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An Experimental Study on the Heat Focusing of the Metallic layer in a Severe Accident

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1. Introduction

In a severe accident, the core melt forms a molten pool in the lower head. The molten pool is typically divided into an upper metallic layer (mostly consisting of Fe and Zr) and a lower oxide pool (largely consisting of UO_2 and ZrO_2) by the density difference [1]. By flooding the reactor cavity that surrounds the vessel, significant energy can be removed from relocated corium materials through the vessel wall.

The aim of this study is to investigate the heat focusing depending on the aspect ratios and heat transfer characteristic of upper boundary for applications related to severe accident phenomena. Experiments were carried out for Rayleigh numbers and aspect ratio in the range of 8.49×10^7~5.49×10^9, 0.128~0.512 respectively. Also, the conditions of the top wall and the side wall are considered: (a) top plate cooling, side wall adiabatic, (b) top plate adiabatic, side wall cooling, (c) both walls cooling. In order to achieve high Rayleigh numbers, the heat transfer experiments were replaced by mass transfer experiments based on heat and mass transfer analogy concept. A sulfuric acid–copper sulfate (H_2SO_4–$CuSO_4$) electroplating system was adopted as the mass transfer system.

2. Previous studies

The metal layer receives heat from the corium pool and undergoes Rayleigh-Benard convection together with heat transfer to the vessel wall, subject to a highly elevated heat flux; see Fig. 1. This heat flux focusing is intensified for a thin metal layer since the transverse area for heat transfer is small. For a given thermal load at the lower boundary of the metallic layer, the fluid behavior is controlled by the thickness of the layer. This “Focusing effect” can be counteracted only by on mechanism, owing to the small aspect ratio (H/R) and heat transfer characteristic of upper boundary at which this focusing effect begins to become important [1].

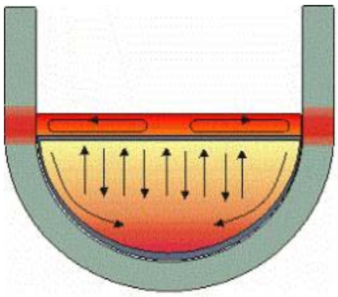


Fig. 1 Distribution of relocated molten core material.

Liu and Theofanous [2] investigated the correlations concerning heat transfers at the top/bottom and side boundaries. The experimental apparatus, called the MELAD (Metal Layer Demonstration), consists of a rectangular water box 50cm long, 10cm wide, and 10cm in height. The top and one of the sides are cooled to desired temperatures; the other side is thermally insulated, and the bottom is heated by direct electrical current using a steel foil. The front and back faces of the apparatus are insulated to create a 2D behavior. They explained that the test results are very good agreement with Globe-Dropkin correlation and that the local formulation of the Globe-Dropkin correlation combined with the Chu-Churchill correlation for the side wall are quite adequate.

Bonnet and Seiler [3] carried out an experimental study on the thermal hydraulic phenomena in corium pools at high internal Rayleigh number (10^{15} to 10^{17}) in cavities with volumetric heating. The BALI experiment has been designed to create a data base about heat transfer distribution at corium pool boundaries for in-vessel or ex-vessel configurations. They reported that a good agreement is observed with COPO Ⅱ results.

Although the studies on the focusing effect have continued, the test sections were mainly consisted of rectangular pool and hemi-cylindrical geometry and the investigation of influence on the aspect ratio (H/R) which significantly affects the focusing effect is insufficient. Also some of the studies show merely the comparison between the typical correlations and test results. Therefore, the phenomenological study needs to be performed by varying the parameters.

3. Experiments

3.1 Experimental apparatus

Figure 2 shows the system circuit. The apparatus is a cylindrical tank made of acryl, of which the bottom is the copper cathode and the top and side are copper anodes. The radius of tank is 0.074m, and the height of side wall is varied. The lower plate was analogous to the hot wall and the top plate and side wall was analogous to the cold wall in the heat transfer system.

The test matrix shown in Table I. The Rayleigh number and aspect ratio (H/R) ranged from 8.49×10^7 to 5.49×10^9 and 0.128 to 0.512, respectively.

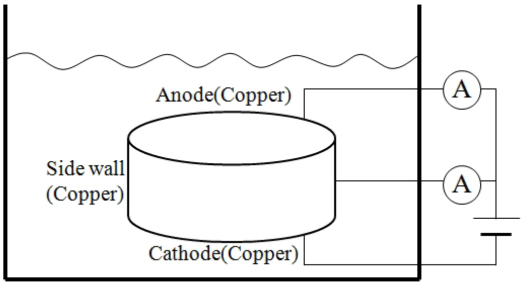


Fig. 2. The experimental apparatus.

Table I: Test matrix.

Pr	***R*(m)**	***H*(m)**	***H/R***	***Ra_H***
2,014	0.074	0.01	0.135	8.49×10^{7}
		0.015	0.202	2.87×10^{8}
		0.02	0.270	6.79×10^{8}
		0.04	0.540	5.43×10^{9}

3.2 Experimental Methodology

In order to achieve high Rayleigh number, mass transfer experiments were performed replacing heat transfer experiments based upon analogy [4]. A sulfuric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system was employed as the mass transfer system. A more detailed explanation of the methodology can be found in Chung et al. [5, 6].

4. Results and discussion

Figure 3 compares the experimental results with existing heat transfer correlations. The experimental results agreed well with the heat transfer correlations of Dropkin and Somerscales [7] and Globe and Dropkin [8]. The other correlations showed smaller Nusselt numbers than the current experimental results. However, their slopes were similar, which means that the effect of Ra_H to those Nusselt numbers is similar.

