Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Natural Convection Heat Transfer Experiments on an Inclined Helical Coil

Young-Chan Byun and Bum-Jin Chung
Department of Nuclear and Energy Engineering, Institute for Nuclear Science and Technology, Jeju National University #102 Jejudaehakno, Jeju, 690-756, Korea
[*]*Corresponding author*: *bjchung@jejunu.ac.kr*

1. Introduction

Research interests for the compact heat exchanger increase with growing needs on compact nuclear systems. Accordingly, the heat exchangers of helical coil types are adopted replacing the once-through type and the U-tube type ones. When the helical coil type heat exchangers are used for nuclear propulsions, the heat transfer of inclined helical coil becomes an important problem due to the shaking of the ship.

This study measured the natural convection heat transfer from the outside surface of the helical coil in a circular duct varying the coil inclination and turn number. It is also conducted using a circular duct having same height of the helical coil. Based upon the analogy concept, a mass transfer system was used instead of a heat transfer system. A cupric acid-copper sulfate electroplating system was employed as the mass transfer systems.

2. Previous studies

Sedahmed et al. [1] carried out natural convection mass transfer experiments on the outside of a helical coil in an open channel using a H_2SO_4–$CuSO_4$ solution. They suggested mass-transfer correlation (1) using the diameter, *D*, as the characteristic length.

$$Sh_D=0.55(Gr_DSc)^{0.25},\ 5.5\times10^5\le Ra_D\le 9.4\times10^8 \qquad (1)$$

Moawed [2] performed a similar experiments for Ra_D of 1.5×10^3~1.1×10^5. The heat transfer coefficient of the first turn of a helical coil was almost same as that of a single horizontal cylinder, but the heat transfer coefficient of the next turn was reduced by the effect of the plume that developed from below.

Natural convection of a helical coil in an open channel can be described in terms of a combination of two phenomena: natural convection on an inclined cylinder and the influence of the plume produced at the lower turns on the heat transfer of the upper turns. Lia and Tarasuk [3] reported that the heat transfer rate of an inclined cylinder is highest when the cylinder is horizontal, and decreases as the inclination from the horizontal increases. According to Moawed [2], the plume from the lower turns produces two effects on the heat transfer of the upper turns. The first is the preheating effect: the hot plume that develops at the lower turns degrades the heat transfer of the upper turns. The second is the forced convection effect: the plume provides an initial velocity and increases the intensity of the flow turbulence for the next turn, which could improve the heat transfer of the upper turns.

The literature on the heat transfer study on the helical coil inside a duct has not been found to the best of the authors' knowledge and it would be worse especially when it is inclined.

3. Experiments

3.1 Apparatus and Test Matrix

Test apparatus is consisted of a cathode (copper helical coil) and an anode (copper plate) in a tank of top opened, as shown in Fig. 1. The helical coil is connected by acryl gantries adjusting its inclination. Several ducts were used to match the heights of the helical coils.

Table 1 is the test matrix. Experiments were carried out for Ra_D=4.55×10^6 and *Pr*=2094 with varying the inclination of the helical coil and the number of turns with/without a duct. The pipe diameter D is 0.003m, the pitch of a helical coil P 0.03m and the radius R 0.025m.

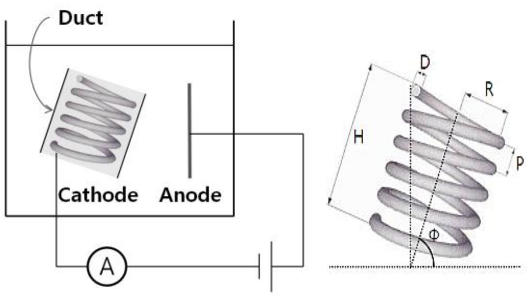

Fig. 1 The test apparatus.

Table I: Test matrix.

Ra_D	*Pr*	Inclination, *Φ*	Duct	Turn number, *N*
4.55×10^6	2094	0°(Horizontal), 15°, 30°, 45°, 60°, 75°, 90°(Vertical)	With or Without	1, 2, 4, 6, 8, 10

3.2 Experimental Methodology

Heat and mass transfer system are analogous as governing equations and parameters are mathematically the same class [4]. Thus, heat transfer experiments can be replaced by mass transfer experiments, and vice versa. In this study, the cupric acid-copper sulfate(H_2SO_4-$CuSO_4$) electroplating system was adopted for mass transfer system using a limiting current technique. Chung et al. [5] have conducted a series of tests on applications of analogy-based experimental methodology.

4. Results and discussion

Fig. 2 compares the present experimental datum with the correlation of Sedahmed [1] in the vertical coil, which shows good agreement.

