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Boundary Condition Dependent Natural Convection in a Rectangular Pool with Internal Heat Sources

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1. Introduction

This paper presents results of steady-state experiments concerned with natural convection heat transfer of air in a rectangular pool in terms of the Nusselt number (Nu) versus the modified Rayleigh number (Ra′) varied from 10^9 to 10^{12}. Cable-type heaters were immersed in the working fluid to simulate uniform volumetric heat generation. Three types of boundary conditions were adopted in the test: I. bottom cooled, II. top cooled, and III. top and bottom cooled. The other sides were kept insulated. The normalized upward heat transfer ratio, $Nu_{up}/(Nu_{up}+Nu_{dn})$, turned out to be 1.3 in the range of Ra′ between 1.05×10^{10} and 3.68×10^{11} in boundary condition III. Whereas the upward heat transfer coefficients for conditions II and III were similar, the downward heat transfer coefficient for condition I was less than that for condition III.

2. Experimental Apparatus

The SIGMA RP (Simulant Internal Gravitated Material Apparatus Rectangular Pool) consists of a semicircular test section, demineralized water system, heat exchanger, and the data acquisition system (DAS).

2.1 Test Section

SIGMA RP is of a rectangular cavity 500 mm long, 160 mm wide, and 500 mm high. The walls of the test apparatus were made of acryl. The upper and lower plates of the test section were made of copper to enhance heat transfer. The pool height, which is the distance between the upper and lower plates, had a tolerance of 1.0 mm. The test section was built for heat transfer as well as temperature distribution measurements. The width-to-height ratio (Y/L) of the rectangular pool was greater than 0.25 to avoid the wall effect according to Dinh et al. [1].

2.2 Heating Method

Forty thin cable-type heaters, 4.2 mm in diameter and 500 mm in length, were installed to simulate internal heating in the pool. The heater average resistance was 210 Ω within 5 %. The heaters were uniformly distributed to supply a maximum power of 2 kW to the rectangular pool. The distance between centers of the heaters was 40 mm horizontal and 50 mm vertical. The temperature increased at 0.0012 ℃/s with a deviation of 0.0002 ℃/s. The rate of temperature rise at any location in the pool did not differ by more than ±12 % from the mean value. The results demonstrated practicability of the internal heater method to simulate uniform volumetric heat generation in SIGMA RP. The physical properties of the fluids which were needed to compute the dimensionless numbers and Ra′ were determined at the mean (T_m) of maximum (T_{max}) and boundary (T_b) temperatures. The subscript 'm' refers to the physical property at $T_m=(T_{max}+T_b)/2$. All data were recorded once a steady state had been established. The steady state was such that the temperature fluctuation stayed within ±0.2℃ over a period of 1 h.

2.3 Results

Figure 1 illustrates the upward heat transfer data for the isothermal upper wall and insulated lower wall. A correlation has been developed as

$$Nu_{up} = 0.176 Ra'^{0.247} \qquad (1)$$

in the range $9.93\times10^9 < Ra' < 3.32\times10^{11}$.

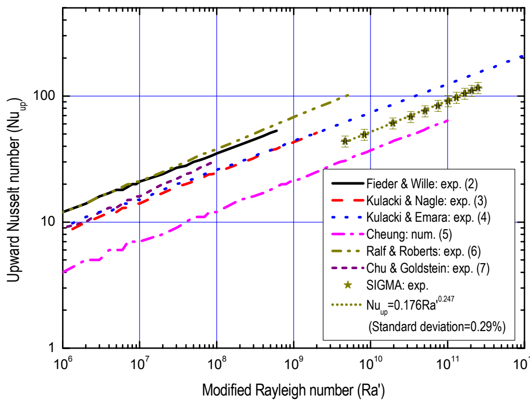

Figure 1. Upward Nusselt number with isothermal upper wall and insulated lower wall.

Figure 2 presents the upward heat transfer data with isothermal upper and lower walls. Nu was less than previous correlations in the range of Ra′ = 10^{12}. A correlation has been developed as

$$Nu_{up} = 0.191 Ra'^{0.238} \qquad (2)$$

given $1.05\times10^{10} < Ra' < 3.68\times10^{11}$.

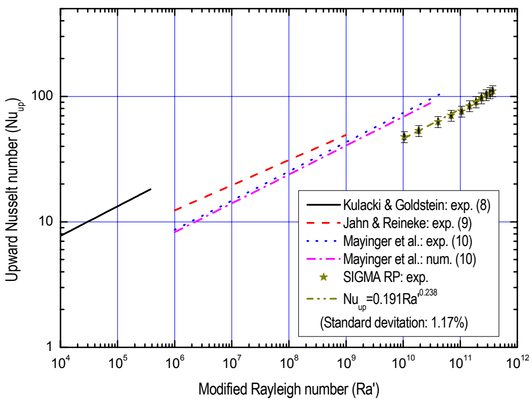

Figure 2. Upward Nusselt number with isothermal upper and lower walls.

Figure 3 shows the downward heat transfer data with isothermal upper and lower walls. The data lay between Jahn and Reineke [9] and Mayinger et al. [10] in the range $10^{10} < Ra' < 10^{12}$. A correlation has been developed as

$$Nu_{dn} = 1.285 Ra'^{0.114} \quad (3)$$

for $1.05\times10^{10} < Ra' < 3.68\times10^{11}$.

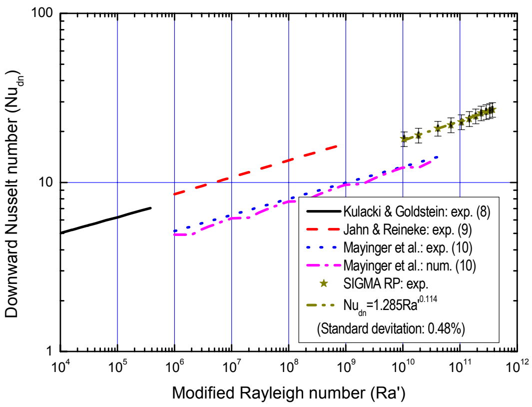

Figure 3. Downward Nusselt number with isothermal upper and lower walls.

3. Conclusion

A series of natural convection tests were conducted in a rectangular pool with volumetrically heated air at high Ra′. The internal heating method using the cable-type heaters was adopted in this experiment, Results showed the feasibility of simulating the volumetric heat source. Major findings from this study may be summarized as follows.

1. The volumetric heating by internal heaters has successfully been adopted to produce uniform heat source in a rectangular pool.
2. When the upper and lower walls of the rectangular pool were isothermally cooled, the normalized upward heat transfer, $Nu_{up}/(Nu_{up}+Nu_{dn})$, approximated 1.3 in the range $1.05\times10^{10} < Ra' < 3.68\times10^{11}$.
3. The upward heat transfer coefficients between cases II and III were similar given the same Ra′. On the other hand, the downward heat transfer coefficient in case I was less than in case III. It was observed that extension of the isothermal core region resulted in enhancement of the downward heat transfer.

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