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MEASUREMENTS AND ANALYSES OF COLBURN FACTOR IN FIN AND FLAT TUBE COMPACT HEAT EXCHANGERS

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Abstract. *A fin and tube compact heat exchanger composed of microchannels flat tubes were tested in a wind tunnel for the measurement of Colburn factor in order to evaluate the prediction error of literature correlations. The experiments were conducted at ambient air pressure of 93 kPa and relative humidity of 60%, with air velocity between 1 to 4 m/s. The compact hat exchanger had a frontal area of 0.245 x 0.175 m^2 and total heat transfer surface area of 1.5 m^2. The deviation between experimental data and correlations predicted values were found to be in the range of 2 to 30%.*

Keywords: *compact heat exchanger, microchannels, flat tubes, Colburn factor*

1. INTRODUCTION

Microchannel compact heat exchangers are being widely adopted in modern applications due its compactness, reduced fluid charge, lightness, resistance to higher pressure and cost (Tibiriçá and Ribatski 2013). They are characterized by hydraulic diameters in the order of 1 mm, both in the air and liquid sides. Evaporators and condensers used in refrigeration cycles are typical heat exchangers that are using microchannel design. Despite the advantages, the prediction methods for heat transfer and pressure drop in microchannel flows, with phase change, are emerging constantly, year after year, with better performances. In this context, this work has the objective measure the Colburn factor in a compact microchannel heat exchanger and compare with predictions from literature correlations in order to analyze the prediction performance.

2. EXPERIMENTAL METHODOLOGY

The experiments were performed in a laboratory of the Heat Transfer Research Group at EESC-USP using a wind tunnel operating in open loop mode. A compact heat exchanger was installed inside the wind tunnel where the air speed was controlled in the range of 1 to 4 m/s. the air speed was measured by hot wire anemometry. Water was used inside the tubes of the compact heat exchanger to impose the temperature difference needed to determine the heat transfer rate along the heat exchanger. Type-T thermocouples were used to measure inlet and outlet air temperature, and inlet and outlet water temperatures. During the experiments the air pressure were measured be 93 kPa and inlet humidity of 60%. Figure 1 shows the region of the wind tunnel where the tests were performed.

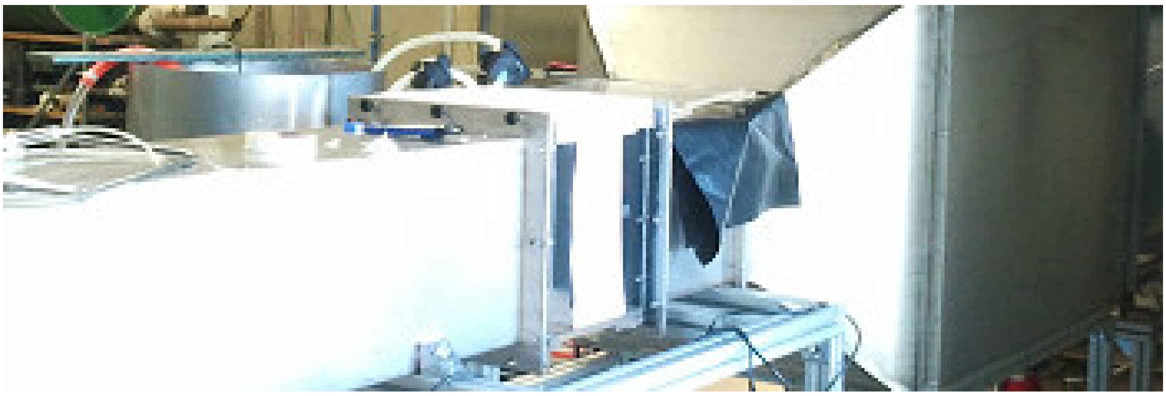

Figure 1. Detailed view of the test section installed inside the wind tunnel

The test section installed inside the wind tunnel is showed in Figure 2. The internal water flow occurs inside an array of flat microchannel tubes and the external air flow occurs over the array of the louvered fins. The frontal area of the heat exchanger was 0.245 x 0.175 m^2 and total external surface area was 1.5 m^2.

Figure 2. View of the test section from the interior side of the wind tunnel

In order to determine the external flow Colburn factor, the global heat transfer coefficient, U, were measured using epsilon-NUT method. The equations for data reductions are described bellow.

Firstly the heat transfer rate between air and water was determined by the energy analyses over the heat exchanger.

$$\overline{q} = \frac{q_{air} + q_w}{2} = \frac{\left|\dot{m}_{air} c_{p,air} \left(T_{airw,in} - T_{air,out}\right)\right| + \left|\dot{m}_w c_{p,w} \left(T_{w,in} - T_{w,out}\right)\right|}{2} \tag{1}$$

where q_{air} and q_w are the heat transfer rate measured by the air side and water side respectively. The heat exchanger effectiveness is measured by the equation

$$\varepsilon = \frac{\overline{q}}{C_{\min}\left(T_{w,in} - T_{air,in}\right)} \tag{2}$$

where C_{min} is the heat capacity of the air side flow.

