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Experimental Investigation of Heat Transfer Study on Plate Fin Heat Exchangers with Wavy Fins

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Abstract

Objectives: This study investigates the variation of heat transfer parameters using wavy fin located in the plate heat exchanger. Methods/Statistical Analysis: Velocity and temperature relations, fanning friction factor for iso-temperature and Colburn factor are evaluated for different flow rates of Reynolds Number from 200 to 2000 and its various fin pitches within 9 mm respectively. Similarities were found between this experimental data and semi empirical correlations of Plate Heat Exchanger. Findings: The various parameters are evaluated using this experimental setup and we obtained the optimum j/f for swirl flow regime with Reynolds Number of around 200 to 210. The general correlations for friction factor and Colburn factor were derived by multiple linear regression analysis. Application/Improvements: This studies show the periodic growth of parameters in the wall region of cross section of cross flow heat exchanger. Also we obtained the higher heat transfer co-efficient by using wavy fin with reasonable pressure fall.

Keywords: Correlations, Heat Transfer, Plate Heat Exchangers, Wavy Fins

1. Introduction

Plate fin heat exchanger is a type of compact heat exchanger that made up of a stack of alternate flat plates called parting sheets and corrugated fins brazed together as a block[1–3]. They possess high degree of compactness, high efficiency (> = 95%) and capable of handling multiple streams[4,5]. A typical plate fin assembly with sidebars is shown in Figure 1.

The PFHE core is prepared of layers of plate and fins. Fluid will be flowing throughout the passage formed in linking the plate and the fins. Hot and cold fluids flow alternatively in every plate fin assemblage and heat transfer takes place linking them[6,7].

2. Experimental Investigation

2.1 Experimental Setup

In this study, the experimental setup used was schematically shown in Figure 2. The test section was placed in the air duct. The hot and cold fluids pass through the test section in a counter flow manner. The water temperature was raised to 80°C is the hot fluid circulates through the test section. The compressed air is the cold fluid supplied by a double stage reciprocating air compressor and passes through a flow meter, a rectifier, flow regulator and the test section. Air flow rate can be controlled by means of the flow regulator. Flow straightness or rectifiers are provided in the duct to have a uniform flow throughout the exposed area of the test section. The water is heated in an insulated water tank by an immersion heater and is circulated through the test section by means of a pump. A flow control valve is provided to adjust the flow rate of water.

The test section shown in Figure 2 is made up of two hollow rectangular boxes that provide passage for hot water to pass through it in a counter flow manner to through the air flow. The counter flow arrangements enable maximum heat transfer between the two fluids. The wavy fins are arranged in between these two rectangular boxes. The rectangular boxes of the test section resembles the plates in the plate fin heat exchangers to provide uniform heat flux

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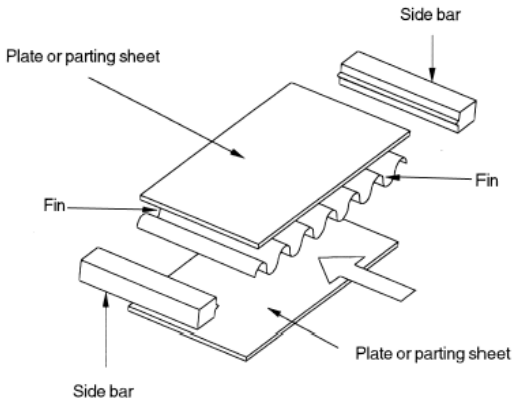

Figure 1. Plate-fin assembly.

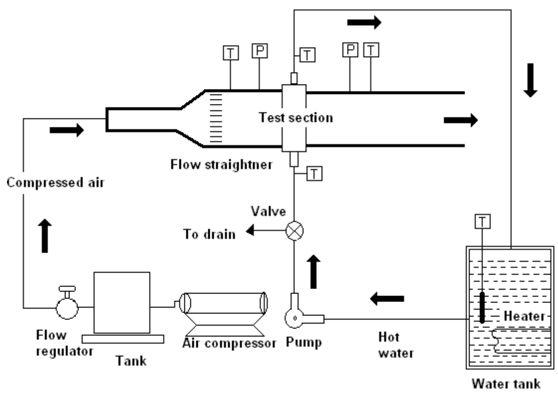

Figure 2. Schematic of experimental setup.

throughout the plate areas, the hot water is passed from the bottom of the test section. The Height (H), Width (W) and Length (L) of the each plate in the test section are 10, 100 and 50 mm respectively. The side bars are provided at the end of the plates to pack the wavy fins tightly in between the plates. Temperature of air at both inlet and outlet of the test section are measured with 10 resistance thermometers, 5 at the inlet and other 5 at the outlet each with an accuracy of + 0.01°C. The temperature of the water at the inlet and outlet of the test section is measured by means of resistance thermometers placed at the corresponding locations. The pressure drop is measured by using a digital manometer with an accuracy of +0.5 Pascal connected to the pressure taps located in the duct.

