Applied Thermal Engineering 63 (2014) 304–322

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

A review on natural convection in enclosures for engineering applications. The particular case of the parallelogrammic diode cavity

A. Baïri[a,*], E. Zarco-Pernia[a], J.-M. García de María[b]

[a] Université Paris Ouest, LTIE-GTE EA 4415, 50, rue de Sèvres, F-92410 Ville d'Avray, France
[b] Universidad Politécnica de Madrid, Ronda de Valencia 3, E-28012 Madrid, Spain

HIGHLIGHTS

- Natural convection in enclosures. Large collection of studies on cavities of different shapes.
- Engineering applications.
- Analysis of the results obtained from different solving techniques.
- Review of parallelogram-shaped, natural convective diode cavity.
- Influence of the main physical parameters on the natural convective heat transfer.

ARTICLE INFO

Article history:
Received 5 July 2013
Accepted 31 October 2013
Available online 9 November 2013

Keywords:
Natural convection in cavities
Thermal engineering
Parallelogram-shaped cavity
Engineering applications

ABSTRACT

This paper presents a review of some results of research on natural convection in cavities. The compilation serves to underline the broad spectrum of scientific and engineering fields where the knowledge of natural convection in enclosures is advantageously applied. The principal cavity geometries treated in the literature and their effect on the flow features are revisited. A great variety of configurations of the enclosures with different shapes and inclinations, thermal boundary conditions, initial conditions, heat source distributions, nature of the fluid and radiative properties, are examined. The review also considers the achievements and limitations of the different experimental, numerical, analytical and inverse methods approaches used when dealing with this problem. Published works cover a wide range of Rayleigh numbers going from rather simple laminar, steady-state cases to highly unstable, transient and turbulent flows.

The review is particularly devoted to the parallelogram-shaped cavity, also called convective diode cavity, and hence a comprehensive list of published works is provided for this case.

Contents

* Corresponding author.
E-mail addresses: abairi@u-paris10.fr, bairi.a@gmail.com (A. Baïri).

1359-4311/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2013.10.065

1. Introduction

Convection represents one of the three basic modes of heat transfer. This thermal exchange phenomenon involves mass transfer. Convection is forced when it is produced by external mechanical factors such as fans or pumps. When it is spontaneous, it is termed natural or free convection. Besides the advantage of its spontaneous nature, natural convection excludes the risks of mechanical malfunction existing for systems actuated by forced convection. This is quite important in engineering, since the need for electrical supply and electronic regulation required for such systems is therefore eliminated. This results in reducing electrical and electronic failure risks and induces important cost savings. Device reliability, which is a fundamental aspect for practical applications, is also increased. Reduction of electrical consumption contributes to environment preservation and market competitiveness of products. The absence of external mechanical devices also reduces overall size as well as sound and electromagnetic noise, whose limitation often represents an important constraint in industrial equipment specification. These few advantages explain the continuously increasing interest to resort to this thermal transfer phenomenon, especially for equipment located in limited volumes (or cavities), a frequently encountered situation in many applications. Natural convective exchanges are closely related to fluid flow produced within the volume considered. This flow is characterized by local phenomena that can either increase or, on the contrary, limit the transfer.

Engineering application of natural convection requires solving combined problems of heat transfer and fluid mechanics which depend on several parameters among which the geometry of the enclosure and the local values of the thermal and physical properties of the convected fluid. The relative position of active flow sources with respect to the gravity field also plays an important role in determining the nature of the flow. Each application thus requires a specific analysis.

A large number of articles have been published in the last decades in specialized literature, each examining a particular aspect depending on the objective pursued. Observations and conclusions found by the scientific community contribute to a better understanding of the phenomenon. Experimental setups are more and more efficient and pertinent, in all domains. Nevertheless, several aspects remain unclear and continue to be the object of active research throughout the world. In fact, the solution of coupled thermo-mechanical problems represents one of the most complex domains in physics.

In the present review are presented the main results of research activity related to natural convection in cavities. Given the large number of articles, it is obviously not manageable to provide an exhaustive list. Thus, only those articles that are suited for engineering applications and the most illustrative of the issues treated in the present work are retained.

After listing the main application domains and reviewing the methods used for solving convection transfer in engineering problems, the principal cavity geometries (configurations) and their influence on the characteristics of the flow are presented. More details are provided for parallelepiped-shape cavities with rectangular and square sections, being the most frequently treated in the literature, as well as their 2D models namely the rectangle and the square. The influence of some geometrical and physical parameters on the nature of the flow and hence on the convective exchanges in the cavity are presented. Among the most important ones, the aspect ratio, the inclination relative to the horizontal direction, the nature of the coolant fluid, the thermal boundary conditions, the initial conditions and the radiative characteristics of the fluid and of the enclosure boundaries.

The particular case of parallelepipedic geometry which has a parallelogram-shaped section is treated in this review. Studies concerning this enclosure are presented in this review as thoroughly as possible.

2. Domains of application

Natural convection in a confined environment is exploited in several activity areas. Electrical and electronic industries use it for the thermal regulation of components and devices used in various sorts of industrial equipment. Among other applications of free convection, one can cite: aeronautics, computers, automobile, nuclear energy, maritime transportation, civil engineering, solar, eolian, geothermal, heliometric and terrestrial equipment, as well as pharmaceutics, food industry and agriculture.

3. Solutions through experimental, numerical, theoretical and inverse technique approaches

Natural convective phenomena are treated numerically, experimentally and/or theoretically (analytically). The numerical approach requires the solution of non-linear partial differential equation systems consistent with fluid mechanics and thermodynamics conservation principles for extensive quantities in the considered volume. The Navier–Stokes equations governing the problems consist of continuity equation, momentum balance equations and energy balance equation, which represent the conservation of mass, linear and angular momentum and energy respectively. The numerical solution of the problem depends on the characteristics of the resulting flow. In each case, an appropriate, sometimes complex method must be used to obtain a reliable solution. The continuously improving numerical methods and computer technology facilitate deeper analysis of certain aspects of natural convection that are not yet fully understood. When applicable, numerical simulation presents several advantages provided that the mathematical and physical models are satisfactory. The numerical approach saves the cost and effort of experimental setups and measurement devices required for physical tests. It also saves time, since it enables bypassing instruments mounting, calibration, data measurement and processing. Numerical code development is nevertheless hindered by the limited capacity of