Natural Convection Heat Transfer in SIGMA Experiment

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1. Introduction

A loss-of-coolant accident (LOCA) results in core melt formation and relocation at various locations within the reactor core over a considerable period of time. If there is no effective cooling mechanism, the core debris may heat up and commence natural circulation. The high temperature pool of molten core material will threaten the structural integrity of the reactor vessel. The extent and urgency of this threat depend primarily upon the intensity of the internal heat sources and upon the consequent distribution of the heat fluxes on the vessel walls in contact with the molten core material pools. In such a steady molten pool convection state, the thermal loads against the vessel would be determined by the in-vessel heat transfer distribution involving convective and conductive heat transfer from the decay-heated core material pool to the lower head wall in contact with the core material. In this study, upward and downward heat transfer fraction ratio is focused on.

2. Experimental Apparatus

The SIGMA CP (Simulant Internal Gravitated Material Apparatus Circular Pool) loop consists of a semicircular test section, demineralized water system, heat exchanger, and the data acquisition system (DAS). The tests are conducted to check on performance of the water-cooling circuit, cable-type heaters, thermocouples and the DAS. Modified Rayleigh (Ra′) number range is from 10^{11} to 10^{15}. Water loop temperature is used to obtain the average heat flux on the bottom and top of the pool.

2.1 Test Section

The test section is made of a circular pool, whose diameter, height, and thickness are 500mm, 250mm, and 100mm, respectively. The pool's curved wall, with a 25mm thick copper plate, is cooled by a regulated water loop. A water-cooling system is used to maintain the temperature of water surrounding the test section nearly constant with time. The semicircular front and rear plates are thermally insulated. Over the period of two hours, the maximum variation of water temperature in the outer pool was less than 2℃. Forty-five (45) T-type thermocouples are mounted inside the copper wall and on the copper wall at different angular locations in order to obtain local heat fluxes. Each thermocouple is calibrated prior to testing.

2.2 Heating Method

Two thin cable-type heaters, with a diameter of 6.3mm and a length of 2000mm, are used to simulate internal heating in the pool. This method is the same as Mini-SIGMA CP [1]. They are uniformly distributed in the semicircular section, and thus can supply a maximum of 3kW power to the pool. The uniformity of heat generation rate is identified by the temperature at six (6) different locations. Average temperature rise rate is 0.044(℃/sec) and 0.0007(℃/sec).

2.3 Results

Figure 1 shows that angular heat flux profile along the lower wall. From experimental data, two distinguished results are known. In the range of 0°to 70° the trend is similar to the UCLA 3D hemispherical result[2], but in the range of 70° to 90° the trend is similar to the SIMECO 2D semicircular [3].

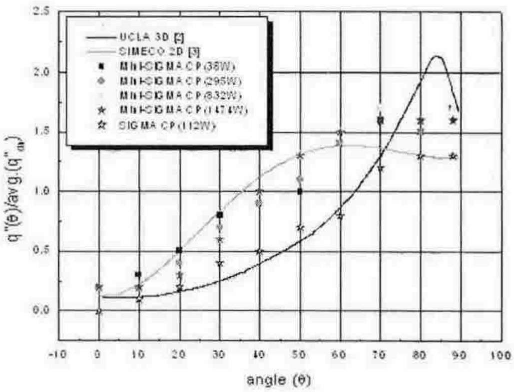

Figure 1. Heat flux profile along the lower wall.

Figure 2 shows that upward Nusselt number (Nu_{up}) at the different modified Rayleigh (Ra′) number. Experimental data has 5% uncertainty. The data trend is more or less similar to Mayinger et al. numerical correlation [4]. The SIGMA CP results are underestimated in contrast to other correlations as Ra′ increases.

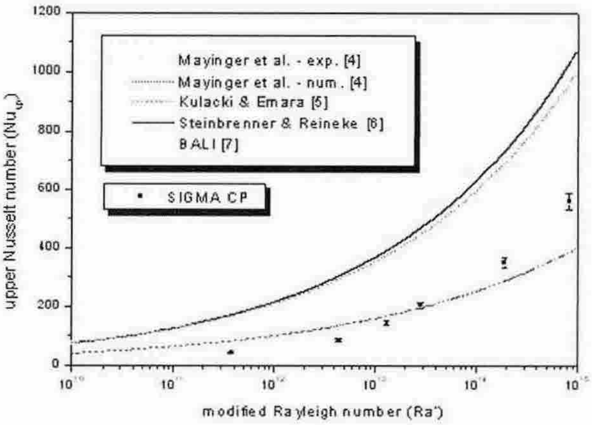

Figure 2. Upward Nusselt number versus modified Rayleigh number.

Figure 3 shows that the downward Nusselt number (Nu_{dn}) varying with the modified Rayleigh (Ra') number. The experimental data has a 5% uncertainty. The data trend lies between the Theofanous et al. correlation [8] and the Mayinger et al. rectangular correlation.

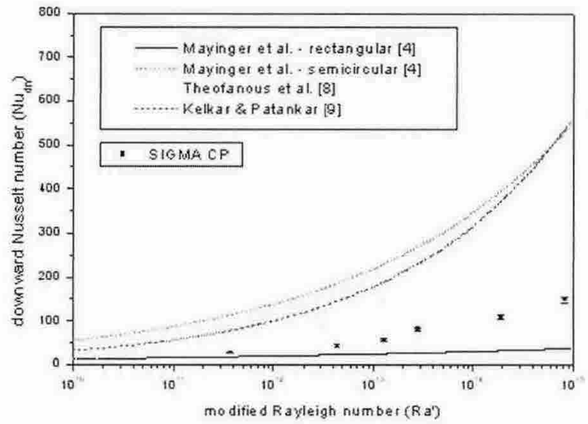

Figure 3. Upward Nusselt number versus modified Rayleigh number.

3. Conclusion

This study is focused on two standpoints. The first is uniform heat source in the test section. Uniform heating by internal cable type heaters is identified in the large size. The second is the ratio of Nu_{up} and Nu_{dn}. In this study Nu_{up} and Nu_{dn} is obtained respectively as varying Ra' number. The ratio of Nu_{up} and Nu_{dn} is 1.8 in case of Ra' number is 3.8×10^{11}. The ratio of Nu_{up} and Nu_{dn} is 3.8 in case of Ra' number is 8.3×10^{14}. It needs more experimental data to correlate in the high Ra' range.

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