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EXPERIMENTAL STUDY THE FLOW PATTERN IN THERMAL CAPILLARY CONVECTION

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Abstract: In the present research, the thermal capillary convection has been experimentally investigated by the aid of particle image velocimetry (PIV) technique. There is one liquid layer in a rectangular cavity with different temperature's sidewalls. The cavity is 52mm×42mm×20mm, 4mm in height of the silicon oil liquid layer. A sidewall of the cavity is heated by electro-thermal film, another sidewall is cooled by the semiconductor cooling sheet. The velocity field and the stream lines in cross section in liquid layer have been obtained at different temperature difference. The present experiment demonstrates that the pattern of the convection mainly relates with temperature difference.

Keywords: thermal capillary convection, surface tension, PIV

1. INTRODUCTION

With the development of the spaceflight techniques, Microgravity Science has been given birth to our world. There are a lot of special mass transfer laws in microgravity environment, many secondary effects covered by gravity on ground become important processes and factors. The Microgravity fluid physics studies basic physics laws of the fluid mechanics in microgravity environment, it relates with material manufacture in space, biology sample preparation. It is a link core in many microgravity sciences, and it is also the basement in application of microgravity sciences. The fluid balance, movement, thermal transfer, and mass transfer are important processes[1]. The phenomena introduced by gravity, for example buoyancy convection, sedimentation, will disappear in microgravity environment, new phenomena inspire scientists' interesting. In recent years, many scientific problems about the convection driven by surface tension have been studied[2~7]. Thermal capillary convection in a fluid layer is a typical process, it has strong application in space material manufacture.

Thermal capillary convection is driven by non-uniformity of surface tension, which comes from non-uniformity of surface temperature. It is an important fluid convection phenomenon in many fields, such as crystal growth and film science etc. The convection driven by surface tension bring on the flow of surface, and then formed a return-flow because of mass conservation. In mechanics theories, there is a shear flow near free surface, it is easy to cause instability or introduce oscillation. Because there is little opportunity to do space experiment, a lot of simulate microgravity experiments have been done on ground. While discussing an actual system of thermal capillary convection, thermal transfer is important. The coupling of thermal transfer and convection driven by surface tension is the basic character. Gravity influence also can not be neglected, the buoyancy forces still be present. In order to decrease gravity function, typical length should be much smaller in the experiment on ground.

PIV (Particle Image Velocimetry) technique has been developed and applied widely in measurement of

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fluid mechanics[8,9], it records flow structure in a cross-section simultaneously, the velocity field could be obtained by image processing. In the present experiment, PIV technique observes the evolution of convection at different temperature difference, and studies the mechanism of thermal capillary convection.

2. THE EXPERIMENT MODEL

Figure 1 shows a schematic diagram of experimental facility. The horizontal cross-section of the container is rectangular with cross-section of 52mm×42mm. Two opposite lateral walls are made of transparent K9 glass for flow visualization and PIV application. K9 glass is 6mm in thickness. Other two opposite lateral walls are made of copperplates, which are also 6mm in thickness. Electro-thermal film heated the copperplate in the right side of the cavity, eurotherm controller controlled temperature; semiconductor cooling sheet and radiator cooled another copperplate in the left side of the cavity. Temperature differences between two copperplates will be formed, and measured by T type thermocouple. The bottom of the cavity is made by adiabatic materials, whose surface can not reflect laser light. There is 4mm in height of silicon oil liquid layer in the experimental cavity. In the present experiment, temperature difference was increased at a constant speed. The fluid flow will evolve from stable convection to un-steady convection with increasing of temperature difference.

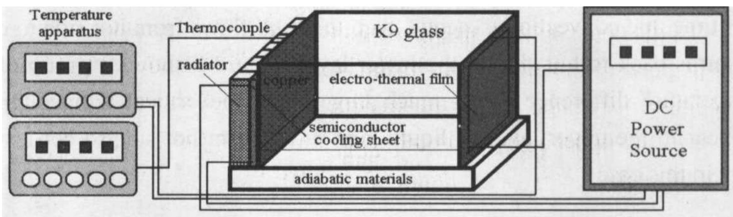

Fig. 1 Schematic diagram of the experiment apparatus

3. DIAGNOSTIC METHOD

PIV technique measured velocity field. The principle of PIV requires to illuminate a cross-section by using a pulse laser light sheet for flow field measured, to record the sequence of particles images by CCD camera (or a film), and to use image matching method of a sub-area template between two frames obtained the displacement (or velocity) at each sub-area. The advantages of PIV technique is that a velocity field on a section could be measured, the structure of flow field could be obtained.

