TEMPERATURE MEASUREMENT IN GAS/AIR BY USING TWO-COLOR LIF METHOD

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ABSTRACT:The development of experimental methods for measuring the temperature and velocity in a fluid flow has been an important step toward understanding the transport phenomenon of heat and fluid flow in various engineering fields. Temperature measurement with a relatively large temperature range can be carried out using the laser-induced fluorescence (LIF) technique. In recent years, temperature measurement of liquid/water by LIF has been further developed and applied and extended to the simultaneous measurement of temperature and velocity fields in combination with PIV. It has been found that the measurement accuracy of LIF can be considerably improved using two-color LIF[1-2]. The purpose of the present paper is to solve problems to develop a technique for simultaneous measurement of temperature and the velocity field of gas/air using two-color LIF method and PIV. Temperature measurement of gas/air using two-color LIF was carried out by spraying a mist of the fluorescence solvation liquid. However, water mist cannot be used for the visualization of the LIF method because it is vaporized and diminished at once. To avoid this problem, propylene glycol or ethyl glycol whose vapor pressure is much lower than water was used as the solvent of fluorescence. A supersonic moisture chamber was used as the atomizer. This technique was applied to the measurement of temperature distributions of the one-side heated vertical plate. It shows that a high temperature region generated by laminar thermal plume is observed near the heated side. It can be concluded that the present system of two-color LIF thermometry is found to be very effective for the study of such a thermal structure of plumes and that the two-color LIF technique was well-suited to measuring the temperature field of air.

1. Introduction

The development of experimental methods for measuring the temperature and velocity in a fluid flow has been an important step toward understanding the transport phenomenon of heat and fluid flow in various engineering fields.

Temperature measurement with a relatively large temperature range can be carried out using the laser-induced fluorescence (LIF) technique (Nakajima et al 1990, Sakakibara et al 1993). In recent years, temperature measurement by LIF has been further developed and applied (Coppeta and Rogers 1998, Lemoine et al 1999, Coolen et al 1999, Lavieille et al 2001), and extended to the simultaneous measurement of temperature and velocity fields in combination with PIV (Hishida and Sakakibara 2000, Kim and Lee 2002). It has been found that the measurement accuracy of LIF can be considerably improved using two-color LIF (Coppeta and Rogers 1998, Sakakibara and Adrian 1999, Funatani et al 2004). This technique eliminates the influence of laser intensity fluctuations observed in the single-color LIF technique, which is a significant error source in the temperature measurement. However, this technique requires an additional CCD camera for imaging the intensity distribution of the second fluorescent dye. Therefore, the weak point of this technique is the complexity of the measurement system in comparison with single-color LIF. This appears to be a more serious problem when two-color LIF is extended to the simultaneous measurement of the temperature and velocity fields in thermal flows.

In the past, temperature in gas flows was studied using the NO-LIF method (Bessler and Schulz 2004) or the Acetone PLIF method (Thunber et al. 1997). But the S/N ratio for the variation of temperature in these methods is lower than that with two-color LIF and they require a UV laser, which is expensive.

The purpose of the present paper is to solve problems to develop a technique for simultaneous measurement of temperature and the velocity field of gas/air using two-color LIF method and PIV.

2. Measurement techniques

2.1 Improvement of Visualization techniques

In the present study, temperature measurement using the two-color LIF technique described in Sakakibara and Adrian (1999) is carried out. In this method, two fluorescent dyes with different temperature sensitivities are used as temperature sensors, and the intensity ratio of the emission lights from two fluorescent dyes are used to eliminate the influence of the intensity fluctuation in the laser.

Therefore, the temperature of the fluid can be measured when the relationship between the intensity ratio and the temperature is known. In the temperature measurement, it is necessary to separate the excitation light and two kinds of emission light with filters. Therefore, two monochrome CCD cameras have been used in the temperature measurement by the standard two-color LIF technique. It is to be noted that the selection of the dyes and filters is an important issue as it may change the accuracy of the temperature measurement.

