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Experimental PIV and interferometric analysis of natural convection in a square enclosure with partially active hot and cold walls

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ABSTRACT

In this paper a PIV and Holographic interferometry measuring campaign on natural convection in a square cavity (side $H = 0.05$ m) filled with air at atmospheric pressure ($Pr = 0.71$) is presented. Two strips (cold and hot) are applied on the vertical sides of the enclosure; tests involve three different configurations, with the hot strip in the middle of one wall, and the cold strip at the bottom, in the middle or at the top of the opposite wall. For each configuration measures are performed with different temperatures of the hot strip. The aim of the paper is to investigate the relation between dynamic and temperature fields and to describe how the flow and the heat transfer inside the cavity are influenced by the temperature of the hot strip and the position of the cold strip. Velocity maps, streamlines maps and interferograms are presented; the average Nusselt number and an expression of *Nu(Ra)* for each configuration are calculated. Results show that the configuration with the cold strip at the top of the wall produces the fastest dynamic field and the highest Nusselt number.

1. Introduction

Natural convection in enclosures plays a major role in a number of applications: cooling of electronic or mechanical systems, solar energy, insulating materials, building design, etc. In most cases knowledge about natural convection is used either to maximize or minimize the heat exchanged in a particular situation.

For this reason, many authors have given particular attention to this kind of phenomenon and different studies have been done, especially in the recent years, both numerically and experimentally.

General description of natural convection, with particular dedication to the knowledge of convection in cavities can be found in references [1–4].

A very large amount of studies is present in literature especially regarding rectangular cavities, with analysis considering different aspect ratios. While numerical methods allow a complete characterization of the cavity (in terms of dynamic and thermal fields), it is rare to find a complete experimental analysis of the cavity. Also, most papers consider configurations where each wall presents a homogeneous condition, either isothermal, adiabatic or with a constant heat flux.

The concern about partially heated or cooled walls is more recent, and also, for a given geometry (for example for square cavities), the number of boundary conditions that can be studied is virtually infinite. This is the reason why literature regarding cavities with partially active walls is still limited: numerical studies involving this particular situations are those by Türkoglu and Yücel [5] and Valencia and Frederick [6] who investigated the effect of heater and cooler position; reference [7] combines the effect of aspect ratio with the effect of heater size and position and also very recent studies dealing with partially heated walls are refs. [8] and [9].

Regarding experimental work, Turner and Flack [10] describe a rectangular cavity with a concentrated hot source, and analyze the temperature field in it through a Wallaston prism schlieren interferometer.

No papers containing both dynamic and thermal experimental investigations have been found for the geometry and boundary conditions analyzed; only a previous papers by Paroncini et al. [11] contains some experimental results concerning natural convection in square enclosures with partially active walls.

In this paper a measuring campaign on natural convection in a square enclosure filled with air is presented. The enclosure has two active strips (hot and cold) on the side walls and is filled with air at atmospheric pressure. Investigation is carried by analyzing temperature and velocity fields at different Ra (obtained by changing the hot strip's temperature, in the range $Ra = 5.5 \times 10^4 \div 2.5 \times 10^5$ for holographic interferometry and $Ra = 5.5 \times 10^4 \div 4.0 \times 10^5$ for PIV) and different positions of the cold strip on the wall. The

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Nomenclature

g	modulus of the gravity vector [ms^{-1}]
h	active strip distance from the cavity bottom [m]
H	dimension of the cavity's side [m]
l	height of the strips [m]
Nu_h	local Nusselt number
Nu_{ave}	average Nusselt number
Pr	Prandtl number
Ra	Rayleigh number
T	temperature [K]
x	cartesian axis coordinate [m]
X	dimensionless cartesian axis coordinate
y	cartesian axis coordinate [m]
Y	dimensionless cartesian axis coordinate

Greek letters

ε	dimensionless length of the active strips
θ	dimensionless temperature
ζ	dimensionless position of the cold strip

Subscripts

ave	average
c	cold
cal	calculated
exp	experimental
h	hot
max	maximum

techniques used in this study are 2D PIV for defining the velocity field and holographic interferometry for visualizing the temperature field and calculating the average *Nu* number.

2. Experimental equipment

Two equipments are described, corresponding to the two analyzing methods.

