MEASUREMENT OF THE TEMPERATURE FIELD IN A RAYLEIGH-BENARD TURBULENT CONVECTION CELL BY LASER INDUCED FLUORESCENCE

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Abstract The temperature field in a Rayleigh-Bénard convection cell is an important information for the understanding of the physical mechanism of the convection. By use of the LIF (Laser Induced Fluorescence) technique, the temperature field is first measured around a single rising plume in a quasi-infinite media, then in a cylindrical cell of aspect ratio one. Plumes are not emitted regularly in a turbulent Rayleigh-Bénard convection cell and statistics on plumes have been completed.

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INTRODUCTION

Rayleigh-Bénard convection has been an active field of research for the last twenty years (see [1,2] for a review). It is believed that it is the driving force of ocean currents like the Gulf Stream. The cold and salty water under the ice floe of Artic is denser and thus, have the tendency to sink. Convection cells in the sun, the earth mantel or the atmosphere are other example of Rayleigh-Bénard convection [1,2]. Although, Rayleigh-Bénard convection is ubiquitous in nature, 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. This gives global information about the heat transfer, as for instance, the Nusselt number scaling or the critical Rayleigh numbers corresponding to transitions of regimes. 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 local 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 themselves. 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 Γ = 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 the LIF (laser 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 combined 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 temperature difference between the top and bottom plates of the cell varies from 15 to 70°C. The cell can reach Rayleigh numbers in the range of 10^7 to 10^9. The Rayleigh number is defined as $Ra = \frac{\alpha g L^3 \Delta T}{\kappa \nu}$. 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 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. By measuring the intensity of the fluorescence light by an intensified camera and using a preceding calibration, a temperature field can be obtained 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.

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 (see Fig. 1) and how is the temperature distributed in mushroom shape plumes.

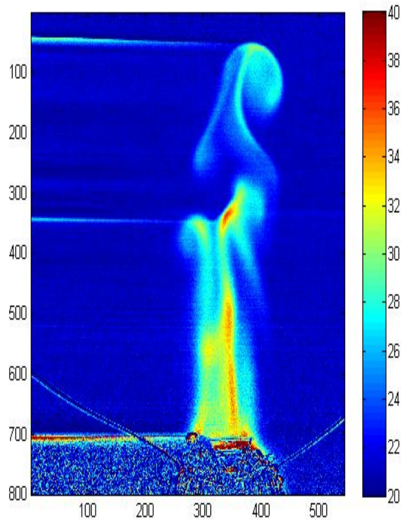

Figure 1: Temperature field around a plume emitted from a small heating element. The temperature scale is on the right in celcius.

In the Rayleigh-Benard cell, the large scale circulation is nicely visualized by the temperature field. Plumes are not emitted at a constant rate. There are moment of high activity where lots of plumes are emitted and moment where almost no plumes are emitted. Statistics on the plumes dynamics have been completed.

References

[1] Ahlers G., Grossmann S., Lohse D., Heat transfer and large scale dynamics in turbulent Rayleigh-Bénard convection, *Review of Modern Physics*, **81,** 503-537, 2009

[2] Lohse D., Xia K.-Q., Small-scale properties of turbulent Rayleigh-Bénard convection *Annual Review of Fluid Mechanics* **42**, 335-364, 2010

[3] Brown E., Ahlers G., Rotation and cessetions of the large-scale circulation in turbulent Rayleigh-Bénard convection, *Physics of Fluids*, **18,** 125108, 2006

[4] He X., Tong P., Measurement of the thermal dissipation field in turbulent Rayleigh-Bénard convection, *Physical Review E,* **79**, 026306, 2009

[5] Funfschilling D, Ahlers G., Plume motion and large-scale circulation in a cylindrical Rayleigh-Bénard cell, *Physical Review Letters*, **92** 194502-1, 2004

[6] Zhou Q., Sun C., Xia K.-Q., Morphological evolution of thermal plumes in turbulent Rayleigh-Bénard convection, *Physical Review Letters*, **98**, 074501, 2007

[7] Xia K.-Q., Sun C., Zhou S.-Q., Particle Image Velocimetry measurement of the velocity field in turbulent thermal convection, *Physical Review E,* **68**, 066303, 2002

[8] Maqua C., Castanet G., Lemoine F. Doué N., Lavergne G. Temperature measurements of binary droplets using three-color laser-induced fluorescence, *Experiment in Fluids* **40** 786-797, 2005

[9] Castanet G., Delconte A., Lemoine F., Mees L., Gréhan G., Evaluation of temperature gradients within combusting droplets in linear stream using two colors laser-induced fluorescence *Experiment in Fluids* **39** 431-440, 2005

[10] Dunan P., Castanet G., Lemoine F., A two-color LIF thermometry applied to temperature measurements of droplets, *Experiment in Fluids* 1-14 (2011) In press.