Characterisation of BAM:Eu\textsuperscript{2+} tracer particles for thermographic particle image velocimetry

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Thermographic particle image velocimetry is a recently developed laser-based imaging technique for simultaneous single-shot temperature and velocity measurements in turbulent flows. The technique is based on thermographic phosphors, which are solid materials with temperature-dependent luminescence properties. Micrometre-size thermographic phosphor particles, which accurately trace the flow temperature and velocity, are seeded into the flow. The velocity field is measured with ordinary particle image velocimetry (PIV), using laser light scattered by the phosphor particles. Temperature imaging is performed simultaneously using a two-colour intensity ratio approach based on the temperature-dependent spectrum of the phosphorescence emission of the same phosphor particles following UV excitation.

Using phosphors as gas-phase tracers has several advantages. It requires relatively simple instrumentation in terms of lasers and camera and a single seeded tracer. These materials are also chemically inert, have a high melting point (2200 K), and are in general insensitive to temperature and pressure, which is particularly advantageous in reacting flows. However, even though several different phosphors have already been used as tracer particles, little is known about their emission characteristics as individual particles in the gas. Data regarding the emission intensity per particle and the signal dependence on, for example, the laser fluence or oxygen content, are needed to develop and properly assess the limitations of the technique.

This paper introduces a benchmark procedure for the characterisation of phosphor particles in the gas phase, based on particle counting. By measuring the instantaneous seeding density, it allows quantification of the emission intensity per particle and the study of the influence of various parameters affecting the signal. The system is used to characterise 2 \textmu m BAM:Eu\textsuperscript{2+} particles, a phosphor with attractive luminescence properties such as a high quantum efficiency and a short phosphorescence lifetime.

Using 2 \textmu m BAM:Eu\textsuperscript{2+} particles only a moderate seeding density of around 10\textsuperscript{11} particles/m\textsuperscript{3}, similar to that used in conventional PIV experiments, is required to obtain precise temperature measurements (Fig. 1). At this level of seeding, the particles have no effect on the gas properties. By varying the laser energy, it is also shown that above 2 mJ/cm\textsuperscript{2} BAM:Eu saturates and the emission intensity has a weak dependence on the laser fluence. These two results show that high-speed lasers can be used for excitation despite their low pulse energies, permitting time resolved measurements at kHz rates (Abram et al. 2013).

By alternately seeding the phosphor particles in air and in nitrogen, the presence of oxygen is shown to have no effect on the emission intensity (Fig. 2), as well as on the measured temperature. The decrease in the emission intensity with temperature is also characterised in the range 300-950 K (Fig. 2)

Fig. 1 Temperature precision as a function of the seeding density.

Fig. 2 Temperature dependence of the intensity per particle, in air and nitrogen.

The results indicate that the phosphor BAM:Eu\textsuperscript{2+} is a very suitable tracer for gas-phase temperature and velocity imaging in turbulent flows. It requires modest particle seeding densities and little laser energy, and the emission is independent of the gas composition.

There are an infinite number of phosphors involving different luminescence mechanisms, resulting a wide range of temperature sensitivities, emission lifetimes and emission intensities. Most of them have not been investigated for thermometry, let alone for their use as tracers in gas flows. This work should therefore serve as a model for the future characterisation of phosphors to extend the capabilities of this promising technique.

References