AN EXPERIMENTAL STUDY OF TRANSIENT NATURAL CONVECTION IN A SIDE-COOLED CAVITY

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Summary Transient natural convection in a side-cooled cavity is experimentally investigated. The shadowgraph technique is used to visualize the flow in the cavity. The results indicate that the flow development is characterized by the following distinct processes: (a) the initial growth of the vertical thermal boundary layers and horizontal intrusions; (b) the interaction of the intrusions and filling up of the cavity; and (c) the stratification and formation of double layer structures.

INTRODUCTION

Natural convection has attracted numerous researchers due to a great number of applications in industry. In particular, transient natural convection in cavities is a topic of primary interest because cavities of different geometries filled with fluid are central components of many engineering systems.

It is found that in the literature studies concerning natural convection cooling of an initially isothermal fluid in cavities are rare. A few numerical simulations were conducted [1, 2], but a very limited number of experiments were carried out [3]. In [3], a rectangular cavity with only one vertical wall cooled and the other three walls insulated was considered. The lack of experimental data for cooling of fluids in cavities has motivated this study. In the present study, the transient natural convection in a side-cooled cavity is studied experimentally. The shadowgraph technique is employed to visualize the development of the flow in the cavity.

EXPERIMENTAL SETUP

We consider transient natural convection in a side-cooled cavity, as sketched in Fig. 1. The cavity is a cubic of 0.1 × 0.1 × 0.1 m^3. All walls are made of Perspex except the two copper sidewalls used to cool the fluid in the cavity. The cavity is filled with preheated water, and the water temperature is kept constant using two constant temperature water baths attached to the copper sidewalls. This process lasts for a relatively long time to ensure that the fluid in the cavity is isothermal and motionless before the experiment starts. Two circulator systems are used to provide hot and cold water for the water baths, respectively. At the start of the experiment, the hot water valve is turned off and the cold water valve is turned on. As a consequence, the cold water replaces the hot water in the water baths in order to cool the two sidewalls adjacent to the water baths. Due to the presence of a temperature deference between the fluid in the cavity and the sidewalls, transient natural convection is initiated in the cavity.

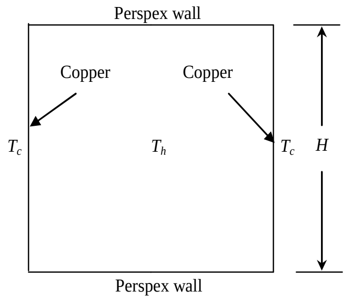


Fig. 1 Schematic of the experimental model.

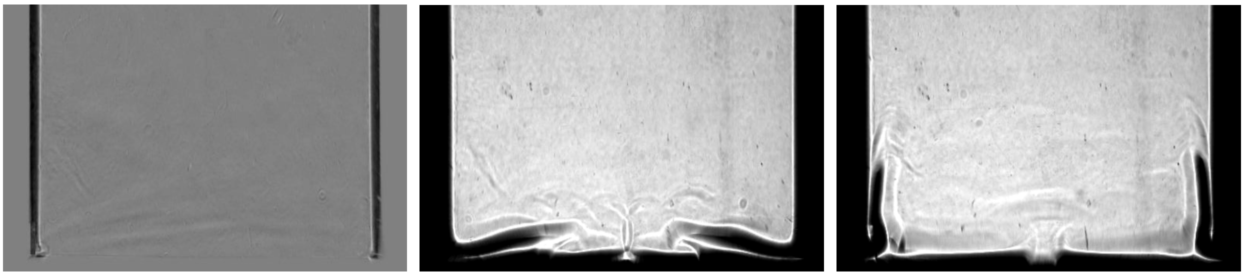
The flow field is visualized using the shadowgraph technique, which is an optical method to reveal non-uniformities in transparent media. A temperature variation within a flow filed results in a density variation and in turn a refractive index variation. When light passes through such a flow field, initially parallel light rays are refracted so that patterns, which may identified with the temperature field, are formed on a screen (more details may be found in [4, 5]).

