Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Influence of Chimney Width in Natural Convection Heat Transfer on a Vertical Finned Plate

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1. Introduction

The Reactor Cavity Cooling System (RCCS) is installed the Very High Temperature Gas Reactor (VHTR) to remove the afterheat of the reactor and to protect the reactor pressure vessel from overheating at a Loss-Of-Coolant Accident (LOCA) or a heat rise accident.

The RCCS adopts the chimney system to increase the flow rate. Also the fins installed in the inner walls of the chimney will provide an additional cooling performance by increasing the heat transfer area. On the other hand, the fins also increase the friction loss i.e. the pressure drop. Thus, in order to improve the heat transfer performance of the RCCS, an optimization among the fin parameters is necessary.

Many experimental and numerical studies regarding the fin and the chimney are available [1~6]. However, there are little the studies on the natural convection heat transfer of the fin system located inside the chimney. Furthermore, due to the experimental difficulties, experimental studies for high Rayleigh number are very limited.

In this study, the natural convection heat transfer of the fin system located inside the chimney was measured. Based on the analogy concept, heat transfer experiments were replaced by mass transfer experiments using a sulfuric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system. The experiments were conducted by varying fin spacing, fin height, chimney width, and chimney height.

2. Previous studies

2.1 Fin geometry

Wooldridge and Welling [5] argued that the natural convection heat transfer in the vertical plate fins is affected by Rayleigh number (*Ra*), Base plate length (*L*), Fin thickness (*t*), Fin height (*H*), and Fin spacing (*S*), as shown in the Fig. 1.

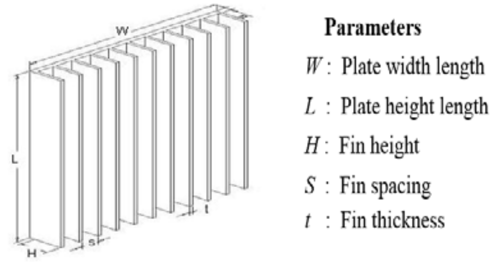


Fig. 1. The shape and parameters of rectangular plate fin.

2.2 Parametric influences

When *S* reduces to a certain extent, the number of fins increases and hence the heat transfer area increases resulting in the heat transfer enhancement. However, for a very small *S*, the heat transfer is impaired due to flow reduction by the increase of frictional loss [6, 7].

The increase of *H* results in the heat transfer enhancement by the increase of the heat transfer area [8] and by the chimney flow pattern, which induces the entrance of the fresh fluid from the front side of the fins.

Natural Convection heat transfer in the chimney is affected by the chimney height (H_{Duct}) and chimney width (W_{Duct}). Lim and Chung [9] studied experimentally the natural convection heat transfer on a vertical circular tube in the chimney. According to their study, the heat transfer rate of the vertical circular tube was increased with the increasing H_{Duct}, due to a chimney effect. The chimney effect is defined as increasing the acceleration section with H_{Duct} and increasing heat transfer rate.

Asako et al. [10] studied experimentally and numerically the effect of W_{Duct}. When W_{Duct} is small, the heat transfer rate is the highest. However with increasing W_{Duct}, the heat transfer rate is reduced, and then was equal to that without the chimney. According to Lim and Chung [9], the influence of the driving force by buoyancy at small W_{Duct} is larger than it at large W_{Duct}. That is, the chimney effect does not occur when W_{Duct} is larger than critical W_{Duct}.

2.3 Experimental Methodology

In order to achieve high Rayleigh number, mass transfer experiments were performed replacing heat transfer experiments based upon analogy [11]. A sulfuric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system was employed as the mass transfer system. A more detailed explanation of the methodology can be found in Chung et al. [12, 13].

3. Experiments

Figure 2 shows the system circuit. A duct and a connected heated section are immersed in a tank of top opened. The duct acts as the chimney and the fins are located in the inner wall of the heated section. The finned plate (Cathode) is the heated wall in the heat transfer system.