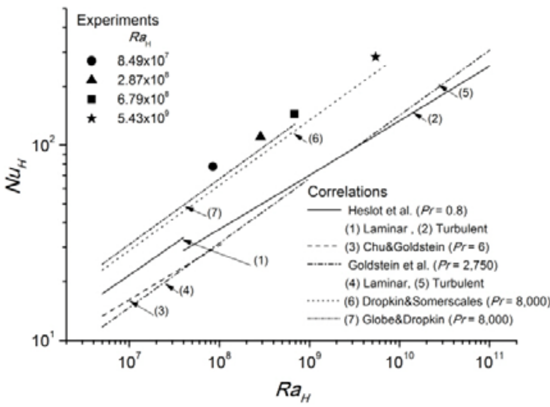
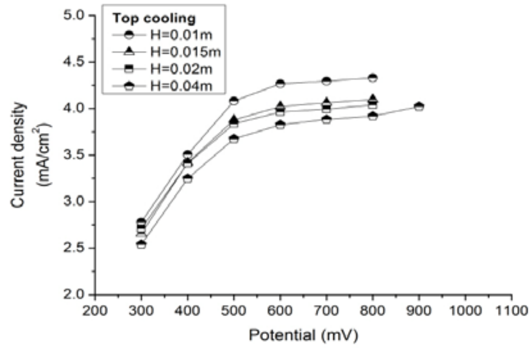
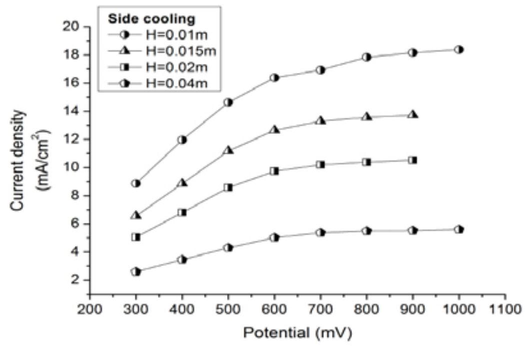


Fig. 3. Comparison of the test results with the Rayleigh-Benard natural convection.

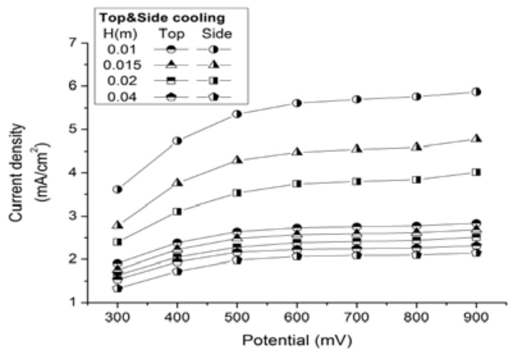
Figure 4 presents the variation of current density (heat transfer) in the three configurations: (a) top plate cooling, side wall adiabatic, (b) top plate adiabatic, side wall cooling, (c) both walls cooling. Fig 4(a) shows that heat transfer decreases as the distance between the hot bottom and cold top increases. Comparison of Fig. 4(a) and (c) shows that the reduction of current densities according to the increased heights becomes large with the cooling of side wall. The current densities of the top and side walls appeared in Fig. 4(a) and (c) shows that more heat is transferred to the side wall (focusing effect) than the top plate. Comparison of Fig. 4(b) and (c) reveals that the side wall cooling only cases show much higher current densities than both cooling cases. This means that the top cooling disturbs the side cooling. The enhancement of top cooling in a severe accident condition reduces the heat focusing to the side walls. Reversely, when the top cooling is not enough heat is focused to the side wall about 3 times.



(a) Top wall cooling



(b) Side wall cooling



(c) Top and side wall cooling

Fig. 4. The variation of current density depends on potential.

Figure 5 shows the mass transfer coefficient measured at the bottom plate according to the aspect ratio (H/R) in the three different cooling conditions. The heat transfer was enhanced by decreasing the aspect ratio (H/R) due to the interaction between the heated and cooled plumes.

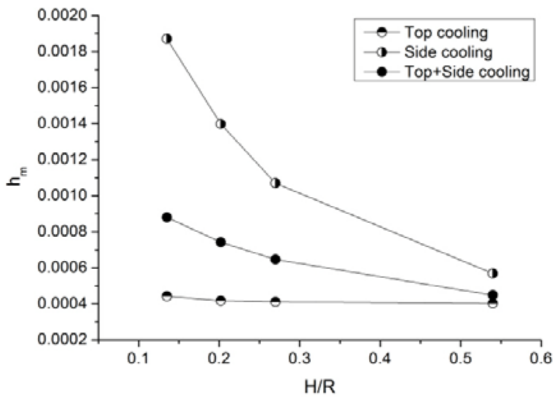


Fig. 5. h_m according to the aspect ratio (H/R).

5. Conclusions

An experimental study was performed to investigate the focusing effect appeared in the metallic layer in a severe accident condition. Mass transfer experiments, based on the analogy concept, carried out in order to achieve high Rayleigh number. The height of the side wall was varied for three different cooling conditions: top only, side only, and both top and side.

The experimental results agreed well with the Rayleigh-Benard convection correlations of Dropkin and Somerscales [7] and Globe and Dropkin [8].

The test results for the three configurations (only top cooling, only side wall cooling and both walls cooling) presented that the heat transfer on side wall cooling condition without top cooling is biggest. Also, the heat transfer was enhanced by decreasing the aspect ratio (H/R). The Rayleigh-Benard convection between the top and bottom plates, disturbs the side cooling. In order to mitigate focusing effect, the cooling condition of upper boundary and enough thickness of metallic layer were required.

ACKNOWLEDGMENT

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