The number of thermal units, NUT, is calculated using a cross flow NUT-ε relation, Eq. (3), based on numerical solutions of similar heat exchanger problems, Kakaç and Liu (2002).

$$NUT = f(\varepsilon, C_r) \tag{3}$$

where $C_r = \frac{C_{\min}}{C_{\max}}$ is the ratio of air to water heat capacities.

The global heat transfer coefficient is determined by Eq. 4

$$UA = \frac{1}{R_{tot}} = NUT.C_{\min} \tag{4}$$

The external heat transfer coefficient, h_o, is obtained by subtracting the internal convection thermal resistance and the tube wall resistance from the total thermal resistance using Eq. (5). Internal heat transfer coefficient was calculated by single phase correlations. In case of two phase flows the it can be calculated by correlations indicated in Tibiriçá et al. (2017).

$$\frac{1}{UA} = \frac{1}{\eta_o h_o A_o} + \frac{\delta_w}{k_w A_w} + \frac{1}{h_i A_i} \tag{5}$$

The Colburn factor was determined by the following relation:

$$j = \frac{h_o}{\rho_m V_c c_p} \mathrm{Pr}^{2/3} \tag{6}$$

Using error propagations formulas, the uncertainty for the Colburn factor was calculated to be lower than 8%.

The experimental Colburn factors, j, was compared with the correlation of Chan and Wang (1997) given by Eq. 7 and correlation of Ryu and Lee (2015) given by Eq.8. The correlation of Chan and Wang (1997) has been widely cited in literature and it is frequently used in the design of compact heat exchangers. The correlation of Ryu an Lee (2015) is a new and simpler correlation that was selected to be tested in this work in order to verify if it has the performance indicated by their authors.

$$j = \mathrm{Re}_{L_p}^{-0.49} \left(\frac{\theta}{90}\right)^{0.27} \left(\frac{F_p}{L_p}\right)^{-0.14} \left(\frac{F_p}{L_p}\right)^{-0.29} \left(\frac{T_d}{L_p}\right)^{-0.23} \left(\frac{L_l}{L_p}\right)^{0.68} \left(\frac{T_p}{L_p}\right)^{-0.28} \left(\frac{\delta_f}{L_p}\right)^{-0.05} \tag{7}$$

where θ is louver angle, F_p is the fin pitch, L_p louver pitch, T_d tube depth, L_l louver length, T_p tube pitch, δ_f is the fn thickness. The Reynolds number is the one based in the louver pitch.

$$j = \mathrm{Re}_{L_p}^{\left(-0.484 - 1.887/\ln \mathrm{Re}_{L_p}\right)} \left(\frac{F_d}{L_p}\right)^{0.157} \left(2.24 - 0.588 \ln\left(\frac{F_p}{L_p \sin\theta}\right)\right) \tag{8}$$

where F_d is the flow depth,

3. RESULTS

Figure 3 presents the experimental results for Colburn factor against the Reynolds number based on the louver pitch. Curves for the correlations of Chang and Wang (1997) and Ryu and Lee (2015) are plotted on the same figure. As can be observed, Chang and Wang (1997) had better predictions for higher Reynolds numbers and Ryu and Lee had better performance for lower Reynolds values. The average absolute error for both correlations, considering all data points, was in the order of 15%. Local errors ranged from 2 to 30%. When comparing the correlation curves by each other, a divergence around of 20% is noted, with Chang and Wang (1997) giving higher values.

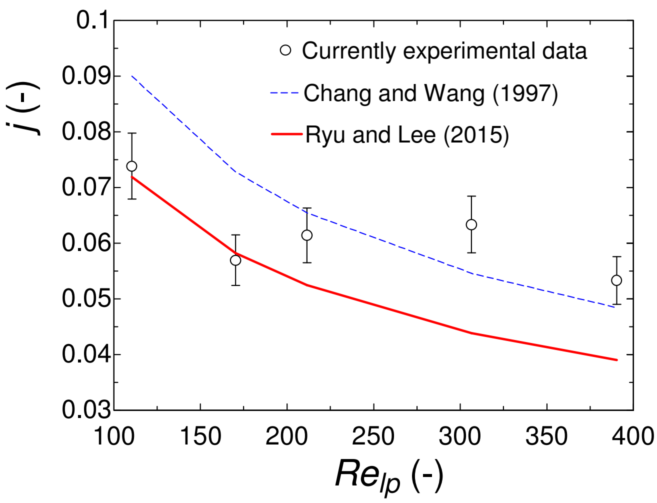

Figure 3. Comparison between experimental Colburn factor and correlations values.

4. CONCLUSIONS

Experimental tests were performed in a wind tunnel for the measurement of Colburn factors on a compact fin and tube heat exchanger composed of microchannel flat tubes. The tests were performed in order to evaluate the performance of literature correlations. Chang and Wang (1997) and Ryu and Lee (2015) correlations were compared against the experimental data and a mean absolute error near 15% was found for both correlations. Local prediction errors ranged between 2 to 30%. Based in these results both correlations can be used for design of compact heat exchangers.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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