Experimental Study on Local Liquid Velocity and Temperature for Subcooled Boiling Flow in a Vertical Annulus

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1. Introduction

Subcooled boiling phenomena occur due to the thermally non-equilibrium state in the two-phase heat transfer system such as nuclear power plant, heat exchanger, refrigerator, and so on. However, until now, previous studies for the prediction of subcooled boiling flow have not been satisfactory to cover various geometries and wide range of flow conditions. Also, an available experimental database for the development of mechanistic subcooled boiling flow model is still limited to the narrow range of flow condition and geometry.

Recently, KAERI (Korea Atomic Energy Research Institute) conducted SUBO (SUbcooled BOiling) program for the basic understanding and clarification of subcooled boiling flow. It consists of two stages; 1) stage-I for the measurement of local bubble parameters and 2) stage-II for the measurement of local liquid parameters such as a mean liquid velocity and a mean liquid temperature. Stage-I test has already been done and more details are found in the paper of Yun et al. [1]. Present study is focusing on the stage-II experiment of SUBO program. The liquid parameters were obtained at the same flow condition of stage-I test. It is expected that present data provide a complete data set of subcooled boiling flow for a benchmark, validation and model development of the CFD codes or existing safety analysis codes.

2. Test Facility and Experiments

2.1 Test Facility

Test section of the SUBO test facility is a vertically arranged annulus with an in-direct heater rod at the channel center as depicted in Fig. 1. The inner diameter of the outer wall is 35.5mm, and the outer diameter of the inner wall (heater rod) is 9.98mm. The maximum available mass flux and heat flux of the SUBO are 6000 kg/(m^2s) and 934 kW/m^2, respectively. The maximum operational pressure of the test facility is 500 kPa.

For the measurement of a local mean liquid velocity and a mean liquid temperature, a specially designed Pitot tube in which a TC was incorporated was applied. It consists of two pressure tubes for a static and total pressure readings, of which ID/OD of each tube are 0.5/0.9 mm, respectively. To measure the liquid velocity at the exact location, the total pressure tube was positioned at the center of the probe, while the static pressure tube was installed apart 0.9mm from the center of the total pressure tube. The K-type TC of which diameter is 0.25mm was installed at the central location of the top of the total pressure tube.

For the measurement of the propagation of the local bubble parameters along the test section, the Pitot tubes were installed at six elevations. Among them, five (L/Dh=18.4, 43.3, 68.2, 93.1, 117.5) were installed in the heated region and one (L/Dh=123.4) was installed in the unheated adiabatic region located at the top of the test section. The radial distribution of the local bubble parameters were obtained at 11 locations between the heater rod and the outer pipe at each elevation.

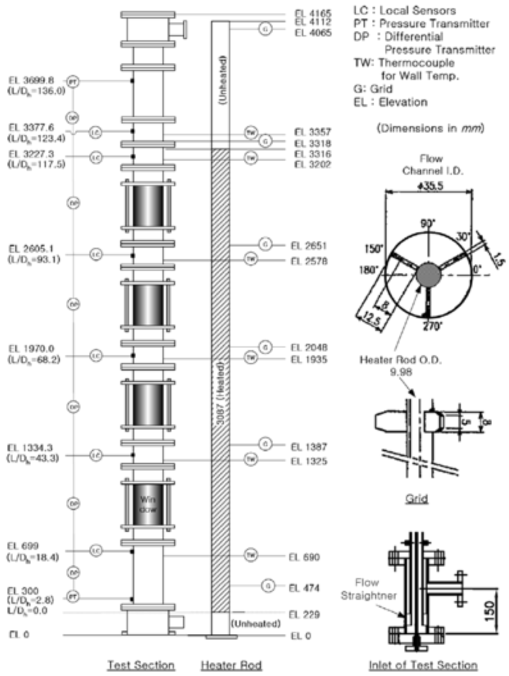
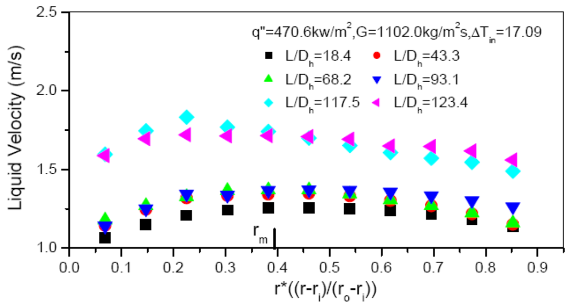


