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Characteristics of mixed convection heat transfer in a lid-driven square cavity with various Richardson and Prandtl numbers

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ABSTRACT

In mixed convection flows, a common knowledge is that the heat transfer in a cavity is increased with increasing Grashof or Reynolds number when its respective Reynolds or Grashof number is kept at constant. On the other words, the heat transfer would increase if the flow proceeds toward pure natural convection or forced convection dominated regimes. An unanswered question is that would the heat transfer be increased continuously with simultaneously increasing both Grashof and Reynolds numbers, while keeping the Richardson and Prandtl numbers constant. And to what extent the mixed convection flows would change from laminar to chaos. These questions motivate the present study to systematically investigate the flow and heat transfer in a 2-D square cavity where the flow is induced by a shear force resulting from the motion of the upper lid combined with buoyancy force due to bottom heating. The numerical simulations cover a wide range of Reynolds ($10 \leq Re \leq 2200$), Grashof ($100 \leq Gr \leq 4.84 \times 10^6$), Prandtl ($0.01 \leq Pr \leq 50$), and Richardson ($0.01 \leq Ri \leq 100$) numbers. The average Nusselt numbers are reported to illustrate the influence of flow parameter variations on heat transfer, and they are also compared with the reported Nusselt number correlations to validate the applicability of these correlations in laminar flow regimes. Time traces of the total kinetic energy and average Nusselt number are presented to demonstrate the transition of the flows from laminar to chaos.

1. Introduction

Mixed convection heat transfer is perhaps one of the most frequently encountered physical processes in applied engineering, such as solar collectors, cooling of electronic devices, heat exchangers, materials processing, crystal growth, float glass production, metal coating and casting, and among others. In order to understand the complex physical phenomena associated with fluid flow and heat transfer, numerous studies of mixed convection driven by a combination of buoyancy and shear forces in rectangular or square cavities have been reported extensively in the literature. The study of such a problem is generally grouped into the horizontal [1–10] or vertical [11–15] side wall sliding lid-driven cavity problems except that the horizontal or vertical walls are differentially heated. In most of these studies, the authors were mainly concentrated on identifying the flow regimes and heat transfer characteristics when the Richardson number ($Ri = Gr/Re^2$) was varied, viz. the flow and heat transfer is dominated by forced convection when $Ri \leqq 1$, it is dominated by natural convection as $Ri \geqq 1$, and it is a mixed regime when Ri is of the order of 1.

In mixed convection flows, the parameters that affect heat transfer are Pr, Gr, and Re. The Gr and Re are generally grouped into a single parameter Ri. The variation of Ri is made by either changing Gr or Re and keeping one of these two parameters fixed. It has been shown that the heat transfer, in terms of Nusselt number, in a lid-driven cavity increases with increasing Pr, if Gr and Re are kept constant [2]. For a fixed Pr, the heat transfer is increased with increasing Gr or Re when its respective Re or Gr is kept constant [2,5,7,9,10,15]. An unanswered question is that would the heat transfer be increased continuously with simultaneously increasing both Gr and Re, while keeping Ri and Pr constant. And to what extent the mixed convection flows would change from laminar to chaos. These questions have not been addressed in the literature. Moreover, the characterization of heat transfer performance in mixed convection flows is generally made by evaluating the magnitude of Nusselt number. In order to provide useful information for design applications, the experimentally measured mean heat flux values [7] and numerically calculated average Nusselt number [2,16] were used to produce Nusselt number correlations. These Nusselt number correlations are assumed to be valid for a wide range of mixed convection

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