Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Numerical Investigation of the Heat Transfer of a Vertical Cylinder in a Chimney

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1. Introduction

The 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 heat removal.

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 and also due to the pressure loss along the chimney and the down-flow from the exit. Thus the heat transfer will be affected by the exit length.

The present work investigated the heat transfer and the flow behavior of a hot cylinder located at the inlet of a duct, varying the exit length using FLUENT 6.2. The height of the vertical cylinder was 0.069m and the diameter was 0.054m, which corresponded to Ra_H 5.55×10^{10}. The diameter of the duct was 0.06m and the height was varied from 0.069m to 2m.

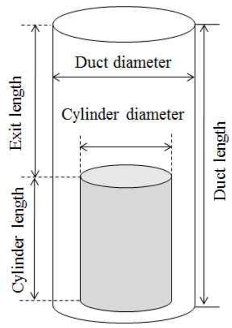

Fig. 1. Geometry of the problem.

2. Previous study

The phenomena and heat transfer correlations of natural convection on a vertical cylinder are well known. For the laminar natural convection, Bejan [1] performed the scale analysis theoretically from governing equations and proposed the relation between the variables. Eq. 1 is the laminar natural convection correlation developed on vertical plates proposed by Le Fevre [2].

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

The presence of a duct enhances the heat transfer, what is called a chimney effect [3]. The investigation on the chimney effect was firstly carried out by Haaland and Sparrow [4]. They performed numerical study for the heat transfer of a heat source located at the inlet of a vertical duct and revealed that even though the flows in a duct were driven by the natural convection, as the mass flow rates are always same at each elevation of the duct, the flows ascending from the bottom of the heated section showed the similar behaviors as the forced convection. The heat sources act as the thermal pump and the duct increase the heat transfer. Kazansky et al. [5] investigated the natural convection heat transfer of air on a vertical plate located in a chimney, varying the height of the duct experimentally and numerically. They presented the effect of chimney through the heat transfer rates, temperature and flow fields and visualized the flow pattern occurring in a duct. The results showed that the heated plates acted as pumping effect and mass flow rates increased with the duct height. And the presence of the duct enhanced the heat transfer rates about 10 times higher than those for an open channel.

3. Numerical Studies

The FLUENT 6.2 was used [6]. The GAMBIT mesh was used to generate the 2D model. The concentrated grids were given for the region close to the boundary layer of the cylinders, while coarse grids were given for the rest of the domain. Simulations were carried out using the Boussinesq approximation and the temperature of heated wall was kept at 400 K for a constant temperature condition. The segregated solver was used with a second order upwind algorithm for momentum, pressure and, energy in the laminar model, whereas the SIMPLE algorithm was used for pressure-velocity coupling discretization. The residual values of the momentum and energy were 10^{-6}. Table 1 presents the test matrix for FLUNET simulations.

Table I: Test matrix.

Ra_L	Geometry	L_t (m) [D_t=0.06m]
5.79×10^9	Both cathode	0
	Ducted cathode	0.073, 0.1, 0.15, 0.2, 0.25, 0.3, 0.5, 0.8, 1.1, 1.3, 1.5, 2

D=0.054m, H=0.06m

4. Results and discussion

Fig. 2 shows the calculated heat transfer rates for the different exit lengths of the duct. The closed circle presents Nu_H in a duct and the open circle Nu_H in the open channel and the open triangle represent the predictions from the heat transfer correlation by Le

Fevre [2]. The calculated result for an open channel cylinder shows satisfactory agreement with Le Fevre [2]. The Nu_H for the exit length of 0.073m is less than that for the open channel as the flows ascending on the side wall are interfered as the gap between the vertical cylinder and a duct is so narrow that the flows is unable to be fully developed. However, with increasing the exit length, the Nu_H increases and from about 0.6m the Nu_H becomes constant.

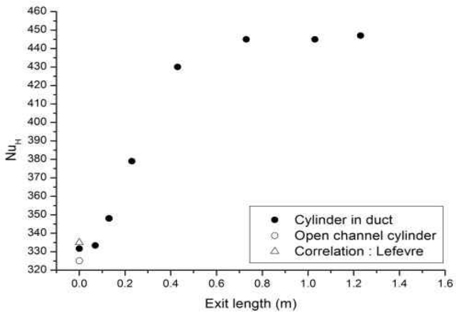

Fig. 2. Nu_H according to exit length.

Fig. 3 show the velocity profiles between the cylinder and the duct along the flow direction at each elevation. The heights of the ducts are 0.003m, 0.08m, 0.43 and 1.0m. In case of the exit length 0.003m and 0.08m, the velocity increases near the cylinder steeply and decreases gradually, which are the typical of the natural convection. Then, with increasing the exit length, the peak moves to the middle of the heated wall and the duct and the velocity profiles become similar to those for the forced convection inside a duct. Therefore, for 0~0.1m of the exit lengths, the velocity peaks appear near the heated wall and the flows seem to be natural convection dominant. However, for 0.1~0.8m of the exit lengths, the velocity peaks move to the center of the channel between heated wall and the duct and the flows seem to be forced convection dominant. And at this range the heat transfers are enhanced due to the duct. When the exit length exceeds 0.8m, the heat transfer rates no longer increases due to down-flow from the exit and homogenization of the temperature profile.

5. Conclusions

The effects of the exit lengths on the heat transfer of a vertical cylinder in a duct were investigated numerically. The calculated result for an open channel was in satisfactory agreement with the correlation developed for vertical plates. The presence of a short duct decreases the heat transfer rates of the vertical cylinder, but the increases of the exit length enhanced the heat transfer rates due to the extension of the region of buoyant acceleration. However, after a certain exit length, the increase of the exit length does not affect the heat transfer. This study has the relevance with the design of the test facility for PDRC (Passive Decay Heat Removal System) in SFR (Sodium-cooled Fast Reactor).

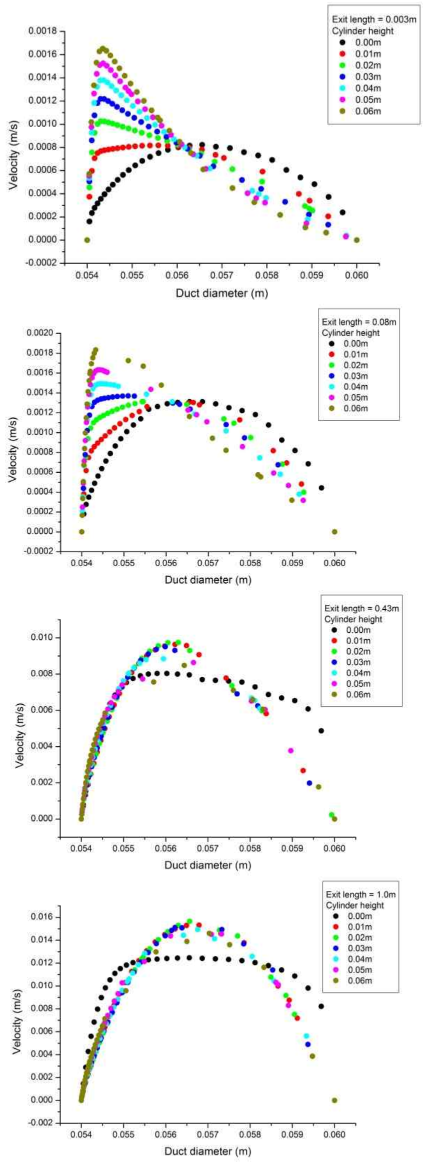

Fig. 3. Velocity of elevation by exit length.

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