Investigation of air-side thermal and hydraulic performances of integrally-moulded spiral fin-and-tube heat exchangers

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Introduction

Currently, spiral fin-and-tube heat exchangers become one of the favorable kinds of heat exchangers in waste heat recovery systems[1,2]. However, welding defects of the welded spiral fin-and-tubes result in large contact thermal resistance and low connection strength between fins and parent tube[3,4]. Therefore, we designed and manufactured an integrally-moulded spiral fin-and-tube heat exchange using the improved manufacturing process without welding, so that the contact thermal resistance between its fins and parent tube is zero, and the joint strength is high. There are several characteristics for the integrally-moulded spiral fin-and-tube heat exchangers:

(1) Larger smooth contact area between its fins and parent tube without welding defects;

(2) Stability of air-side thermal and hydraulic performance and longer service life.

In this work, a three-dimensional CFD model is established to simulate the air-side thermal hydraulic performances of the integrally-moulded spiral fin-and-tube heat exchanger. The correlations for *Nu* and *f* factors can be employed when the tube bundles are in staggered arrangement, and the parameters such as *Re*=3500-9200, *Lt*=100-120mm, N_{row} =7, L_l=75-90mm, w_1=3.6mm, w_2=1.8mm, F_p=6–10 mm and so on may be important for accuracy of the correlations for *Nu* number and *f* factors.

The integrally-moulded spiral fin-and-tube

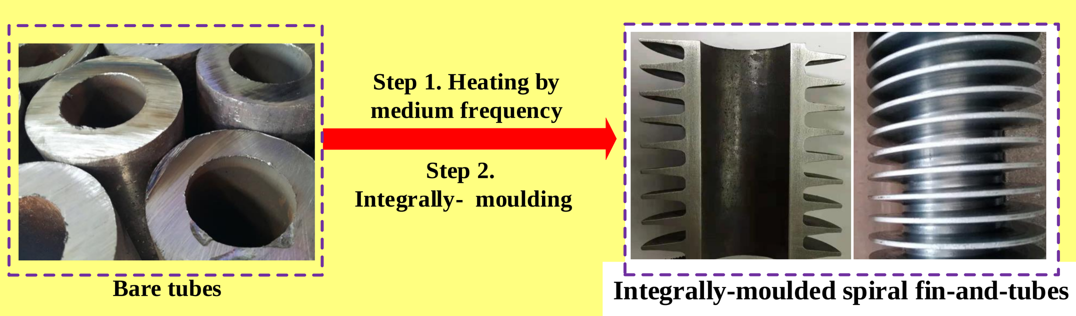

Fig. 1. The schematic diagram of the manufacturing process

As Fig.1 shows, the intergrally-moulded spiral fin-and-tubes are manufactured through an integrally-moulded technology by our group. The manufacturing process mainly contains two steps: First step is heating by medium frequency and second step is integrally-moulding.

Modeling

The physical model shown in Fig. 2 has been used in this work to investigate the influence of longitudinal tube pitches, transverse tube pitch and fin pitches shown in Table 1 on the air-side thermal and hydraulic performances of integrally-moulded spiral fin-and-tube heat exchangers. In the simulation, the turbulence model were employed, and The grid independency validation and model validation by experiment have been conducted.

Table 1. Geometry of tube models.

Examples	S_1, mm	S_2, mm	F_p, mm
case1	110	80	8
case2	110	90	8
case3	100	80	8
case4	100	80	6

