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Forced Convection Heat Transfer Experiments of the Finned Plate in a Duct

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1. Introduction

Forced convection in a finned channel has been studied widely. Using plate-fins is one of the cheapest and easiest ways to dissipate unwanted heat and it has been commonly used for many engineering applications successfully [1, 2]. Thus, the studies have been focused on the optimization of fin geometries to maximize the heat transfer rate [3-5].

The forced convection heat transfer rates were affected largely by the fin spacing, fin height, and tip clearance. As the fin spacing decreases and fin height increases, heat transfers from the fins to the ambient are enhanced as they are directly proportional to the surface area. For a large tip clearance, the fluid tends to escape from the inner fin region to the outer wall region resulting in the decrease of the overall heat removal capability [6]. Thus, the parametric influences of these variables are to be investigated to develop a generalized heat transfer correlation for the geometry.

This study is a preliminary experimental study for plate-fin geometries such as fin spacing, fin height and duct width. Mass transfer experiments were carried out based on the analogy concept, using a copper sulfate electroplating system. The work has the relevance with the Reactor Cavity Cooling System performance enhancement study in the VHTR.

2. Previous Studies

2.1 Fin Geometry influences

Dogan and Sivrioglu reported that the average heat transfer coefficient first increases with fin spacing up to a maximum value and then it decreases with the increase in fin spacing. The value of fin spacing at which the heat transfer takes its maximum value, is defined as optimum fin spacing, S_{opt} [7]. Seri presented for an increased fin height hence increases the area of heat transfer and thus enhances the thermal effectiveness [8].

2.2 Tip clearance influence

Li et al. investigated that the hydraulic and thermal performance of a plate-fin heat sink undergoing cross flow forced convection with and without tip clearance. When tip clearance exists, the fluid decelerates as the flow enters the fin-to-fin channel of the heat sink; maximum velocities occur at the wall region. Most coolant fluid bypasses through the top side of the heat sink. When tip clearance does not exist, the flow entering the fin-to-fin channel accelerates; maximum velocities occur in the fin-to-fin channel, which forces more coolant fluid to enter the fin-to-fin channel and increases the velocity in this space [9].

3. Experiments

3.1 Mass Transfer Method

Mass transfer rates were measured instead of the heat transfer rates as the analogy between heat and mass transfer can be applied when the boundary conditions are of same type. Measurements were made using a cupric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system [10].

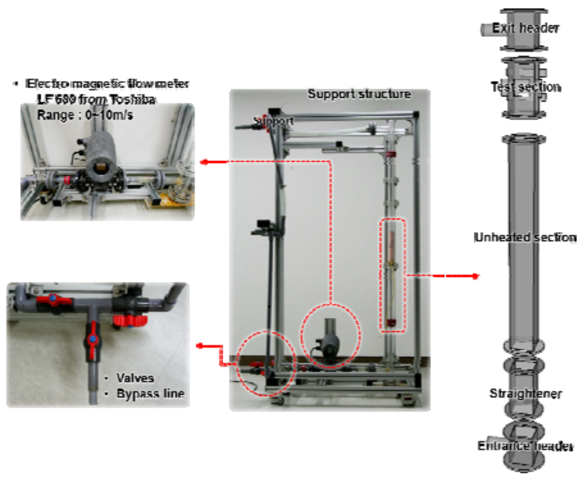


Fig. 1. Experimental apparatus.

3.2 Apparatus and Test matrix

Figure 1 shows an image of the test apparatus, which is a closed loop consisted of an acryl square duct, a chemical pump and an electromagnetic flow meter and bypass system and relevant pipes and valves. The acryl square duct is composed of the entrance header, the flow straightener, the unheated section, the test section and the exit header. Fig. 2 shows the experimental system circuit. Fluid flows from the reservoir through the pump and electromagnetic flow meter and then goes test section. In order to achieve the fully developed condition before entering the test section, the flow straighteners together with the unheated section of enough length was employed. Fig. 3 presents the copper cathodes presenting the plate-fin installed inside of acryl square duct.

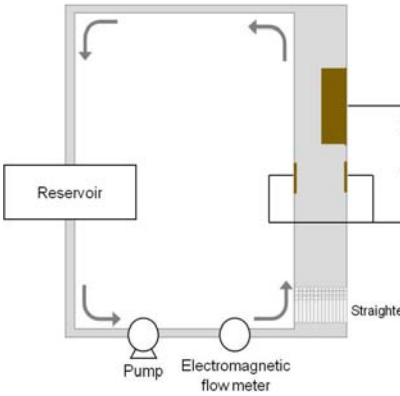


Fig. 2. Experimental system circuit

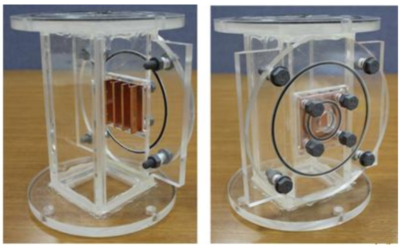


Fig. 3. The cathode of plate-fin in a test section.

