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ENGINEERING WITH AND FOR LIGHT ABSORPTION AND SCATTERING: A QUARTER CENTURY OF EXPERIMENTAL RESEARCH AT RTL

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(Invited paper)

ABSTRACT. Characterization of particles requires detailed understanding of light interaction with homogeneous/inhomogeneous and regular/irregular shaped particles, or fractal-like structures, within optically thin or thick media. Even after the development of such theoretical understanding, focused experiments need to be carried out to measure scattered light intensity profiles and change in the absorption due to particles present in a given medium. Eventually, the data from such experiments are to be processed thoroughly with the help of robust inverse analyses to determine the required properties. This trilogy of particle characterization research was one of the focus areas of the Radiation Transfer Laboratory at the University of Kentucky over the last quarter century. This paper focuses only on the experimental works conducted and highlights a wide number of research papers published at the RTL for characterization purposes.

Characterization of small particles, such as those from 10 nm to 100,000 nm in size is crucially important in many diverse disciplines, including pharmaceutical and biological systems, environmental and process control and monitoring, atmospheric and oceanographic remote sensing, as well as combustion studies. Scattering, absorption and emission characteristics of particles are used for diagnosis and thermal therapy of cancer cells, plasmonic solar cell applications, and precise patterning of nanoparticles by spectrally selective heating. The number of papers that appear each year in the particle characterization literature attests the importance of the problem. Still, the need for more reliable and extensive characterization methodologies are emphasized in every paper, particularly because of the specific environmental concerns, process control and monitoring demands, and the development of new designer materials that require more complete and accurate descriptions. With the increasing use and financial rewards of such advanced cutting-edge technologies, the demand for nondestructive, in situ and real time diagnostics and measurements of particle properties in different systems would likely to increase.

For particle characterization applications, light can be considered as an ideal tool, only if its amplitude, wavelength and polarization are used properly. We intuitively sense this as light absorption and scattering dominates our lives, sometimes without us knowing it. With the help of absorption and scattering we see the objects around us, we identify colors and shades, sometimes we burn or form new objects, and sometimes we feel warm simply by being exposed to sun or a flame. Yet, this intuition has to be expressed starting from the first principles, based on mathematics and experimental physics. This is an intellectual challenge, that we can hope to achieve it with the design and construction of dedicated experimental systems.

If absorption and scattering of light are to be used to characterize particles or clouds, we first need to develop a fundamental understanding of how light is absorbed or scattered by any size and shape structure. This theoretical understanding, however, is useful for such characterization only if the ideas can be coupled with through experimental methodologies. In addition, these experimental measurements should be fed into inverse analyses to arrive at the required properties. This trilogy, i.e. the three-step process including the accurate solution of the forward problem, carefully designed experiments, and reliable inverse analyses should be carried out in a coherent way.

This paper is to discuss the experimental systems developed at the Radiative Transfer Laboratory of the University of Kentucky over the years. The research for these experimental efforts was funded by different companies and funding agencies, resulted several MS and PhD thesis, and has been reported extensively. The applications of this effort have covered a wide range of practical problems, started with the work focused on flame and exhaust characterization with laser light scattering and absorption.

Reference [1] was about the characterization of laboratory flames and to determine the spatial distribution of soot particles within axisymmetric systems. This paper analyzed first the traditional light-transmission approaches such as onion-peeling and Abel inversion techniques, then reported a new and much-improved technique for flame applications. This relatively simple approach was extended to irregular geometries and non-scattering systems using optical tomography. Following these studies, polarized light based systems were developed and different experimental apparatus were designed and built for latex spheres [2], pulverized coal flames [3], diesel engine exhaust [4], and particles from explosive pellets [5]. All these applications were for spatially homogeneous physical systems. Later, scattering tomography was introduced to expand the know-how to radially inhomogeneous scattering systems in R eference [6].

After these early developments, an experimental system was proposed based on elliptically polarized light scattering (EPLS) [7, 8], which was detailed later in Reference [9]. Soon after, an industrial prototype was developed and explained in a trade magazine [10]. During that time the third generation of the EPLS was designed and built in the RTL, and applied to cotton fibers [11], bubbles [12], metallic particles [13]. Also, the extension to fat and casein in milk [14] and to bubbles and foam [15] were shown.

