Natural Convection Cooling Characteristics in Narrow Rectangular Channel at Horizontal and Low Slopes Conditions

Dongwook Jang[a*], Huiyung Kim[a], Jonghark Park[a]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeok Daero, Yuseong Gu, Daejeon, 305-353, KOREA*
[*]*Corresponding author: dwjang@kaeri.re.kr*

***Keywords : Horizontal Natural Convection, Research Reactor, Spent Fuel**

1. Introduction

In the process of fuel replacing in research reactors, nuclear fuel can fall into the reactor pool due to the carelessness of the operator or mechanical failure of the tools. The nuclear fuel of a research reactor, due to its length-wise shape, lays horizontally when it falls to the bottom. When the fuel is placed horizontally, the side plates or fuel plates block the flow of coolant, which reduces the cooling performance.

This study performed a preliminary experiment to investigate the natural convection cooling characteristics under the limited conditions as mentioned above.

2. Methods and Results

2.1 Test section and Experimental Apparatus

In a previous paper, the heat flux associated with Critical Heat Flux(CHF) under horizontal conditions was calculated to determine the maximum power of the test section to be used in the experiment.[1] As a result of the calculation, it was predicted that CHF would occur around 20~40kW/m^2, and based on this, a test section was manufactured as shown in Fig 1.

The heating section was made of STS, and the outer surface of the heating element was insulated with Bakelite.

Fig. 1. Test section

An experimental apparatus consisting of two pools and a test section was manufactured as shown in Fig. 2 to simulate horizontal natural convection. The test section was connected to the pools on both ends with bellows pipes, as the bellows are flexible and easy to adjust to horizontal.

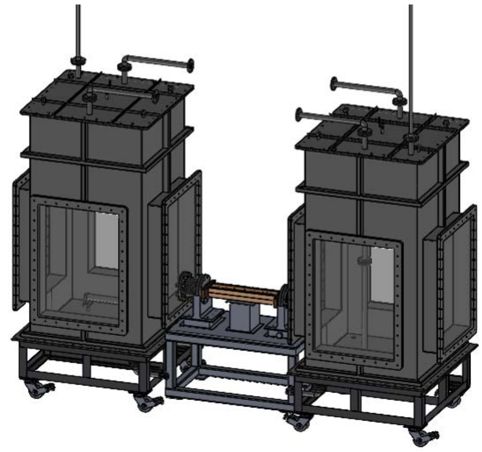

Fig. 2. Drawing of Experimental Apparatus

In this experiment, the temperature of the heated wall was measured at five points in the longitudinal direction, and the temperature of the inlet and outlet coolant was also measured. The temperature measurement positions and sensor numbers are presented in Fig. 3.

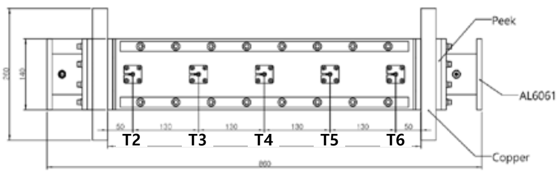

Fig. 3. Location of sensor position and number

3. Test Results and Disscussion

3.1 Horizontal Natural Convection

In a research reactor, spent fuel is cooled in the core for one day after the reactor is shut down, and then moved to the spent fuel storage pool. At this time, the spent fuel is cooled down to 2% of the full power. Therefore, it can be assumed that decay heat of the spent fuel under normal conditions are less than 2% of the full power.

The previous preliminary experiment was performed under the condition of 2% of the full power, which is 600W, according to the above assumption. As a result of the preliminary experiment, it was confirmed that at 600W, the channel wall temperature did not increase any further and remained constant. [1]

In this experiment, Fig. As in 4 and 5, the output was maintained at 300 W for 15 minutes and then increased stepwise to 600 W. Fig. 6 and 7 show the wall temperature when maintained at 300W and the wall temperature when the output is increased to 600W, respectively.

As a result of the experiment, even at 300W, the channel wall temperature continued to rise and reached the temperature at which boiling occurred at about 800 seconds. After boiling occurred, it was confirmed that the temperature at the inlet and outlet of the channel fluctuated significantly, as the air bubbles inside the channel escaped and cold water from the outside came in. Afterwards, as the output increased, the temperature oscillation amplitude at the channel entrance and exit gradually decreased, and it was confirmed that the wall temperature in all areas barely oscillated and maintained a constant level around 600W.