2.2 Experimental Procedure

The heater raises the temperature of the water until it reaches 80°C. Then the heater is switched off and the hot fluid circulates through the test section by means of the pump. The hot fluid heats up the plates in the test section. The wavy fins placed in the test section are heated by conduction heat transfer from the plates. Compressed air is passed through wavy fins in the test section. The air absorbs the heat from the wavy fins by means of forced convection.

Changing the flow rate of air through the test section can vary the velocity of the air flow. The velocities corresponding to the laminar and turbulent flow regimes are initially fixed by using a pitot tube a sharp temperature increase is observed at the outlet of the test section in the airside immediately after compressed air is passed through the test section. The temperature data are recorded in a data logger for every 30 seconds. This time interval for recording the data is chosen to have a better coverage of the temperature data and is based on previous research. From the difference between the temperatures of the water and the mass flow rate of water, the total heat supplied to the plates can be estimated. The difference between the temperatures of air at the measured time intervals corresponds to the average heat transfer coefficient of the wavy fins placed in the test section. The pressure drop data is shown in the digital pressure manometer. The same procedure should be repeated for other flow rates and the temperature and pressure data are noted.

3. Data Reduction Method

In this experiment, the hot fluid flowing inside the plates heat the wavy fins in the test section. The heat transferred from the hot water to the plates can be calculated as shown in Equation (1).

$$Q_w = m_w Cp \nabla T_w \tag{1}$$

The heat from the hot plates is then transferred to the wavy fins by conduction. The wavy fins heat the air that is passing through the test section. The heat transferred to the air from the wavy fin is calculated as shown in Equation (2).

$$Q_a = \frac{h_{fin} A_{fin}}{\varepsilon} \left(T_{fin} - T_a\right) \tag{2}$$

Based on the characteristic length, Reynolds number (3), friction factor (4), Nusselt number (5) and the Colburn j factor (6) are defined as follows:

$$\mathrm{Re}_{dh} = \frac{udh}{u} \text{ Where, u} = \frac{U_0}{\varepsilon} \tag{3}$$

$$f_{dh} = \left(\frac{\Delta P}{2\rho_f u^2}\right)\frac{dh}{L} \quad (4)$$

$$Nu_{dh} = \frac{h_{fin} dh}{\lambda_f} \quad (5)$$

$$j_{dh} = \frac{Nu_{dh}}{\mathrm{Re}\,\mathrm{Pr}^{\frac{1}{3}}} \quad (6)$$

4. Correlations for j and f

The thermal performance is defined by j (Colburn factor) and the pressure drop characteristic is defined by f (friction factor). They are functionally related to Re, α, β, γ and can be represented as shown in Equation (7 and 8).

$$f \,\alpha\, \mathrm{Re}, \alpha, \beta, \gamma \quad (7)$$

$$j \,\alpha\, \mathrm{Re}, \alpha, \beta, \gamma \quad (8)$$

By using power law expressions,

$$f = A\, \mathrm{Re}^{a1}\, \alpha^{a2}\, \beta^{a3}\, \gamma^{a4} \quad (9)$$

$$j = A\, \mathrm{Re}^{b1} \alpha^{b2}\, \beta^{b3}\, \gamma^{\,b4} \quad (10)$$

Where

α = (Fp/Fh), β = (Fp/L), γ = (Fp/Lw).

A multivariable regression analysis is carried out for the 100 sets of data points under laminar and the correlations for j and f are obtained.

$$f = 1.1785\, \mathrm{Re}^{-0.3525} \alpha^{1.86}\, \beta^{-0.528}\, \gamma^{\,0.869} \quad (11)$$

$$j = 0.07856\, \mathrm{Re}^{\,-0.4585}\, \alpha^{-0.1845}\, \beta^{0.1843}\, \gamma^{-0.0011} \quad (12)$$

5. Results and Discussions

The geometric parameters of the wavy fins like fin pitch, fin height and fin length influencing the performance of wavy fin heat exchanger. The effects of these parameters on the performance of wavy fins are discussed in this chapter.

5.1 Wavy Fin Arrangements

The wavy fin (Fp = 5 mm) has the highest j factor for laminar region as shown in Figure 3. Wavy fin with low fin pitch has the highest heat transfer coefficient. This is due to the fact in wavy fin arrangement, the flow passage increases as the fin pitch decreases.

The friction factor increases as the fin pitch is increasing with constant fin height. As the flow rate increases the friction factor increases as shown in Figure 3. The comparison of j factors of various fin pitches for laminar as shown in Figure 4. The comparison of f and j experimental results with correlation under the laminar region is shown in Figures 5 and 6.

Flow area goodness factor (j/f) decides the performance of different compact heat exchangers. The significance of j/f is that it is inversely proportional to the core free-flow area for fixed operating conditions. Thus, larger values for j/f suggest a lower frontal-area requirement for the heat exchanger. The wavy fins with better j/f values in a particular region are suited for working perfectly in the corresponding ranges of Reynolds number. The comparison of j/f values of various fin pitches for laminar as shown in Figure 7.