These ideas were also extended to limited angular measurements to investigate the time dependent behavior of foams [15], powders [16], multi-walled carbon nanotubes [17], as well as to titanium trioxide wires [18]. In addition, the EPLS concept was combined with imaging techniques and applied to optically thick media; this work will be discussed soon in an upcoming paper [19].

More recently, it was demonstrated that absorption by nano-size particles on surfaces can be enhanced significantly by employing evanescent waves and with the help of a probe in the proximity [20]. This work is currently further explored at the University of Kentucky.

Complex problems such as particle characterization can only be solved if the thorough physical understanding of light-matter interaction is achieved, dedicated experimental systems are built and calibrated, and the experimental data are interpreted in unambiguous way. Building dedicated experimental systems is a crucial part of this trilogy. This abstract lists only the ideas and the references of the experimental works carried out at the RTL; the presentation itself will discuss the experiments in more details.

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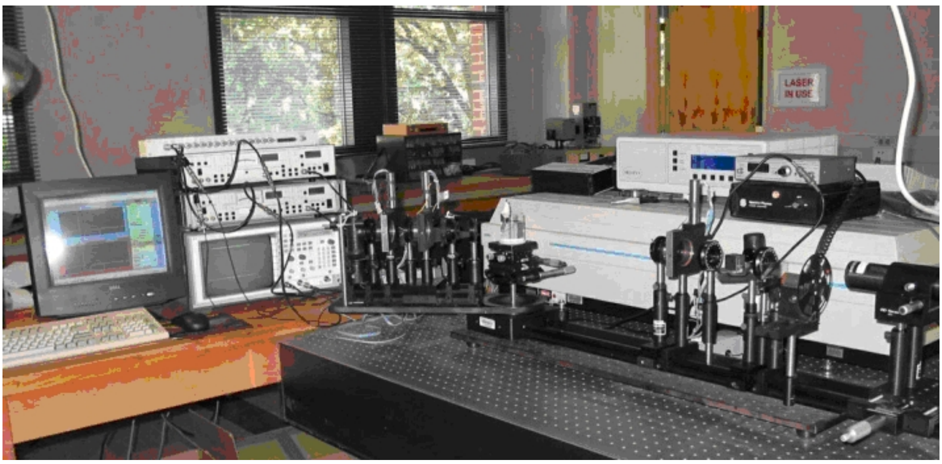

Figure 1. The third generation EPLS System at the Radiation Transfer Laboratory.

References

[1] S. Chakravarty, M.P. Mengüç, D.W. Mackowski and R.A. Altenkirch, "Application of Two Inversion Schemes to Determine the Absorption Coefficient Distribution in Flames", in *ASME National Heat Transfer Conference*; Houston, TX, 1988; H.R. Jacobs editor (ASME HTD-Vol. 96), Conference Proceedings; pp. 171-78.

[2] B.M. Agarwal and M.P. Mengüç, "Single and Multiple Scattering of Collimated Radiation in an Axisymmetric System", *Int. J. Heat Mass Transfer* **34**, 633-47 (1991).

[3] M.P. Mengüç, D. Dsa, and S. Manickavasagam, "Determining the Radiative Properties of Pulverized Coal Particles from Experiments", in *ASME-JSME Thermal Engineering Joint Conference*; Reno, NE, 1991; J.R. Lloyd, Y. Kurosaki, Eds., Conference Proceedings Vol. 5; pp. 22-33.

