Spacer Grid Effects on Post-CHF Heat Transfer in an Annulus Geometry

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1. Introduction

The term 'Post-CHF' was generally used in the two-phase flow regime in tube flow occurring downstream of the CHF. It has various other names such as dispersed flow, liquid-deficient flow, mist flow and film boiling because the two-phase regime is characterized by a continuous vapor phase with discrete liquid drops and a non-wetted heated surface. The regime has been adopted in a lot of applications including nuclear power plants, fossil power plants, steam generators, refrigeration systems and spray cooling, In particular, this regime has a considerable importance in the areas of light water reactor(LWR) accident analysis (off-normal operating conditions) and design in heat exchangers operating in the once-through mode where subcooled liquid enters the exchanger and superheated vapor exits.

Recently, innovative PWRs adopt very high power density increases and so require increased safety margins. For instance, advanced PWRs would be going to use a new-type of spacer grid and mixing vanes as a passive enhancement technique of heat transfer. Therefore, it requires improved knowledge of heat transfer in the region which is extremely important to safety analysis and assessments. Although extensive studies of the heat transfer characteristics for this flow situation have been carried out by numerous researchers, there have been very few systematic investigations of rod spacing devices or in particular mixing vanes as the passive enhancement technique.

Actually, Leung et al. [1] of University Ottawa in Canada investigated on the effects by obstacles like fuel element spacers. They used a tubular geometry instead of actual rod-bundle or rod-annulus geometry to eliminate uncertainties in the predictions of sub-channel flow conditions and to avoid difficulties in the measurement of temperature in rod-type geometries. Their experiment was designed to obtain film-boiling temperature measurements with a flow obstacle-equipped tube cooled with an upward flow of R-134a.

Using different types of flow obstacles with a blockage-area ratio of 37.8% and shaped into a ring, a cube, and a hexagon, they acquired the results of surface-temperature distributions at various thermodynamic qualities between various shapes of obstacles are shown in Figure 1. The results of flow obstacles compared with plain surface show a strong enhancement effect on heat transfer at locations downstream of the obstacle.

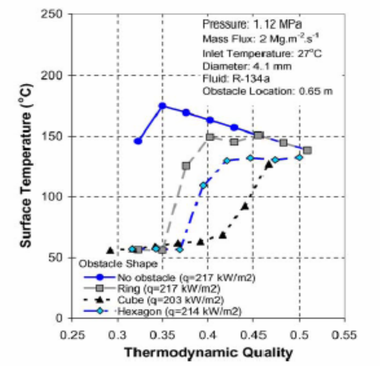

Figure 1. A comparison of surface-temperature distributions for various obstacles [1].

Recenlty, Anglart et al. [2] of the Royal Institute of Technology in Sweden performed an experimental investigation of the post-dryout heat transfer in annulus test section. The test section has an annular geometry with 10 mm rod outer diameter and 22.1 mm tube inner diameter with seven spacers located along itself to keep the rod and the tube equidistant. Their experimental results showed a very strong influence of spacers on post-dryout heat transfer. Or, post-dryout patches that appeared upstream of the last spacer were effectively quenched.

Really, physical understanding of influence of a flow obstacle on the occurrence of burnout and the phenomena after the burnout has not been sufficiently reported yet. Mori and Fukano [3] visualized the phenomena of burnout for BWR type spacer in a boiling two-phase flow within an annular channel. As the results, the spacer has a cooling effect and in other cases, causes the dryout of the cooling water film on the heating surface resulting in the burnout of the heating tube. Figure 2 shows the spacer and the dryout phenomena .

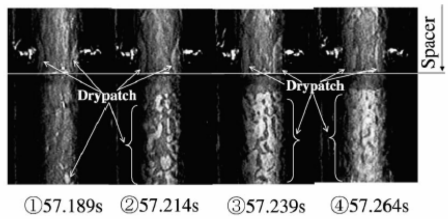

Figure 2. A visualization of a spacer effect [3].