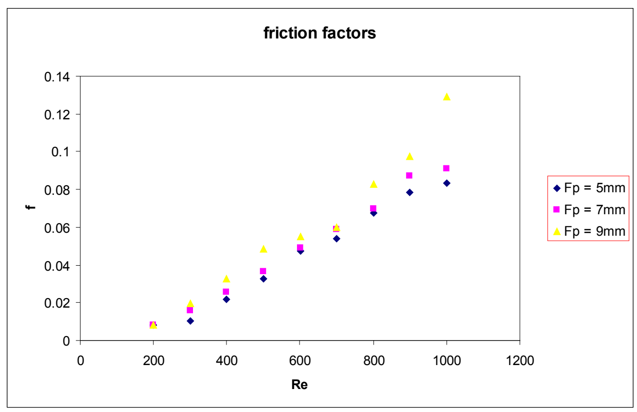

Figure 3. The comparison of f factors of various fin pitches for laminar.

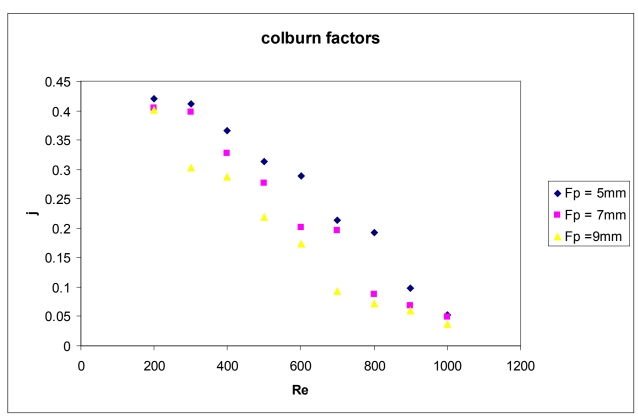

Figure 4. The comparison of j factors of various fin pitches for laminar.

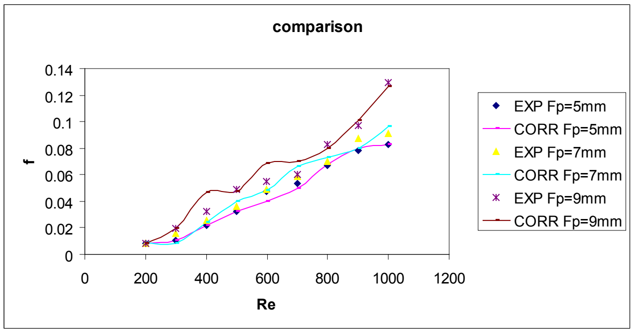

Figure 5. Comparison of f experimental results with correlation (laminar).

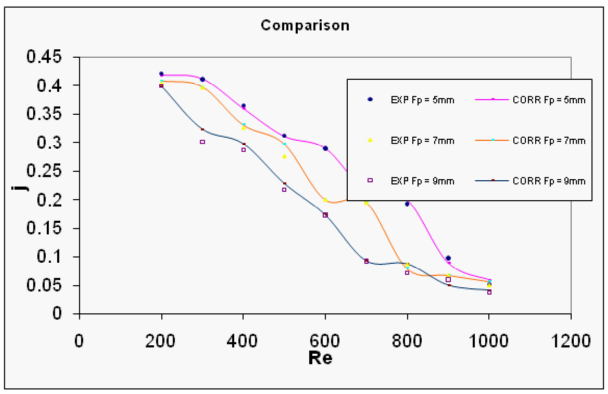

Figure 6. Comparison of j experimental results with correlation (laminar).

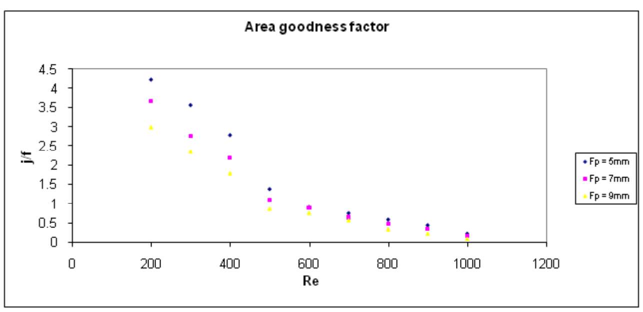

Figure 7. Comparison of j/f values of various fin pitches for laminar.

6. Conclusion

The performance of various wavy fins is experimentally investigated under laminar and turbulent flow regimes. From the experimental results, the following conclusions are made:

- The heat transfer and the friction factor for wavy fin have been analyzed and are shown to be affected by the fin geometric parameters α, β, and γ along with the Reynolds number.
- Generalized empirical correlations are developed for both laminar and turbulent flow regimes using multivariable regression analysis.
- The correlations show 10% mean deviation with the present experimental data. The wavy fin has the highest j factor for laminar region as shown in above figures.
- The friction factor increases as the pitch is increasing with a constant fin height and length. The Colburn factor decreases as the pitch is increasing.
- At low velocity region the thermal performance will be high.

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