Influence of the Chimney Dimensions on the Heat Transfer of a Vertical Cylinder in a Duct

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1. Introduction

A thermally insulated chimney attached to a vertical heated section induces an increase in the natural convection flow in the heated vertical cylinder and leads to a higher heat transfer rate. The flows in the chimney are originally driven by the natural convection. However its behavior is similar to the forced convective flows as the heated vertical cylinder is located in a duct or chimney and then the mass flow rate at every elevation should be the same. Heat transfer in the chimney depends on the dimensionless geometrical parameters (Fig. 1), such as the extension ratio (the total length of chimney system, L_t, over the heated section length, L_h), the expansion ratio (the diameter of chimney, D_t, over the diameter of heated vertical cylinder, D_h), the aspect ratio of cylinder (the length of cylinder, L_h, over the diameter of cylinder, D_h), and the location of cylinder in a duct (the top or bottom of chimney).

Although some works [1-3] have been done on the heat transfer in the chimney, arrangements detailed experimental investigations on the determination of the optimal location of the heated cylinder in the chimney are rare. And previous studies have been performed for extension ratio 1.0-5.0.

This work investigated the influence on the chimney dimensions (entrance and exit length, and diameter) on the heat transfer of a vertical cylinder in a duct. The measured mass transfer rates for the natural convection of vertical cylinder in a duct were presented for Prandlt number 2,094, Rayleigh number 4.55×10^9, 5.79×10^{10}, and 1.69×10^{11}. Experiments were performed using a copper sulfate electroplating system to simulate heat transfer based upon the analogy concept.

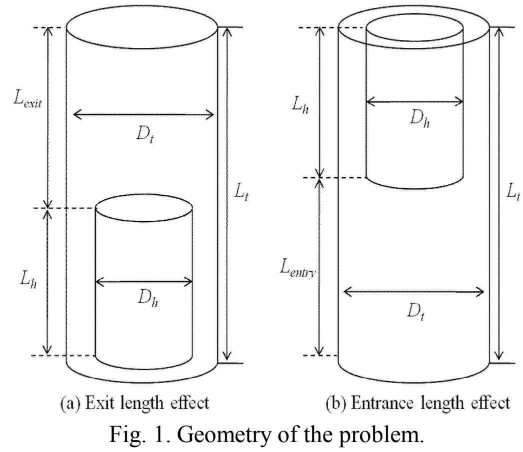

Fig. 1. Geometry of the problem.

2. Previous study

Kazansky et al. [1] studied using air natural convection heat transfer from a vertical electrically heated plate, placed in a chimney of variable height both experimentally and numerically using air. They showed the flow visualization and reported that an enhancement of the air flow rate up to 10 times was achieved than an open channel. Auletta and Manca [2] carried out an experimental study on a channel-chimney system in order to elucidate the behavior of heat transfer and fluid flow. The results are presented in terms of local air temperature measurements. Inflows of air are detected in the lower extension ratio, particularly structure for an expansion ratio greater than one close to the corner regions in the chimney. Campo et al. [3] investigated the effects of the unheated entry or unheated exit section on the natural convection heat transfer in air flow in vertical parallel plate channels resulting from the thermal boundary conditions of uniform heat flux and uniform wall temperature. They reported that due to the chimney effect, the system with an unheated exit draws a higher volume rate and causes a higher heat transfer coefficient.

3. Experiments

3.1 Experimental Methodology

Heat and mass transfer are analogous when the boundary and initial conditions are of the same type [4]. In the present work, measurements were made using limiting current technique with a cupric acid-copper sulfate (H_2SO4-$CuSO_4$) electroplating system. Chung et al. [5-6] applied the methodology to typical natural- and forced-convection heat transfer problems and verified that it could predict the known heat transfer correlations. A more detailed description can be found in [5].

Table 1: Test matrix.

Ra_L	Geometry	Height of duct [m, D=0.06]	Diameter of duct [m, H=0.50]
4.55×10^9, 5.79×10^{10}, 1.69×10^{11}	Bare cathode	0	0
	Ducted cathode	0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00, 1.10	0.06, 0.08, 0.10, 0.12, 0.14

3.2 Apparatus and Test Matrix

Test apparatus is the cathode located in a duct, which is submerged in a solution tank made of acryl with the top open. The diameter of the duct was varied from 0.06m to 0.14m, and the heights from 0.30m to 1.10m.

