Diffuse back-illumination setup for high temporally resolved extinction imaging

This work presents the development of an optical setup for quantitative, high-temporal resolution line-of-sight extinction imaging in harsh optical environments. The application specifically targets measurements of automotive fuel sprays at high ambient temperature and pressure conditions where time scales are short and perceived attenuation by refractive index gradients along the optical path (i.e., beam steering) can be significant. The illumination and collection optics are optimized to abate beam steering, and the design criteria are supported by well-established theoretical relationships. The general effects of refractive steering are explained conceptually using simple ray tracing. Three isolated scenarios are analyzed to establish the lighting characteristics required to render the observed radiant flux unaffected by the steering effect. These criteria are used to optimize light throughput in the optical system, enabling minimal exposure times and high-temporal resolution capabilities. The setup uses a customized engineered diffuser to transmit a constant radiance within a limited angular range such that radiant intensity is maximized while fulfilling the lighting criteria for optimal beam-steering suppression. Methods for complete characterization of the optical system are detailed. Measurements of the liquid-vapor boundary and the soot volume fraction in an automotive spray are presented to demonstrate the resulting improved contrast and reduced uncertainty. The current optical setup reduces attenuation caused by refractive index gradients by an order of magnitude compared to previous high-temporal resolution setups.

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