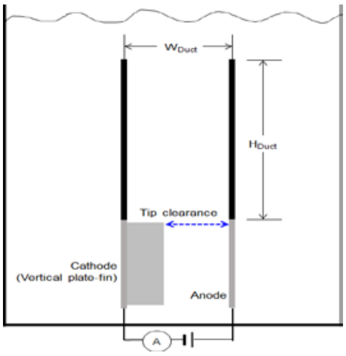


Fig. 2. The experimental apparatus.

The test matrix is shown in Table I. The Rayleigh number ranged from 2.3×10^6 to 6.8×10^8 and Prandtl number was 2,014. To confirm effect of the chimney, the experiments were conducted with and without the duct. The duct height (H_{Duct}) and duct width (W_{Duct}) were 0.6~0.86 m and 0.01~0.06 m, respectively.

Table I: Test matrix.

<table>
<tr><th>H(m)</th><th>S(m)</th><th>Ra_S</th><th>H_{Duct} (m)</th><th>W_{Duct} (m)</th></tr>
<tr><td rowspan="3">0.005,
0.01</td><td>0.002</td><td>6.79×10^5</td><td rowspan="3">0(open),
0.06,
0.46,
0.86</td><td rowspan="3">0(open),
0.010,
0.015,
0.020,
0.040,
0.060</td></tr>
<tr><td>0.003</td><td>2.3×10^6</td></tr>
<tr><td>0.007</td><td>6.79×10^8</td></tr>
</table>

Fixed W=0.05m, L=0.05m, t=0.003m

4. Results and discussion

Figure 3 compares the current experimental results with the existing heat transfer correlations developed for open channel natural convection heat transfer of the vertical finned plates.

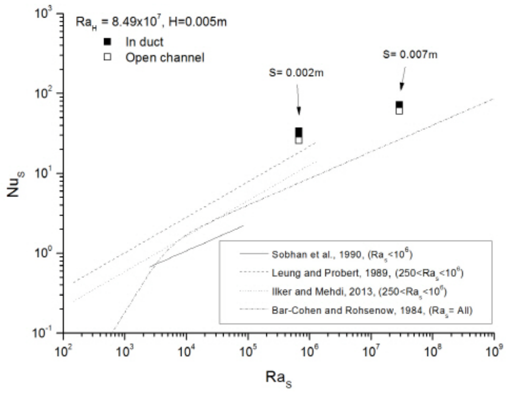
The Nu_S of the finned plate with the duct is slightly higher than that without duct. The duct enhances the heat transfer only slightly. This is because the flow is driven by the buoyancy of the heated fluid near the fin surface. The duct influence becomes important in force convection conditions.

The Nu_S of current results differed from the existing heat transfer correlations, but showed almost similar trend. It may be explained by the large *Pr* value of this experiment. The thermal boundary layer is very narrow for high *Pr* fluid and thus the interference between boundary layers developed from the base plate and fins is limited, and the negative heat transfer of the fin decreases.

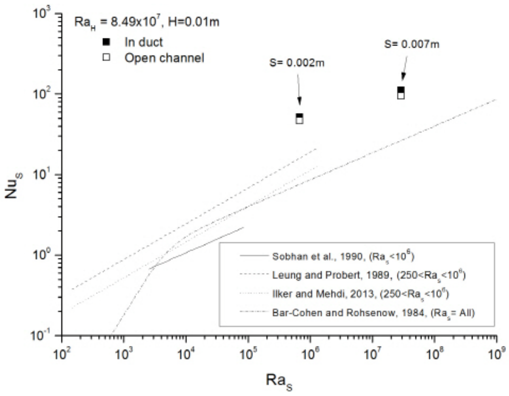
Figure 4 shows the measured Nu_S's for two different *S*, *H* and three different duct heights, H_{Duct} and varying the tip clearance, *TC*. The known heat transfer enhancements due to the decrease of *S* and the increase of *H*, appear for the same H_{Duct} [7-9].