A system of Digital Particle Image Velocimetry (DPIV) of DANTEC measurement technology A/S with FlowMap PIV 2000 Processor was used to quantitatively measure the 2-D velocity field in a vertical cross-section of the cavity during the development of thermal capillary convection, as shown in Fig.2. An argon ion laser was applied to illuminate the flow field. Pulse lights were shaped by an electro-optical shutter, which was controlled by a center processor with CCD camera synchronization. The resolution of CCD camera is 768×484 pixels with 11.6μm ×13.6μm pixel pitch. The silver-coated hollow glass spheres of 10μm in diameter as tracer particles are suspended in liquid layer. By using a cycling lens, a 1.0mm thin light sheet is shaped to illuminate a vertical cross-section at the center part of the container. This cross-correlation technique of DPIV image matching processing was used to obtain both magnitude and direction of velocity vector at the same time. Figure 3 shows the arrangement of PIV in the present experiment.

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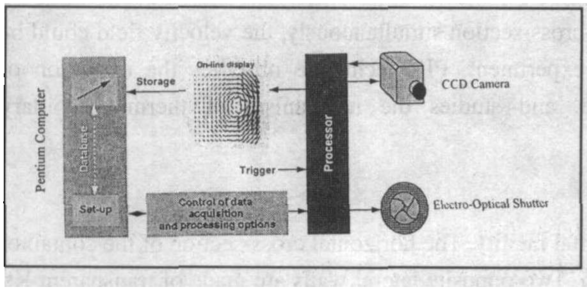


Fig. 2 Schematic block diagram of DPIV system

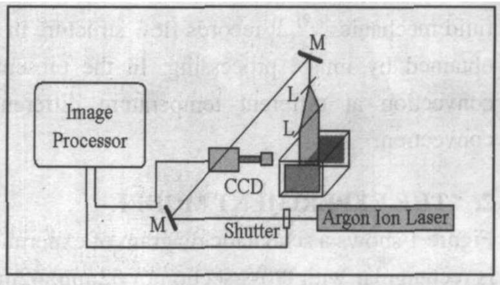
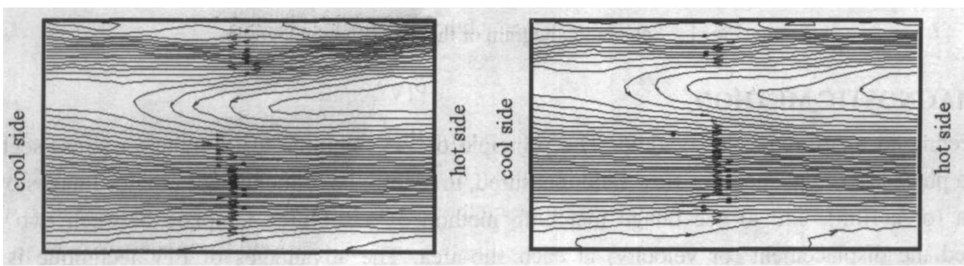


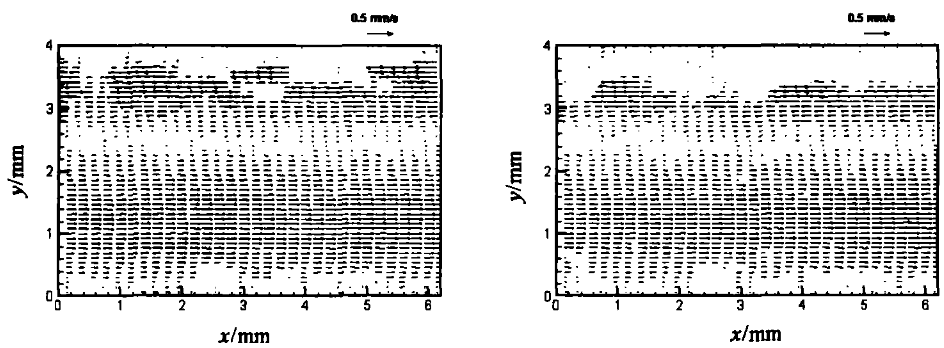
Fig. 3 Arrangement of PIV in the experiment

