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Temperature measurement techniques for gas and liquid flows using thermographic phosphor tracer particles

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ABSTRACT

Optical diagnostics for fluid temperature measurements continue to further our understanding of flows involving heat transfer and/or chemical reactions, which are intrinsic to key areas including energy production, the process industries, transportation, heating/cooling systems and naturally-occurring thermal convection. Besides temperature, all flows must also be described by their velocity. As these flows are often turbulent, an important capability is to measure both velocity and temperature at the same time to capture, for example, the turbulent heat flux term appearing in the energy conservation equation.

This paper reviews temperature measurement techniques for fluid flows that are based on thermographic phosphors, which are materials that possess temperature-dependent luminescence properties. Phosphor particles are seeded into the fluid flow of interest. Following laser excitation, the luminescence of the particles is detected, and the temperature measurement is derived using either the spectral intensity ratio or the lifetime. The same particles can also be used for velocity measurements using well-established particle-based approaches, such as laser Doppler velocimetry (LDV) or particle image velocimetry (PIV), producing instantaneously correlated vector-scalar data. First introduced over a decade ago, this concept has since evolved and is currently capable of two-dimensional measurements in the temperature range 200–900 K. At lower temperatures a single-shot spatial precision better than 4 K is possible, as is imaging at sampling rates in the multi-kHz range. The approach is flexible, allowing, for example, techniques which probe single particles for point measurements with a 200 μm spatial resolution. Besides many validation experiments, the method has been applied in internal combustion engines, a falling film absorber, a high-pressure reaction vessel and in enclosed wind tunnels to study various turbulent heat transfer and reactive flow phenomena.

The objective of this article is to provide the first review of this emerging field. The focus is on 1) the method: how has the principle of phosphor thermometry been used for flow measurements, and what instrumentation and processing steps were implemented; 2) how phosphor particles were characterised, and which phosphors are best-suited to temperature measurements in flows; and 3) the applications of the technique. Throughout, and with a detailed analysis of various sources of error, the review endeavours to compare the work and identify common aspects, advantages and limitations of the studies that led to successful flow measurements, and therefore should serve as a guide for researchers using the method. The article also briefly summarises the various challenges which the authors consider are key to the future development of these diagnostics.

Contents

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1. Introduction

The universal role of temperature in heat and mass transport processes and chemical reactions makes it a variable of fundamental thermodynamic importance, and much effort is directed toward the measurement of gas and liquid temperatures. Methods that do not disturb delicate yet sometimes hostile flow systems are preferable and so a rich variety of optical diagnostic approaches have been developed, especially since the advent of the laser, and used to remotely probe the temperature of fluid flows both in-situ and in laboratory scale experiments. We highlight the areas of convective heat transfer, which underlies the exchange of thermal energy in a huge range of engineering components and process industries, such as the cooling of power generation engines and electronic microchips, oil and gas extraction, transportation, material processing, refrigeration, and the ventilation of buildings and transport vehicles; turbulent natural convection, which occurs in systems of geophysical interest like the Earth's oceans, atmosphere and mantle; and turbulent combustion, where the influence of the turbulent flow field on the reaction chemistry variously alters flame ignition, propagation, stabilisation and extinction and may lead to dangerous flow instabilities/feedback e.g. thermoacoustic oscillations in gas turbines, in turn affecting their safe operation as well as the efficiency and emission of harmful pollutants. Given the importance of such fluid flows in energy and combustion science, and in many scientific fields beyond these, detailed and comprehensive knowledge about them is needed. The inherent

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