There are the critical values of *TC/H*, within which the Nu_S's are influenced: For *S* of 0.002m, *TC/H* is 7 and for *S* of 0.007m, *TC/H* is 3.

Within the critical values of the *TC/H*, the Nu_S's improved by increase of H_{Duct}, as the increase of H_{Duct} makes the chimney effect stronger. For larger *TC/H* than the critical values, the Nu_S is constant with the *TC/H*, since a fluid generated by the heated fins does not flow through the top section of the duct, and will be circulated within the duct. In other words, the duct will be not perform the function of the chimney. According to Lim and Chung [9], the driving force of heated fin is reduced with increase of W_{Duct}, and chimney effect is not generated from the W_{Duct} that is larger than a specific W_{Duct}.

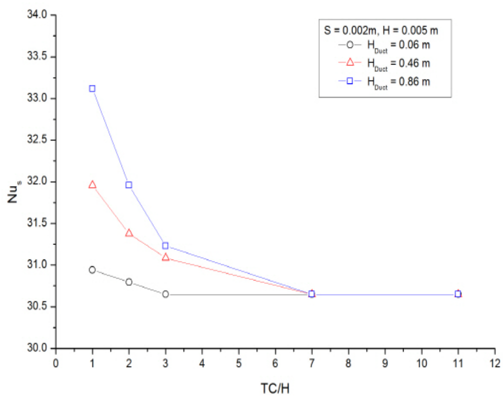


(a) *H*=0.005m

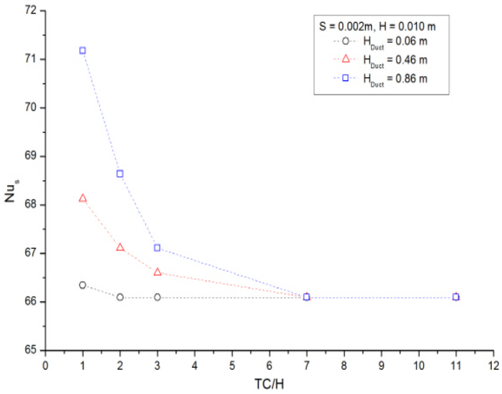


(b) *H*=0.010m

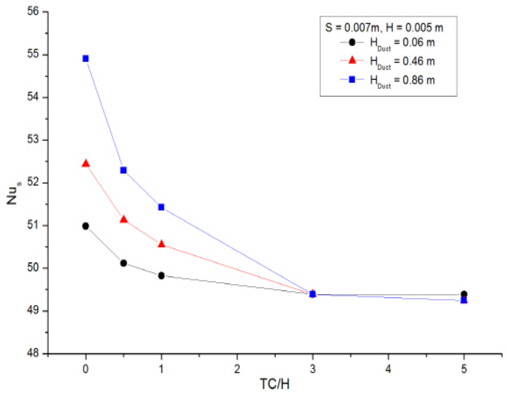
Fig. 3. Nu_S according to Ra_S on vertical plate-fin.



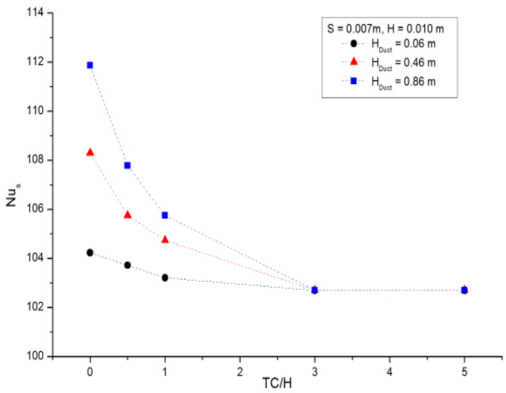
(a) *S*=0.002m, *H*=0.005m



(b) *S*=0.002m, *H*=0.010m



(c) *S*=0.007m, *H*=0.005m



(d) *S*=0.007m, *H*=0.010m

Fig. 4. Nu_S according to *TC/H.*

5. Conclusions

This study experimentally investigated the natural convection heat transfer of the vertical finned plate in the chimney. Using an analogy, the heat transfer systems were replaced by mass transfer systems.

