Development of Instantaneous Temperature Imaging in Sooty Flames

Doctoral Dissertation

Qing N. Chan

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School of Chemical Engineering
Faculty of Engineering, Mathematical and Computer Sciences
The University of Adelaide, Australia

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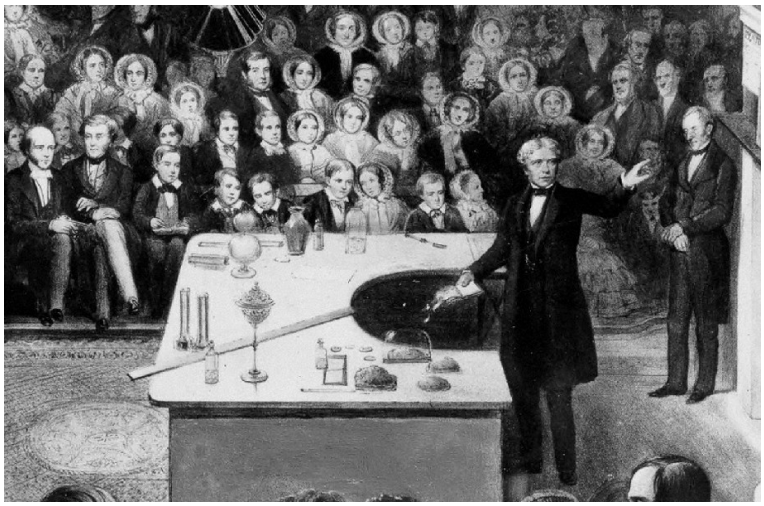

"It is to this presence of solid particles in the candle-flame that it owes its brilliancy."

Michael Faraday

19$^{\text{th}}$ century British Physicist

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Declarations

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Abstract

This dissertation reports on the single-shot temperature imaging in sooty flames, based on the development of two-line atomic fluorescence (TLAF), with neutral Indium atom as seeded thermometry species. The TLAF technique in the linear excitation regime has previously been demonstrated to be feasible in sooty environments but single-shot imaging, which requires a higher signal-to-noise ratio (SNR), has been elusive.

The previous TLAF theory has been extended from the linear excitation into the nonlinear excitation fluence regime. Nonlinear regime two-line atomic fluorescence (NTLAF) provides superior signal, and improves single-shot precision from ∼250 K for the linear TLAF to ∼100 K for the NTLAF. The NTLAF technique is shown to resolve the temperature profiles across a range of equivalence ratios for natural gas, hydrogen, and ethylene laminar premixed flames, with deviation from radiation-corrected thermocouple measurements not exceeding 100 K, and typically ∼30 K. Measurements in lightly sooty flames demonstrate good capacity of the NTLAF technique to exclude interferences that hamper most two-dimensional laser-based thermometry techniques.

The developed technique has been further assessed in a laminar nonpremixed flame. The results show the expediency of the technique in the study of the reaction zone, and reveal interesting findings about the Indium formation process. The temperature profile across the reaction zone shows good agreement with laminar flame calculations. Indium fluorescence is observed to be strongest at the flame front, where the temperature exceeds 1000 K.

Indium has been typically seeded into flame as Indium Chloride dissolved in distilled water. The feasibility to improve on the signal quality of the developed

technique, through the substitution of distilled water with an organic solvent (namely acetone, isopropanol, methanol, and ethanol) as the seeding solution, has been examined. Acetone and methanol are shown to enhance the fluorescence signal intensity the most (approximately threefold to fivefold at stoichiometric flame condition) when used. Acetone and methanol are also shown to improve the fluorescence emission across a range of equivalence ratios, most significantly in the rich combustion region, as well as a twofold enhancement in the SNR. The use of acetone or methanol, has the potential to reduce the precisoin of the measurements down to $\sim$60 K.

The use of the NTLAF technique for measurements in flames with high soot loadings was assessed. In particular, the interferences from soot or its precursors on the fluorescence measurements have been evaluated. The findings indicate that interferences, such as spurious scattering and laser-induced incandescence (LII), from soot are not significant. However, interferences from soot precursors, predominantly condensed species (CS) and perhaps polycyclic aromatic hydrocarbons (PAH), are substantial. Potential detection schemes to correct or circumvent these interferences have been identified.

The technical feasibility of the NTLAF technique to be used concurrently with the LII technique to provide simultaneous single-shot imaging of temperature and soot concentration has been demonstrated. The joint NTLAF-LII method has been applied to laminar premixed and nonpremixed flames, as well as a wrinkled nonpremixed flame. No significant interference of the two measurement techniques on each other is observed, for the detection and timing schemes employed. The images also reveal that, whilst NTLAF has a limited operating range, this range is sufficient to span all regions with soot. This observation demonstrates the applicability of the joint NTLAF-LII method in assessing the coupled dependency of temperature and soot in flame.

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