研 究 速 報

3D Particle Imaging Thermometry and Velocimetry (PITV) using Liquid Crystal

—1st Section; Optical Characteristics of the Micro-capsulated Liquid Crystal—

感温液晶粒子を用いた3次元粒子画像温度・速度計測法

—第1報; マイクロカプセル化された感温液晶粒子の光学的特性—

Deoghee DOH*, Toshio KOBAYASHI** and Tetsuo SAGA**
都 徳 熙・小 林 敏 雄・佐 賀 徹 雄

1. INTRODUCTION

In this study a new measurement method for temperature and velocity of a thermal fluid flow is introduced. This technique is a kind of whole field measurement method for temperature and velocity of the flows. Micro-capsulated liquid crystal particles are used for the visualization of the thermal flows and a digital color image processing technique is applied.

In the whole field velocity measurement using the image processing, there are PIV[1)] and PTV[2)]. And for the whole field temperature measurement, infrared thermometers (IR), ultrasonic computed tomography (CT), laser induced fluorescence (LIF)[3)] and liquid crystal method (LCM)[4)] are available. Since the method using thermo-sensitive liquid crystal has such advantages as, the liquid crystal can be easily handled and is inexpensive, the liquid crystal has a small and predictable affect on the flow and thermal field when proper care is taken, and measurement through this method is nearly instantaneous and offers satisfactory accuracy and resolution, LCM is applied in wide thermal fluid engineering fields. In this study, a new consideration belonging to LCM is adopted. In LCM, there are two kinds of measurement methods, painting method and suspending method. The latter method is usually applied for the full-field temperature measurement of thermal fluid flows. The suspending method had been applied by Kimura[5)] at first in a study of heat island problem. Up to now, most simultaneous measurement methods for temperature and velocity have been two dimensional[6)] or quasi three-dimensional measurement technique[7)]. In order to enhance the probabiliry of spatial and temporal correlation between temperature and velocity on the same visualize images, another concept should be taken. To meet the consideration of simultaneous measurement of temperature and velocity of a thermal fluid flow, a new technique is to be developed suspending the thermo-sensitive micro-capsulated liquid crystal particles in a thermal flows as a temperature and velocity sensors, in which the temperature is measured by tracking the color change of the particle and the velocity is measured by tracking the position of the particle in space.

However, as the micro-capsulated liquid crystal particles have an optical characteristic besides the color-to-temperature characteristic, which makes this technique more complicated, the optical characteristic is investigated and identified quantitatively.

Furthermore, since this particle mainly consists of liquid crystal and a capsule lapping the liquid crystal, the heat capacity of the liquid crystal particle makes a time delay for these particles to follow up the temperature of a thermal fluid, which eventually produces a response time problem. The characteristics for the response time are also discussed.

For the success of this technique a color image processing technique applying a neural network and a stereo-pair matching method are adopted. Considering the above main four items, the developed new technique is applied to the

*Pohang University of Science and Technology, Pohang, Korea
**2nd Department, Institute of Industrial Science, University of Tokyo

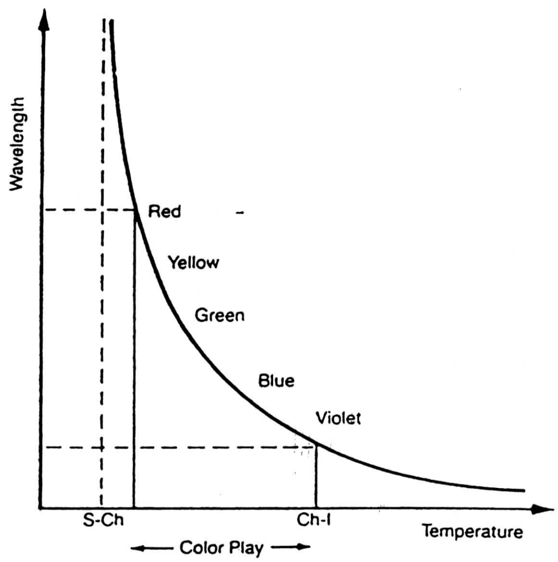

Figure. 1 Typical reflected wavelength and temperature relation.

