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Natural convection and wall condensation or evaporation in humid air-filled cavities subjected to wall temperature variations

H. Sun, G. Lauriat*, X. Nicolas

Université Paris-Est, Marne-la-Vallée, Laboratoire Modélisation et Simulation Multi Echelle (MSME UMR 8208 CNRS), 5 Bvd Descartes, Champs-sur-Marne, F-77454 Marne-la-Vallée cedex 2, France

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ABSTRACT

Heat and mass transfer by natural convection coupled to wall surface condensation or evaporation in a two-dimensional cavity subjected to uniform, but time-dependent wall temperatures is investigated numerically. At initial state, the cavity is filled with quiescent humid air at uniform temperature and density. By decreasing the wall temperature, condensation occurs at the four wall surfaces until an equilibrium thermodynamic state is reached. The walls are then heated and evaporation of the liquid water film is considered. Various time variations of the wall temperature were investigated. Since the mass of humid air and average pressure experience large changes during transient regimes, a weakly compressible formulation has been used. The model considers only condensation/evaporation under the thin film approximation. The computations were carried out for temperatures of humid air varying between 300 K and 350 K, and pressure variations around atmospheric pressure. The typical width of the cavities is $L = 0.1$ m. The results show that very different transient flow structures occur during condensation and evaporation processes. The thickness distributions of the water films condensed at the walls are discussed, and it is shown that the thicknesses reflect the flow structures. The effect of the cavity aspect ratio reveals more complicated results than for convection without phase change at the wall surfaces.

1. Introduction

The study of natural convection in enclosures is of great importance in a number of applications. A considerable number of theoretical, numerical and experimental studies have been thus conducted over the last forty years on natural convection in cavities of various shapes. The idealized problem of natural convection in differentially heated rectangular cavity was the most studied, including different angles of inclination, various flow regimes and temperature dependent fluid properties. Solutal or thermosolutal convection was also widely investigated for uniform wall concentrations of a dilute species in a binary mixture. These works were generally concerned with steady-state situations and were based on the Boussinesq approximation. The applications relevant to these studies are, for example, convection of moist air resulting from different levels of temperature and humidity that occurs in building construction elements, such as hollow bricks, energy efficient housing in warm and humid climates, greenhouses and flat plate solar collectors. Similar situations can be found in insulated container, liquid fuel storage, refrigeration equipment, to name just a few. The problem of wall convective condensation of vapor carried by a non-condensable gas flowing through ducts, or wall evaporation of liquid into a flowing non-condensable carrier gas, was thoroughly investigated during the last past decades, especially for humid air. A large number of works were devoted to forced or mixed convection in vertical ducts, and the assumption of thin film thickness was most often invoked, as in Lin et al. [1]. The flow of falling liquid films over the duct walls were also considered by using boundary layer-type formulations, for laminar as well as for turbulent duct flows. The recent papers by Rao et al. [2,3] give comprehensive overviews on the current state of art pertaining to this problem.

Relative to the numerous published studies on thermosolutal convection in liquid filled cavities, experimental as well as numerical works combining heat and mass convective transport in binary gas mixture has received less attention. Transient natural convection in a binary mixture in square enclosures was numerically considered by Lin et al. [4]. The emphasis was put on the effects of the combined thermal and solutal buoyancy forces on temporal

* Corresponding author.
E-mail addresses: hsun01@univ-mlv.fr (H. Sun), lauriat@univ-mlv.fr (G. Lauriat), nicolas@univ-mlv.fr (X. Nicolas).

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