Cho et al. [4] lately performed an investigation of the effects of egg-crate grid and the grid with swirl vane on reflooding phase in a scenario of LOCA. As the result shows the shorter rewetting time of the grid with swirl vane. Indeed, aforementioned literatures give a strong expression of the effects of spacers on heat transfer, but do not give any physical understanding for actual PWR type spacer. Therefore, it is the objective of this study to present the improved physical understanding on the effects of spacer including new types of mixing vanes being going to be adopted in advanced nuclear power plants.

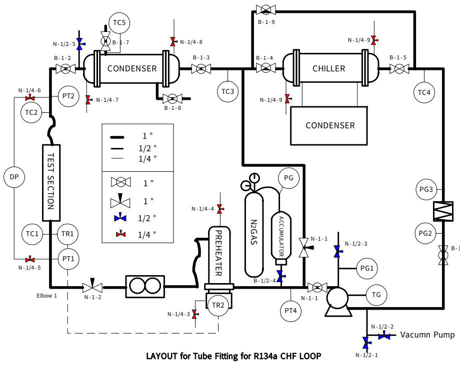

Figure 3. Schematic diagram of experimental test loop

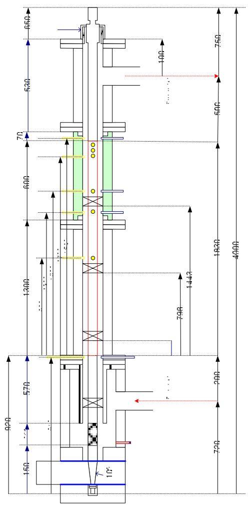

Figure 4. Schematic diagram of the test section

2. Experiment

An experimental study on the post-CHF will be carried out in R-134a thermal-hydraulic loop of KAIST to investigate the effects of a spacer grid in an annulus flow channel with a rod. The experimental loop consists of a closed R-134a flow loop with test section, pump, mass flow meter, pressurizer (accumulator and N_2 gas bottle), pre-heater, chiller (cooling of R134a fluid using refrigerant gas), auxiliary device (vacuum pump removing moisture for purity and chiller pump) and other instrumentation. The test section consists of a body of a inner rectangular flow channel of 19*19 mm^2 and single heater rod with outer diameter of 9.5 mm, and six K-type thermocouples, whose sheath diameter is 0.5 mm, are embedded in the cladding of the heater rod to measure the wall temperature. The length from the bottom end of heated section to each thermocouple is 920, 1320, 1520, 1720, 1800, 1820 mm, respectably. For the measurement of fluid temperature, four K-type thermocouples are installed in the annulus flow channel and four pressure taps are drilled at the flange. The rod over a length of 1830 mm is indirectly heated by a heat element heated directly by Alternating Current and can generate the maximum 22.0 kW thermal energy. Power shape of the heater rod is uniform throughout the heated section.

The schematic diagrams of test loop and test section are shown in Figs. 3 and 4. In particular, for visualization of post-CHF heat transfer mechanism characterized liquid droplets and vapor, visual windows are installed in the exit part including the last spacer. The test conditions using R-134a working fluid have the following flow parameter ranges : inlet temperature of 15~30 ^{o}C, heat flux of 100~222 kW/m^2 , pressure of 1~2 MPa and mss flux of 500~2000 kg/m^2 s.Two types of spacer grids will be used. One type is a grid without any vane and the other is a grid with newly designed vane for advanced nuclear power plants. Four spacer grids are installed in the test section. To evaluate and compare the effect of the spacer grid, the third and fourth grids from the bottom are located near the embedded thermocouples [4].

3. Conclusion

Experimental data on the film-boiling temperature of R-134a flow in an obstacle-equipped channel have been obtained. The results confirm the impact of the obstacle effect by a strong enhancement of heat transfer at location downstream of the obstacle. However the effects of various types of spacer grid on post-CHF phenomena were not well known. This study will carry out the experimental investigation of the heat transfer in post-CHF regime with spacer grid.

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