4. EXPERIMENTAL RESULT

In the present experiment, there is 4mm in height of silicon oil liquid layer in the cavity. Temperature difference between two sides of the cavity increased from 0°C to 50°C at the rate of 1°C/s. Micro PIV technique measured velocity field in this experiment. A light sheet is projected into fluid vertically to illuminate a cross-section along the gradient direction of temperature. The span-wise of the measured area in the present experiment is 6.2mm×4mm, which is in the middle of the cavity. Figure 4 shows four similar flow patterns (including stream lines and velocity fields) at different temperature difference ΔT, it is less than its critical value ΔT_c = 45°C, which is temperature difference of onset of temperature oscillation. At this time, the convection is steady. And the fluid flows from hot side to cool side near free surface, and then turns back to hot side in the lower layer. Figure 5 shows a group of evolutional flow pattern when temperature difference ΔT is much larger than the critical temperature difference ΔT_c. Several eddies appear in the upper layer of liquid, and move from hot side to cool side. The unsteady convection appears in this case.



(a) $t = 0.333$s (b) $t = 0.667$s



(c) $t = 0.333$s (d) $t = 0.667$s

Fig. 4 Velocity field and stream lines at $\Delta T<\Delta T_c$

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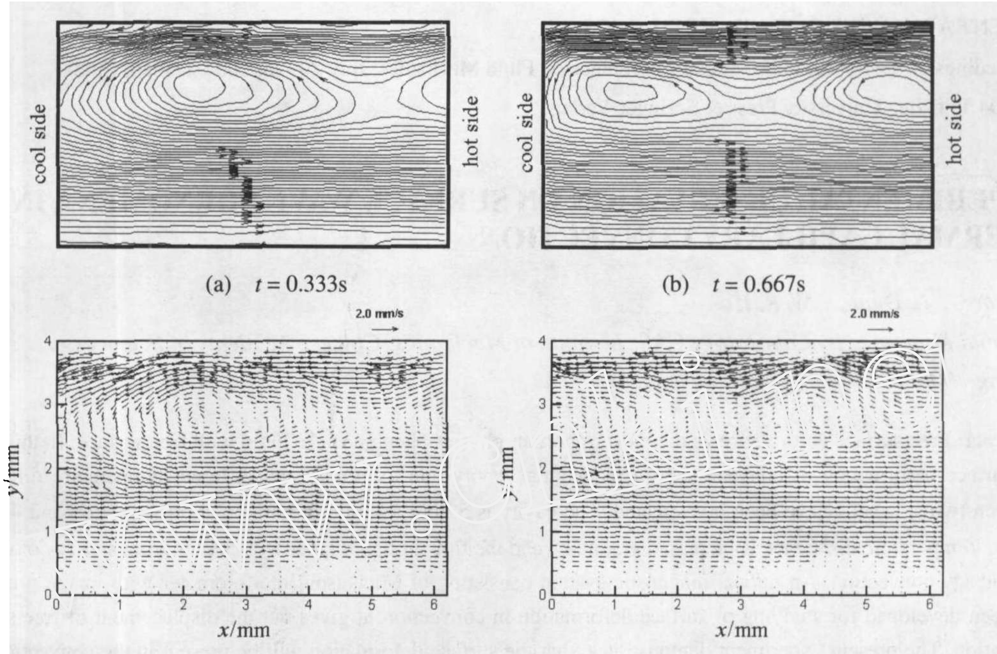

(c) $t = 0.333$s (d) $t = 0.667$s

Fig. 5 Velocity field and stream lines at $\Delta T > \Delta T_c$

5. CONCLUSION

The thermal capillary convection in a rectangular cavity with different temperature's sidewalls has been investigated by PIV technique. The cavity is 52mm×42mm×20mm, 4mm in height of the silicon oil liquid layer. The velocity field and the stream lines in the cross section in this liquid layer have been obtained in different temperature difference. The flow patterns show different evolutional law, while temperature difference ΔT is less than or larger than the critical value ΔT_c. Flow mode has been analyzed at different temperature difference according to the distribution of velocity field, and flow phenomena from stable state to un-steady state also have been analyzed.

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