Parametric study for suppressing the flow instability phenomenon under two-phase natural circulation flow

Sun Taek Lim [a], Koung Moon Kim [a], Dong-Wook Jerng [b], Ho Seon Ahn [a*]
[a]*Department of Mechanical Engineering, Incheon National University, Incheon, Republic of Korea*
[b]*School of Energy System Engineering, Chung-Ang University, Seoul, Republic of Korea*
[*]*Corresponding author: hsahn@inu.ac.kr*

1. Introduction

Early, natural circulation heat transfer system using two-phase flow was focused by many researchers because of its advantage like simple geometry or don't need electrical power for operating at the area of nuclear power plant (NPP) [1,2], thermosyphon reboiler [3]. Most of previous investigations which are belong to the NPP were focused on boiling water reactor (BWR) as an application [4], however, recently, through more and more advanced systems like passive cooling system (PCS), small modular reactor (SMR) adopts two-phase natural circulation phenomena as driving mechanism, the diverse research of two-phase natural circulation phenomenon is conducted [5,6].

One of the most important things of investigating the two-phase natural circulation phenomenon define the flow instability criteria. Because the flow instability can threat the system integrity by pre-matured critical heat flux (CHF) or vibration, many researchers' have effort to suggest the method to reduce flow instability phenomena through experimental or system geometrical condition. However, because of the complex mechanism of flow instability, the two-phase flow instability under forced and natural circulation condition has been reviewed until now and classified various type of instability [7,8]. In addition, even though the real concept of system has multi channels most of previous experimental literatures was conducted by using single channel. In this connection, we investigated the two-phase natural circulation phenomenon using multi-channel test sections similar to real concept of systems.

In this study, we design the experimental facility which has multi channels as test section and analyze the basic phenomenon of two-phase natural circulation through experimental factors. Applied heat to test section, pitch to diameter (P/D) between test section and upper plenum volume are set as experimental factors. As a result, we suggest the optimized design to reduce the flow instability phenomenon.

