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A numerical and experimental analysis on natural convective heat transfer in a square enclosure with partially active side walls

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ABSTRACT

The present study is an experimental and numerical analysis on natural convection of air in square enclosures with partially active side walls.

The experimental study is carried out both through the holographic interferometry in order to obtain the average Nusselt numbers at different Rayleigh numbers.

The temperature distributions in the air and the heat transfer coefficients are measured by a holographic interferometry and compared with the numerical results that are obtained with the finite volume code Fluent 12.1.4.

The aim of this comparison is to investigate the influence of the size and number heat sources on the natural convective heat transfer in a square cavity.

1. Introduction

Natural convection in a square and rectangular cavities is very important for its various engineering applications: it is used, for examples, in solar energy systems, in the cooling of electronic circuits, and in air conditioning. For this reason, it is a good model for both experimental and theoretical studies. Many studies of natural convection in a square and rectangular cavities are presented in the technical literature and many of these studies analyze the convective phenomenon through numerical simulation.

Natural convection in enclosures is a complex phenomenon. Many researches have been performed on natural convection in enclosures, which are heated from one side or heated from the other. Natural convection in enclosures with isothermal vertical wall has been developed to investigate the effects of aspect ratio on the heat transfer rate (wall-to-wall). In such cases, the size and the location of the heater and cooler play an important role in the fluid flow and in the heat transfer mechanism.

Poulikakos [1] and Ishihara et al. [2] studied enclosures with partially heated and cooled zones on a single sidewall. These works are focused on the impeded flow regime, and in order to research the fluid flow and temperature distribution basically, both experiments and numerical calculations were performed for an enclosure with a rectangular cross section filled with water as a working fluid.

Aydin and Yang [3] studied numerically the convection of air in a rectangular enclosure with a localized heating from below and the symmetrical cooling from the sides. Localized heating is simulated by a centrally located heat source on the bottom wall and for different values of the dimensionless heat source length are considered.

November and Nansteel [4] studied analytically and numerically the phenomena in square, water-filled enclosures heated from below and cooled along one side. Hasnaoui et al. [5] investigated the natural convection in a rectangular cavity partially heated from below.

Tūrkoglu and Yūcel [6] investigated numerically the effects of the heater and cooler location on the vertical walls in square cavities on natural convection.

Chu et al. [7] studied the effect of heater size, location, aspect ratio, and boundary condition on two dimensional laminar natural convection in rectangular channels. In this study, on vertical walls was partially heated, and the entire opposite vertical wall was kept at a lower temperature.

In the literature for the study with multiple discrete heat sources, there are very few contribution.

Randriazanamparany et al. [8] presented a numerical study of unsteady natural convection inside an air-filled square cavity, heated from two opposite sides and cooled from the other two sides.

Banerjee et al. [9] studied an horizontal planar square cavity with two discrete heat sources flush-mounted on its bottom wall. In this present work reports steady state simulation of natural convection in a horizontal, planar square cavity with two discrete heat sources (representing power-dissipating semiconductor devices in electronics/MEMS applications), flush-mounted on its bottom wall

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Nomenclature

a	thermal diffusivity
g	modulus of the gravity vector (m s^{-2})
H	square cavity side (m)
k	thermal conductivity (W m^{-1} K^{-1})
l	heat source length (m)
L	cavity depth in the experimental tests (m)
$\overline{Nu}$	average Nusselt number of the heat source
Nu_h	local Nusselt number
Nu_{ave}	average Nusselt number
Nu_{higher}	average Nusselt number of the higher source in the configuration $l = H/4$
Nu_{lower}	average Nusselt number of the lower source in the configuration $l = H/4$
Nu_{m-m}	average Nusselt number in the configuration $l = H/2$
Pr	Prandlt number
Ra	Rayleigh number
T	temperature (K)
ΔT	temperature difference between heat sources and cold strips
x	Cartesian axis direction
X	dimensionless Cartesian axis direction
y	Cartesian axis direction
Y	dimensionless Cartesian axis direction

Greek symbols

β	thermal expansion coefficient (K^{-1})
ε	dimensionless length of the heat source
θ	dimensionless temperature
υ	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})

Subscripts

c	cold wall
cal	calculated data
exp	experimental data
h	hot wall
num	numerical data

and two cold sidewalls. The heaters are modeled as constant-flux heat sources. The computational study quantitatively depicts the critical roles played by the heater length and heater strength ratios in ensuring that the devices operate within the ‘safe’ temperature limits specified by the manufacturer. Such quantitative predictions help determine the range in which the heater sizes and/or flux strengths may be varied so that the conditions of operation remain within the specified thermal limit.

