Infrared Measurement of Soot Particles in a Burner Flame

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Introduction

To develop a new-type burner with lower smoke emission for wide range of fuel supply rates, development of intrusive and in-situ measurement of soot particles is needed to evaluate temporal variation of burner performance. In the present work, optical measurement which is usually used in the laboratory-scale-experiment was applied to an industrial test burner to confirm effectiveness of the measurement method as the first step to this goal.

Experimental apparatus

Measurement system was composed of the following three methods: (1) Thermography based on two different wavelength ranges, 3.5 μm ~ 5.1 μm (without CO_2 bands of 4.1 μm ~ 4.5 μm) and 8 μm ~ 14 μm. (2) Multi-channel infrared spectral analysis of soot radiation using the following combination of the Planck's blackbody radiation equation and the Hottel-Broughton equation [1, 2],

$$E_l = \left\{1 - \exp\left(-\frac{kcl}{l^a}\right)\right\} \cdot \frac{c_1}{l^5 \left\{\exp\left(\frac{c_2}{T_p \cdot l}\right) - 1\right\}}, \tag{1}$$

where, E_λ, kcl, l, T_p denote monochromatic emissive power, optical thickness of soot particles, wavelength, temperature of soot particles, respectively. The value of constant a was 0.95 for infrared region. From experimental data of E_λ at several wavelengths, T_p and kcl are estimated using Eq.1. (3) Classical laser extinction method to obtain total soot volume.

An industrial test burner used in the present work has a cross-section of 800 mm × 800 mm and its total length is about 3300 mm. The burner has three sets of optical windows at 800 mm, 1550 mm, and 2350 mm from the burner tile as shown in Fig. 1. As for fuel, heavy-oil was supplied to a single-hole-nozzle placed at the burner tile.

Results

Figure 2 shows a visible image of the flame obtained with a conventional digital camera and two corresponding thermographic images where emissivity was assumed to be 1.0. In the thermographic images a soot cloud was recognized distinctly as low temperature region, which is mainly due to its thin optical thickness. As emissivity of soot particles is dependent on wavelength, the obtained thermographic images give different impression: the image for wavelength of 3.5 μm ~ 5.1 μm shows higher temperature. This suggests possibility to

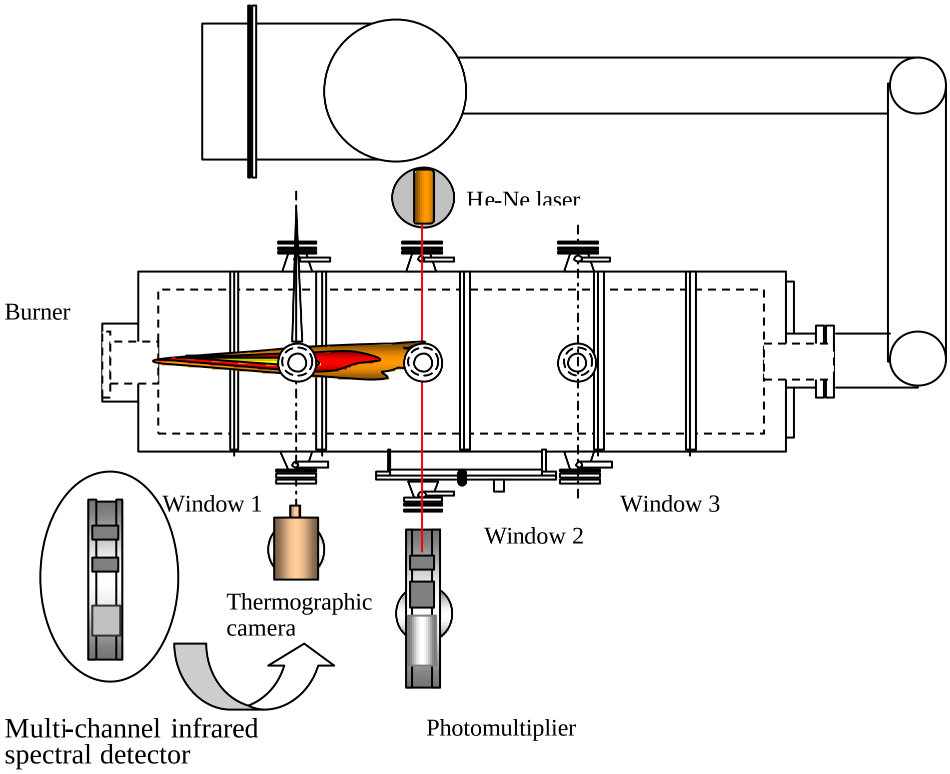

Fig. 1. Schematic of heavy-oil burner and experimental set-up.

obtain temperature distribution of soot clouds from these two images on the basis of wavelength dependence of emissivity of soot particles.