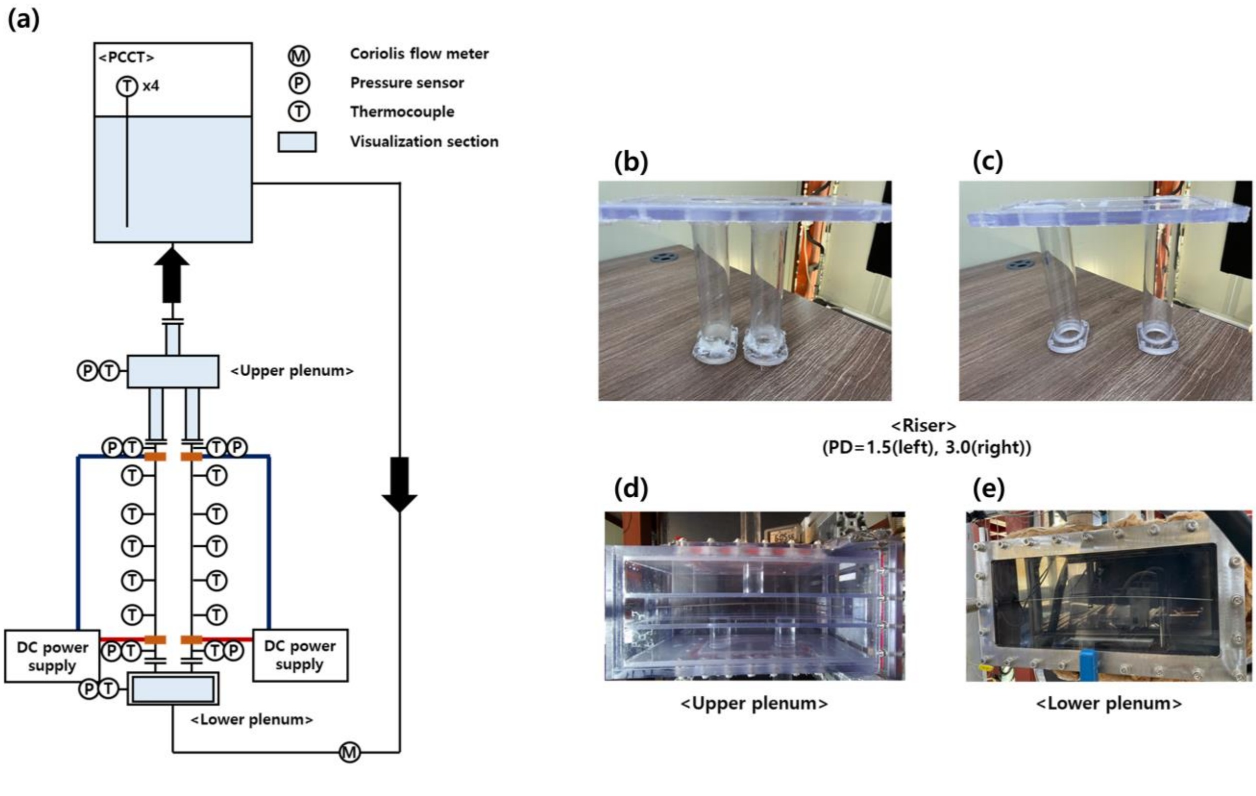

Fig. 1 Schematic of experimental facility (a) and appearance of parts ((b)-(c): riser, (d): upper plenum, (e): lower plenum)

2. Experimental facility

The experimental facility is designed to simulate a two-phase natural circulation phenomenon that acts as the PCCS as can be shown in the Fig. 1. Fig. 1 (a) present overall schematic of the experimental facility. The total height of the facility, which is consisted with a PCCT, two-test sections, lower plenum, upper plenum and connecting line, is 5.9m and the deionized water is used as working fluid. The working fluid is filled the facility up to 5.1m height and flow through the PCCT, downcomer, lower plenum, test sections, upper plenum, riser and PCCT. The two test sections are made of stainless steel with 38.6mm of inner diameter and directly heated by DC power supply. Height of the test sections are 2.35m and totally twenty thermocouples are installed with 0.45m interval to measure surface and fluid temperature. Before/after of copper clamp of the DC power supply, the thermocouple and pressure sensor are installed to measure fluid temperature and pressure as data of inlet/outlet of test section. As can be shown Fig. 1 (b)-(d), the riser and upper plenum are made by polycarbonate (PC) to visualize two-phase flow. Inner diameter of the riser is 35mm similar with test section and change the riser according to the test cases. In addition, even though only single-phase flow exists in the lower plenum, it has window at the front and back to see reverse flow from the test sections as shown in Fig. 1 (e). The volume of the upper plenum is controlled by PC box as can be shown in Fig.2.

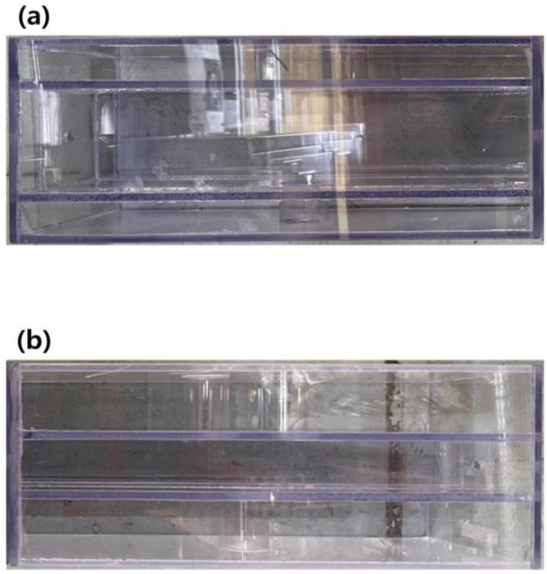

Fig. 2 Appearance of the PC box ((a): 2D, (b): 1D)

The volume of the upper plenum is designed as refer to inner diameter of the test section. If hydraulic diameter of the side area of the upper plenum is bigger 4-time than inner diameter of the test section, it called as 4D. So, we controlled the upper plenum volume as the ratio of hydraulic diameter of the side area of the upper plenum and diameter of the test section. The maximum value is 4D and minimum value is 1D. The Fig.2 (a) and (b) represent the 2D and 1D case each other. Other components are made by stainless steel and the connection line have 42.6mm of inner diameter. The mass flow rate is measured by coriolis flow meter before the lower plenum. All measured data are recorded by data acquisition system (34980A, Keysight) at intervals of 0.5s.

3. Results and discussion

As mentioned above section, the experimental factors are set as heat, PD, upper plenum volume. From 4.3 to 29.8kW/m^2 heat flux is applied to each test sections. In addition to, the range of the PD and upper plenum volume is 1.5 to 3.0 and 1D to 4D. Table. 1 shows the experimental cases according to experimental factors.