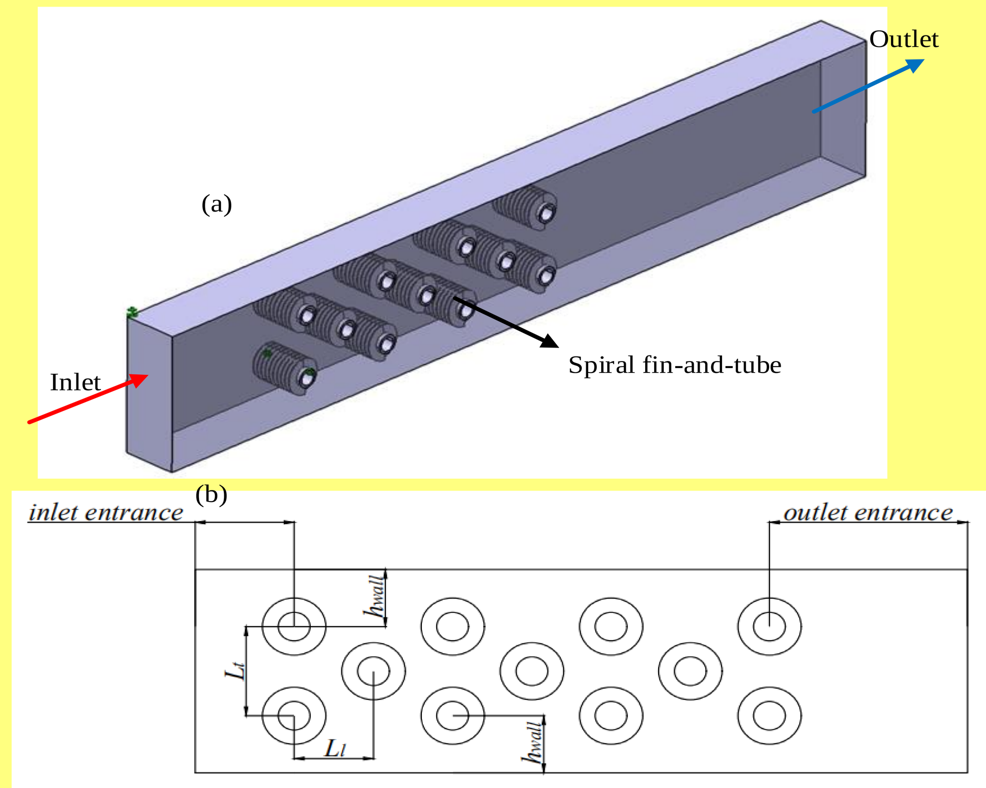

Fig. 2. Geometry details of the physical model.

The friction factor and *j* factor is expressed as follows:

$$f = \frac{\Delta P}{\frac{1}{2}\rho u_{\max}^2}\frac{A_{\min}}{A_o} \quad (1)$$

$$j = \frac{Nu}{\mathrm{Re}\,\mathrm{Pr}^{\frac{1}{3}}} \quad (2)$$

The Nusselt number is expressed as

$$Nu = \frac{h_o d_o}{\lambda} \quad (3)$$

The Reynolds number is expressed as

$$\mathrm{Re} = \frac{\rho u_{\max} d_o}{\mu} \quad (4)$$

The hydro thermal performance factor:

$$HTPF = Nu/f^{1/3} \quad (5)$$

The hydro thermal performance factor:

$$JF = j/f^{1/3} \quad (6)$$

Results and discussions

THERMAL-HYDRAULIC OF SPIRAL FINNED TUBE HEAT EXCHANGERS

The thermal and hydraulic performance data obtained as a result of HTPF where these values are compared to each other with respect to the change in Reynolds numbers are given in Fig. 3. It is easily observed that the performance factor increases with the increasing of Re number, which reveals that increasing the Re number could enhance the heat transfer performance.

And the HTPF of case1 and case2 is higher than that of other cases as the range of the Reynolds number is around 3500-9500. The longitudinal tube pitch has little effect on the HTPF at same Re number by comparing case1 and case2 shown in Fig. 3. Also, it is observed that the HTPF of case3 is smaller than that of case1, which implies that increasing the transverse tube pitch could improve thermal-hydraulic performances. It could be found that the augmentation of the fin pitch results the decrease of the HTPF, which indicates the fin pitch has a important influence on heat transfer process.

COMPARISON BETWEEN H-TYPE AND SPIRAL FINNED TUBE HEAT EXCHANGERS

It can be found that the *JF* factor of spiral finned tube heat exchanger is nearly close to that of the H-type finned tube heat exchangers with fin pitch of 25mmm and is higher than that of the H-type finned tube heat exchangers with fin pitch of 17mm at same Re number shown in Fig. 4, which indicates the spiral finned tube heat exchangers has fine heat transfer performances.

CORRELATIONS OF *Nu* AND *f* FACTORS

The correlations of integrally-moulded spiral fin-and-tube heat exchangers, in terms of the *Nu* and *f*-Fanning friction factor have been developed based on the simulation results.

$$Nu = 0.073\,\mathrm{Re}^{0.6486}\left(\frac{F_t}{F_p - w_1}\right)^{-0.2102}\left(\frac{L_l}{L_t}\right)^{-0.0736}\left(\frac{L_t}{d_f}\right)^{0.2962} \quad (7)$$

$$f = 0.0867\,\mathrm{Re}^{-0.1272}\left(\frac{F_t}{F_p - w_1}\right)^{-0.3506}\left(\frac{L_l}{L_t}\right)^{-0.3034}\left(\frac{L_t}{d_f}\right)^{0.56} \quad (8)$$