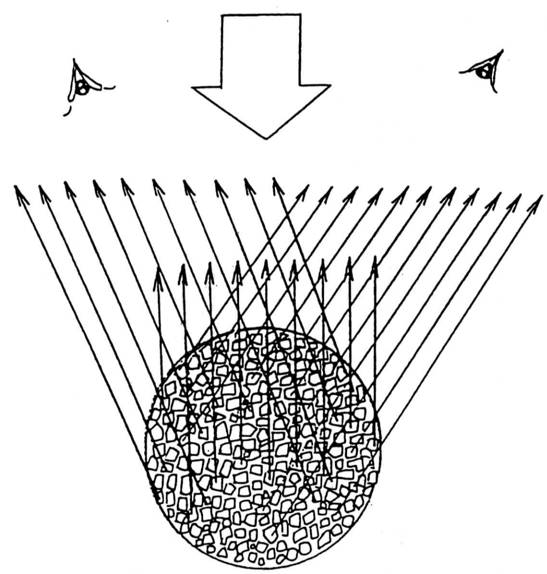

Figure. 2 Bragg-type scattering of the micro-capsulated liquid crystal particle.

measurement of three-dimensional simultaneous temperature and velocity of a thermal fluid flow. For the explanation of the whole procedure of this technique, this paper consists of four parts of sub-subjects. The first part focuses on the optical characteristic, the second part discusses about the characteristics of the response time of the microcapsulated liquid crystal, the third part is for the newly considered color image processing technique applying a neural network, and the last part is concerned with the three dimensional simultaneous measurement for temperature and velocity of a vertical buoyant jet.

2. OPTICAL CHARACTERISTICS OF MICRO-CAPSULATED LIQUID CRYSTAL PARTICLE

Most cholesteric mixtures turn from colorless to red at a low temperature and pass through the other colors of the visible spectrum in sequence (orange, yellow, green, blue, violet) before turing colorless again at a higher temperature still. The color changes are reversible and on cooling the color change sequence is reversed. A typical wavelength (color)/temperature response is shown in Figure 1. This characteristics can be adjusted by an addition of chemical materials. Since the liquid crystal is prone to deterioration due to chemical reaction with reactants within the ambient fluid as well as radiation due to ultra-violet light. Reactions with reactants in the ambient fluid is prevented through the encapsulation of the liquid crystal and deterioration is prevented by filtering out the ultra-violet components from all light sources illuminating the liquid crystals. When the liquid crystal is encapsulated, a bragg-type scattering effects, usually can be seen in X-ray scattering phenomenon, occurs shown in figure 2. This bragg-type scattering gives rise to the characteristic iridescent colors around the micro-capsulated liquid crystal particle at a constant incident light direction. This effect is not desirous for using the liquid crystal particle as a tracer for color changes that comes from temperature changes because the color is changed accoriding to the viewing angle, though the temperature of the particles is maintained constant. For the verification of the optical characteristic of the micro-capsulated liquid crystal particle, an experiment examining the characteristic quantitatively is done.

Figure 3 shows a schematic picture for investigating the Bragg-Scattering effects. The micro-capsulated liquid crystal (AR15C25R, diameter 0.5 mm, specific gravity 1.02) is in the transparent acrylic resin cylinderical vessel (height 250 mm, diameter 150 mm) maintaining constant water temperature which is controlled by the constant water baths. Furthermore, the micro-capsulated liquid crystal is put into a small thin glass bulb (diameter 2.5 mm, thickness 0.5 mm) together with a Chromel-Alumel thermocouple 7 to measure the temperature of the liquid crystal. Each color

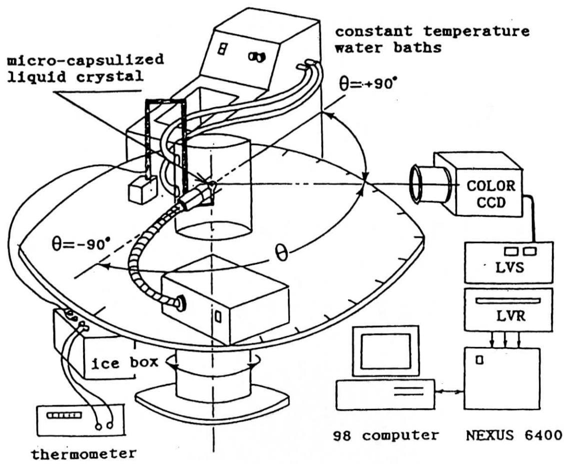

Figure. 3　Experimental apparatus.

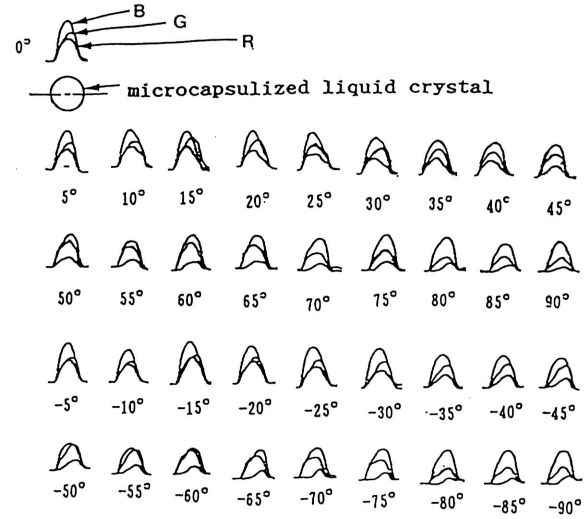

Figure. 4　Histogram distribution of RGB.