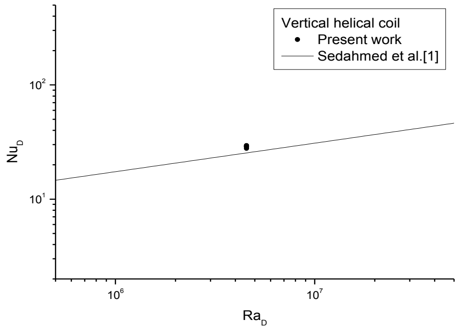

Fig. 2 Comparison with the existing correlation.

Fig. 3 shows the measured natural convection heat transfer rates in the open channel. They decreased as the inclination changed from vertical to horizontal and the slopes increase with turn number. The differences of Nu_D among the turn numbers were maximized at 45° and minimized at 0° and 90°. This can be explained by the effects of the plume generated from below. As the Φ decreases up to 45°, the misalignment between the direction of buoyancy and the coil increases and the effects of the generated plume at the lower turns to the upper turns are decreased. However further decrease in Φ leads the increased influence within the same turns.

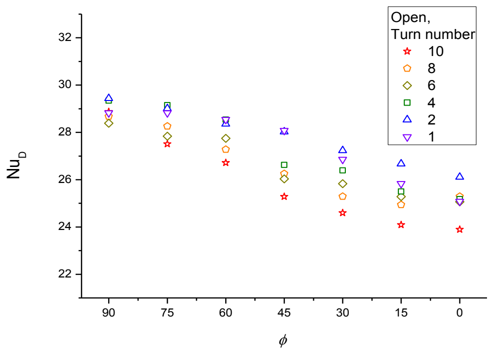

Fig. 3 Nu_D vs. Φ in open channel.

Fig. 4 shows the measured natural convection heat transfer rates in a duct. The heat transfer was enhanced when the inclination Φ is vertical and impaired when Φ is horizontal.

When the helical coil is located within a duct, hot plume can only escape through the open end. Thus the heat transfer decreases with the inclination, Φ decreases. The differences in heat transfer among the turn number is minimized at 45° and maximized at 0° and 90°.

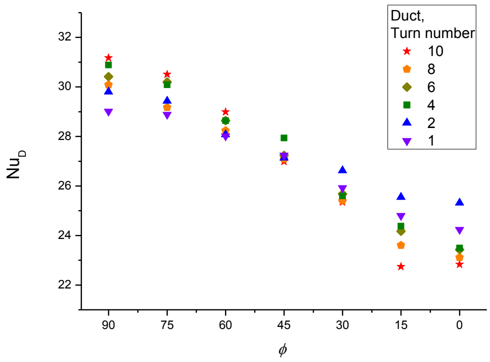

Fig. 4 Nu_D vs. Φ with a duct.

Fig. 5 compares the measured heat transfer rates with and without a duct. Both decrease with the decreasing inclination angle but the slope with a duct is steeper than without one.

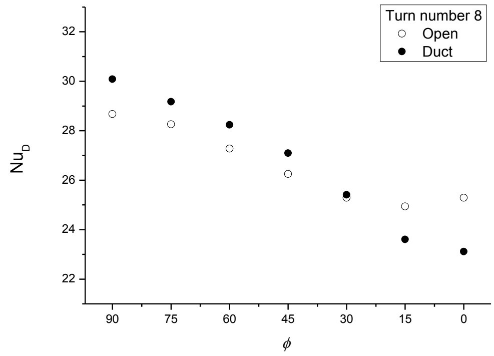

Fig. 5 Comparison of Nu_D with/without a duct.

5. Conclusions

The natural convection heat transfer of inclined helical coil with/without a duct was investigated experimentally. Nu_D decreased with the decreasing inclination. The heat transfer were enhanced with a duct at the vertical inclination and impaired at the horizontal inclination.

REFERENCES

[1] G.H. Sedahmed, L.W. Shemilt and Frank wong, "Natural convection mass transfer characteristics of rings and helical coils in relation to their use in electrochemical reactor design," Chemical Engineering Science, Vol. 40, pp. 1109-1114, 1985

[2] M. Moawed, "Experimental investigation of natural convection from vertical and horizontal helicoidal pipes in HVAC applications," Energy Conversion and Management, Vol. 46, pp. 2996-3013, 2005

[3] J. Lia and J.D. Tarasuk, "Local free convection around inclined cylinders in air: An interferometric study," Experimental Thermal and Fluid Science 5, 235-242, 1992

[4] A. Bejan, "Convective Heat Transfer," third ed., Wiley, New York, pp.186-528, 2003

[5] 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