, pitch to diameter ratio and rib height to diameter ratio. The correlation is expressed as Eq. (3). Figure 5 presents the comparison between experimental and predicted friction factor in tube 1#. It can be seen that all of the data points from Eq. (3) agree well with the experimental values with the maximum deviation under ±10%, showing that the correlation can predict the friction factor very well. It should be mentioned that the above correlation is applicable with the Reynolds number ranges from 15,000 to 65,000.

\[
f = 21.335 \cdot Re^{0.219} \cdot \left( \frac{p}{d_l} \right)^{-0.328} \cdot \left( \frac{e}{d_l} \right)^{0.979}
\]  

(3)
4. Conclusions

In this paper, the flow resistance characteristic of corrugated low finned tubes was studied experimentally. The results showed that all the enhanced tubes had a larger friction factor than the smooth tube due to the turbulence augmentation and rotational flow produced by helical rib. The friction factor ratios slightly increased with the raise of Reynolds number. All the experimental data were fitted as the function of Reynolds number, Prandtl number, tube pitch and rib height. The research results can provide a foundation for designing heat exchangers using this enhanced tube.

Acknowledgments

This work was supported by the 2016 Shanghai Leading Talents Training Program for Professor Xiaoying Tang.

References

[1] Sheikholeslami, M., Gorji-Bandpy, M., Ganji, D. D. (2015) Review of heat transfer enhancement methods: Focus on passive methods using swirl flow devices. Renewable and Sustainable Energy Reviews, 49: 444-469.

[2] Bergles, A. E. (1997) Heat transfer enhancement-the encouragement and accommodation of high heat fluxes. Journal of Heat Transfer-Transaction of the ASME, 119(1): 8-19.

[3] Vicente, P. G., Garcia, A., Viedma, A. (2004) Experimental investigation on heat transfer and frictional characteristics of spirally corrugated tubes in turbulent flow at different Prandtl numbers. International Journal of Heat and Mass Transfer, 47(4): 671-681.

[4] Pethkool, S., Eiamsa-ard, S., Kwankaomeng, S., et al. (2011) Turbulent heat transfer enhancement in a heat exchanger using helically corrugated tube. International Communications in Heat and Mass Transfer, 38(3): 340-347.

[5] Ren, B., Jun, S., Tang, X. Y., et al. (2019) Experimental investigation on heat transfer performance of corrugated low finned tubes. In: 2019 5th International Conference on Energy Equipment Science and Engineering. Harbin.

[6] Ren, B., Tang, X. Y., Lu, H. L., et al. (2017) Experimental investigation on condensation in corrugated low finned tubes in presence of noncondensable gas. In: ASME 2017 Pressure Vessels and Piping Conference. Hawaii. pp. V03AT03A068.

[7] Ren, B., Tang, X. Y., Lu, H. L., et al. (2018) Experimental study on characteristics of condensation and flow resistance inside horizontal corrugated low finned tubes. In: ASME 2018 Pressure Vessels and Piping Conference. Prague. pp. V03AT03A041.

[8] Gnielinski, V. (1976) New equation for heat mass transfer in turbulent pipe and channel flows. International Chemical Engineering, 16: 359-368.