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Editorial

Optics and Spectroscopy for Fluid Characterization

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Abstract: This Editorial provides an introduction to and an overview of the special issue "Optics and Spectroscopy for Fluid Characterization".

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1. Introduction

All over the world, there is a huge and ever-increasing interest in the development and application of optical and spectroscopic techniques to characterize fluids in engineering and science. The large number of review articles that are frequently published in these areas is evidence of this. Recent examples have focused on applications of optical diagnostics to gas phase environments [1–5], liquids [1,4,6,7], and multiphase systems [7–10]. A key feature of such light-based methods is that they are usually non-intrusive, and hence they do not notably affect the system under investigation. As a consequence, optical techniques have been developed for many decades and represent the gold standard in many fields. The list of individual techniques utilizing absorption, refraction, diffraction and scattering effects is long and so is the list of the parameters that can be determined. The latter includes macroscopic properties such as temperature, chemical composition, thermophysical quantities, and flow velocity, but molecular information, e.g., about isomerism and intermolecular interactions, can also be obtained. This special issue entitled "Optics and Spectroscopy for Fluid Characterization" aims to demonstrate the breadth of the field in terms of methodology as well as applications.

2. Content of the Special Issue

The special issue starts with an educational and comprehensive review article [11] written by Andreas Fischer (University of Bremen) which lays out the basics of light scattering, highlighting its application to imaging flow velocimetry. The article describes the different flow measurement principles, as well as the fundamental physical measurement limits. Furthermore, the progress, challenges and perspectives for high-speed imaging flow velocimetry are considered.

The contributed articles discuss a large variety of methods and applications. Yan et al. [12] describe the use of a passive technique—flame emission spectroscopy—for in situ measurements of alkali metals evaporated during the incineration of municipal solid waste (MSW). They succeeded in detecting sodium, potassium, and rubidium species in the flame of an industrial incinerator. This suggests that their method is suitable for monitoring technical facilities for biomass and waste combustion. In another gas phase study, Shutov and colleagues [13] demonstrate a non-linear optical spectroscopic technique, termed Femtosecond Adaptive Spectroscopic Technique Coherent Anti-Stokes Raman Scattering (FAST CARS), to quantitatively map species' concentrations. Using the example of molecular oxygen, they illustrate how CARS can be used for the visualization of a gas flow in a free-space configuration. This method is proposed to be applicable to performing gas flow imaging utilizing any Raman-active species.

Liquid systems have been studied in a number of papers in this special issue as well. Collaborative activity by the Universities of Bremen and Manchester applied infrared spectroscopy to biosurfactants produced by microorganisms in a fermentation process [14]. Such biosurfactants represent amphiphilic compounds with polar and non-polar moieties and they can be used to stabilize emulsions, e.g., in the cosmetic and food sectors. They are highly viscous fluids and their structures may be affected when exposed to light and elevated temperatures. In this study, attenuated total reflection Fourier-transform infrared (ATR-FTIR) spectroscopy was applied to analyze the structure and aging of rhamnolipids as a representative of a complex biosurfactant. However, cell suspensions represent even more complicated systems that can be studied by optical techniques. Tang et al. [15] combined Raman spectroscopy with a discriminant analysis data evaluation approach to successfully distinguish between eight different cancerous human cells. The comparison of two methods—Linear Discriminant Analysis (LDA) and Quadratic Discriminant Analysis (QDA)—revealed better performance of the QDA when applied to the Raman spectra. Further, fluorescence imaging is another technique that is frequently used to study biological samples. The evaluation of such images, however, is not always straightforward. For this purpose, Zhu et al. [16] propose a sparse-representation-based image fusion method. They combine principle component analysis (PCA) to initially extract geometric similarities and classify the images. In a second step, the constructed dictionary is used to convert the image patches to sparse coefficients by a simultaneous orthogonal matching pursuit (SOMP) algorithm. As proof-of-concept, the proposed method is successfully applied to fluorescence images of biological samples.

The three remaining papers are concerned with fluid–solid interfaces that are widespread in nature, science, and engineering. Kiefer et al. [17] propose an infrared spectroscopic method to study metal–liquid interfaces that are of interest in electrochemistry and catalysis. They utilize an attenuated total reflection (ATR) spectroscopy approach in which a thin film of fluid is placed in between the ATR crystal and a metal plate. They obtain IR spectra from aqueous salt and acid solutions and an aluminum plate to demonstrate that useful information about the molecular interactions at the metal–liquid interface can be deduced. Chang et al. [18] employ a transmission infrared spectroscopy approach to study the molecular interactions between the ionic liquid 1-butyl-3-methylimidazolium trifluoromethanesulfonate and nano-sized alumina at elevated pressures. Interestingly, in contrast to the results obtained under ambient pressure, the local structures of both counter-ions appear disturbed under high pressure. They conclude that there is a formation of pressure-enhanced alumina/ionic liquid interactions under high pressure. Finally, liquid–solid interactions can also be used in a chemical sensing, in particular using surface-enhanced Raman scattering (SERS) spectroscopy, where the plasmonic enhancement of an electromagnetic field in the presence of nanostructured metal surfaces is utilized. Perozziello and co-workers [19] demonstrate that the development of new and efficient SERS substrates can be inspired by nature. They use natural nanomaterials with suitable structures and cover them with a thin gold layer. This approach allows high-sensitivity Raman spectroscopy to be performed at a relatively low cost, and thus it opens up new possibilities for the development of chemical and biochemical sensors.

3. Conclusions and Outlook

In conclusion, the papers in this special issue impressively demonstrate the huge diversity of the topic "Optics and Spectroscopy for Fluid Characterization". The ever-increasing availability of optical equipment in terms of light sources, detectors, and optical components at reasonable cost are important drivers of new developments in this field. In addition, a growing number of industries are realizing the potential of optical methods in terms of process analysis and material characterization. Therefore, it is foreseeable that the area of optics and spectroscopy for fluid characterization will experience further growth and will see fascinating new applications in the near and distant future.

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