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Natural Circulation Flow with Inclined Downward Facing Heating Channel

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1. Introduction

Natural circulation flows are adapted in various engineering cooling channels in nuclear power plants such as IVR-ERVC(In-vessel retention through external reactor vessel cooling)[1] and ex-vessel molten corium cooling system[2]. And also the natural circulation flow loops usually have inclined downward facing heating channels. Under the IVE-ERVC condition, the boiling-induced natural circulation flow is generated in a coolant path between a hot hemispherical vessel wall and cold coolant reservoir [1]. The engineered corium cooling system of an ex-vessel core catcher under consideration is a passive system consisting of an inclined engineered cooling channel made of a single channel between the body of the core catcher and the inside wall of the reactor cavity [2]. Under severe accident conditions, water is supplied to the engineered cooling channel. The water in the inclined channel absorbs the decay heat transferred from the corium through the carbon steel structure of the core catcher body and boils off as steam.

In this paper, a small-scaled natural circulation flow experiments with the inclined heating channels are investigated.

2. Experimental method and results

An experimental facility with an inclined heating channel was designed and prepared to test a natural circulation loop as shown in Fig.1. A downward facing heating block, which was made by brass with 10 degree inclination, 0.5m horizontal length, and 0.2m width, can supply heat flux up to 500kW/m^2 to the flow channel. 14-thermocouple (K-type) is embedded in the heating block to measure the heating block temperature. The flow channel has a rectangular shape with 0.029m gap size and 0.2m width. The water tank is prepared to supply coolant with constant hydraulic head to the flow channel. The main tank is connected to the water tank using 1 inch circular pipe, therefore the natural circulation flow can be generated from the water inlet to the water outlet. The coolant temperatures though the natural circulation flow loop are measured by T-type thermocouples with 1.6mm diameter located on the central position of the flow channel cross section as shown in Fig.2. Polycarbonate support columns with 0.01m diameters are installed the flow channel apart for 0.06m each other to maintain the uniform flow gap distance as shown in Fig.3, therefore the support columns affected on the natural circulation flow rate as flow resistance. Another flow resistance is generated by an inlet flow distributor as shown in Fig.4. The inlet flow distributor has circular shape and 4-inlet hole with 5mm diameter and 40mm spacing. The natural circulation flow rate is measured by magnetic flow meter which is installed on the coolant flow path between the outlet and inlet.