As an alternative to the two monochrome CCD cameras in the standard two-color LIF, a two-color LIF method using a single color camera was described by Funatani et.al. (2004). A flowchart of this method is summarized in figure 1, which indicates the separation of the color images to RGB images and the subsequent image analysis. It should be noted that the R, G, and B filters of the color CCD camera pass light having a wavelength ranging from 575 nm to 640 nm, 490 nm to 575 nm and 400 nm to 485 nm, respectively. When the Ar-ion laser (wavelength 488 nm) is used as an excitation light and Rhodamine B (RhB, emission wavelength 575 nm) and Rhodamine 110 (Rh110, emission wavelength 520 nm) are selected as the temperature-sensitive and insensitive dyes, respectively, the R and G filters of the color CCD camera act to separate the excitation light and the emission light.

Temperature measurement of gas/air using two-color LIF was carried out by spraying a mist of the fluorescence solvation liquid. However, water mist cannot be used for the visualization of the LIF method because it is vaporized and diminished at once. To avoid this problem, propylene glycol or ethyl glycol whose vapor pressure is much lower than water was used as the solvent of fluorescence. A supersonic moisture chamber was used as the atomizer. The average diameter of the mist was about 3 micrometers.

The fluorescence intensity from the mist is much smaller than that of a water solution, and it is difficult to visualize clearly. In the past, a two-color LIF, Ar-ion laser whose wavelength is 488nm was used as the light source, and the tracer particles supplied to the fluid for velocity measurement appeared weakly on the Green image but could be eliminated using image processing with a median filter of 7 × 7 pixels. Such a process cannot be applied when the fluorescence intensity becomes too small. To solve this problem, a DPSS laser whose wavelength is 445nm was used as light source because the shorter wavelength can reduce the incidence of the laser beam to the Green image of the color camera. Furthermore, a short-pass filter (<480nm) is used to decrease the incidence.

Figure 2 shows the emission spectrum of the mixture of these dyes (RhB: 2.0 mg /L, Rh110: 0.2 mg /L) measured by a spectrometer. The shape of the emission spectrum shows that the emission spectrum at T=15°C has a larger value than that of T=65°C at the wavelength of maximum RhB emission (575 nm), and less difference at the maxima of Rh110 emission spectra (520 nm). Note the shift of the emission spectrum due to the change of the temperature. This means that a 445-nm DPSS laser can be used as the light source for the two-color LIF method.