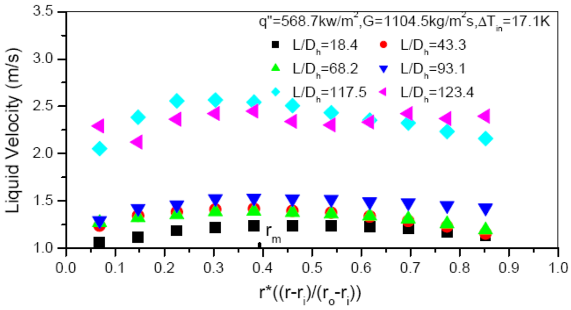
Fig. 1. Schematics diagram of SUBO test facility

2.2 Experimental Results

Fig. 2 shows the profile of a local liquid velocity obtained from Base-RL case and Q2-RL case, where Q2-RL has a larger heat flux than Base-RL case as shown in the figure. Here, L/Dh=18.4 of both cases can be treated as a single-phase flow because it apparently belongs to wall voidage region in which both local and average void fractions are very much small. As it goes downstream of the test channel, the liquid velocity profile changes significantly due to the high void fraction near the heated wall. The Base-RL shows well the general trend of the liquid velocity depending on the local void fraction. As shown in Fig.2 (a), the liquid velocity profile at the lower elevations follows comparatively well that of the single-phase flow, however as it goes downstream in which a higher void fraction is observed near the heater surface, the peak liquid velocity moves significantly to the heated wall. The movement of a peak liquid velocity of present data implies that the local liquid velocity profile should be investigated with the effect of enhanced turbulence in the two-phase flow system.



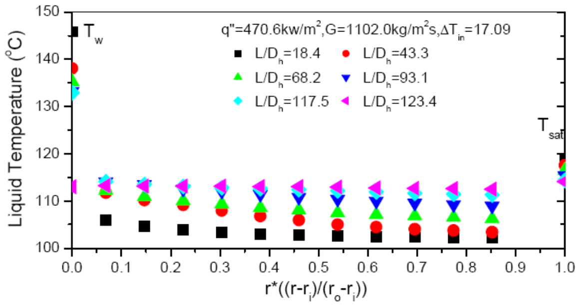
(a) Base-RL Case



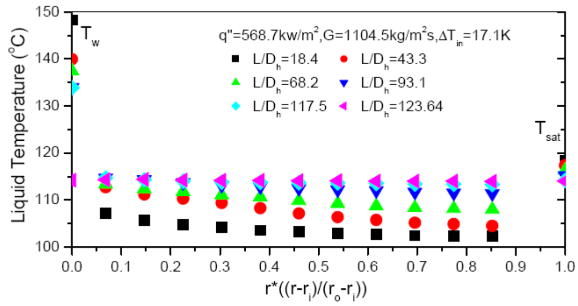
(b) Q2-RL Case

Fig. 2 Liquid Velocity Distribution in SUBO Test

The measured mean liquid temperature was plotted with wall temperature (T_{wall}) of a heater rod and saturation temperature (T_{sat}) on the measuring plane in Fig. 3 for both of Base-RL and Q2-RL cases. The wall temperature is dependent on the heat flux, the mass flux, the inlet subcooling and the saturation temperature at the measuring plane. The highest wall temperature was found at the lowest elevation, L/Dh=18.4 and it decreases as goes upward for a given case. In the present low-pressure condition, the static pressure effect resulted by a hydrostatic head of liquid is significant on the wall temperature. That is, it governs the saturation temperature and then wall temperature distribution. The wall temperature at L/Dh=123.4 reached to the saturation temperature because there is no heat input at this elevation. The figure also shows clearly that the liquid subcooling is minimum at the inner wall and it increases as goes outer wall at each measuring plane for both cases. The increased heat flux in Q2-RL case affected the increase of liquid temperature when compared to that of Base-RL case.



(a) Base-RL Case



(b) Q2-RL Case

Fig. 3 Liquid Temperature Distribution in SUBO Test

3. Conclusions

As a series of basic subcooling boiling flow test, local two-phase flow parameters were obtained in SUBO (SUbcooled BOiling) test facility under steam-water flow condition. From the test, local liquid parameters were measured at 6 elevations along test channel and 11 radial locations of each elevation.

The liquid velocity profile showed that the location of maximum liquid velocity changes from that of a single-phase flow in an annulus due to the void effect. The temperatures of a heated wall and a liquid temperature were also measured to be used in the evaluation of energy partitioning and interfacial heat transfer models for subcooled boiling flow. The present subcooled boiling data is expected to provide one of complete data sets for a benchmark, validation and model development of the CFD codes or existing safety analysis codes.

Acknowledgement

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REFERENCES

[1] Yun, B.J., Bae, B.U., Euh, D.J., Song, C.-H., Park, G.C., 2009. Characteristics of the local bubble parameters of a subcooled boiling flow in an annulus, Nuclear Engineering and Design, To be published.