RESULTS

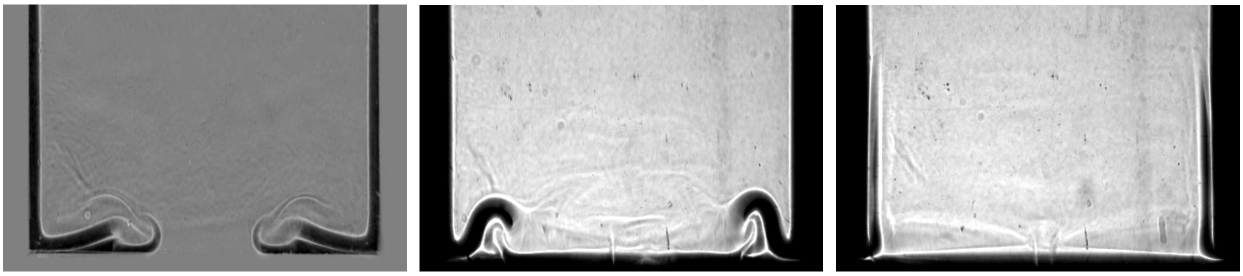
In the experiments, the two sidewalls are approximately isothermal and their temperatures (T_c) are fixed at 10^{o}C. The initial temperature (T_h) of the water in the cavity ranges from 20^{o}C to 40^{o}C with a step of 5^{o}C for different runs. The corresponding Rayleigh number (*Ra*) ranges from 1.9×10^8 to 5.89×10^8 where $Ra = g\beta(T_h\text{-}T_c)H^{\,3}/\nu\kappa$, ($g$ is the acceleration due to gravity, β is the coefficient of thermal expansion, ν is the kinematic viscosity and κ is the thermal diffusivity).

Fig. 2 presents the development of the flow in the cavity following sudden cooling for Ra = 2.89×10^8. At early times, the boundary layers adjacent to the sidewalls are growing, and the two horizontal intrusions discharged from the vertical boundary layers are formed and travel towards each other, as shown in Fig. 2(a) at times t = 10 and 18 s (These two images were processed by subtracting a background image recorded immediately before the start of the experiment so that the thermal boundary layers can be clearly identified in the images).

As time increases, the two horizontal intrusions meet and interact at the center of the bottom boundary (see t = 22 s in Fig. 2(b)). Clearly, separations of the two intrusions arise near the bottom corners respectively (also see [5]). Due to accumulation of cold fluid on the bottom, the two intrusions are drawn closer to the sidewalls, forming upright flow structures near the bottom corners (see t = 32 s in Fig. 2(b)). It is also observed that the cavity starts to be filled with cold fluid discharged from the vertical boundary layers, and the filling up process starts from the bottom and extends upwards. The continuous filling of cold fluid leads to stratification in the core, which also extends upwards (refer to numerical results in [1]). Due to the presence of stratification, double-layer structures of the vertical boundary layers, represented by two bright strips in the shadowgraph images in Fig. 2(c) (refer to [5]), are formed. As time increases further, the fluid in the cavity ultimately approaches an isothermal state, at which the temperature of the fluid is equal to that of the two sidewalls.



t = 10 s | t = 22 s | t = 56 s

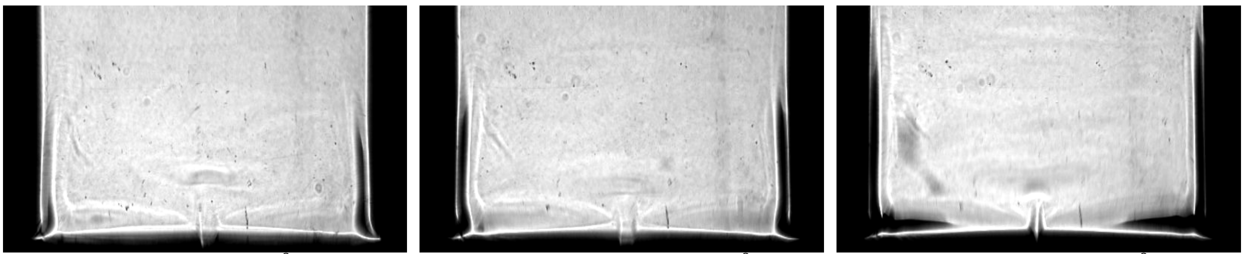


t = 18 s | t = 32 s | t = 94 s

(a) | (b) | (c)

Fig 2. Development of the flow in the cavity for $Ra = 2.89\times10^8$.

The effect of the Rayleigh number on the double layer structures is shown in Fig. 3. It is clearly shown that, as the Rayleigh number increases, the double layer structures become more distinct and grow faster (the measured length of the double layer structures are approximately 0.029 m, 0.034 m and 0.05 m for $Ra = 1.9\times10^8$, $Ra = 2.89\times10^8$ and $Ra = 5.89\times10^8$ respectively). A higher Rayleigh number means a higher temperature difference, and therefore more cold fluid is discharged into the core, leading to faster stratification and faster growth of the double layer structures.



(a) $Ra = 1.9\times10^8$ | (b) $Ra = 2.89\times10^8$ | (c) $Ra = 5.89\times10^8$

Fig. 3. Double layer structure at different Rayleigh number at t = 80 s.

CONCLUSIONS

Transient natural convection in a side-cooled cavity is experimentally investigated. The shadowgraph technique is used to visualize the flow in the cavity. The results indicate that the flow development is characterized by the following distinct processes: (a) the initial growth of the vertical thermal boundary layers and horizontal intrusions; (b) the interaction of the intrusions and filling up of the cavity; and (c) the stratification and formation of double layer structures.

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