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Open Channel Natural Convection Heat Transfer on a Vertical Finned Plate

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1. Introduction

Passive cooling by natural convection becomes more and more important for the nuclear systems as the station black out really happened at the Fukushima NPPs. In the RCCS (Reactor Cavity Cooling System) of a VHTR (Very High Temperature Reactor), natural convection cooling through duct system is adopted. In response to the stack failure event, extra cooling capacity adopting the fin array has to be investigated.

The finned plate increases the surface area and the heat transfer increases. However, the plate of fin arrays may increase the pressure drop and the heat transfer decreases. Therefore, in order to enhance the passive cooling with fin arrays, the parameters for the fin arrays should be optimized. According to Welling and Wooldridge [1], a natural convection on vertical plate fin is function of *Gr*, *Pr, L, t, S,* and *H*.

The present work investigated the natural convection heat transfer of a vertical finned plate with varying the fin height and the fin spacing. In order achieve high Rayleigh numbers, an electroplating system was employed and the mass transfer rates were measured using a copper sulfate electroplating system based on the analogy concept.

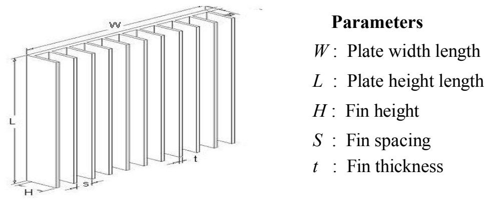

Fig. 1 The shape and parameters of rectangular plate fin

2. Previous studies

Natural convection heat transfer phenomena for vertical plates are well known and many heat transfer correlations have been developed. For the laminar natural convection, Bejan [2] performed the scale analysis from governing equations and proposed the relation among the variables. Le Fevre suggested the Equation (1) for the laminar natural convection heat transfer correlation for vertical plates [3].

$$Nu_H = 0.67(Gr_H Pr)^{1/4} \text{ at } Gr_H < 10^9 \quad (1)$$

One of the earliest studies of the heat transfer form fin arrays in that of Starner and McManus [4] who presented heat transfer coefficients of four differently dimensioned fin arrays with the base vertical. They showed that incorrect application of fins to a surface actually may reduce the total heat transfer to a value even below that of the base alone.

Welling and Wooldridge [1] have studied heat transfer from plate-fin heat sinks experimentally. They reported optimum values of the ratio of fin height to spacing.

3. Experiments

3.1 Experimental apparatus

Figure 2 shows the apparatus and system circuit. The apparatus consisted of a cathode with/without fin arrays and an anode of a flat copper plate. Table I presents test matrix for the preliminary experiments.

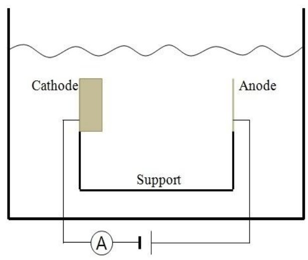

Fig. 2. The experimental apparatus.

Table I: Test matrix.

L (m)	*W* (m)	*H* (m)	*S* (m)	Ra_s
0.05	0.05	0.005	0.002	6.79×10^5
		0.0075	0.003	2.29×10^6
		0.010	0.007	2.91×10^7
		0.015	0.02	6.79×10^8

Fixed CuSO4 = 0.05M, H2SO4 = 1.5M, Pr = 2,014.

3.2 Experimental Methodology

An analogy between heat and mass transfer is established as the governing equations and parameters are of the same type [2]. Thus the heat transfer system can be replaced by the mass transfer system and vice versa. In the present work, measurements were made using limiting current technique with a cupric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system as the mass transfer system.

4. Results and discussion

Figure 3 shows that the current experimental results agree well with the existing heat transfer correlations and that this study extended the Ra_S ranges.