The measured mass transfer coefficients was the difference with the existing heat transfer correlations due to the large value of the *Pr*, but exhibited similar trends with the existing heat transfer correlations.

The heat transfer rate is increased by the decrease of the fin spacing and the increased fin height due to increased heat transfer area and chimney flow pattern. The chimney effect enhances heat transfer rate of vertical finned plate and the chimney effect on the Nu_s was stronger for the narrow chimney width, and became stronger by the higher chimney. The chimney effect was not observed when the chimney width becomes larger than a certain value depending on the *S*.

In this study, the heat transfer rate on vertical finned plate in the chimney was confirmed by experiment for high values of Ra_S. This work has the relevance with the RCCS performance enhancement activities.

REFERENCES

[1] S. E. Haaland and E. M. Sparrow, Solutions for the channel plume and the parallel-walled chimney, Numerical Heat Transfer, Vol. 6, pp. 155-172, 1983.
[2] T. S. Fisher and K. E. Torrance, Experiments on chimney enhanced free convection, Journal of Heat Transfer, Vol. 121, pp. 603-609, 1999.
[3] K. E. Starner and H. N. Mcmanus, An Experimental Investigaion of Free Convection Heat Transfer from Rectangular Fin Arrays, J. Heat Transfer, Vol. 85, pp. 273-278, 1963.
[4] C. B. Sobhan, S. P. Venkateshan, and K. N. Seetharamu, Experimental studies on steady free convection heat transfer from fins and fin arrays, Heat and Mass Transfer, Vol. 25, pp. 345-352, 1990.
[5] J.R. Welling, C.B. Wooldridge, Free convection heat transfer coefficients from rectangular vertical fins, Journal of Heat Transfer, Vol. 87, pp. 439-444, 1965.
[6] C.W. Leung and S.D. Probert, Heat-Exchanger Performance: Effect of Orientation, Applied Energy, Vol. 33, pp. 235-252, 1989.
[7] B. Yazicioglu and H. Yuncu, A Correlation for Optimum Fin Spacing of Vertically-Based Rectangular Fin Arrays Subjected to Natural Convection Heat Transfer, Journal of Thermal Science and Technology, Vol. 29, pp. 99-105, 2009.
[8] Ilker Tari and Mehdi Mehrtash, Natural convection heat transfer from inclined plate-fin heat sinks, International Journal of Heat and Mass Transfer, Vol. 56, pp. 574-593, 2013.
[9] C.K. Lim and B.J. Chung, Influence of the Entrance and Exit Lengths on the Natural Convection Heat Transfer of a Cylinder in a Duct, Journal of Energy Engineering, Volume 21, pp.18-25. 2012.
[10] Y. Asako, H. Nakamura, and M. Faghri, Natural convection in a vertical heated tube attached to a thermally insulated chimney of a different diameter, Trans. ASME, Vol. 112, pp. 790-793, 1990.
[11] E.J. Fenech and C.W. Tobias, Mass transfer by free convection at horizontal electrodes, Electrochimica Acta, Vol. 2, pp. 311-325, 1960.
[12] S.H. Ko, D.W. Moon, B.J. Chung, Applications of electroplating method for heat transfer studies using analogy concept, Nuclear Engineering and Technology, Vol. 38, pp. 251-258, 2006.
[13] B.J. Ko, W.J. Lee, B.J. Chung, Turbulent mixed convection heat transfer experiments in a vertical cylinder using analogy concept, Nucl. Eng. Des., Vol. 240, pp. 3967-3973, 2010.