Table 1 shows the test matrix. The *Pr* was 2,014 with H_2SO_4 1.5M and $CuSO_4$ 0.01M and fin heights were 0.010m and 0.015m, respectively. For the fin height of 0.010m, two different duct widths of 0.010m and 0.015m were employed and for the fin height of 0.015m, the duct widths were 0.015m and 0.020. Ra_s was 6.8 x 10^5, 2.3 x 10^6, and 3.0 x 10^7, for which fin spacing of plate-fin was varied from 0.02m to 0.07m and the Re_{Dh} from 100 to 10,000 covering the laminar and turbulent flow conditions.

Table I: Test matrix for plate-fin on forced convection.

Pr	H (m)	W_D (m)	S (m)	Ra_S	Re_{Dh}
2,014	0.010	0.010, 0.015	0.002, 0.003, 0.007	6.8 x 10^5, 2.3 x 10^6, 3.0 x 10^7	10~6,500
	0.015	0.015, 0.020			

4. Results and Discussion

4.1 Comparison with the existing correlations

Figure 4 compares the current test results with the heat transfer correlations developed for the plate-fin together with the correlation for the flat plate. The symbols indicate the present data and the lines show the existing correlation. Two lines denoting the upper and lower bounds of each heat transfer correlation, are shown in the figure. As shown in Fig. 4, the test results and the correlations were very much scattered but they show that the Nu_{Dh}'s enhance with the Re_{Dh}.

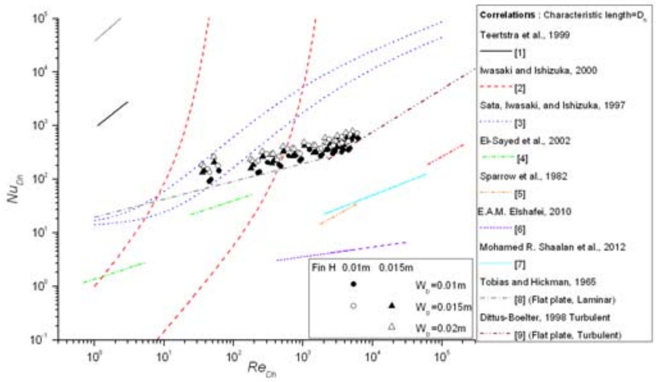


Fig. 4. The comparison of the experiments and existing correlations.

The measured Nu_{Dh} were similar to the correlation of Sata et al. and higher than those from the heat transfer correlations for the flat plate in laminar and turbulent conditions.

4.2 Heat Transfer of Fin Geometries and Duct Width

Figure 5 presents the heat transfer rates with respect to the Re_{Dh} for fin height 0.01m. Fig. 5(a) was the heat transfer rates without the tip clearance. Meanwhile, Fig. 5(b) was the heat transfer rates when the tip clearance is 0.005m.

In both of Fig. 5(a) and (b), the heat transfer rates were enhanced with the increase of the Re_{Dh} as the flow rate increased. The heat transfer rates were enhanced with the decrease of fin spacing as the heat transfer area increased.

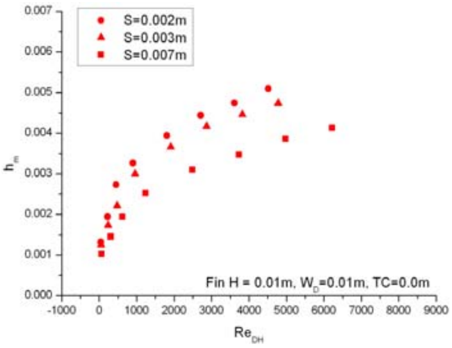
When comparing Fig. 5(a) with Fig. 5(b), the heat transfer rates of Fig. 5(a) were higher than those of Fig. 5(b) due to the bypass flows. Fig. 6 also confirms the same results with Fig. 5.

Figure 7 compares the heat transfer rates for the fin height 0.010m and 0.015m. The higher finned plate shows the higher heat transfer rates due to the enlarged heat transfer area.