Zhao et al. [10] performed a two-dimensional calculation and theoretical for laminar natural convection induced by two discrete heating elements flush mounted to one vertical wall of a square enclosure.

Mű̈ftű̈o et al. [11] investigated the natural convection in an open square cavity with discrete heaters to determine the optimum positions of discrete heaters by maximizing the conductance.

Paroncini et al. [12,13] investigated experimentally and numerically the natural convective heat transfer in a square enclosure with partially active side walls.

Deng [14] numerically investigated the laminar natural convection in a two-dimensional square cavity due to two and three discrete heat source–sink pairs on the vertical sidewalls. Main efforts were focused on the size and arrangement effects of the sources and sinks on the fluid flow and heat transfer characteristics.

In this paper, an experimental and numerical analysis is performed to explore the heat transfer characteristics for natural convection in a square enclosure.

This study is focused on the effects of the size and the number of sources in the enclosure.

The holographic interferometry is used to study thermal behavior of the heat transfer. The objective of the heat transfer analysis is the investigation of the Nusselt numbers distribution at different Rayleigh numbers.

For each configuration studied, the experimental and numerical correlation connecting the Rayleigh numbers with the corresponding Nusselt numbers are analyzed.

The isothermal patterns obtained with the holographic interferometry are compared with the ones obtained from a numerical study performed using Fluent 12.1.4 [15] with a two dimensional model.

Finally, for each configuration, a relationship between the average Nusselt numbers and the correspondent Rayleigh numbers is elaborated.

2. Experimental system: Holographic interferometry

The main components of the experimental apparatus, shown in Fig. 1, include the test-cell, the pneumatic self-leveling table, the holographic interferometer, the optical instruments, two thermostatic baths and the data acquisition system. The test cell is filled with air of the laboratory ($Pr = 0.71$) at atmospheric pressure, the room temperature of 297 K, and a relative humidity of 50% is set.

The most important component of the experimental setup is the test cell where the convective motion happens.

The test cell is a square transversal section with sides of 0.05 m in length ($H = 0.05$ m).

In the first configuration, there are two sources made of aluminum material: one strip is located on the left lateral wall and it is heated and maintained at a temperature T_h by a fluid that circulates through a thermostatic bath, while the other one is located on the right wall and it is maintained at a fixed temperature T_c. These sources have a length of $l = H/2$, and they are located in the middle of the lateral walls.

In the second configuration, there are four sources made of the same materials of first configuration. The sizes of the sources are all kept the same as $H/4$: a source pair is located on the left lateral

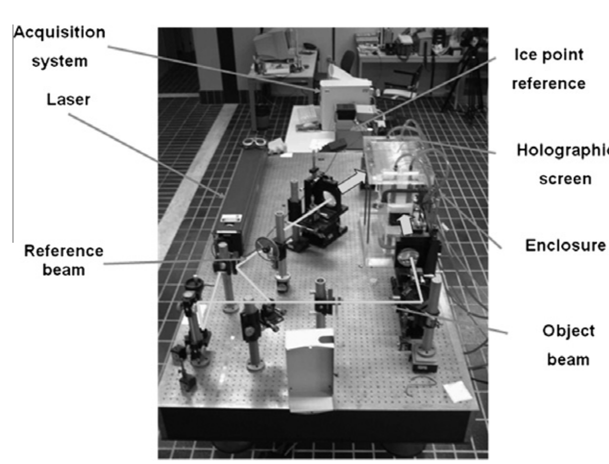

Fig. 1. The holographic interferometry.