International Communications in Heat and Mass Transfer 38 (2011) 442–448

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Predictions of buoyancy-induced flow in various across-shape concave enclosures ☆

Chin-Lung Chen [a,*], Chin-Hsiang Cheng [b]

[a] Department of Mechanical Engineering, Lee-Ming Institute of Technology, Taipei, Taiwan, ROC
[b] Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan, Taiwan, ROC

ARTICLE INFO

Available online 8 January 2011

Keywords:
Buoyancy-driven flow
Finite difference method
Concave enclosure

ABSTRACT

The present study was conducted to numerically investigate the steady laminar buoyancy-driven and convection heat transfer characteristics within three different across-shape concave enclosures for the Prandtl number of 0.71 and 4, the Grashof number range $10^4 \leq Gr \leq 2 \times 10^5$, and the gap range $0 \leq H_1/H_2 \leq 0.25$. The steady Navier–Stokes equations, governing the flow under Boussinesq approximation, are solved with the dimensionless stream function-vorticity formulation in terms of curvilinear coordinates using the finite difference method. The results show that the effects of various shapes, the strength of the vortex is relatively bigger in the rectangular–rectangular concave enclosure than in the rectangular–circular concave enclosure at the same Grashof number. Heat transfer from the different across-shape concave enclosures is evaluated, and flow and heat transfer characteristics are discussed.

1. Introduction

The buoyancy-induced flow in a fluid-filled concave enclosure is a topic of interest for many researchers, due to its wide ranging of applications in concentrating solar collectors [1,2], lubrication systems [3,4], electronic equipment cooling [5,6], and solar energy systems [7,8], to crystal growth [9,10]. Natural convection arises in a fluid due to the density variations caused by the temperature differences of the system.

Unfortunately, it seems that most previous convection focused mainly on the flow with concave surface and plate, for example, Yang et al. [11] experimentally investigated the slot jet impingement cooling on a semi-circular concave surface when jet flows were ejected from three different slot nozzles. Results are obtained and the average heat transfer rates for impingement on the concave surface are found to be more enhanced than the flat plate results due to the effect of curvature. Numerical study of the formation of Goertler vortices in natural convection over a rotating concave surface was studied by Lin and Chen [12]. It was seen that the buoyancy force and Coriolis force are found to significantly affect the flow structure and heat transfer. However, centrifugal force has minor stabilizing effect on the flow. A recent study by Eren et al. [13] dealt with the nonlinear flow and heat transfer characteristics for a slot jet impinging on a slightly curved concave. The experimental results presented in this report exhibits new correlations for local, stagnation point, and average Nusselt numbers as a function of jet Reynolds number and dimensional circumferential distance. In addition, Miao et al. [14] predicted the three-dimensional flow and heat transfer of concave plate that is cooled by two staggered rows of film-cooling jets. Results of this study demonstrate that the blowing ratio is one of the most significant film-cooling parameters over a concave surface. Lately, Jefferson-Loveday et al.[15] performed LES of impingement heat transfer on a concave surface. It is concluded that the presence of feedback mechanisms should be considered when designing experiments and/or numerical simulations for this case, and that the importance of boundary conditions for LES should not be neglected. Thus, the buoyancy-induced flow phenomenon in a concave enclosure has not been clarified.

Recently, in buoyancy-induced flow, concave enclosure may play an important role in the flow and heat transfer characteristics. Therefore, the effects of concave enclosure have also been studied by a number of authors. To name a few, Ouyang et al. [16] were mainly focused on the analysis of CdTe vertical Bridgman growth in a rectangular concave enclosure and in a circular concave enclosure. The present study reveals that although the two ampoule configurations are quite different, their influence on the melt-sold interface shape is modest, and undesirable concave interface appears in both cases. To name a few reports concerning the irregular concave enclosures, Banerjee et al. [17] conducted numerical simulation of transport process during Czochralski growth of YAG crystals in a circular enclosure. Results have been obtained for thermal boundary conditions that do not change with time, a constant diameter growing crystal for which the pull velocity changes with time.

On the other hand, according to the data obtained, it is recognized that the concave enclosure shape has profound influence on the natural convection heat transfer. Unfortunately, the effects of concave enclosure geometry on the flow and thermal behavior have not been

☆ Communicated by W.J. Minkowycz.

* Corresponding author. Department of Mechanical Engineering Lee Ming Institute of Technology, No.2-2, Lee Juan Road, Tai-shan, Taipei County, 24305 Taiwan, ROC.
E-mail address: chencl@mail.lit.edu.tw (C.-L. Chen).

0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2010.12.027