# Experimental study on heat transfer characteristics of downward facing inclined heating channel

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## 1. Introduction

In the event of a severe accident in a nuclear power plant, there is a risk of the reactor vessel failure, leading to the transfer of corium to the lower part of the containment building, threatening its integrity. As a result, various ex-vessel corium cooling strategies have been developed. Europe adopt a strategy that involves placing a structure called a core catcher beneath the reactor vessel to secure the integrity of the containment building. The core catcher can cool the heated ex-vessel corium through pool boiling at the top and through a downward-facing inclined heating channel, where a coolant water flows, at the bottom. To verify this concept, KAERI has established the Variable PECS Experimental facility (VPEX), which has downward facing inclined heating channel, and plans to conduct experiments to evaluate the cooling ability of the core catcher. As a mock-up facility, a small-scale facility called SPEX was constructed [1]. This study aims to present the results of heat transfer experiments conducted at this SPEX facility.

## 2. Experimental facility and methods

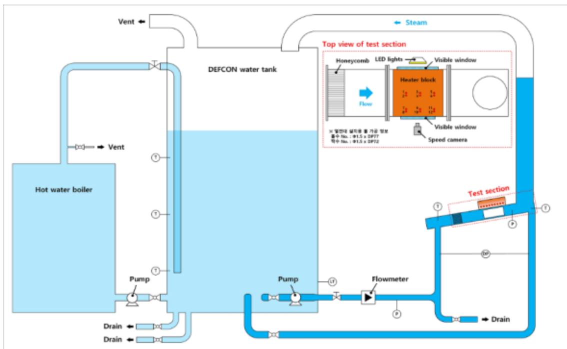


Fig. 1. SPEX test facility

Figure 1 shows the schematic of the SPEX test facility. Using a boiler connected to the tank, the coolant water is heated to the required temperature condition. Water is then moved to the cooling channel using a pump while the flow is heated by heaters installed at the top of the test channel. This setup can verify the coolability of the channel and the integrity of the heaters. The heater area is 1 $m^2$ (0.33 × 0.3 $m^2$), and the heat flux at the top of the channel is controlled through the heat output of nine heater rods inserted into the heater block. The channel area is 0.3 m wide and 0.1 m high. Due to the smaller heating area compared to the overall facility, experiments were conducted under forced circulation conditions instead of natural circulation. Pressure could be controlled by changing total height of water and fixed at 1.2 bar (water height 2.0 m) in this study. Pressure may affect heat transfer results because it can change the saturation temperature of water, but due to the limitation of water tank height, tests were conducted at fixed pressure. Tests performed in this study are outlined in the following experimental matrix (Table I).

Table I: Test matrix

| Flow rate (kg/s) | Inlet temperature (℃) | Total heating power (kW) |
|---|---|---|
| 6 | 100 | 5~35 |
| | 90 | |
| 4 | 100 | |
| 2 | 100 | |

## 3. Results and discussions

### *3.1 Effect of mass flow rate*

Figure 2 shows the boiling curve of the experiments with varying mass flow rate. Figure 3 shows the convective heat transfer coefficient with respect to heat flux for different mass flow rate. It was confirmed that as the flow rate decreases, the convective heat transfer coefficient decreases, indicating that coolability of cooling channel goes down. This is due to the faster removal of steam and quicker re-contact of water with the wall as the flow rate increases. However, since the variation in the heat transfer coefficient is within 10%, it is considered that the actual effect of the flow rate on the cooling performance is insignificant.

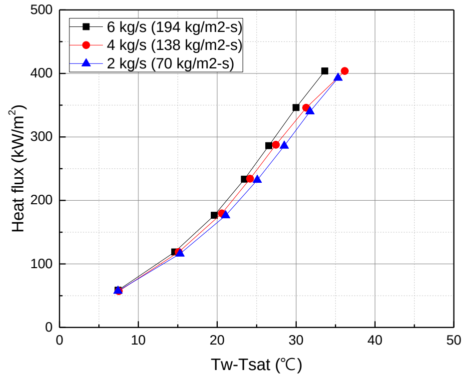


Fig. 2. Boiling curve with varying mass flow rate

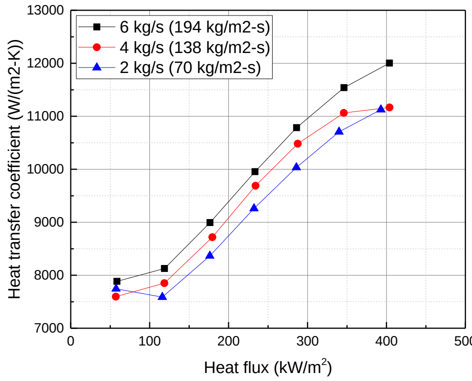


Fig. 3. Heat transfer coefficient with heat flux for different mass flow rate

*3.2 Effect of inlet subcooling temperature*

Similar to the analysis for flow rate variations, we compared the boiling curve (Fig. 4) and the convective heat transfer coefficient (Fig. 5) to examine the changes in the heat transfer characteristics of the channel with subcooling of water. It was observed that with subcooling, the convective heat transfer coefficient decreases, leading to reduced coolablility. Generally, in natural convection flow, an increase in subcooling leads to a higher convective heat transfer coefficient and increased coolability. However, in forced convection, results different from natural convection due to the influence of flow have been reported [2]. Further analysis is needed on this matter, especially considering that our experimental setup, VPEX, is based on natural convection circulation, which may yield different results from SPEX.