Therefore, it was confirmed that under horizontal conditions, natural convection flow was not formed in one direction, and that cooling proceeded in the form of bubbles generated due to boiling coming out of the channel and coolant flowing into the space.

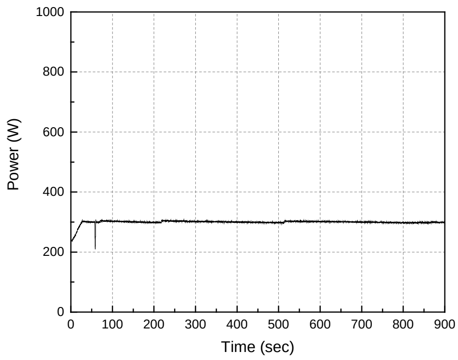

Fig. 4. Power curve #1 of horizontal experiment

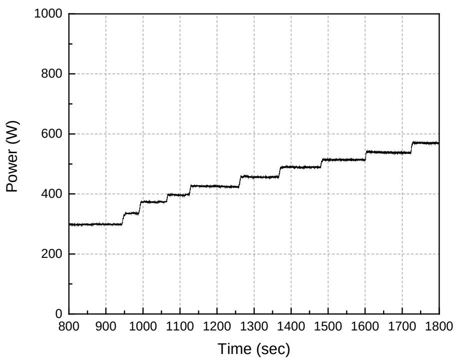

Fig. 5. Power curve #2 of horizontal experiment

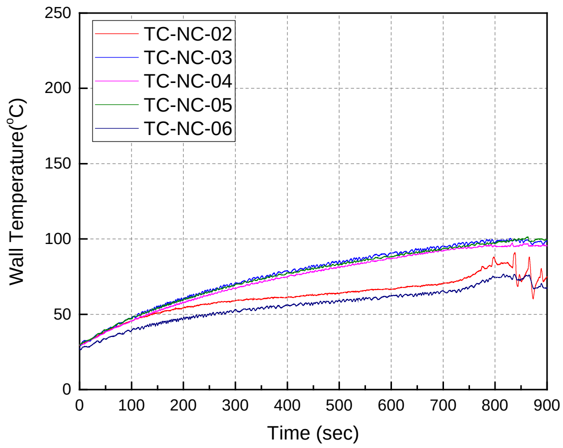

Fig. 6. Temperature curve #1 of horizontal experiment

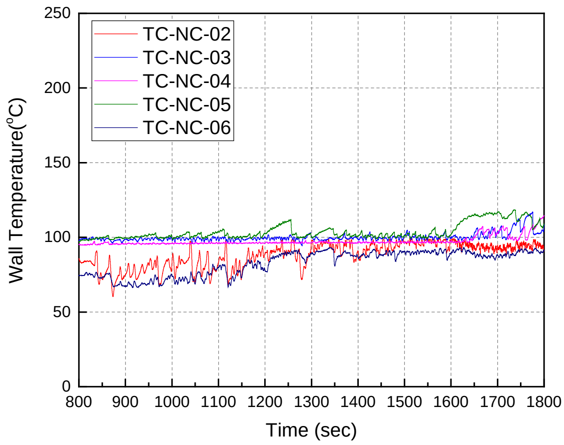

Fig. 7. Temperature curve #1 of horizontal experiment

3.1 Natural Convection at Low Slopes Conditions

In this segment of the study, an investigation was undertaken to elucidate the characteristics of natural convection under conditions of minimal inclination angles. The experimental framework entailed altering the inclination angle incrementally from 0.5 degrees to 12.5 degrees, encompassing a total of seven distinct conditions as depicted in Fig. 8. The power output of the experimental apparatus was maintained at a consistent level up until the onset of boiling within the channel, subsequent to which it was progressively elevated until the critical heat flux (CHF) was reached upon boiling.

Initial observations at the minimal inclination angle of 0.5 degrees are presented in Fig. 9. As illustrated, similar to horizontal orientation, fluctuations in temperature attributable to bubble formation were noted at both the inlet and outlet of the channel. Conversely, upon examining the results at a slightly increased inclination angle of 1 degree, as detailed in Fig. 10, a distinct temperature gradient was observed from the inlet towards the outlet, akin to typical natural convection phenomena. This indicates that efficient natural convection can be achieved at an inclination angle as slight as 1 degree, with similar observations recorded for inclination angles exceeding this threshold.