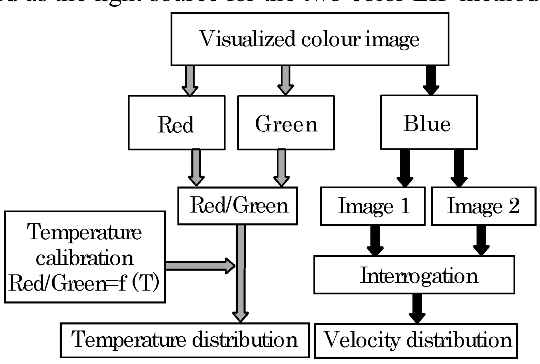
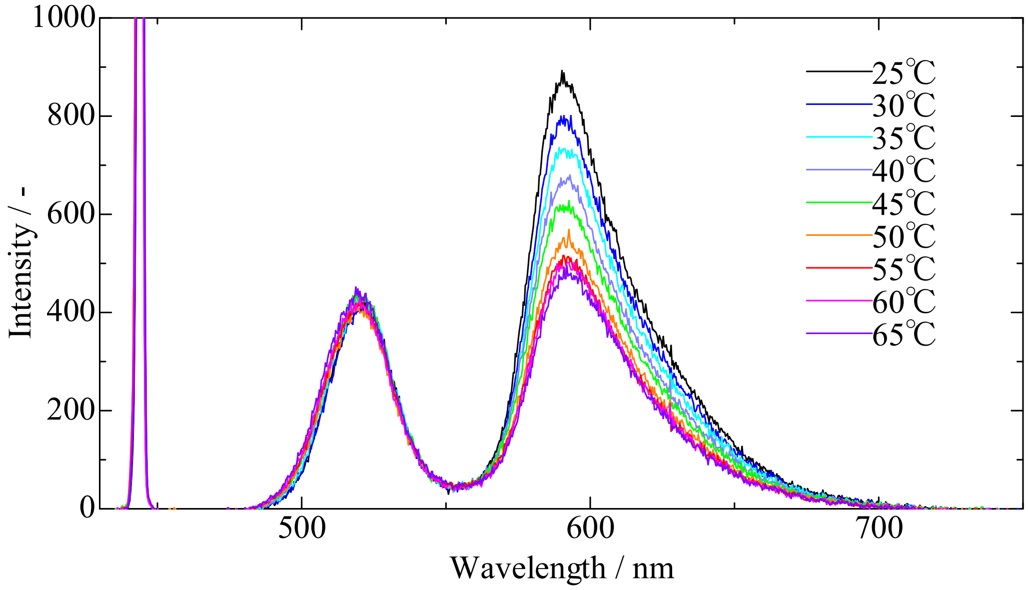
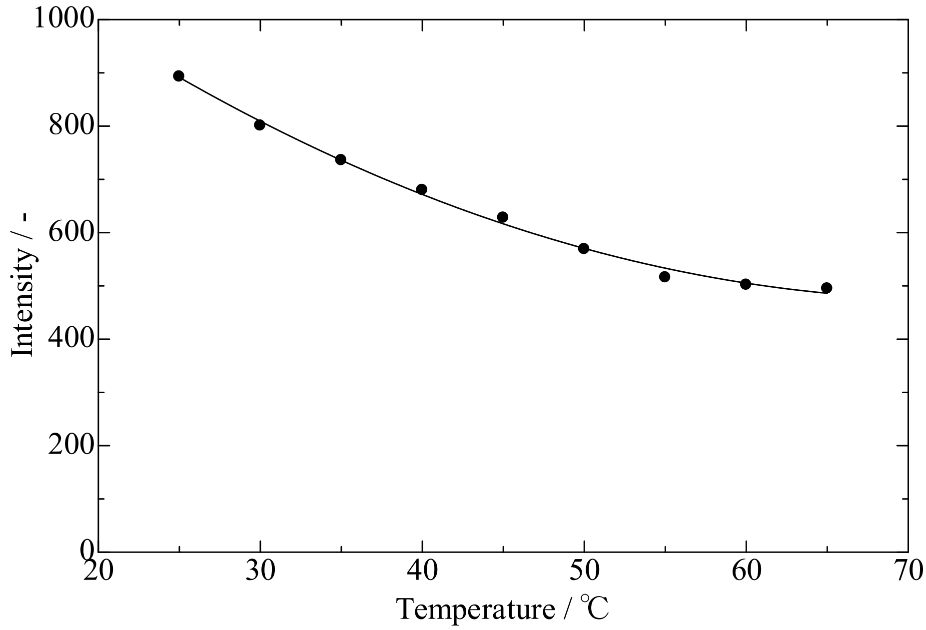


Fig.1 Flow chart of two-color LIF system



(a) Emission spectrum



(b) Relationship between temperature and peak intensity of RhB

Fig.2 Emission spectrum of the mixture of RhB and Rh110

2.2 Experimental setup

The simultaneous measurement of the temperature and velocity fields of air was carried out in an experimental apparatus as shown in figure 3. The test section's volume was 400 × 400 × 300 mm^3. The temperature of the atmosphere was Tc = 20°C, and a buoyant plume was generated by a heating plate ($1.0\times10^4 W/m^2$). The test section was visualized by Diode laser (445nm, 1.0W). A single color camera (14 Bit, 4,928×3,264pixels) was used to record the visualized image.