Figure 3 shows temporal profiles of T_p and *kcl*. Since soot particles did not always exist in measurement volume, some errors originating in the case of no soot particle were involved in Fig. 3. Although T_p and *kcl* show wide fluctuations from this reason, obtained value of T_p 1400 K is reasonable as compared to temperature of 1200 K measured with thermocouples

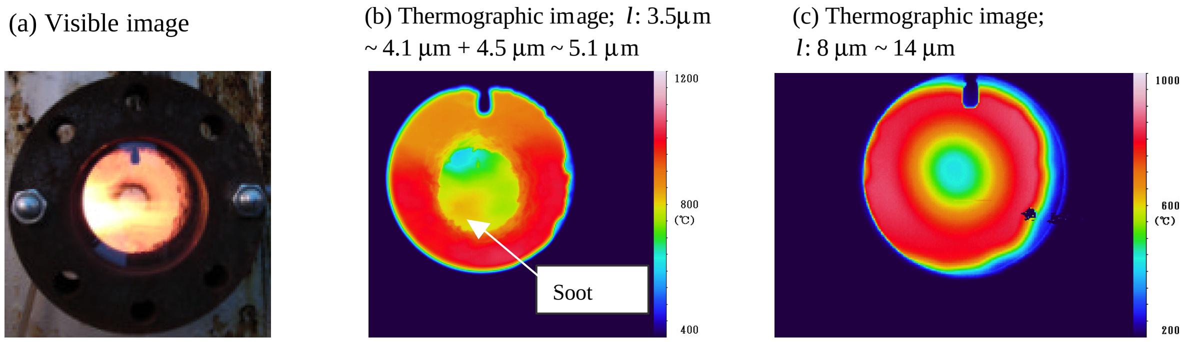

Fig. 2. Visible and thermographic images of soot particles obtained at window 1.

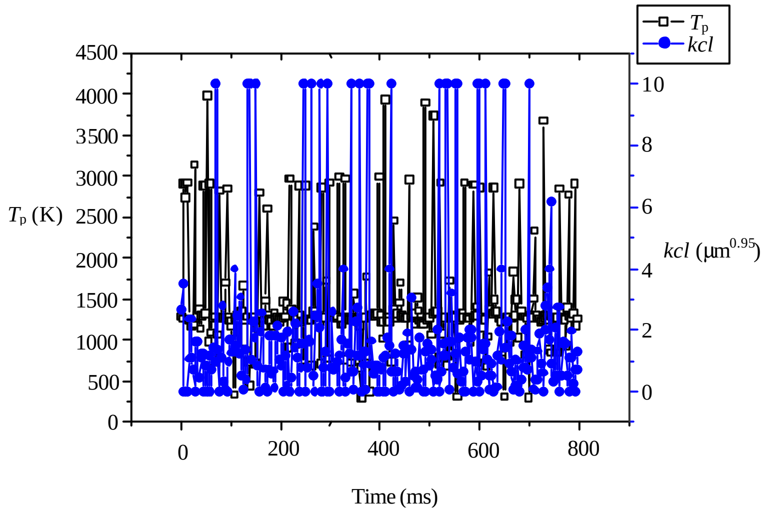

Fig. 3. Temporal profiles of kcl and temperature of soot particles T_p

suspended in the burner. The value of kcl was estimated to be 1.0 ~ 3.0 in Fig. 3, which agrees well with the value of 1.0 ~ 3.5 obtained from combination of a narrow-band filter and the thermographic camera on the assumption that temperature of soot particles is 1200 K.

Total soot volume measured by the laser extinction method is shown in Fig. 4. This result that total soot volume at the window 3 is larger than that at the window 2 is contradictory to the thermographic images which display that no apparent soot cloud can be seen at the window 3. One reason for this contradiction is over-estimation of length of the optical path at the window 2. Since it was difficult to obtain real-time value of length of optical path, it was estimated to be 0.8 m for the both windows. However, the length of optical path at the window 2 can be smaller than 0.8 m from the thermographic images showing existence of soot cloud at the window 2. The other reason is that fly ash was also detected at the window 3 by laser extinction method. This explanation is supported by the result that total soot volume in the case of no flame, namely only air supply with no fuel, shows almost the same value in the case of flame. The fly ash, which was deposited over a lower floor of the burner, was involved into a main flow by a swirling air supplied from the burner inlet. This effect is significant, in particular for downstream measurement.

Conclusion

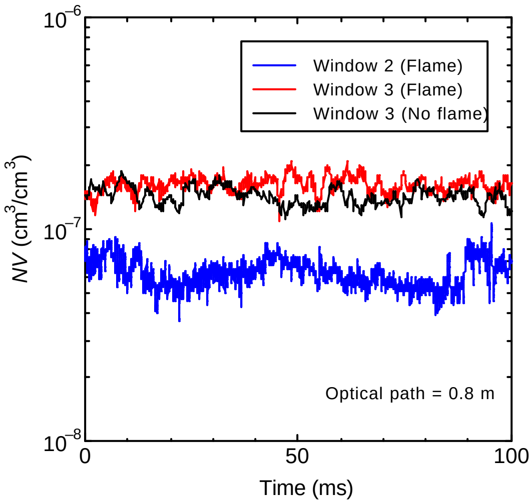

Fig. 4. Temporal profiles of total soot volume by the laser extinction method.

Infrared measurement was applied to an industrial test burner for intrusive and in-situ measurement of soot particles. The experimental results show validity of thermographic image techniques and multi-channel infrared spectrum analysis and indicate the problem of laser extinction method.

Acknowledgement

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References

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