Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Natural Convection Mass Transfer inside Vertical Cavities with Active/Inactive lids

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1. Introduction

Natural convection inside vertical cavities of complex geometry has drawn research attentions for many practical applications in the design of heat or mass transfer devices such as nuclear reactors, electronic circuit board enclosures and transformer cores. The existing literatures [1-3] state that the rates of heat or mass transfer at complex surface cannot, in most cases, be obtained by summing them at the individual surfaces of which the surface is composed, due to hydrodynamic interaction of the flows developed for different faces. Previous investigation of natural convection inside vertical cavities has been limited mainly to the laminar flow conditions and the simple geometrical cavity such as bottom-closed and top-closed cavity.

The present work is to investigate the effects of the top and bottom lids in vertical cavities for the wide ranges of flow conditions covering transition and turbulent flows and for the extended geometrical cavity, experimentally. Two types of cavities were used, namely, cavities with active lids and cavities with inactive lids. The measurements of mass transfer were conducted for $9.26\times10^9 \le Ra \le 7.74\times10^{12}$ and for four different geometrical cavities: both-open, bottom-closed, top-closed and both-closed cavities. Using the analogy concept between heat and mass transfer system, a cupric acid-copper sulfate electroplating system using limiting current technique was employed as the mass transfer experiments.

2. Previous study

A few experimental studies are reported [1-3], where the copper electroplating system was used commonly as the means of mass transfer measurement. Somerscales and Kassemi [1] measured natural convection mass transfer in bottom-closed cavity with active lids for $7.1\times10^7 \le Ra_D \le 6.9\times10^9$. Krysa et al. [2] conducted experiments in two types of bottom-closed cavities with active and inactive lids. Two characteristic lengths for Rayleigh number were used respectively, as L_W for active bottom and as the height H for inactive bottom. The tests were carried out for $2\times10^7 \le Ra \le 1.2\times10^{10}$. They reported the fact that the mass transfer rates for active bottom were higher than that for inactive bottom because the flows ascending from active bottom encouraged the boundary layer on the longer faces to be more fully developed. Sedahmed et al. [3] performed the experiments in the ranges of $1\times10^8 \le Ra \le 5.02\times10^9$ for the cavities with active bottom and active top. They showed that the heat transfer rates for bottom-closed cavity were higher than those of top-closed ones due to the oscillatory flows resulted from the interaction of the flows developed between sides wall and base wall.

3. Experiments

3.1 Experimental Methodology

An analogy of heat and mass transfer is established as the governing equations and parameters are of the same type [4]. This study employed a cupric acid-copper sulfate (H_2SO_4-$CuSO_4$) electroplating system using limiting current technique as the means of the mass transfer. This technique of mass transfer measurement presents a quick and accurate method in determining the mass transfer coefficient. Chung et al. [5-6] applied the methodology to the typical heat transfer problems of natural convection and mixed convection and showed the usefulness of the methodology. A more detailed description can be found in [5].

3.2 Apparatus and Test Matrix

The test apparatus is shown in Fig. 1, which is made of basically acryl pipes of inner diameter 0.035m. In the acryl pipes, copper cavities of the cathode are lined so that it can be simulated as the heated wall. The upper and lower acryl pipes without copper lining are connected to the acryl flange. The maximum height of test section is 0.5m and the inner diameter of the cathode which simulates the heated wall is 0.032m. The anode copper rod is 0.002m of the diameter.

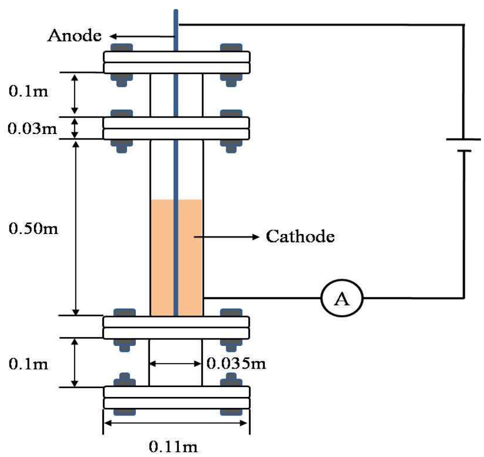

Fig. 1. Test apparatus.