The diameter of the cylinder was 0.054*m*, and the heights were 0.03*m*, 0.07m, and 0.10*m*. Table 1 is the test matrix and the geometries.

$$Nu_L = 0.67(Gr_L \,\mathrm{Pr})^{0.25}\, at Gr < 10^9 \qquad (1)$$

4. Results and discussion

Fig. 2 and 3 present the test results obtained for various exit and entrance lengths using the 0.03, 0.07, and 0.10m high cathode cylinders. The measured Nusselt number for the open channel was compared with the heat transfer correlation of Le Fevre [7] and was in good agreement.

The extended exit length enhanced the heat transfer up to a certain length due to the extended buoyant acceleration inside the duct. But further extension does not vary the heat transfer because of a cold down-flow from the outlet section of the duct and homogenization of the temperature profile along the flow direction. On the other hand, the extension of the entrance length reduced the heat transfer up to a certain length due to the increase of the amount of fluid driven by the heat source and further extension does not affect the heat transfer due to a cold up-flow from the inlet section of the duct.

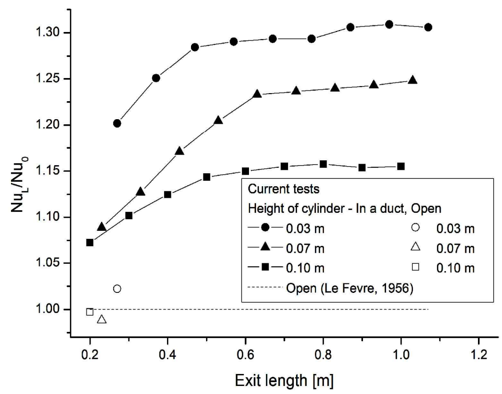

Fig. 2. The effects of exit length.

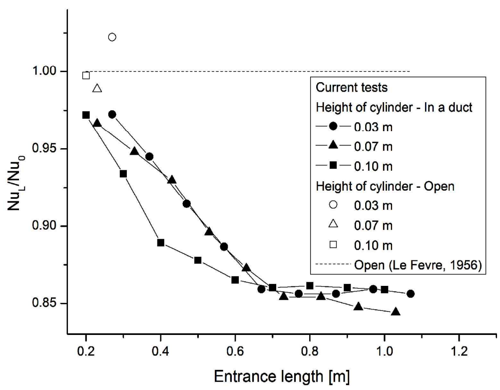

Fig. 3. The effects of entrance length.

Fig. 4 presents the test for the fixed diameter of the cylinder by varying the diameter of duct. The Nusselt number decreases with increasing the diameter of duct, and then beyond a certain diameter becomes similar to that at open channel.

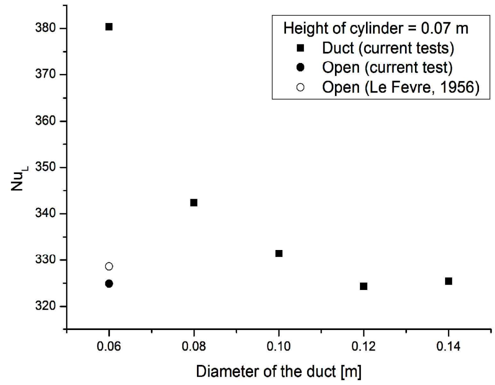

Fig. 4. The effect of varied diameter of duct.

5. Conclusions

The influence of the chimney dimensions on the heat transfer of a vertical cylinder in a duct was investigated experimentally. Nusselt numbers measured at open channel condition agreed well with the existing laminar heat transfer correlation for vertical plate developed by Le Fevre. The increase of the exit length enhanced the heat transfer for a while and then further increase does not affects the heat transfer. The increase of the entrance length impaired the heat transfer for a while and then further increase does not affects the heat transfer. Thus it is concluded that there are certain limiting entrance and exit lengths that affect the heat transfer. The Nusselt number decreased with increasing the diameter of duct, until Nusselt number becomes similar to that at open channel beyond a certain diameter.

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