Measurement of the Superheated Steam Temperature in a Post-CHF Dispersed Droplet Flow Regime

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1. Introduction

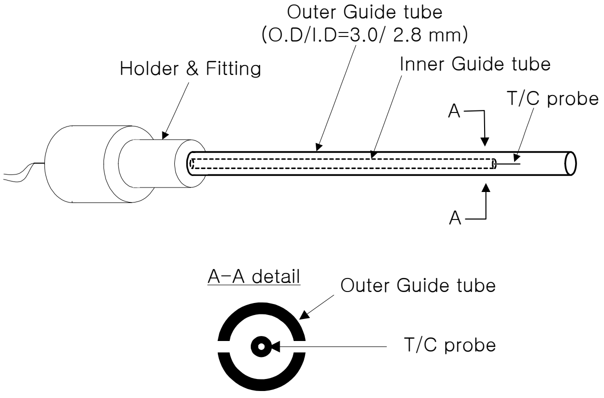
Heat transfer in the post-dryout dispersed flow regime has often been modeled with the assumption of thermodynamic equilibrium between liquid and vapor phases. In such equilibrium models, the heat energy transferred from the wall is assumed to be totally absorbed by the evaporation of the liquid phase. The vapor temperature would thus be equal to the local saturation temperature, so long as the equilibrium quality of the two-phase mixture does not exceed unity. Other more phenomenological models have attempted to consider the possible existence of thermodynamic non-equilibrium, where superheated vapor would coexist with entrained liquid droplets.

Some of the thermodynamic non-equilibrium models and correlations are history-dependent in the sense that knowledge of the location and conditions of the fluid at the dryout point is required. Other groups of non-equilibrium correlations for dispersed flow boiling attempts to use only local parameters to predict wall heat transfer [1].

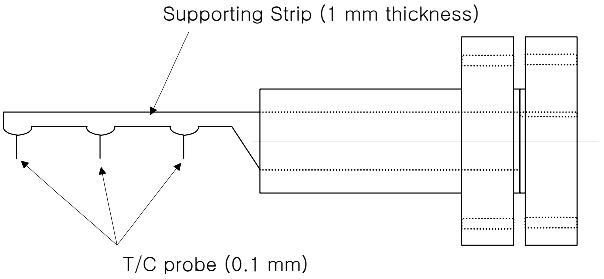
All the analytical models and correlations, whether of the history-dependent or local parameter class, have emphasized the need for determining the non-equilibrium vapor temperature as a first step in calculating post-dryout heat transfer. Challenges to verify or improve the correlations and models, however, have been greatly hindered by a lack of experimental data on the existence and magnitude of thermodynamic non-equilibrium. The main topic of this study is how to measure the superheated steam temperature in a post-CHF dispersed droplet flow. As a first step of this attempt, two different kind of superheated steam probes were devised. One is lake-type and the other is enveloped-type, described in the following section.

2. Design of superheated steam probe

One of difficulties in measuring the superheated steam temperature in the post-CHF dispersed flow regime is caused by a number of droplets of which the temperature is nearly saturation temperature of corresponding system pressure and which continuously contact the measuring tip. To avoid this droplet attachment from the measuring tip, two kind of superheated steam probes were designed: rake-type and enveloped-type. Figure 1 show the configurations of these probes. The enveloped-type probe has an outer envelope to prevent droplet from a wetting of the measuring tip. For the rake-type probe, basic idea was adopted from that of the RBHT experiment [2]. Three thermocouples, of which the outer diameter is 0.1 mm, were supported as depicted in the Fig. 1(b).



(a) Enveloped-type



(b) Rake-type

Fig. 1 Superheated steam probe

3. Experimental results and discussions

The experiments were performed using the 2x2 reflood test facility of KAERI [3]. The total heated length was 1,800 mm and the superheated steam temperature was measured at the 1,410 mm as shown in Fig. 2. The tests were performed under an atmospheric pressure condition. In Fig. 3, measured superheated steam temperatures are compared with the cladding temperature. The flooding velocity (V_f) is 1.0 and 1.4 cm/s for the Fig. 3 and Fig. 4, respectively. The subcooling degree of inlet coolant and linear heat flux from the heater rod are described in the corresponding figures. At the higher flooding velocity than 2.0 cm/s, the superheated steam temperature are not measured during the reflood period due to the higher droplet entrainment and dispersed rate in the subchannel. For the higher flooding velocity condition, the probe should be revised for a better performance and this is a main topic of a successive study.