Table 1 is the test matrix and the geometries. This work considers a set of cavities of constant diameter D_i of 0.032m with varying heights of the vertical cavity H

from 0.05m to 0.4m, which corresponds to $9.26\times10^9 \leq Ra \leq 7.74\times10^{12}$. The characteristic length L_w used in calculating *Sh* and *Ra* was calculated from the equation (1) proposed by Weber et al. [7]

$$L_W = \frac{\pi D_i H + \pi D_i^2 / 4}{\pi D_i} = H + \frac{D_i}{4} \quad (1)$$

Table I: Test matrix.

D_i (m)	H (m)	Sc	Ra_{Lw}	Geometry
0.032	0.05~0.4	2,094	9.26×10^9 ~ 7.74×10^{12}	Both-open, bottom-closed, top-closed, both-closed

4. Results and discussion

The mass transfer rates measured for four geometries are shown in Fig. 2 (Active lids) and 3 (Inactive lids). The horizontally flat sides of the symbols denote the closed face/faces. With active lids, bottom-closed cavity showed the highest mass transfer rates and then followed both-closed, top-closed and both-open ones in both laminar and turbulent flows. While, with inactive lids the similar trends were observed except that the mass transfer rates for both-open were higher than top-closed ones. And the use of active lids enhanced the mass transfer rates.

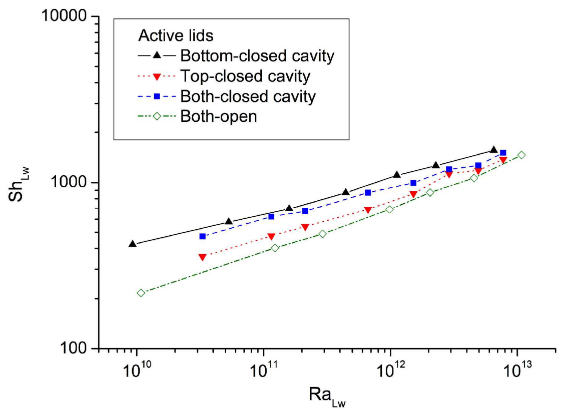

Fig. 2. Mass transfer rates for cavities of active lids.

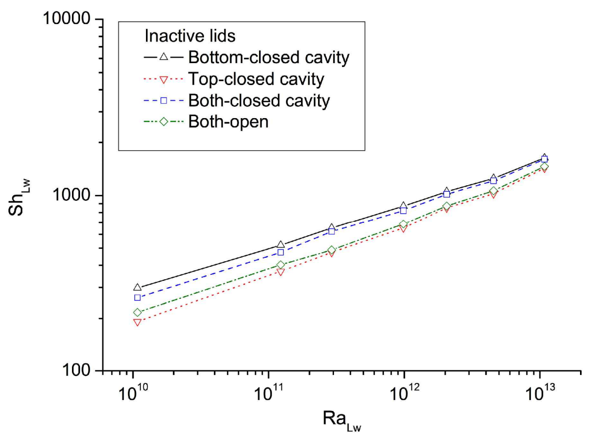

Fig. 3. Mass transfer rates for cavities of inactive lids.

Active lids located horizontally in top and bottom of the cavity is the circular heated surfaces corresponded to 5.53×10^9 of Ra_D and caused the turbulent flows [8]. Thus, the flows developed from top and bottom result in interactions with the flows ascending on the side surfaces of the cavity, and consequentially the mass transfer rates increased. On the basis of the results, the empirical correlations for four geometries were derived in Table 2 as the forms of $Sh = cRa^n$.

Table II: The empirical correlations.

	Active lids		Inactive lids	
Geometry	Lam. (c/0.271)	Tur. (c/0.285)	Lam. (c/0.252)	Tur. (c/0.281)
Bottom-closed	0.65	0.37	0.84	0.35
Both-closed	0.59	0.34	0.77	0.34
Top-closed	0.47	0.31	0.61	0.30
Both-open	(0.67/0.25)	(0.31/0.28)	(0.67/0.25)	(0.31/0.28)

5. Conclusions

The effects of active or inactive lids on the natural convection mass transfer inside vertical cavities were investigated. With active lids, the bottom-closed cavity showed the highest mass transfer rates and then followed both-closed, top-closed, both-opens in laminar and turbulent flows. While, with inactive lids the similar trends were observed except that it was higher for both-open than for top-closed one. This study concluded that the use of active lids increased the mass transfer rates in comparison with inactive lids due to the hydrodynamic interactions of the flows developed for the different heated surfaces. The empirical correlations were proposed.

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