Combined velocity and temperature measurements of natural convection using temperature sensitive particles

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1. Introduction

In this paper, a technique for combined measurement of velocity and temperature is proposed using only a single non-intensified high-speed camera and a single-pulsed UV laser. A temperature-dependent luminophor is incorporated into ion-exchanged spherical particles with diameters of 15 μm. These particles are small enough to accurately follow the fluid flow. Therefore, the particles can be used not only as a temperature indicator for the lifetime-based temperature measurements, but also as tracer particles for the PIV measurements. The PIV analysis can be carried out using images common to the temperature measurements. The proposed approach can be applied to the flow of any working fluid by selecting a suitable base-sphere. The new approach is demonstrated.

![Image](https://example.com/image.png)

Fig. 1 Basic concept of the TSP method for combined measurement of temperature and velocity

2. Methods

The temperature sensitive particles (TSPs) could be made easily by mixing a small amount of dye and common PIV tracer particles. The concept of this novel TSP method is presented in Fig. 1. Time is indicated on the horizontal axis, and the vertical axis shows the relative intensity of luminescence normalized by its initial value. The gray columns in Fig. 1 indicate the integrated luminescence intensity for each image frame. The luminescence at the moment of excitation is not included in any of the frames. Each image frame was recorded using a high-speed camera, and the dead-time between frames was 100 ns. For the temperature analysis, the TSP method assumes that the temperature in the interrogation window is uniform and constant during the exposure time of the sequential images. At high temperature, the image intensity in the interrogation window decreases quickly. The lower the temperature is, the longer the decay time of the intensity is. Pulsed excitation light was used for the lifetime measurements, where the decay constant was simply estimated from the intensity ratio between two or more time-sequential image frames within the luminescence decay period associated with one pulse.

3. Overview of experiments

In the present paper, the TSPs method was applied to a double convective flow in a rectangular cavity. A calibration was performed for temperature uniform conditions at first. Then the relation between temperature and the lifetime was obtained for each pixel position. Images at temperature uniform conditions were analyzed applying the calibration data and the differences between the known temperature value and the estimated value were investigated to clarify the accuracy of the proposed method. The accuracy of the temperature measurement of the proposed technique was ±0.35–0.4°C. A transient velocity and temperature of a double convective flow were also measured successfully.

4. Conclusion

The aim of this study was to develop a combined measurement method to determine instantaneous temperature and velocity distributions, which can be applied to liquid and gas flows over a relatively wide temperature range. TSPs were developed as tracer particles, prepared from ion-exchange spheres treated with a dye without a binder material. Since temperature is known to affect the luminescence lifetime of these particles, the decay in light intensity was captured by a high-speed camera without an image intensifier. The normalized intensity was represented by a single exponential function of elapsed time, and the relationship between the temperature and the decay constant was represented by an empirical function. The temperature coefficient was calculated for each local position with an accuracy of ±0.35–0.4°C. Simultaneously, the velocity field was calculated by the PIV method. The proposed combined technique was applied to the study of natural convection in a liquid. The measured temperature and velocity distributions were found to be consistent with each other, thus confirming the effectiveness of this method.