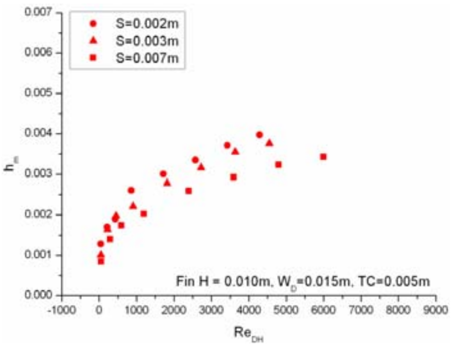
5. Conclusions

Forced convection heat transfer experiments were performed for the vertical plate-fins in a duct. Based on the analogy between heat and mass transfer systems, mass transfer rates were measured using the cupric acid copper sulfate electroplating system. The fin spacings were varied from 0.002m to 0.007m, fin heights 0.01m and 0.015m, Re_{Dh} from 10 to 6,500, and duct widths from 0.010m to 0.02m.

The test results showed that the heat transfer rates enhanced with the increase of fin height and the decrease of fin spacing as they enlarge the heat transfer area. And the heat transfer rates were impaired with the increase of the duct width as the bypass flows increased to tip clearance region.

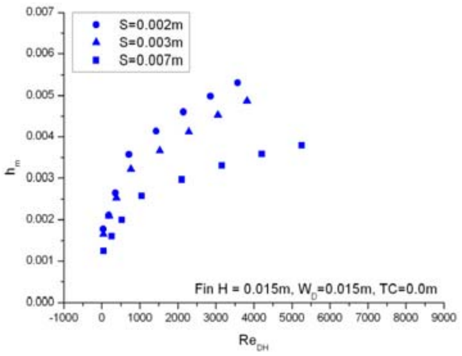


(a) Fin H=0.01m, W_D=0.01m

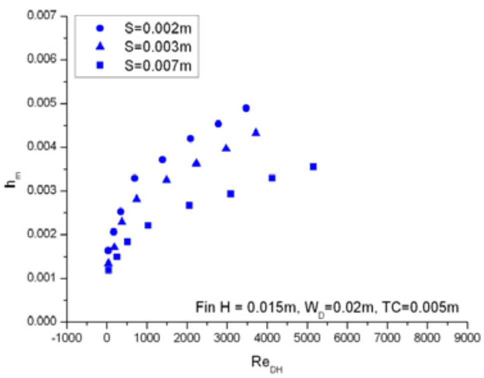


(b) Fin H=0.01m, W_D=0.015m

Fig. 5. h_m according to Re_{Dh}, Fin H=0.01m.

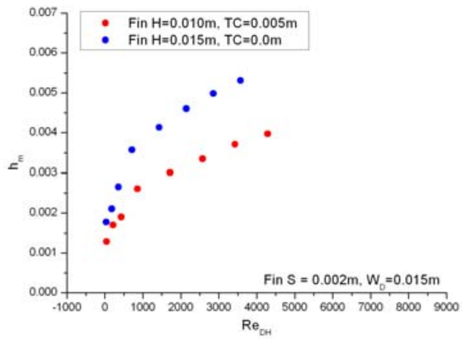


(a) Fin H=0.015m, W_D=0.015m

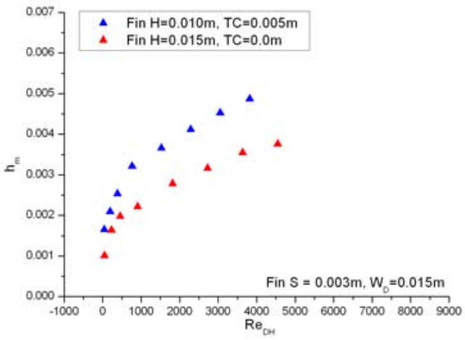


(b) Fin H=0.015m, W_D=0.02m

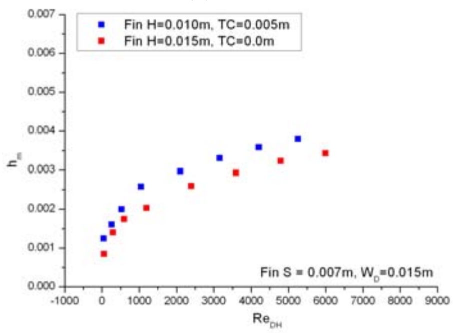
Fig. 6. h_m according to Re_{Dh}, Fin H=0.015m.



(a) Fin S=0.002



(b) Fin S=0.002



(c) Fin S=0.007

Fig. 7. h_m according to Re_{Dh}, W_D=0.015m, Fin H=0.01m, 0.015

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