Experimental factor	**Range**
Heat flux	4.3, 7.2, 12.4, 16.5, 24.4, 29.8 kW/m^2
Pitch to diameter	1.5, 2, 3
Upper plenum volume	1, 2, 4D

Table. 1 Experimental factor

2.1 Effect of heat flux

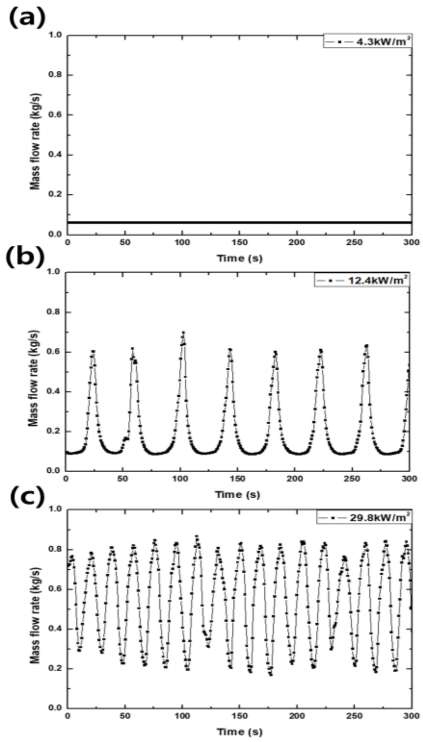

Fig. 3 Mass flow rate tendency according to heat flux

Fig.3 represent the mass flow rate tendency for 300-seconds according to heat flux value ((a): 4.3kW/m^2, (b):12.4kW/m^2, (c): 29.8kW/m^2) with 4D of upper plenum volume and 1.5 of PD. At the 4.3kw/m^2 case, only single-phase natural circulation was induced, so, the flow instability phenomenon is not occurred. As applied heat flux is increased, two-phase flow was induced, consequently flow instability phenomenon was occurred like Fig. 3 (b) and (c). At the 12.4kW/m^2 case, instability was occurred regularly with approximately 50 second of period. In addition, incubation period exists for occurring instability. On the other hand, at the 29.8kW/m^2 case, more intensive flow instability was occurred. Although it is also looks like regular shape, some irregular points exist compare with 12.4kW/m^2 case and there is no incubation period. It means that the mechanisms causing instability in the two experimental conditions are different. However, because define the type of flow instability is out of scope of this paper, not mention here. As a result, more heat flux is applied at the test section, more intensive flow instability is occurred.

2.2 Effect of pitch to diameter

It is difficult to define the effect of pitch to diameter at the flow instability phenomenon. Fig. 4 shows flow tendency according to pitch to diameter (from 1.5 to 3; Fig. 4 (a)-(c)) at 12. 4kW/m^2 of heat flux case.

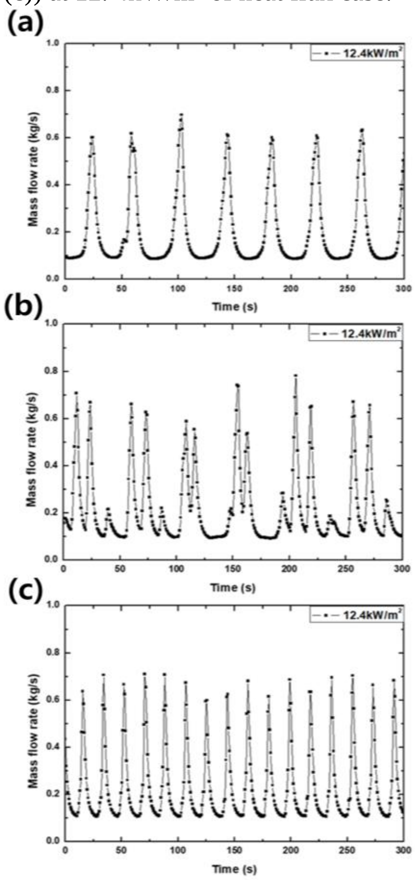

Fig. 4 Flow tendency according to pitch to diameter

As the pitch to diameter is increased, the flow instability which is occurred in the system shows more intensive pattern. However, except the pitch to diameter 1.5 case (Fig. 4 (a)), it is hard to define which flow tendency is more unstable. In bundle geometry system, there exist not only main flow from downcomer but also secondary flow between test sections. Therefore, it is not correct to judge the stability only refer to flow tendency of main flow. So, we analyze stability of the secondary flow between test section using inlet temperature data. If the inlet temperature is increased, it means that the reverse flow is exist, so, can judge the secondary flow instability is intense. Fig. 5 represent the inlet temperature tendency according to pitch to diameter (from 1.5 to 3; Fig. 5 (a)-(c)) at 7.2kW/m^2 heat flux condition.

