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Experiments for the Scaling Analysis of AHX

Jeong-Hwan Heo and Bum-Jin Chung *
Department of Nuclear and Energy Engineering, Jeju National University,
66 Jejudaehakno, Jeju, 690-756, Korea.
**Corresponding author: bjchung@jejunu.ac.kr*

1. Introduction

The SFR (Sodium-cooled Fast Reactor) is under development with a goal to improve fuel efficiency and safety. It adopts the PDRC (Passive Decay Heat Removal Circuit) as the safety feature, which is one of the essential characteristic design concepts of the SFR. The AHX (Air Heat Exchanger) is a part of the PDRC. The AHX is composed of helical tube banks inside a stack. The hot sodium flows down inside the helical tubes and cold air cools the outside of the helical tubes. The natural convective air flow driven by the heat transfer from the helical tube interacts with the stack and results in a complex phenomenological behavior. The heat removal capacity of the AHX is to be proven by experimental means in order to get the Design Certificate from the regulatory body. The present work is to discuss the experiments required for the scale analysis of the AHX for deriving the preliminary parameters.

2. Theoretical Background

2.1 Natural convection in AHX

Fig. 1 shows the prototype of the AHX. It is composed of helical-shape tubes of about 25. The AHX have the hot sodium flow down inside the helical tubes within the stack and the heat removal is accomplished by the natural convection of air outside the helical tube bank.

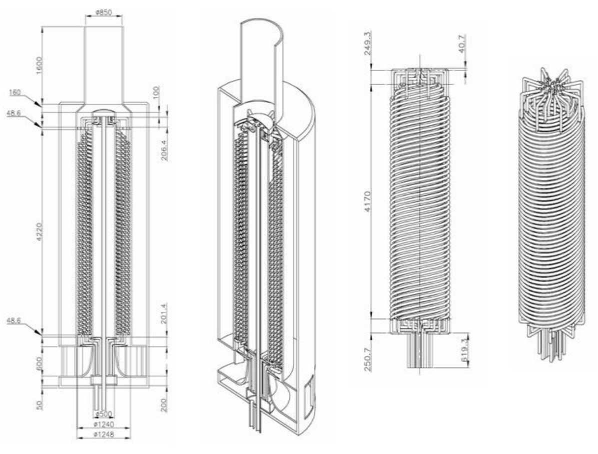

Fig. 1. Prototype of AHX

The air flow inside the stack is resulted from the natural convection but it is basically a duct flow. Thus the air mass flow rates in any position within the stack should be same in spite of the difference in buoyancy. The air flow near inlet has insufficient buoyancy forces due to low temperature but is affected by downstream flow, which results in the velocity increase. In the other hand, the air near the outlet is affected by the upstream flow and results in the velocity decrease. Thus the natural convection in helical tube is a duct flow and is expected to be the complex flow patterns of the mixed convection type neither the pure natural convection nor the pure forced convection.

Another parameter is the height of the stack. It is expected that the chimney effect occurs due to the pressure difference resulted from the height difference of both the inlet and outlet of the stack. When the air flow is across the tube bank, the flow separation point will vary depending on the flows and also, the heat transfer is expected to change. In addition, for cases that the tube bank is positioned parallel and slightly different to the flows, the phenomenological differences are expected. The temperature rise in air when passing through the stack, results in the variable property effect.

In order to maintain the phenomenological similarity, the Grashof number is expected to be the scaling parameter. However the characteristic length for the Grashof number is not clear: the total length of helical tube (L), heated height (H), tube diameter (D) and tube pitch (P). The difficult situations are encountered in considering the effect of curvature and tube bank, as well.