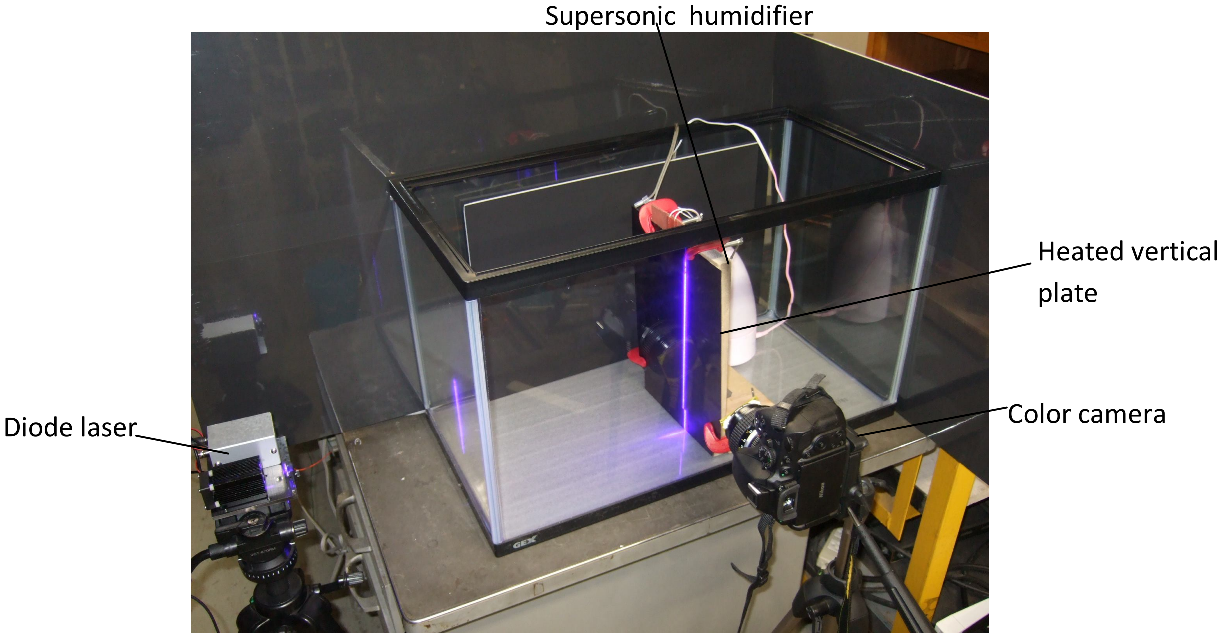


Fig.3 Experimental setup

3. Results

3.1 Temperature measurement

Figure 4 shows the temperature distributions which visualized the one-side heated vertical plate. It shows that a high temperature region generated by laminar thermal plume is observed near the heated wall. It can be concluded that the present system of two-color LIF thermometry is found to be very effective for the study of such a thermal structure of plumes and that the two-color LIF technique was well-suited to measuring the temperature field of air.

It is also necessary to evaluate the tracking accuracy of the fluorescence solvent mist to the temperature of atmosphere. The temperature variance of ethyl glycol mist (3 micrometer, 20°C) surrounded by air (40°C) was evaluated by numerical simulation using an unsteady one-dimensional thermal diffusion equation of sphere coordinates (Fig.5). It shows that the temperature of the fluorescence mist was close to the air temperature, with less than 0.1K difference. In this evaluation, the influence of heat transfer by the difference of velocity between the mist and the atmosphere was not called into account. Therefore, the actual tracking accuracy will be higher because the influence of the heat transfer has the effect of improving the tracing accuracy.

4. Conclusions

A technique for the simultaneous measurement of the temperature and velocity fields of gas/air using the two-color LIF method and PIV was developed. In particular, two problems were solved to improve the accuracy of the temperature measurement.

(1) Temperature measurement of gas/air using two-color LIF was carried out by spraying a mist of propylene glycol or ethyl glycol, which are suited for mist visualization.