[4] B.M. Vaglieco, D. Monda, F.E. Corcione, and M.P. Mengüç, "Optical and Radiative Properties of Soot Agglomerates at D.I. Diesel Engine Exchange", in *Heat Transfer in Fire and Combustion Systems-1993*; Atlanta,

GA, 1993; B. Farouk, M.P. Mengüç, R. Viskanta, C. Presser, S. Chellaiah, Eds., (ASME HTD-Vol. 250), Conference Proceedings; pp. 137-143.
[5] S. Ghosal, S. Manickavasagam, M.P. Mengüç, J. Sheng, and H. Blomquist, "Optical Sizing of Particles Generated by Propellant Combustion", in *Third Mediterranean Combustion Symposium*; Marrakech, Morocco, 2003; Conference Proceedings.
[6] M.P. Mengüç and P. Dutta, "Scattering Tomography and Application to Sooting Diffusion Flames", *ASME J. Heat Transfer* **116**, 144-51 (1994).
[7] R. Govindan, S. Manickavasagam, and M.P. Mengüç, "On Measuring the Mueller Matrix Elements of Soot Agglomerates", in *First International Symposium on Radiative Heat Transfer*; Kusadasi, Turkey, 1995; (Begell House, NY, 1996), Conference Proceedings.
[8] S. Manickavasagam, R. Govindan, and M.P. Mengüç, "Estimation of the Morphology of Soot Agglomerates by Measuring their Scattering Matrix Elements", in *IMECE*; Dallas, TX, 1997; K. Annamalai editor (ASME HTD-Vol. 352), Conference Proceedings; pp. 29-32.
[9] M.P. Mengüç, and S. Manickavasagam, "Radiation Transfer and Polarized Light", *Int. J. Eng. Sci.* **36**, 1569-93 (1998).
[10] S. Manickavasagam, M.P. Mengüç, Z. B. Drozdowicz, and C. Ball, "Size, Shape, and Structure Analysis of Fine Particles", *Am. Ceram. Soc. Bull.* **81**, 29-33 (2002).
[11] M. M. Aslan, J. Yamada, M.P. Mengüç, and A. Thomasson, "Characterization of Individual Cotton Fibers via Light Scattering: Experiments", *AIAA J. Thermophys. Heat Transfer*, **17**, 442-49 (2003).
[12] M. M. Aslan, C. Crofcheck, D. Tao, and M.P. Mengüç, "Evaluation of Micro Bubble Size and Gas Hold up in Two Phase Gas-Liquid Colums via Scattered Light Measurements", *J. Quant. Spectrosc. Radiat. Transfer* **101**, 527-39 (2006).
[13] M. M. Aslan, M.P. Mengüç, S. Manickavasagam and C. Saltiel, "Size and shape prediction of colloidal metal oxide MgBaFeO particles from light scattering measurements", *Journal Nanopart. Research* **8**, 981-94 (2006).
[14] C. Crofcheck, J. Wade, M. M. Aslan, and M.P. Mengüç, "Effect of Fat and Casein Particles in Milk on the Scattering of Elliptically-Polarized Light", *Trans. ASAE* **48**, 1147-55 (2005).
[15] J. N. Swamy, C. Crofcheck, and M.P. Mengüç, "Time Dependent Scattering Properties of Slow Decaying Foams", *Colloids and Surfaces A-Physicochemical and Engineering Aspects* **1-3**, 80-86 (2009).
[16] C. Saltiel, Q. Chen, S. Manickavasagam, L.S. Schandler, R.W. Siegel, and M.P. Mengüç, "Identification of Dispersion Behavior of Surface-Treated Nano-Scale Powders", *J. Nanopart. Research* **6**, 35-46 (2004).
[17] C. Saltiel, S. Manickavasagam, M.P. Mengüç, and R. Andrews, "Light Scattering and Dispersion Behavior of Multi-Walled Carbon Nanotubes", *J. Opt. Soc. Am. A* **22**, 1546-1554 (2005).
[18] M. Kozan, J. Thangala, R. Bogale, M.P. Mengüç, and M.K. Sunkara, "In-Situ Characterization of Dispersion Stability of WO3 Nanoparticles and Nanowires", *J. Nanopart. Research* **10**, 599-612 (2008).
[19] B. Gay, R. Vaillon, and M.P. Mengüç, "Elliptically Polarized Experiments based on Imaging of Optically Thick Scattering Media", *in preparation* (2011).
[20] E.A. Hawes, J.T. Hastings, C. Crofcheck, and M.P. Mengüç, "Spatially Selective Melting and Evaporation of Nanosized Gold Particles", *Optics Letters* **33**, 1383-85 (2008).

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