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Influence of the Exit Length and Geometry of the Chimney on the Heat Transfer

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1. Introduction

A chimney is frequently used to enhance the natural convection heat transfer in many practical applications such as the natural draft device, heat exchangers and passive safety system. It provides effective and stable means of the heat removal as thermally insulated chimney induces an increase in the natural convective flow in the heated vertical cylinder and leads to a higher heat transfer rate.

The natural convection heat transfer inside a duct becomes very complex due to the interactions between the flows along the heated wall and unheated surface of the chimney (Fig.1).

This work investigated the influence on the exit length and the geometry of a duct on the heat transfer of a vertical cylinder in the duct. Two different types of duct geometries (circular and square) were used. Heights of the duct and the heights of the cylinder inside the duct were varied. Experiments were performed using a copper sulfate electroplating system to simulate heat transfer based upon the analogy concept.

2. Previous studies

Haaland and Sparrow [1] accomplished a numerical study for natural convective flow in a vertical channel with a point heat source (channel plume problem) or distributed heat sources situated at the channel inlet (chimney problem) and showed that a higher flow rate of fluid through a confined open-ended enclosure can be induced by the chimney. Campo et al. [2] investigated the effects of the unheated entry or unheated exit section on the natural convective 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 flow rate and causes a higher heat transfer coefficient. They found a reduction in the maximum wall temperature when an insulated extension was placed downstream of the heated part and that the larger the Rayleigh number, the less relevant the reduction. Andreozzi et al. [3] carried out a parametric analysis by means of a numerical simulation in a channel-chimney system symmetrically heated at uniform heat flux. They showed that an optimal configuration in terms of dimensionless geometric and thermal parameters which enhance the mass flow rate by chimney effect.

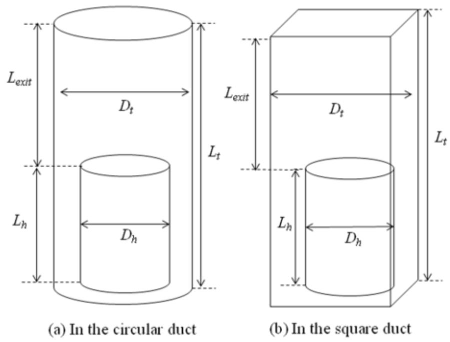

Fig. 1. Geometry of the problem.

3. Experiments

3.1 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 hydraulic diameters of the circular and square duct were all 0.06*m*, and the heights ranged from 0.30*m* to 1.10*m*. The diameter of the cylinder was 0.054*m*, and the heights were 0.03*m*, 0.07*m*, 0.10*m*, 0.15*m* and 0.20*m*. Table 1 is the test matrix.

Table 1: Test matrix.

Ra_L	Geometry	Height of duct [*m*] [Hydraulic diameter=0.06]
4.55×10^9, 5.79×10^{10}, 1.69×10^{11}, 5.69×10^{11}, 1.35×10^{12}	Bare cathode	0
	A circular duct	0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00, 1.10
	A square duct	

3.2 Experimental Methodology

An analogy of heat and mass transfer is established as the governing equations and parameters 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. A more detailed description can be found in [5-6].

4. Results and discussion

The measured Nusselt number for the open channel was in good agreement with the correlation of Le Fevre [7] (Eq. 1).

$$Nu_L=0.67(Gr_L Pr)^{0.25} \text{ at } Gr_L < 10^9 \quad (1)$$

Figs. 2 and 3 present the test results for various exit lengths and cathode heights in a circular and a square ducts respectively. The extended exit length enhanced the heat transfer due to the extended buoyant acceleration inside the duct. The heat transfer does not increase after a certain exit length except the 0.20*m* heated cylinder case. This may be explained by the homogenization of the temperature profile along the flow direction and a cold down-flow from the outlet section of the duct. It should be noticed that at 0.20*m* cylinder, no trend to the heat transfer up to a certain length by fully thermal developed flow is observed. Thus we may conclude that with a sufficient heat input, the heat transfer seems to increase proportional to the exit length.

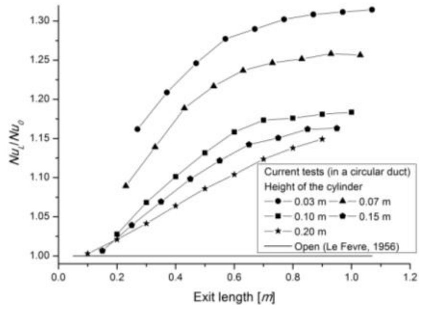

Fig. 2. The effects of exit length in a circular duct.

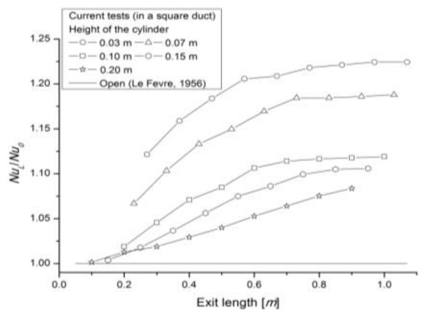

Fig. 3. The effects of exit length in a square duct.

The comparisons the circular and the square duct are shown in Fig. 4. The hydraulic diameter of both circular and square duct is same (0.06*m*). The circular ducts show higher heat transfer rates than the square ducts. This is explained by the difference in the cross-sectional areas. Even though the hydraulic diameters are the same, the area of non-circular duct is larger than the circular duct, which leads the decrease in the average velocity of the fluid. And the difference of Nusselt number between the circular and the square duct increases with the exit length. These trends become more obvious as the height of the heated cylinder is longer.

5. Conclusions

The influence of the exit length and geometry of the chimney on the heat transfer of a vertical cylinder in the duct was investigated experimentally. The Nusselt numbers measured at open channel condition agreed well with the existing laminar heat transfer correlation for vertical plate developed by Le Fevre [7].

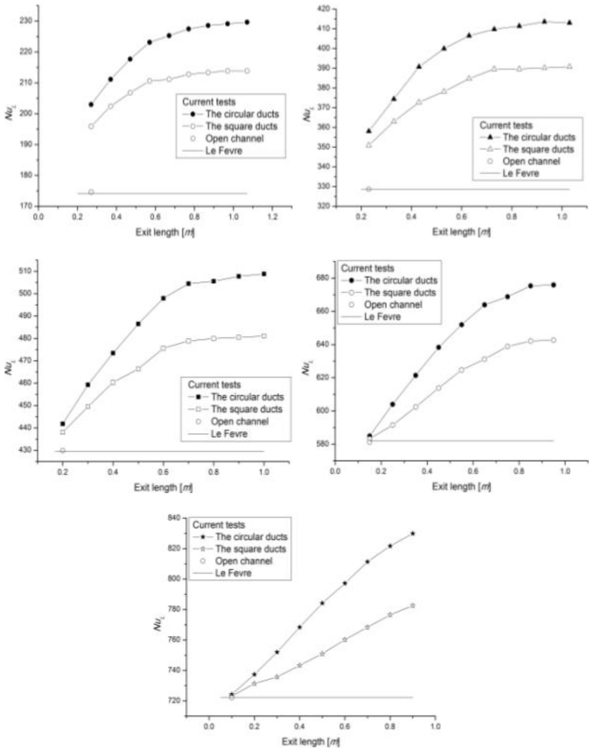

Fig. 4. Comparisons between circular and square ducts.

The heat transfer was enhanced proportional to the exit length up to a certain length and then further increase does not affect the heat transfer. However when the heat input increases, the effective length also increases. The Nusselt numbers in the circular duct were larger than those in the square duct as the cross-sectional area was smaller.

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