image obtained by the 3-plane color camera (SONY DXC-3000A) is separated into R, G, and B images and recorded in the optical disc (LVR, LVS 5000). After the R, G, and B signals are digitized to 256 levels (8 bits), the color image processing is carried out by the image processor (NEXUS 6400) controlled by a personal computer. A so-called relative angle between the light beam (halogen cold light, 150W) and the color camera is changed by rotating a round table on which the cylinderical vessel and the halogen lamp are loaded, while the camera is fixed. The temperature of the water in the transparent acrylic resin cylinderical vessel is controlled constant at a certain temperature. The direction of the illuminating light beam, a halogen lamp beam, is changed by rotating the circle plate on which the lamp system is put while the direction of viewing of the color camera is fixed at one direction. The angle constructed by the direction of the light beam and the direction of the viewing of the camera is called the optical relative angle here. The optical relative angle is changed from −90° to +90° against the fixed viewing direction of the color camera by 5° step by rotating the circle plate. At each step, the color of the liquid crystal particle is stored as an analog signal onto the optical disc through the color camera. As a post processing, the color data of the particle is converted into the 8 bit R, G, B intensities.

Figure 4 shows the histogram distribution on the center line of the micro-capsulated liquid crystal particle at temperature 20°C. It can be said that when the optical relative angle is same, the color pattern of the micro-capsulated liquid crystal is very similar.

Figure 5 shows the relation between Hue and the relative angle when the temperature of the micro-capsulated liquid crystal is at 31.5°C, in which the relative angle is changed 1° step angle. This fact implies that whatever the color is different at a certain optical relative angle under a fixed temperature condition, the color shown at that relative angle and temperature condition is unchangeable. It can be concluded that the hue value increase according to the increase of the relative angle at a constant temperature. And the relation is also different at different temperature. The likelihood step changes of hue value at some relative angle are considered due to the system resolution. The above result means that the bragg-type scattering is occurring around the micro-capsulated liquid crystal and this effects makes difficult for the micro-capsulated liquid crystal to be applied to the temperature measurement. This facts also can be extended to an applicable meaning. In order to use this micro-capsulated liquid crystal particle as a temperature sensor, a consideration should be taken. In other words, in an experiment in which the measuring area is wide, thus making the relative a bigger, another calibration experiment for color-to-angle, color-to-position of particle in the measuring area, is necessary[8]. Therefore, it is desirable to keep the relative angle between the camera and the particle position small to avoid the color differences from the bragg scattering. To overcome the above problem explained, an optimum camera position which avoids the color differences has been adapted for the spatial tempera-

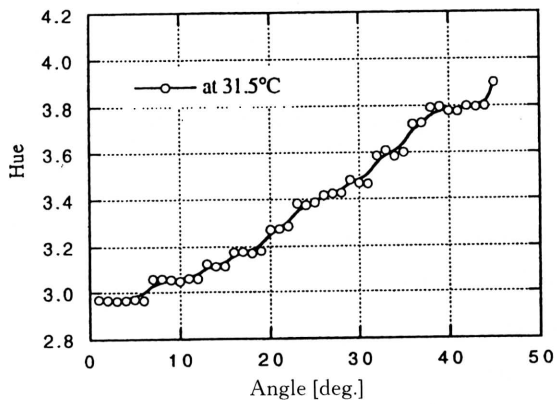

Figure. 5　Hue versus relative angle

ture measuring area in this study.

3. CONCLUSIONS

In order to use the micro-capsulated liquid crystal particle as a temperature tracer for the measurement of temperature of a thermal fluid flow, the optical characteristics of the micro-capsulated liquid crystal particle should be considered. For the verification of the optical characteristic, an experiment for this has been done and the characteristic has been quantified. From the results, it can be deduced that even if the temperature of the micro-capsulated liquid crystal particle is maintained constant, the color of the particle itself, which corresponds to the maintained temperature, is different according to the optical relative angle which is constructed by the camera projection line, the position of a micro-capsulated liquid crystal particle, and the direction of an incident light.

Since this bragg-type scattering occurs when using the micro-capsulated liquid crystal as a temperature tracer in thermal fluid flow, some considerations should be paid. If the optical relative angle is large in an experiment, an experiment for the calibration of the bragg-type scattering should be taken. As an another counteract for the bragg-type scattering the experimental optical conditions, such as the range of measurement the distance of the camera from the measurement area, and the position of the incident light beam should be adjusted to avoid the bragg-type scattering.

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