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Preliminary Experiments on Natural Convection Heat Transfer of the Vertical Plate with Fin Arrays

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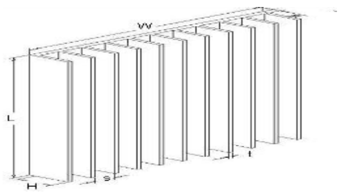
1. Introduction

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 of the fin arrays should be optimized.

According to Welling and Wooldridge [1], a natural convection on vertical plate fin is function of $Nu = f(Gr, Pr, L, t, S, H)$. Present study aimed at the determination of the effects of geometric parameters, L(fin length) and S(fin spacing), and H(fin height) on the heat transfer, in order to find optimum parameters on the natural convection heat transfer.



Parameters
W : Plate width length
L : Plate height length
H : Fin height
S : Fin spacing
t : Fin thickness

Fig. 1 The shape and parameters of rectangular plate fin

2. Previous study

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

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

Incropera [4] presented summaries of many convection cooling options after an extensive review and discussion of work done on the convective cooling of electronic equipment

One of the earliest studies of the heat transfer form fin arrays in that of Starner and McManus [5] who presented heat transfer coefficients of four differently dimensioned fin arrays with the base vertical, 45 degrees and horizontal. They showed that incorrect application of fins to a surface actually may reduce the total heat transfer to a value below that of the base alone.

A similar experimental study was conducted by Welling and Woolbridge [1] on rectangular vertical fins. They reported optimum values of the ratio of fin height to spacing.

3. Experiments

3.1 Apparatus and Test matrix

Test apparatus consists of a cathode with/without fin arrays and an anode of a flat copper plate, as shown in Fig. 1. Table 1 presents test matrix for the preliminary experiments.

Table 1 Test matrix for the preliminary experiments

L(m)	*Ra_L*	*Geometry*	*S(m)*	*H(m)*	*Ra_S*
0.02 0.05	6.79×10^8 6.55×10^8	Plate	0	0	-
		Fin	0.003 0.010 0.020	0.005 0.010 0.015	2.3×10^6 8.5×10^7 6.8×10^8
Pr 2,014 fixed					

3.2 Experimental Methodology

An analogy between heat and mass transfer is established as the governing equations and parameters are of the same type [6]. 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. A more detailed description can be found in the papers of Chung et al. [7-8].

4. Results and discussion

In Fig. 2, (a) presents Nu_L according to variation of Ra_L and (b) presents Nu_S according to variation of Ra_S *and* (c) presents Nu_H according to variation of Ra_H.

In Fig. 2(a), The experimental results for the flat plate are in good agreements on the correlation of Le Fevre for the vertical rectangular plate [3].

Through mathematical analysis of experimental results, it is found that the relation expression of convective heat transfer coefficient h and L.

$$h \propto L^{-0.25} \quad (2)$$

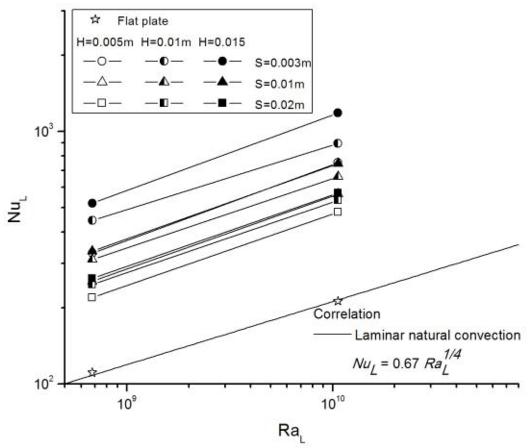
In Fig. 2(b), Nu_S increase with increasing H when L is fixed. And Nu_S decrease with increasing L when H is fixed. Through fitting analysis of experimental results on Fig. 2(b), it is found that the relation expression of convective heat transfer coefficient h and S.

$$h \propto S^{-0.4} \quad (3)$$

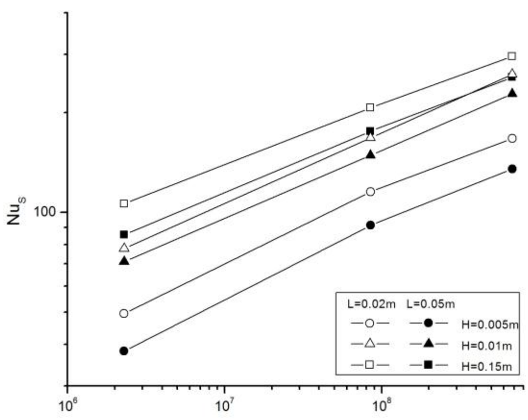
In Fig. 2(c), Nu_H increase with increasing S when L is fixed. And Nu_H decrease with increasing L when S is fixed. Through fitting analysis of experimental results on Fig. 2(c), it is found that the relation expression of convective heat transfer coefficient h and H.

$$h \propto H^{0.6} \quad (4)$$

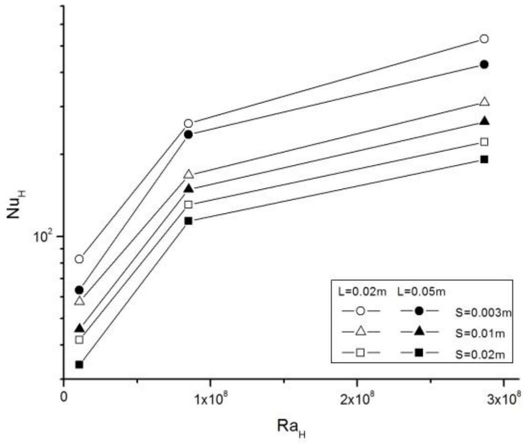
From the expression (2)-(4), it is concluded that a heat transfer in vertical rectangular fin is directly proportional to H, and is inversely proportional to S and L.



(a) Ra_L vs. Nu_L



(b) Ra_S vs. Nu_S



(c) Ra_H vs. Nu_H

Fig. 2 The comparison of the flat plate and the finned plate

5. Conclusions

The effects of geometric parameters on rectangular vertical fin were investigated experimentally.

Measured Nusselt numbers agree well with the existing laminar heat transfer correlation for the vertical plate developed by Le Fevre.

A heat transfer in vertical rectangular fin is directly proportional to fin height, it is inversely proportional to fin spacing and fin length.

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