2.2 Previous study of helical tube

Ali [1] obtained average outside heat transfer coefficients for turbulent heat transfer from vertical helical tubes submersed in water using L and H as the characteristic length. He suggested that increasing the tube diameter for the same Ra (Rayleigh number) and tube length will enhance the outer heat transfer coefficients. Xin and Ebadian [2] used three different helical tubes to determine the outside heat transfer coefficients for natural convection. The tubes were oriented both vertically and horizontally. The Nusselt number as a function of the Rayleigh number was based on the outer diameter of the tube. The correlations of Xin and Ebadian [2] show that the average heat transfer coefficient of the vertical tube was about 10% higher than for the horizontal tube in the laminar flow regime.

3. Experiment method

3.1 Analogy

The values of the High Rayleigh and Grashof number are to be achieved to investigate the natural convection from the AHX tests, which strongly depend upon the facility heights. This study used the analogy concept in order to avoid tall and costly experimental facilities. Using the analogy concept, the heat transfer system can be simulated by the relevant mass transfer system, which could achieve large values of Rayleigh and Grashof number with reasonable test facility heights [3]. With the use of the mass transfer system, the Sherwood number and the Schmidt number replace the Nusselt and Prandtl number, respectively [4].

3.2 Scale analysis of test facility

The temperature of the outside air entering the AHX is about 40℃ and that of heat sources is about 360℃. Therefore, temperature differences between them are about 300℃. Using the properties of the air, Rayleigh and Grashof number by determining all the lengths given in Table I could be calculated.

Table I: Problem Description

*	Ra_*	Gr_*
H	1.1×10^{11}	7.8×10^{10}
D	1.7×10^{5}	1.2×10^{5}
R	9.8×10^{8}	6.9×10^{8}
L	1.7×10^{13}	1.2×10^{13}

Test apparatus is similar to the prototype in Fig. 1 and one of the helical tubes is considered only. Fig. 2 shows the test apparatus and consists of two types. One is only helical tube without the duct and another is considered with the duct.

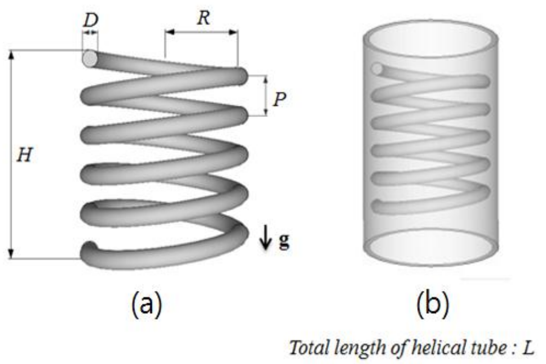

Fig. 2. Test model of helical tube

The properties used in mass transfer experiments used the relation equations suggested by Fenech and Tobias [5]. Using the properties and non-dimensional number of the prototype, the required H, D, R and L can be calculated. The experiments will be performed by varying the magnitude of Grashof number in Table IV under the laminar and turbulent flows. The size of cylindrical cavity for chimney effect is that the height is 80cm and the radius is 6cm.

Table II: Problem Description

*	Prototype		Model (cm)	
	Gr_*	Length (cm)	Resultant value	Ratio of resultant value to prototype
H	7.8×10^{10}	422	99.04	D=1.14 R=10.21 L=532.77
D	1.2×10^{5}	4.9	1.14	H=99.04 R=10.21 L=532.77
R	6.9×10^{8}	43.5	10.21	H=99.04 D=1.14 L=532.77
L	1.2×10^{13}	2270	532.77	H=99.04 D=1.14 R=10.21

4. Conclusions

This study suggests the experimental works for the scale analysis of the AHX. The test matrix is presented in Table II. In order to maintain the phenomenological similarity, the Grashof number is expected for the scaling parameter and the length scale will be one of or the combination of the L, D, R and P. The results of the scaling analysis in mass transfer experiments is expected to suggested the non-dimensional number such as Gr_H, Gr_D, Gr_R, and Gr_L. The study on determination of the scaling parameter in not huge scale, but in-depth phenomenological results can be obtained. The scaling parameter obtained from these results will be used for the development of the AHX test facility.

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