Interfacial Wavy Motion during Film Boiling from a Downward-facing Curved Surface

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1. Introduction

In the process of designing for the APR1400 (Advanced Power Reactor 1400 MWe), the concept of in-vessel retention through external vessel cooling (IVR-EVC) was chosen as a severe accident management strategy. The cavity flooding was selected as the external vessel cooling method because of simpler installation relative to flooding within the thermal insulator. In fact, the IVR-EVC concept had not been considered during the initial design phase of the APR1400. Thus, several issues surfaced while applying the IVR concept at a later stage of design. One of these issues centered about delayed flooding of the reactor vessel because of the large volume between the cavity floor and the lower head. The cavity flooding may take as much as forty minutes depending upon the accident scenario. It is thus not certain whether the flooding time will always be shorter than the time for relocation of the molten core material to the lower plenum of the reactor vessel. In addition, the initial temperature of the vessel, which should be in the vicinity of the saturation point corresponding to the primary system pressure, will far exceed temperature of the cavity flooding water during an accident. Hence, the initial heat removal mechanism for external vessel cooling will most likely be film rather than nucleate boiling. The results of this work indicate, however, that film boiling heat transfer coefficients presently available in the literature tend to underpredict the actual value for the reactor vessel lower head. In this study, In this study, film boiling heat transfer coefficients are obtained from the DELTA (Downward-boiling Experiment Laminar Transition Apparatus) quenching test utilizing the measured temperature histories. They are compared with the other experiment of the same edge angle [1]. The film boiling heat transfer phenomena are visualized through a digital camera.

2. Experimental Setup and Results

2.1 Experimental Setup and Data Reduction

The DELTA test section is a downward-facing curved surface, whose diameter, curvature radius, edge angle, and maximum thickness are 340 mm, 990 mm, 9.88°, and 40 mm, respectively. The test section is made of copper to maintain Bi below 0.1 in the film boiling regime. In case of Bi less 0.1 the conduction heat transfer in the solid may be neglected [2]. The inner cavity of the test section was filled with bulk fiber, and the edge was blazed with a thin stainless steel plate to minimize the azimuthal heat loss and to protect the inner cavity against water. A cylindrical section of the stainless steel is large enough to stay away from water. The hexahedral quenching tank is of $1\times1\times1.1$ m^3. It has a large glass window on one side for visual inspection and recording of pool boiling on the hemispherical surface during quenching using a video camera. During the experiment, the water in the tank was maintained at the saturated condition utilizing four 10 kW and two 7 kW heaters. Prior to quenching experiment, demineralized water in the tank was degassed by boiling for thirty minutes. The test section was heated up to 270 ℃. The heated test section was transferred from the furnace to the quenching tank by an automatic lift. The heated test section was then submerged in the quenching tank. This experiment was designed to measure the temperature profile associated with the film boiling heat transfer coefficient. The film boiling heat transfer coefficient was computed from the temperature history by the lumped capacitance method.

2.2 Experimental Results and Discussion

In the experiments all the local wall temperature differences were found to stay within ±0.5℃ in the film boiling regime, because the thermal conductivity of the test sections was sufficiently high. Hence the conduction heat transfer could be neglected in obtaining the film boiling heat transfer coefficient. Temperature dependent emissivity of Cr-polished copper was taken to be 0.1 in obtaining the contribution of the radiative heat transfer. The ratios of radiation heat flux and film boiling heat flux were always less than 0.02 in the experimental conditions.

Figure 1 compares the current experimental results, El-Genk and Glebov's experimental results [1] and laminar film boiling analysis [3]. This edge angle of the test section in our experiments is the same as that of El-Genk and Glebov [1]. Both test sections are made of copper. The film boiling heat transfer coefficients from our experiments are similar with their experimental results[1]. If the film boiling regime were strictly laminar in our experiments, the heat transfer coefficients should be smaller than those from their experiments [1]. Also, the experimental results are larger than the heat transfer coefficients predicted by the laminar film boiling analysis. It is surmised that similar film boiling heat transfer coefficients result from similar vapor film thickness in the two experiments. It is considered that the Helmholtz instability places limits on the vapor velocity and film thickness.

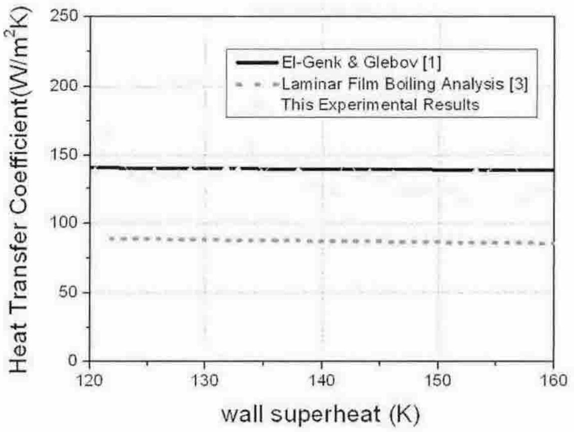

Figure 1. Comparison with the Experimental Results and Other Studies

Figures 2(a) through (d) depict the film boiling heat transfer mechanism for the downward-facing curved surface. Snapshots were taken by the digital video camera at 30 fps. There was the stable laminar film boiling region at the center of the curved surface. The interfacial wavy motion was observed outside the center of the curved surface. Its shape looked like a few concentric circles. But the 30 fps was too smaller to quantify the interfacial wavy motion.

(a) 0 sec

(b) 0.11 sec

(c) 0.2 sec

(d) 0.35 sec

Figure 2. Snapshots of Film Boiling During 0.5 sec

3. Conclusion

Measured film boiling heat transfer coefficients were greater than those given by the laminar film boiling analysis. And there was little difference between the film boiling heat transfer coefficients from two curved surfaces whose diameters were equal to 50 mm and 340 mm, respectively. The interfacial wavy motion resulting from the Helmholtz instability plays an important role in limiting decrease of film boiling heat transfer coefficient with the increasing geometrical size. As expected, the snapshots of film boiling shows the interfacial wavy motion. In the future, the film boiling heat transfer coefficients will be measured at the steady-state experiment. The period and wavelength of the interfacial wavy motion will be quantified by the visualization with high-speed camera over 1000 fps.

REFERENCES

[1] M. S. El-Genk and A. G. Glebov, Film Boling from a Downward-facing Curved Surface in Saturated and Subcooled Water, International Journal of Heat and Mass Transfer, Vol. **39**, No. 2, p. 275.

[2] F. P. Incropera and D. P. Dewitt, Introduction to Heat Transfer, 3rd edition, Chapter 5, John Wiley and Sons, Inc., New York, NY, USA, 1996.

[3] U. C. Lee, G. C. Park, K. Y. Suh, Optimized Emergency Core Cooling System for Advanced Reactors, Final Report of the Korean National Research Laboratory Project, 2004.