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Short Paper

Temperature Measurement by Two-Color LIF Technique Using Nd:YAG Lasers

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1. Introduction

Laser-induced fluorescent (LIF) is one of experimental techniques, which can measure the temperature field non-intrusively (ex. Fujisawa and Adrian, 1999; Sakakibara and Adrian, 1999; Banerjee et al., 2006; Reungoat et al., 2007). This technique relies on the temperature dependence of fluorescent-dye intensities illuminated by lasers. It is well known that the accuracy of the temperature measurement by LIF can be improved by the introduction of two-color LIF technique, which eliminates the major error sources of laser-light fluctuations in the flow field. Illuminations by continuous Ar lasers in conjunction with fluorescent dyes, such as Rhodamine B and Rhodamine 110, are often used in the two-color LIF technique for temperature measurement (Sakakibara and Adrian, 1999; Funatani et al., 2004). However, few studies are reported for the temperature measurement using pulsed lasers, such as Nd:YAG lasers, in spite of the general use in the velocity measurement by PIV for high-speed flow (Coolen et al., 1999).

The purpose of this paper is to propose a new experimental technique for instantaneous temperature measurement using two-color LIF combined with Nd:YAG pulsed lasers. This new technique is applied to the temperature measurement of turbulent buoyant plume issued into stagnant surroundings.

2. Experimental Method

Figure 1 shows an experimental setup used in the present study. The measuring system consists of two monochrome CCD cameras (1280 × 1024 pixels with 12 bits in gray levels), a dichroic filter and a notch filter. Note that the dichroic filter separates the reflection and transmission of light at the wavelength 570 nm, and the notch filter reflects the light having a wavelength range 532 ± 10 nm. The camera calibration is introduced to the two captured images using a calibration plate with grid-line patterns. The image calibration uses a third-order polynomial function with least-square method. The details are described by Sakakibara and Adrian (1999). The illuminations are provided from Nd:YAG laser (wavelength 532 nm, laser power 50 mJ) having a light-sheet thickness of 1 mm.

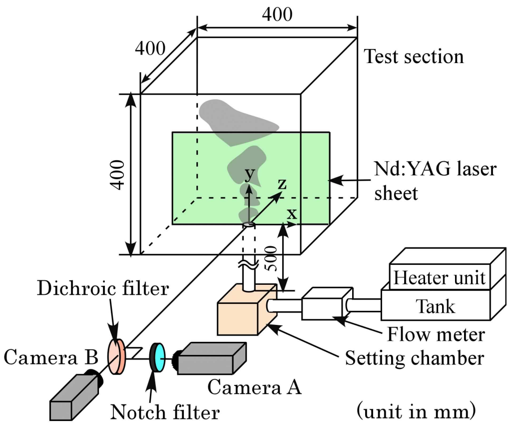

Fig. 1. Experimental setup.

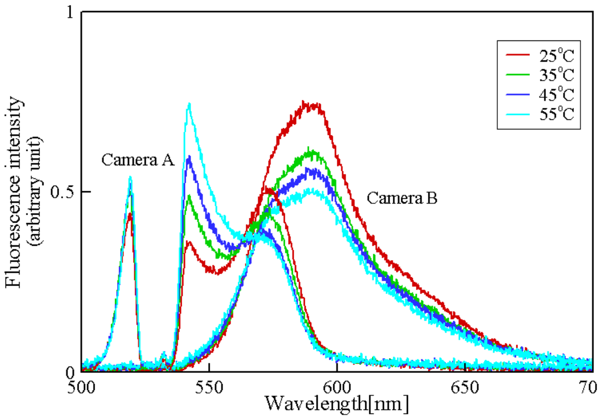

Fig. 2. Spectral distributions of fluorescent dyes.

Note that the two fluorescent dyes are selected as Rhodamine B (0.09 mg/l) and Fluorescein Sodium (6.7 mg/l), which combination of dyes are determined from the temperature sensitivity and the separation of peaks in the emission spectra of several dyes.

The present two-color LIF system is applied to the temperature measurement in a turbulent buoyant plume in stagnant surroundings. The experimental test section is filled with cold water (T_c = 25 deg), in which hot water (T_h = 55 deg) is supplied from a circular nozzle at the bottom of the test section. The diameter of the nozzle is d = 20 mm and the bulk velocity V_0 at the nozzle exit is V_0 = 10 mm/s, so that the source Reynolds number is 390 and the source Froude number is 0.21. For details see Fujisawa et al. (2004). Although the non-uniformity in the fluorescence intensity distribution is almost removed by the introduction of two-color LIF technique, minor influence of light refraction at the plume interface remains in the temperature contours. Therefore, such influence of refraction is removed using the low-pass filtering in the FFT analysis of the visualized image.

3. Results and Discussion

Figure 2 shows the spectra of the fluorescence intensities of the mixed dyes of Rhodamine B and Fluorescein Sodium at some temperatures, which are measured by a spectroscope. The reflected light (captured by camera A) is mainly responsible for the fluorescence from Fluorescein Sodium and the transmitted light (captured by camera B) is from the Rhodamine B, but they are not perfectly separated due to the overlap in the spectra. It should be noted that the fluorescence from Fluorescein Sodium increases with an increase in temperature, but that from Rhodamine B decreases. Therefore, each spectrum shows an opposite tendency to the temperature variations. Thus, the temperature dependence on the fluorescent dye is magnified, when the intensity ratio is plotted against the temperatures. Note that the intensity ratio of the two fluorescent dyes is decreased with an increase in temperature. An example of the calibration curve is shown in Fig. 3, which is normalized by the intensity ratio at temperature T = 25 deg.

Figures 4(a) and (b) show instantaneous temperature contours in the central vertical plane of the turbulent buoyant plume. These results show that the plume structure develops from a circular nozzle and interacts with the stagnant surroundings of cold water. The high temperature region of the plume forms the mushroom type vortices and diffuses into the still surrounding of cold fluid. Note that the uncertainty interval of temperature measurement is about 1deg at 95 % coverage. These results indicate the validity of the present two-color LIF technique.

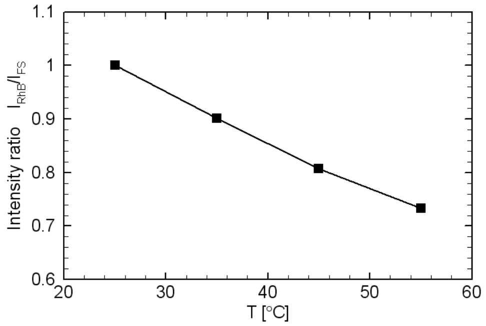

Fig. 3. Intensity ratio versus temperature.

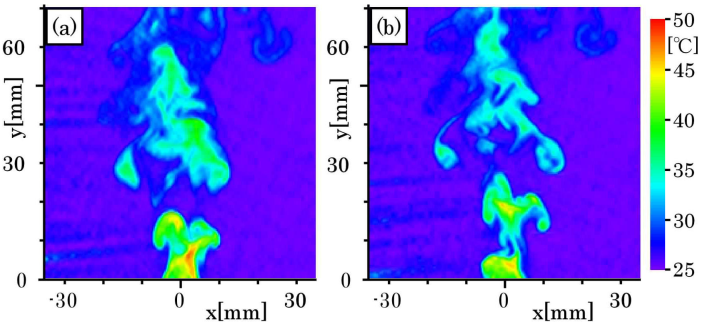

Fig. 4. Instantaneous temperature contours of plume.

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