Measurement of the temperature field in a Rayleight-Bénard turbulent convection cell by Light Induced Fluorescence

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Summary The temperature field in a Rayleigh-Bénard convection cell is a very important information for the understanding of the physical mechanism of the convection. By use of the two colors LIF (Light Induced Fluorescence) technique, first the temperature field of a single rising plume in a quasi-infinite media is measured, then, the temperature field of several interacting plumes is measured and finally, the temperature field in a cylindrical cell of aspect ratio one is measured.

INTRODUCTION

Rayleigh-Bénard convection has been an active field of research for the last twenty years (see [1,2] for a review), but our understanding of the turbulent convection in a Rayleigh-Bénard cell is still not complete. Several non invasive or invasive experimental techniques have been used. Among them, the heat transferred by the cell was measured by measuring the incoming heat flux and the temperature of the top and bottom plates respectively. This gives global information about the heat transfer, for instance, the Nusselt number scaling or the critical Rayleigh numbers corresponding to transitions of regime. By introducing temperature probes equally spaced around a radius either in the wall of the cell or inside of the fluid, the orientation and the behaviour of the large scale flow could be investigated [3] and compared to theoretical models. Other experimentalists [4] have introduced very small thermistors located close to each other, pointing in different directions to get information on the local fluctuations and local dissipation rates and the Reynolds numbers.
The shape of the plumes and their movement has been measured by shadowgraph technique either from the side, or from the top [5]. This technique locates the plumes and determines their shapes but do not give information on the temperature of the plumes itself. A clever way to measure the temperature field is to use thermochromic liquid crystals [6]. Although this later technique is very useful to study the morphological evolution of thermal plumes, the range of temperature where the thermochromic liquid crystal takes different colours is quite limited, what restrict the use of this technique to some special conditions. PIV (Particle Image Velocimetry) technique is another powerful technique used to determine the velocity field [7]. It has been very successfully implemented to investigate the large scale circulation in Rayleigh-Bénard turbulent convection cell of aspect ratio $\Gamma = D/L$ of 1 and ½ (D is the diameter, L is the height).
All these techniques give interesting information that helps us to understand the physical mechanism and to compare these experimental results with models and numerical simulations. In our work, the temperature field is measured by a two colour LIF (light induced fluorescence) technique over a large range of temperature differences. To our knowledge, this technique has not been used previously in the field of Rayleigh-Bénard turbulent convection. The LIF technique is non invasive and has the advantages to be able to be combine with other techniques like Particle Tracking Velocimetry.

Experimental Set-Up and Measurements Technique

The cell is a cylindrical cell of 10 cm diameter and aspect ratio 1. The side walls are in Lexan, the bottom plate is in oxygen free copper and the top plate is in sapphire to allow a good optical access from the top. The bottom plate is heated electrically by a power supply. This cylindrical cell is surrounded by a jacket at the mean temperature of the cell in order to minimise heat leaks through the Lexan side walls. Distilled water is used as fluid. The experimental set-up is given in Fig. 1. The temperature of the cell goes from 15 to 70°C. The cell can reach Rayleigh numbers in the range of 10^7 to 10^9. The Rayleigh number is $Ra = \frac{\alpha g L^3 \Delta T}{\kappa \nu}$. Here α is the thermal expansion coefficient, ΔT the temperature difference between the top and bottom plate, g the acceleration of gravity, κ the thermal diffusivity and ν the kinematic viscosity.

The two-colour LIF is a temperature measurement technique developed among others by some of us [8, 9, 10]. It consists of using a fluorescent dye diluted in the water and illuminated by a laser. The main point of the two-color LIF is to use two different wavelengths in the fluorescence spectra of the dye. By measuring the intensity of the fluorescence light of these two filtered wavelength by intensified cameras and by prior calibration, a temperature field can be measured by the relation [9]: $I_f(\lambda) = K_{opt}(\lambda) K_{spec}(\lambda) V_C I_0 C e^{\frac{\beta(\lambda)}{T}}$
where K_{opt} is an optical constant, K_{spec} is a constant that depends solely on the spectroscopic properties of the tracer, I_0 the laser excitation intensity, C the concentration of the tracer, T, the absolute temperature and V_c the collection volume of the fluorescence photons, β is the temperature sensitivity coefficient.

The advantages of these technique is to be non-invasive, not limited to a small temperature range, to measure the temperature field in a full plane and to be able to be completed by other optical measurements techniques like PIV or Particle Tracking Velocimetry.

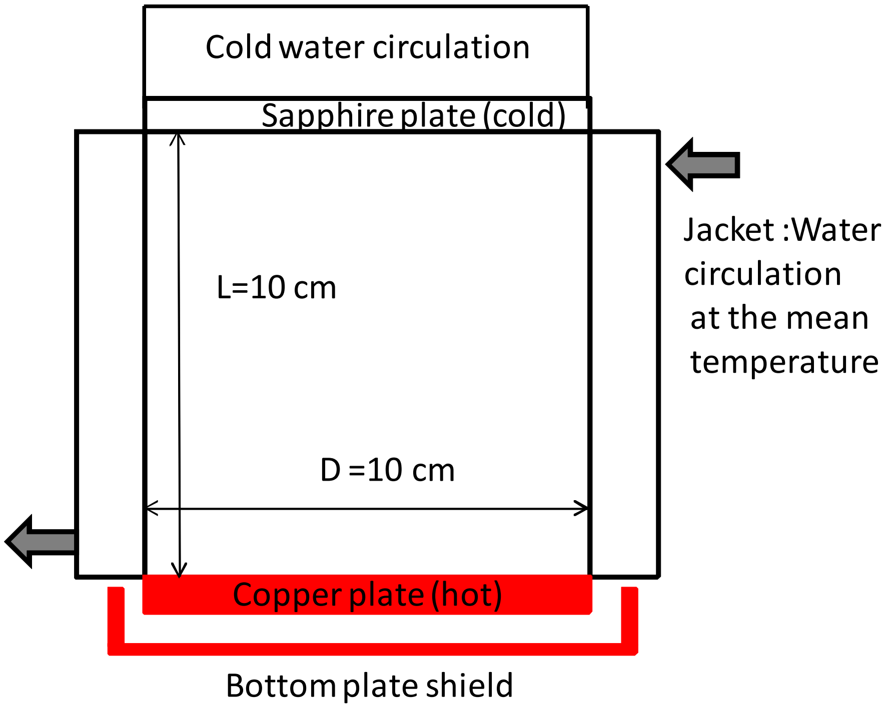

Figure *1: Rayleigh-Bénard convection cell of aspect ratio 1*

Results

The temperature field is first measured around a single plume generated by a small resistance. These measurements allow us to observe how fast a rising plume loses his heat with the time. PIV measurements on the same system give the flow field generated by this single plume, and explain the "mushroom shape" of the plumes observed several time. Then the temperature field of two or more plumes interacting is measured. The plumes have a tendency to merge to create one larger single plume. Finally the large scale circulation is brought to light by the LIF measured temperature field.

CONCLUSIONS

The LIF technique used gives new information on the large scale circulation present in the Rayleigh-Bénard cell. The LIF techniques make it possible to see the plumes from the side and to measure simultaneously the flow and velocity fields of rising plumes.

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