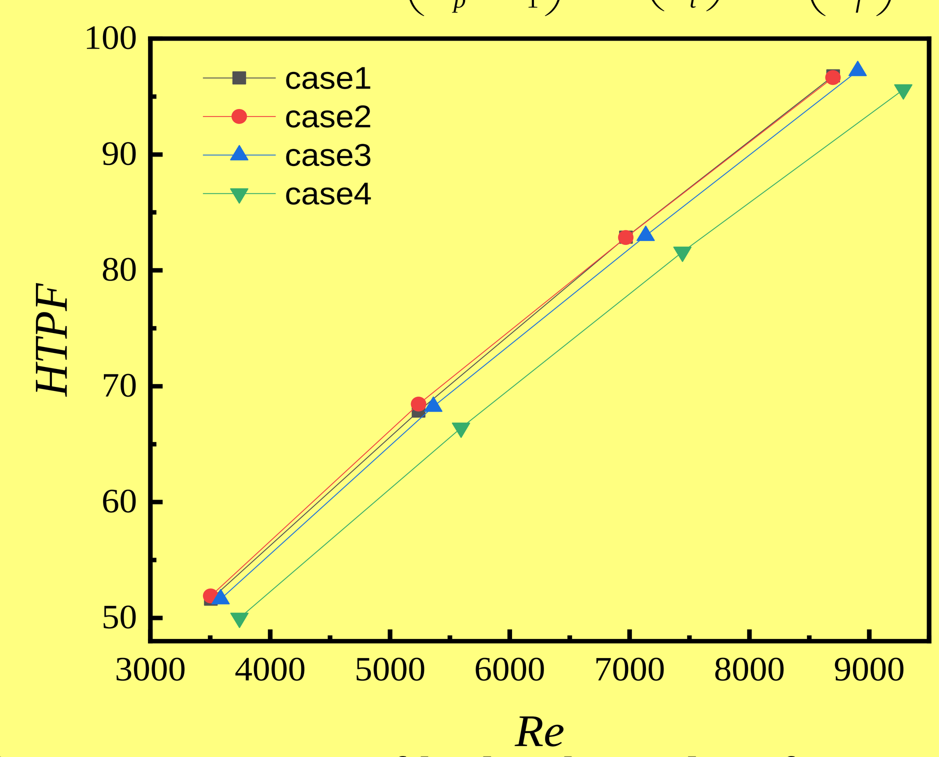

Fig. 3. Comparison of hydro thermal performance factor (HTPF) against Reynolds number for various tube models.

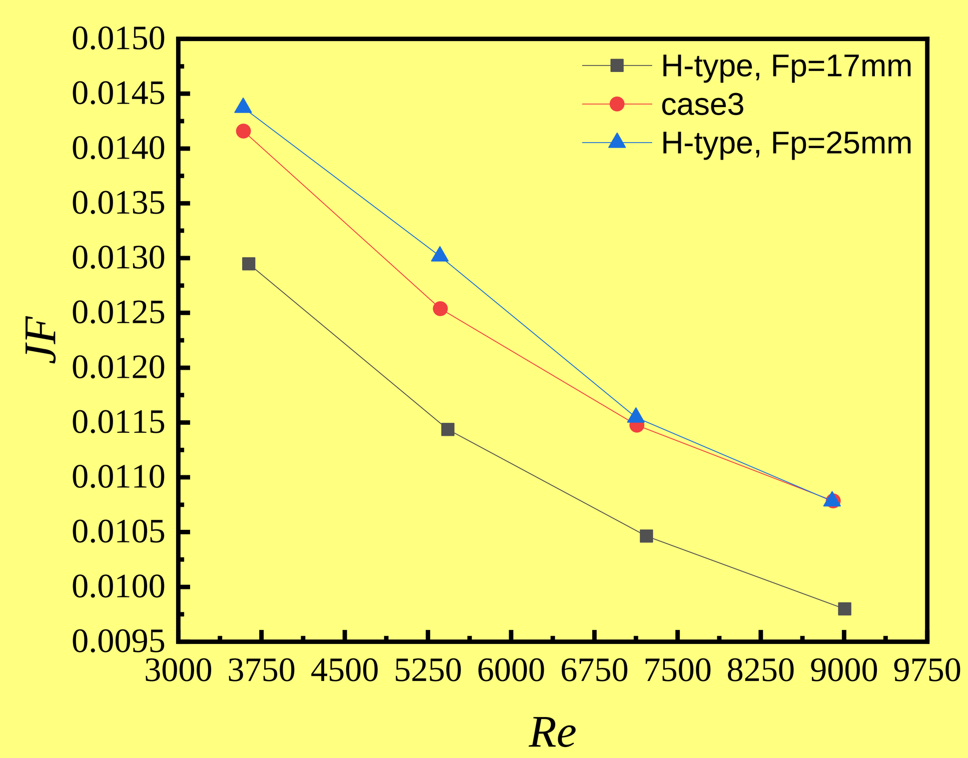

Fig. 4. The effects of fin types on the *JF* factor

Conclusions

The main conclusions drawn from all these work are:

- At the same Reynolds number, the longitudinal tube pitch has little effect on the HTPF;
- The increasing of the fin pitch results the decrease of the HTPF, which indicates the fin pitch has a important influence on heat transfer process;
- The air-side performance correlations, in terms of the *Nu* and *f*-fanning friction factor, are developed to describe the air-side performance of the integrally-moulded spiral fin-and-tube heat exchangers;
- The spiral finned tube heat exchangers have fine thermal-hydraulic performances in comparison with H-type finned tube heat exchangers.

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