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BUOYANCY DROP HYSTERESIS IN A TWO-DIMENSIONAL COUNTERCURRENT LAMINAR OPPOSING MIXED CONVECTION SYSTEM

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ABSTRACT

A laminar, two-dimensional and opposing mixed convection flow confined inside a vertical channel of finite length with adiabatic walls and discrete and isothermal heat sources has been studied numerically by solving the unsteady two-dimensional Navier-Stokes and energy equations. The dynamical behavior of the system is influence by geometrical parameters and three nondimensional parameters: the Reynolds, Richardson, and Prandtl numbers. Results show that for a fixed value of the Reynolds number, if the Richardson number is increased and then decreased along the same path, hysteresis is noted. To understand the principles of this hysteresis behavior, the dynamical properties of the system are analyzed in detail. Numerical predictions of the velocity and temperature fields show that the descending step size does not change the size of the hysteresis effect.

INTRODUCTION

The response of internal forced flow to opposing buoyancy forces is important for understanding heat transfer dynamics due to its relevance in thermal problems related to the cooling of modern electronic equipment, design of compact heat exchangers and solar energy collectors [1-4]. The complexity of gravity driven flows subjected to differential heat sources has been extensively studied in the past. Although multiple studies for laminar opposing mixed convection flows are available in the literature [5-8], most of them focus on studying flow reversion, vortex generation, and the resultant flow and heat transfer characteristics. However, relatively fewer studies deal with the investigation of the self-oscillatory characteristics of Navier-Stokes-type systems in mixed convection [9-12].

Recently, transient laminar flow opposing mixed convection in a vertical channel of finite length subjected to isothermal and discrete heat inputs was studied numerically by solving the unsteady two-dimensional Navier-Stokes and energy equations for the case of symmetrical heating [13]. Results show that with increase in the buoyancy parameter, for a fixed Reynolds number, the system undergoes several transitions and exhibits states of asymmetrical steady-state (symmetry-breaking bifurcation), local vortex oscillation (Hopf bifurcation), global relaxation oscillation (gluing bifurcation), and later chaos. Although it is well known that countercurrent mixed convection systems support multiple dynamical states depending on the value of buoyancy forcing, hysteresis appears not to have been measured or computed for these nonlinear dynamical systems. Nevertheless, the important role of hysteresis has been observed and is well established for a long time [14-16]. Because hysteresis represents a non-trivial impediment to optimizing compact heat exchanger design and cooling of modern electronic equipment, it is desirable to identify conditions such that multiple dynamical states cannot occur. To achieve this goal, the control of these systems requires knowledge of the flow structure and in particular of the conditions for stability and transition to different states.

In this paper, numerical predictions are carried out to examine the changes in the dynamical state of a countercurrent gravity driven mixed convection system when increasing and subsequently decreasing the value of the buoyancy parameter. From the numerical simulations, buoyancy drop hysteresis is observed, such that the transition between different dynamical states proceeds along different paths depending upon the flow's time history. This work deals with quantifying and describing