SIZE EFFECT ON FREE CONVECTION IN A SQUARE CAVITY[*]

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Abstract

Macroscale free convection has been profoundly studied in last several decades because of its extensive applications in various engineering fields [1-4]. Nevertheless, microscale free convection does not capture much attention due to less application requirements in the past [5]. In recent years, however, with the emergence of super large-scale integrated circuit and MEMS, the microscale free convection plays more and more important role in some engineering applications, for instance, microelectronic components cooling, the MEMS devices based on free convection such as micromachined convective accelerometer [6], etc.

In order to disclose the difference between microscale and macroscale free convections and clarify the characteristics of microscale free convection, the size effect on free convection in a square cavity was numerically studied in this paper. The relative importance of three control forces of free convection, inertial force, viscous force and buoyancy force was discussed, the variations of the three control forces with Rayleigh number were illustrated. The results show that the effect of viscous force compared to the inertial force on the free convection increases with the size going down. It is also found that the heat transfer correlation for the case of small Rayleigh number differs from the standard one of macroscale free convection. Finally, the scale effect on free convection coupled thermal radiation was revealed. It is demonstrated that even at high temperature, the convective heat transfer will gradually dominate the heat transfer compared to radiation when the cavity size is small enough.

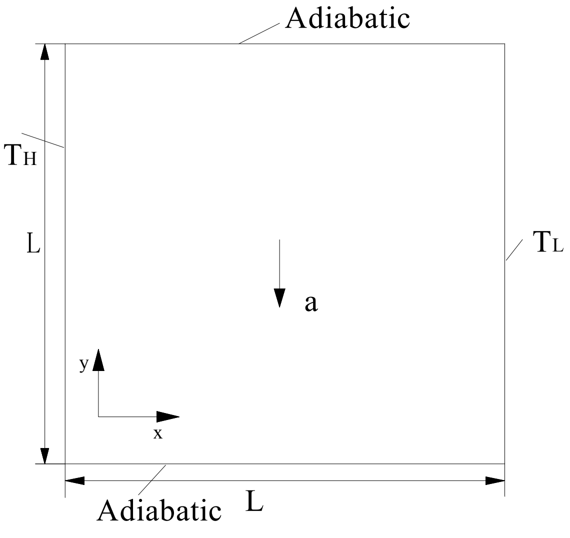

Fig. 1 Computation model

Fig. 1 exhibits the computation model in the present work. The computation code adopts commercial one named STAR-CD. Numerical validations were conducted before analyses and discussions.

Fig. 2 shows the dependence of three control forces on position in different Rayleigh number. Fig.3 reflects the variations of the ratio of the inertial force to viscous force with Rayleigh number. It is obviously seen from Fig.2 and Fig.3 that the importance of the viscous force compared to inertial force in free convection increases with Rayleigh number decreasing, the viscous force will play crucial role in affecting free convection characteristics.

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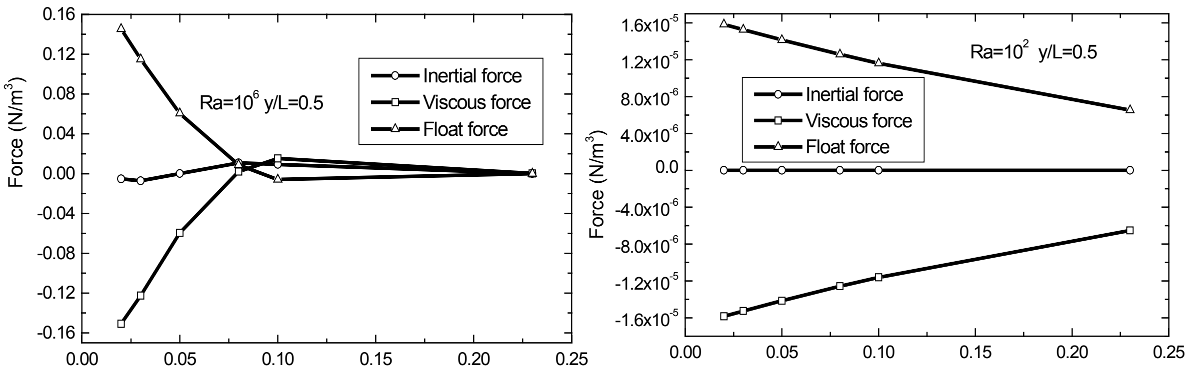
[*] Project financially supported by National Natural Science Foundation of China



(a) Ra=10^6 (b) Ra=10^2

Fig.2 Variations of three control forces with position at different Rayleigh number