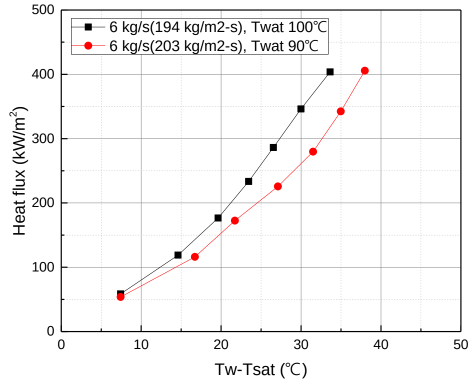


Fig. 4. Boiling curve with varying inlet subcooling temperature

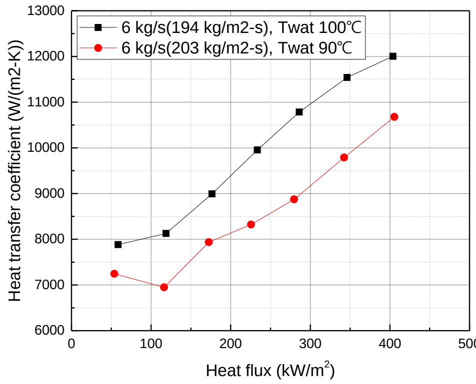


Fig. 5. Heat transfer coefficient with heat flux for different inlet subcooling temperature

*3.3 Comparison of overall results*

Figure 6 shows the boiling curves for overall SPEX results and those from previous studies under similar conditions [2,3]. Compared to the previous studies, the boiling curves in SPEX experiments show a notably lower convective heat transfer coefficient, resulting in a more rightward slope. This difference can be attributed to the larger heating area of the heater block and differences in surface characteristics in the SPEX experiments. Particularly, heat transfer at the surface can vary significantly depending on surface properties such as material and roughness, leading to such discrepancies.

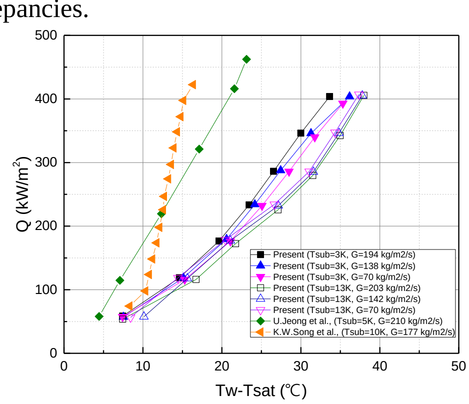


Fig. 6. Boiling curve of overall test results

## 4. Conclusion

In the SPEX experiment results, it was observed that the wall temperature tends to increase with lower flow rates and subcooling levels at the same heat flux. However, the difference was found to be quite small, suggesting that the influence of a 10°C subcooling or flow rate on cooling characteristics is insignificant. However, high-heat flux tests up to the Critical Heat Flux (CHF) were not conducted, so further research may be needed in this regard. Additionally, the heat transfer coefficient was found to increase as the heat flux increased from low to high values, ranging from approximately 6000 to 12000 $W/m^2K$. This characteristic is attributed to the channel and heater surface properties, so it is expected that the VPEX device, which uses the same heating device, will also have similar heat transfer coefficient range. Based on these results, we plan to conduct further studies on the coolability of a core catcher using the VPEX facility.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] J. Kang, S. Jeong, K.H. Park, G.W. Kang, S.H. Hong and B. Lee, Visualization study of flow boiling heat transfer with downward facing inclined heating channel, 10th Korea-China Workshop on Nuclear Reactor Thermal-Hydraulics (WORTH-10), Nov. 26-29, 2023, Jeju, Korea.
[2] U. Jeong and S.J. Kim, Subcooling effect on boiling heat transfer of inclined downward-facing surface under low flow and pressure, International Journal of Heat and Mass Transfer, Vol.127, pp.182-195, 2018.
[3] K. Song, S. Jun, S.M. You, H.Y. Kim, M.H. Kim and S.T. Revankar, Flow boiling heat transfer from downward-facing thick heater block in an inclined channel with plain and microporous coated surfaces, International Journal of Heat and Mass Transfer, Vol.129, pp.1010-1022, 2019.