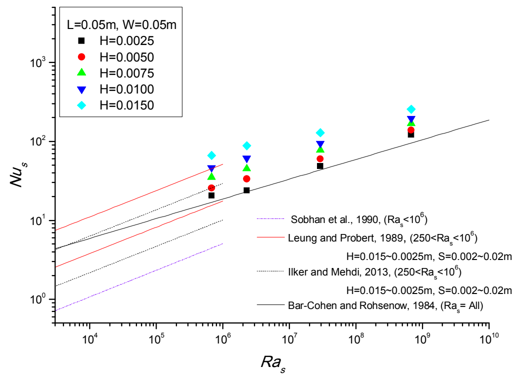

Fig. 3. The comparison of the test results with the Rayleigh-Benard natural convection heat transfer correlations.

Figure 4 shows the variations total mass transfer ratios, Q_m with respect to the plate spacing, S. The total mass transfer ratios are calculated by dividing the measured Q_m with the calculated total heat transfer rates using the heat transfer correlation (1) for the vertical plate of same surface area.

The basic idea of Fig. 4 is that when there are no interactions among the boundary layers formed at the base plate and the fins, the natural convection heat transfer for the vertical finned plate will be the same as the natural convection heat transfer for the vertical flat plate of the same surface area. Thus the ratio will be one for large *S* and the ratio will deviate from one with the interactions of the boundary layers for small *S*.

For $S > 0.007$m, the Q_m ratios are near one showing that the boundary layers do not interact each other. If this is true, for large *S* the natural convection heat transfer rate of the finned plate can be calculated from the heat transfer correlation for a vertical flat plate with the same surface area.

For $S < 0.007$m, one can see the fluctuation of the total mass transfer rates with S. In this experiment, the *Sc*, which corresponds to *Pr*, is very large (2,014). This means that the mass transfer boundary layers are much thinner than the momentum boundary layers and that the thin thermal boundary layer leads the thicker momentum boundary layer. Thus at small *S*'s, two kinds of boundary layer interactions can be conceived. Firstly, the overlap of thermal boundary layers for a very small *S*. In this case, due to the overlap of thermal boundary layer, the mass transfer will be enhanced and the thin thermal boundary layer will experience an enhanced buoyancy force. Thus in this *S*, the mass transfer rate will be much enhanced.

While for *S*'s which permits overlap of momentum boundary layers, the buoyancy force is the same without overlap. However as the momentum boundary layer that has to be driven by the same buoyance will increases. Thus the natural convection velocity and thus the heat transfer will be impaired.

These phenomena can be observed in Fig. 4. For the $S < 0.007$m, the Q_m ratios are less than one. However for $S = 0.003$m, one can see the minimum ratios for all *H*. Thus it can be deduced that for $S < 0.003$m, thermal boundary layers overlap and that for $0.003\text{m} < S < 0.007$m, the momentum boundary layers overlap.

As the fin height increases, heat transfer from the fins to the fluid is directly proportional to the surface area of the fins and it is observed that distinguishably more air enters from the open side of the fin spacing [5]. So, Q_m ratios increased with increasing *H*.

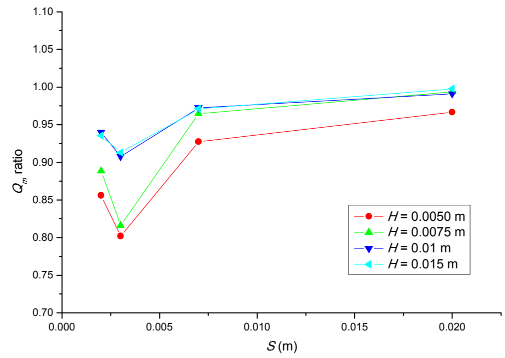

Fig. 4. The Q_m ratio with the fin spacing and fin height.

5. Conclusions

The natural convection heat transfer of vertical plate-fin was investigated experimentally. Heat transfer systems were replaced by mass-transfer systems, based on the analogy concept. The experimental results lie within the predictions of the existing heat transfer correlations of plate-fin for the natural convections. An overlapped thermal boundary layers caused increasing heat transfer, and an overlapped momentum boundary layers caused decreasing heat transfer. As the fin height increases, heat transfer was enhanced due to increased inflow from the open side of the fin spacing. When fin spacing and fin height are large, heat transfer was unaffected by the fin spacing and fin height.

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