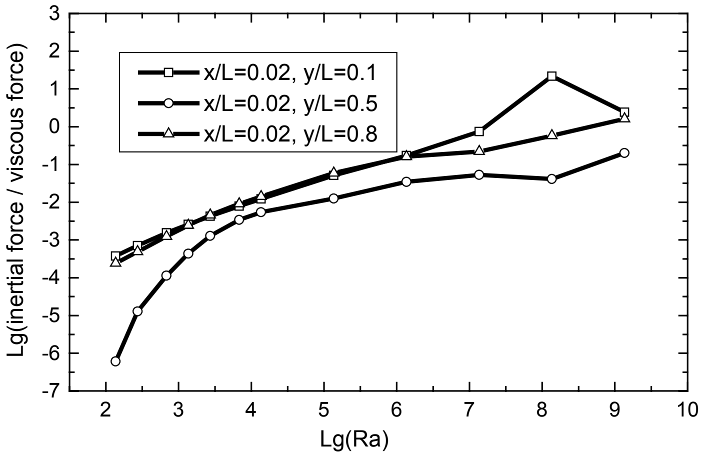


Fig.3 The ratio of inertial force with viscous force versus Ra

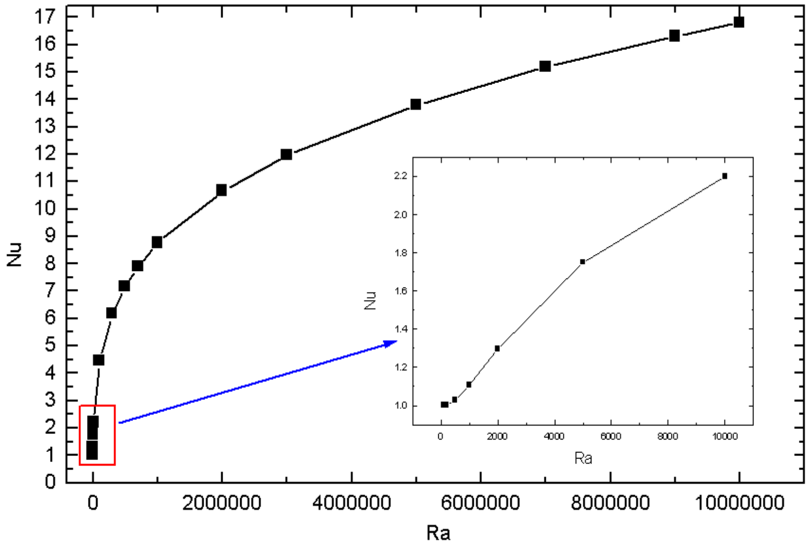


Fig.4 Nu versus Ra

Fig. 4 demonstrates the heat transfer characteristics of free convection in a square cavity. It is noted that when Ra is smaller than 10^3, the Nu nearly tends to unity, which indicates that heat conduction prevails over convection for the case of very small Ra, on the other words, very small scale. It is also found from Fig. 4 that the Nu increases more quickly with Ra in the range of 10^3 to 10^5 than that in the range of 10^5 to 10^7. This must be resulted from the variation of the relative importance of the three kinds of control forces in free convection.

Table 1 shows the percentages of convection and radiation heat transfer in total heat transfer under different temperature in micromachined convective accelerometer. The results are achieved by conventional heat transfer correlation. It should be noted here since the heat transfer coefficient of microscale free convection is larger than that predicted by conventional heat transfer correlation, the real percentage of convection heat transfer in total heat transfer will be larger than that listed in table.1. Obviously, from table.1, the convective heat transfer prevails over the radiation heat transfer in microscale free convection, even at high temperature. This is in contrast with our common idea on large-scale free convection that the radiation heat transfer is of the same order of free convection at room temperature and dominates the heat transfer at high temperature. This phenomena can be attributed to the fact that radiation and free convection have different dependence on the characteristic length, as listed in equations (1) and (2) respectively. It is clear that convection, compared with radiation, becomes more important and even dominant with the size reduction.

$$Q_c \sim L^{1.75} \tag{1}$$

$$Q_{ra} \sim L^2 \tag{2}$$

where Q_c , Q_{ra} are convection and radiation heat transfer respectively, L is the characteristic length.

Table 1 Percentages at different surface temperature in micromachined convective accelerometer

T(K) Percentage	423	573	773	973
Q_{ra}	6.88	10.27	17.69	26.8
Q_c	93.12	89.73	82.31	73.2

References

1. Eckert, E. R. G., Carlson, W. O., Natural convection in a square cavity, International Journal of Heat and Mass Transfer, 2, pp106-120, 1961
2. Newell, M.E., Schmidt, F. W., Heat transfer in natural convection within a rectangular enclosures, ASME Journal of Heat Transfer, 92, pp159-167, 1970
3. De Vahl Davis, G., Jones, I. P., Natural convection in a square cavity, International Journal of Numerical Methods in Fluids, 3, pp227-248, 1983
4. Balaji. C, Venkateshan, S. P., Interaction of surface radiation with free convection in a square cavity, International Journal of Heat and Fluid Flow, Vol. 14, No.3, pp260-267, 1993
5. Kurdyumov, V. N., Linan, A., Free conveciton from a point source of heat, and heat transfer from spheres at small Grashof numbers, International Journal of Heat and Mass Transfer, Vol. 42, pp3849-3860, 1999
6. Luo X.B. et al., A optimized micromachined convective accelerometer with no proof mass, Journal of Micromechanics and Microengineering, Vol.11, No.5, pp504-508, 2001