(2) The influence of tracer particles on the accuracy of the temperature was eliminated by using a 445-nm DPSS laser and short-pass filter.

The measurement technique was successfully applied to the one-side heated vertical channel.

5. Acknowledgements

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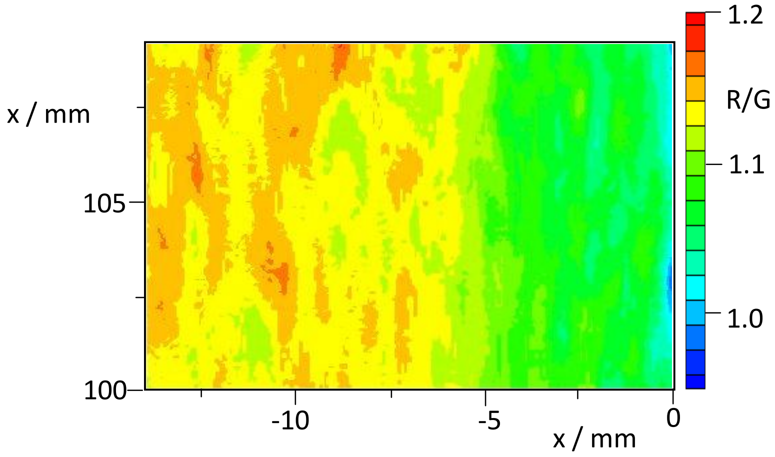
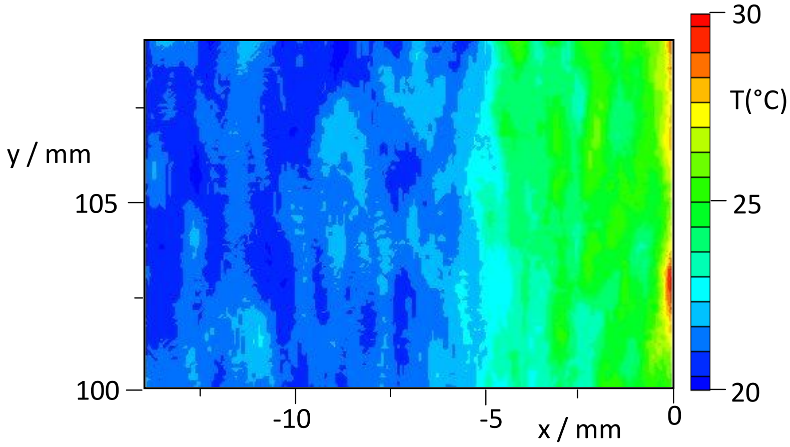


(a) R/G image of heated vertical channel



(b) Temperature distribution

Fig.4 Temperature distribution of thermal plume (x=0: heated boundary)

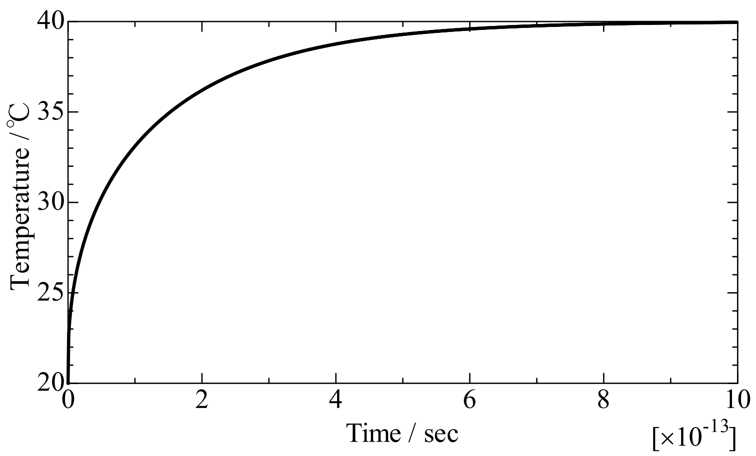


Fig.5 Tracking accuracy of fluorescence mist

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