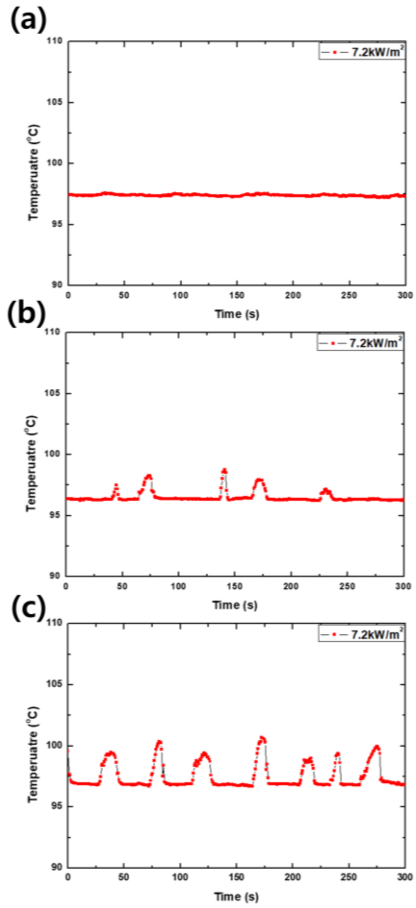

Fig. 5 Inlet temperature tendency according to pitch to diameter

At the pitch to diameter have 1.5 (Fig. 5 (a)), there is no reverse flow in the test section, however, as the pitch to diameter is increased, the reverse flow is induced. As can be shown in Fig. 5 (b) and (c), the reverse flow is occurred as pitch to diameter is increased, and show more intense tendency. Therefore, as the pitch to diameter is increased, the flow instability which is occurred between test section is enhanced. It is because that as pitch to diameter is increased the inertia force of two-phase flow from test section to PCCT is weakened, the reverse flow can be occurred easily.

2.3 Effect of upper plenum volume

Fig. 6 shows the effect of upper plenum volume ((a): 1D, (b): 2D, (c): 4D) with 7.2kW/m^2 heat flux and 3 of pitch to diameter condition.

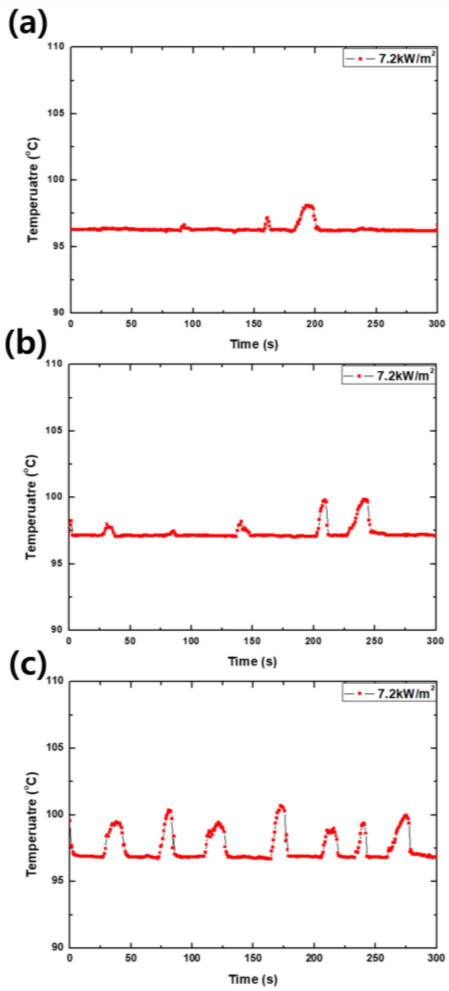

Fig. 6 Inlet temperature tendency according to upper plenum volume

The effect of upper plenum volume represents the similar result with the effect of the pitch to diameter. When the upper plenum has minimum value (Fig. 6 (a)), very small amount of reverse flow is occurred. However, as increased upper plenum volume (Fig. 6 (b)-(c)), the reverse flow is induced more frequently. Also, the reason that the reverse flow is enhanced as increasing upper plenum volume is similar with effect of the pitch to diameter. As upper plenum volume is increased, the inertia force of two-phase flow from test section to PCCT is weakened, so, reverse flow can be occurred easily.

3. Conclusions

The experimental facility which has two-test section as bundle system is designed to investigate two-phase natural circulation phenomenon. The heat flux applied to test section, pitch to diameter, upper plenum volume is set as experimental factor and investigate the method for reducing the flow instability phenomenon. As a result, as increasing heat flux the flow instability phenomenon is enhanced. However, it cannot easily define the stability using pitch to diameter and upper plenum volume because the instability phenomenon exists not only main flow from downcomer but also secondary flow between test section. So, the inlet temperature tendency is used as prove to define reverse flow which is a kind of instability phenomenon. Consequently, as increased pitch to diameter and upper plenum volume, the reverse flow is enhanced because inertia force of two-phase flow is weakened.

Acknowledgments

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