Fig. 8. Test section of low slope condition experiments

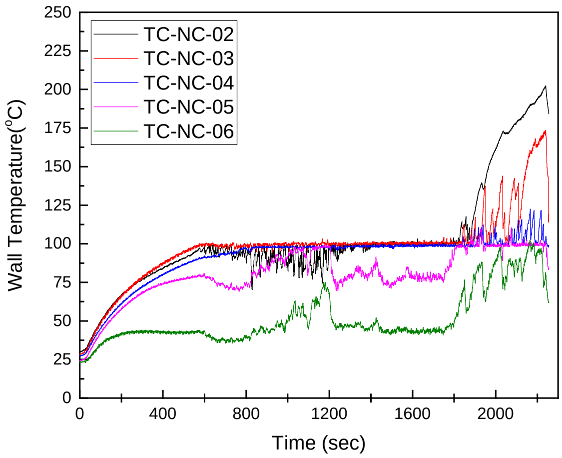

Fig. 9. 0.5 degree experiment results

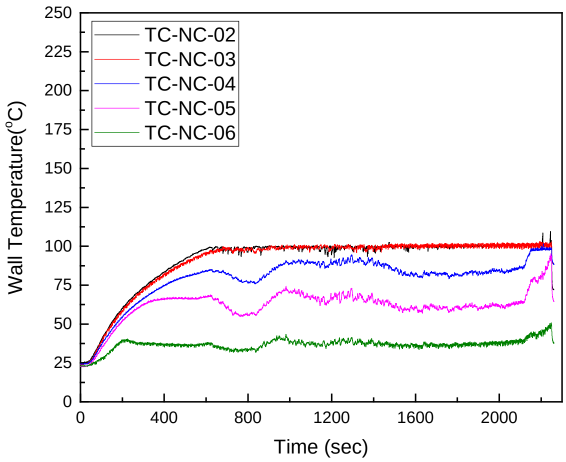

Fig. 10. 1 degree experiment results

In conclusion, Fig. 11 delineates the correlation between the inclination angle and the heat flux at which CHF occurs. It is evident from the figure that a pivotal point is reached at approximately 10 degrees. This observation aligns with the findings of Kim and colleagues [2], who noted that while the heat flux at which CHF occurs escalates rapidly with an increase in inclination angle at lower angles, it plateaus beyond a certain threshold.

In conclusion, the experimental results collectively demonstrate that the integrity of spent fuel remains intact even when it falls and rests horizontally under typical transportation condition. However, when placed horizontally, natural convection does not occur smoothly, which can led to inadequate cooling at higher power levels. To mitigate this issue, if nuclear fuel is designed to have an inclination angle of about 1 degree when it falls to the ground, it can be sufficiently cooled through natural convection even under fairly high power conditions.

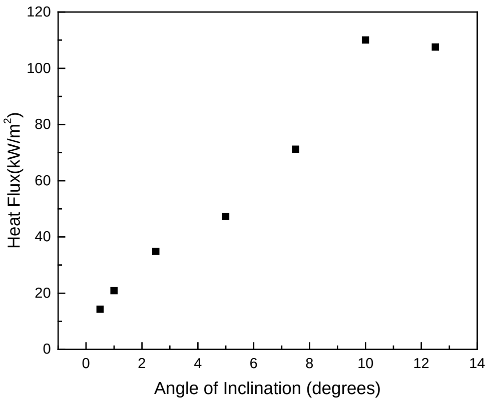

Fig. 11. Relation between inclination angle and CHF

4. Conclusion

Through the execution of two experiments, the characteristics of natural convection were elucidated under conditions of horizontal orientation and low inclination angles. In conditions of absolute horizontality, flow remained absent until the formation of bubbles within the system. Following bubble generation, a pulsating flow through the inlet and outlet at either end was observed. This phenomenon persists up to an inclination angle of approximately 1 degree. Beyond this threshold, it was established that a conventional natural convection flow pattern emerges.

Acknowledgement

This work was funded by the Korea government (MSIT: Ministry of Science and ICT).

REFERENCES

[1] D.W. Jang et al. "Preliminary Experiment of Natural Convection Heat Transfer Characteristics of Horizontal Narrow Gap Rectangular Channel", Transactions of the Korea Nuclear Society Autumn Meeting, Gyeongju, Korea, Oct. 26-27, 2023
[2] Y.H. Kim et al. "Visualization of Boiling Phenomena in Inclined Rectangular Gap", International Journal of Multiphase Flow, Vol. 31, pp. 618-642, 2005.