2.1. Holographic interferometry

The holographic interferometer (Fig. 1) is used to determine the temperature distribution inside the cell. The main elements of the holographic interferometry system are:

- a test cell, filled with air at atmospheric pressure ($Pr = 0.71$);
- a thermal system (two thermostatic baths, the thermal circuit and the temperature control system);
- a pneumatic auto-leveling table;
- a laser light source;
- all the necessary optical instrumentation.

The test cell is an enclosure having a square section (side $H = 0.05$ m) and a "deepness" of 0.42 m (Fig. 2); this length is considered big enough to neglect the end effects and to employ a two-dimensional model. All the surfaces of the enclosure are made of 0.05 m thick Plexiglas (PMMA); this material has proven a good compromise between workability, transparency to laser radiation (in the case of PIV) and thermal insulation properties for realizing the cell's walls. The end vertical walls, in the case of the holographic interferometry cell, are made up of glass to enable the passage of the laser beam. The hot and cold strips are made of aluminium and have a dimension $l = H/2 = 0.025$ m; they extend for the entire test cell deepness (0.42 m). In all experiments, the hot strip is in the middle of the left wall while the cold strip is moved in three different positions in the right wall, creating three different configurations (see Fig. 2). Defining:

$$\zeta = \frac{h}{H} \tag{1}$$

configurations are identified as follows:

- $\zeta = 0.25$, MB (middle–bottom) configuration;
- $\zeta = 0.5$, MM (middle–middle) configuration;
- $\zeta = 0.75$, MT (middle–top) configuration.

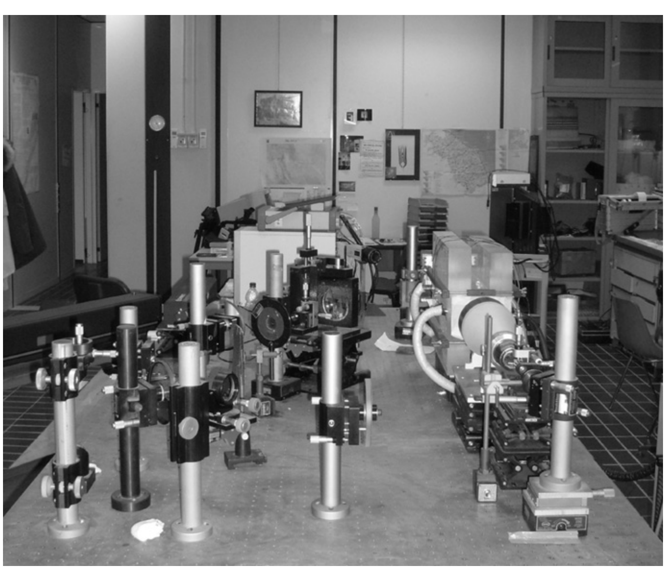

Fig. 1. Holographic interferometer.

For each configuration, the hot strip is heated and maintained at a temperature T_h using a thermostatic bath. This temperature is changed from one test to another to obtain different Rayleigh numbers. The cold strip on the right wall is kept at a temperature T_c by another thermostatic bath, set at 291.15 K and it is constant during all experiments.

The rest of the thermal circuit is the two thermostatic baths with their respective connecting pipes. The thermostatic baths are model "Proline – RP 1840", manufactured by "Lauda Corporation"; the baths accuracy is 0.01 °C and the volume of each bath is 18 l. Each pipe connecting the thermostatic baths with the inlet and outlet valves of the two sidewalls, is coated by a neoprene skin (about 0.02 m thick) for thermal insulation. The thermal fluid is a mixture of 75% water and 25% glycol (percentages in volume at 295.15 K).

The temperature measuring system is made up of seven copper-constantan thermocouples connected with an ice point reference made by "Kaye", model "K170" and an "Hp Agilent 34970A" acquisition system. Six of them are used to measure the temperature on the strips, three on the hot strip and three on the cold strip, located 1 mm under the surface of the test volume (little circles in Fig. 2). These temperatures cannot be used as a reference for the temperature distribution of the fringes during the interpretation of the interferograms (because of the diffraction effects and the high fringes density close to the strips). For this reason the last thermocouple is positioned in the middle of the air region in order to give a reference temperature for analyzing the interferograms. The