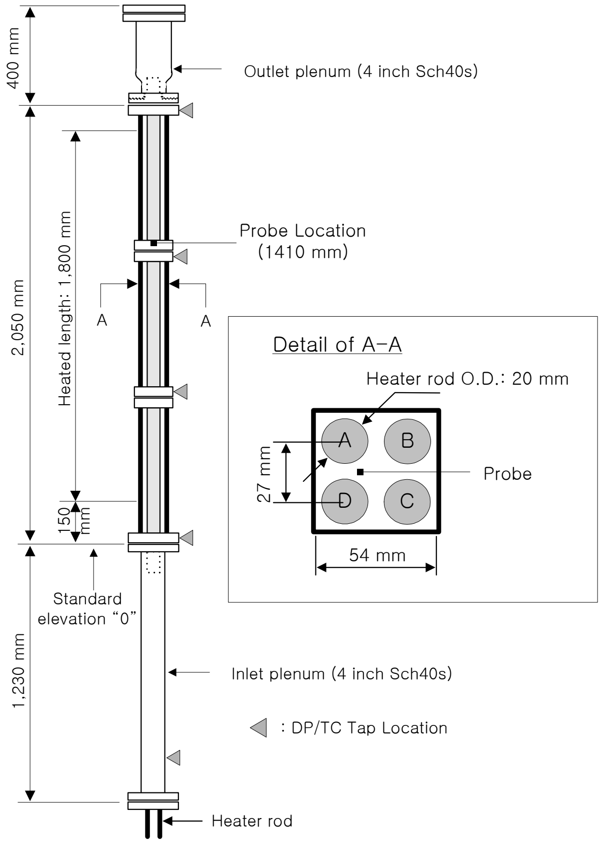


Fig. 2 Configuration of 2x2 reflood test section

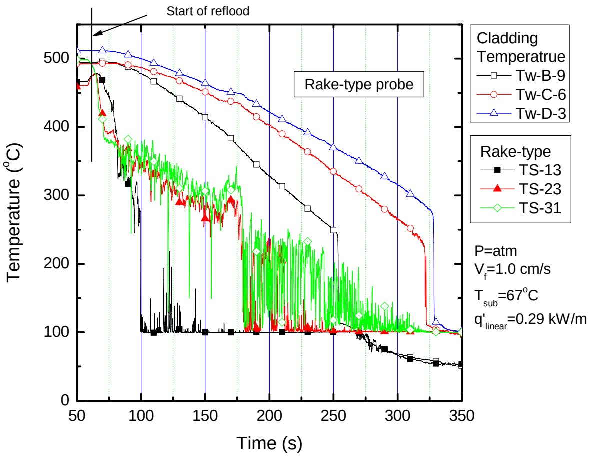


Fig. 3 Measured superheated steam temperature
(V_f =1.0 cm/s, q'_{linear} = 0.29 kW/m)

As can be observed in Fig. 3, the superheated steam temperatures using the rake-type probe show a very fluctuating nature but they lie between the cladding temperature and the saturation temperature. However, for a higher flooding velocity condition shown in Fig. 4, the measured superheated steam temperature using rake-type probe (TS-31) shows a sudden decrease around 95 s and then it is maintained at the saturation temperature. On the other hand, the temperature measured from the enveloped-type probe shows a little bit lower temperature than that of the rake-type probe up to 95 s. However, after 95 s, it shows a linear decreasing trend. Moreover, the inclination of the temperature decreasing for these two types of probes shows a relatively good agreement. The combination of these two types of probes can be a solution for measurement of the superheated steam temperature.

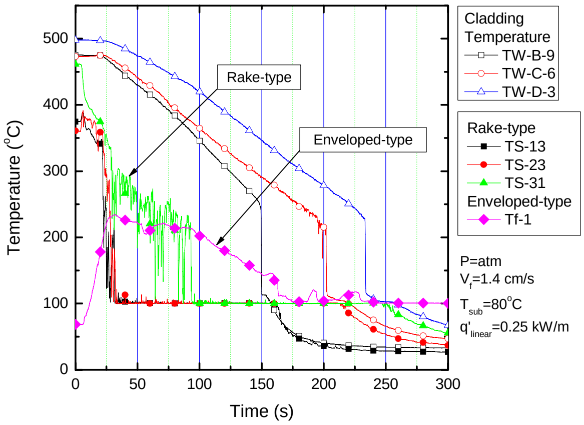


Fig. 4 Measured superheated steam temperature
(V_f =1.4 cm/s, q'_{linear} = 0.25 kW/m)

4. Conclusions

In the present study, the possibility for the measurement of the superheated steam temperature in the post-CHF dispersed droplet flow regime has been investigated. Two types of probes were tested during the reflood condition. The rake-type probe shows a relatively good performance during the initial stage of the test. With the increase of the flooding velocity more than 2.0 cm/s, the measuring performance was decreased steeply. The combination of these two types of probes could be a solution for the possible measurement technique of the superheated steam temperature.

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