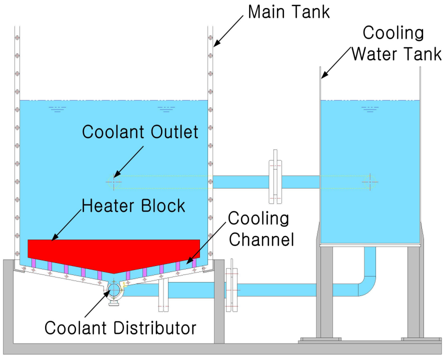

Fig. 1 Schematics of experimental facility

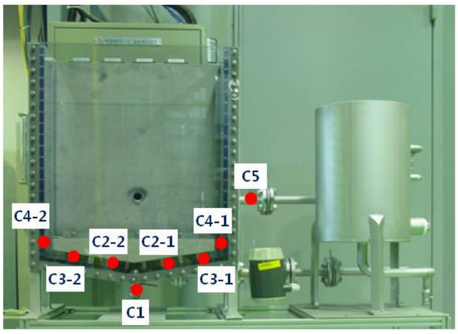

Fig. 2 Measurement positions for coolant temperature

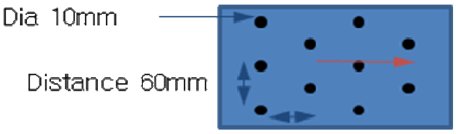

Fig. 3 Locations of support columns

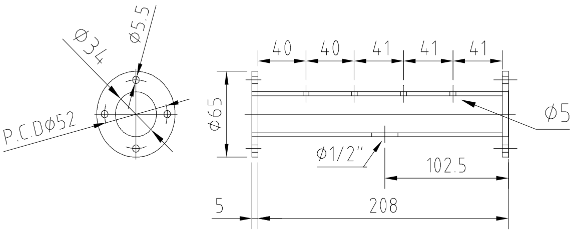

Fig. 4 The details of inlet flow distributor

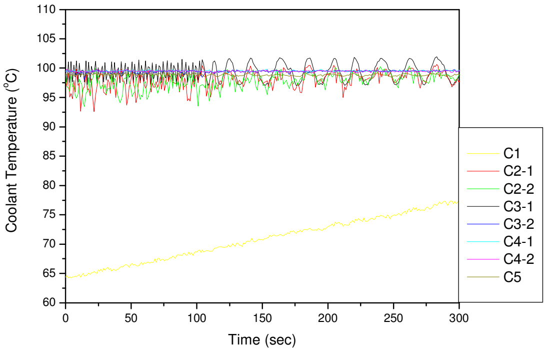

Fig.5 Temporal coolant temperature variation (average heat flux : 142kW/m^2, natural circulation loop opened)

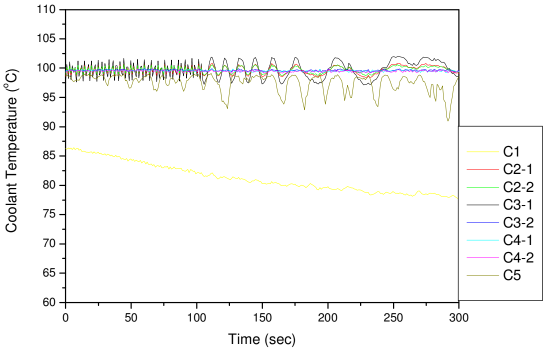

Fig.6 Temporal coolant temperature variation (average heat flux : 142kW/m^2, natural circulation loop closed)

Figure 5 shows temporal temperature variations of the coolant in the flow channel on the 142kW/m^2 heat flux condition. The inlet coolant temperature (C-1) increased monotonically because there is no heat exchanger in the water tank. The coolant temperature oscillated more intensively as the coolant flowed through downstream. It seems that the oscillatory flow may induce due to periodical bubble aggregation and stream venting process occurs.

The natural circulation flow was not detected by the flow meter within the error bound when the average heat flux on the wall was less than 142kW/m^2. Figure 6 shows the temporal temperature variations of the coolant under the no natural circulation flow condition, that is, the Fig. 6 was obtained under the same experimental condition as Fig.5 except for that the re-circulation flow path from the outlet to inlet was blocked artificially. The temperature variations in Fig. 6 were almost same as the Fig. 5. This is why the enough coolant can be supplied to the channel through opposite cold wall, that is counter current flow occurs effectively. The counter current limitation (CCFL) can be evaluated by Wallis parameters (j_k^*) as shown in equations 1 and 2. If critical heat flux condition due to CCFL occurs, then the vapor Wallis parameter should be same as liquid. The critical heat flux value can be evaluated using the channel length (l) and gap size (s) as shown in equations 3 and 4. The critical heat flux on this experimental condition was calculated by about 870kW/m^2, based on the Celata correlation (C_w=1.2, m_w=1.6) [3]. The flow channel cooling capacity by the count current flow seems to be sufficiently large on this experimental condition even though there is no natural circulation loop.

$$j_g^{*1/2} + m_w j_l^{*1/2} = C_w \tag{1}$$

$$j_k^* = j_k \sqrt{\frac{\rho_k}{gD(\rho_l - \rho_0)}} \tag{2}$$

$$j_k = \frac{\dot{m}}{\rho_k A_f} = \frac{q''_{CHF} A_h / h_{fg}}{\rho_k A_f} = \frac{q''_{CHF} l}{\rho_k h_{fg} s} \tag{3}$$

$$q''_{CHF} = C_w^2 h_{fg} \sqrt[4]{g\Delta\rho}\left(\frac{s}{l}\right)\left(\frac{1}{\sqrt[4]{\rho_0}} + \frac{m_w}{\sqrt[4]{\rho_l}}\right)^{-2} \tag{4}$$

3. Conclusion

A small-scaled natural circulation flow experients with the inclined heating channels were investigated. The coolant temperature oscillated more intensively as the coolant flowed through downstream. It seems that the oscillatory flow may induce because bubble aggregation and stream venting process occurs periodically. The natural circulation flow was not detected by the flow meter within the error bound when the average heat flux on the wall was less than 142kW/m^2. This is why the flow channel cooling capacity by the count current flow is sufficiently large under this experimental condition even though there is no natural circulation loop.

ACKNOWLEDGMENTS

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