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Concurrent spectroscopic measurement of emissivity and temperature of burning single coal particles

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Abstract

Temperature and spectral emissivity are parameters of outmost importance in the analysis of combustion systems. For certain small objects their surface temperature and spectral emissivity needs to be acquired with non-contact measurements. This research is aiming at a non-contact method for concurrently determining the surface temperature and emissivity of burning single coal particles using multi-wavelength spectrometry. The coal particles were in the nominal range of 75–90 µm, as classified by sieving. Single particles of coal, were injected in an electric drop-tube furnace heated to 1400 K. Subsequently, the particles were burned in air, one at a time, in a drop tube furnace (DTF) under high temperature and high heating rate conditions. Ignition took place close to the injector tip at the top of the drop-tube furnace, immediately after entering the radiation zone. Upon ignition, volatile matter flames formed around particles and grew bigger with time. Spectrometric observations of a number of those particles were conducted from the top of the furnace injector, viewing downwards the central axis of the furnace along with a particle's path line over a range of wavelengths (600–1000 nm). Both the luminous volatile matter flames and the burning chars were observed. Results will be compared with values published in the literature.

Introduction

Pulverized bituminous coal typically burns in two phases: combustion of volatile species and combustion of residual char. Levendis et al. [1] reported that typical peak volatile flame temperatures of a Pittsburgh #8, HVA, are in the range of 2100-2200 K, whereas typical char temperatures are in the range of 1770-1900 K, at gas temperatures of 1350 K. The particle temperatures were measured by three-color pyrometry using the gray body assumption. Graeser et al. [2, 3]reported average char emissivities between 0.3-0.4 in the wavelength range of 1.25µm to 2.25µm for single bituminous coal char temperatures between 2200K-2800 K in oxy-fuel atmospheres; and average emissivity of bituminous coal chars around 0.4 in the wavelength range of 1.25-2.25 μm, and 0.5 in the wavelength range of 2.4-5.5 μm when the combustion temperature was between 1600K-2500 K in oxy-fuel atmospheres. But data on the spectral emissivity for volatile flame and char of single coal particle in the wavelength range of 600 nm-1000 nm is still missing from the literature. This research used a non-contact method for concurrently determining the surface temperature and emissivity of burning single coal particles using multi-wavelength spectrometer over a range of wavelengths (600–1000 nm).

Experimental Methods and Coal Sample

An *Avantes* AvaSpec-2048 spectrometer measured the radiation intensity in the 600-1000 nm range and calibrated with a pre-calibrated tungsten filament lamp with a *Pyrometer, LLC* lamp. The experimental setup is shown in Fig.1.

Spectrometric temperatures and spectral emissivities were calculated again based on Planck's law(**Eq.1**) using the Newton iteration method and expressing the spectral emissivity as a polynomial function(**Eq.2**)[4]:

$$I(\lambda_j) = \varepsilon_{(\lambda_i)} \frac{c_1}{\lambda_i^5 \left(e^{\frac{c_2}{\lambda_j T_s}} - 1 \right)} \quad j=1,2,3,\dots n \tag{1}$$

$$|f|^2 = \sum_{j=1}^{n} (I_m - I(\lambda_j)) = \sum_{j=1}^{n} \left(I_m - (a_0 + a_1 \cdot \lambda_j + a_2 \cdot \lambda_j^2 \dots + a_n \cdot \lambda_j^m) \cdot \frac{C_1}{\lambda_i^5 \left(e^{\frac{C_2}{\lambda_j T_s}} - 1 \right)} \right)^2 \tag{2}$$

where $I(\lambda_j)$is spectral radiation intensity; I_m is the measured intensity; $\varepsilon_{(\lambda_i)}$is spectral (monochromatic) emissivity; j is the number of measured effective wavelengths in range; c_1, c_2 are Planck 1st 2nd constant. $|f|$ is the absolute residual number. The surface temperature and the spectral emissivities are obtained when f^2 reaches the minimum value.

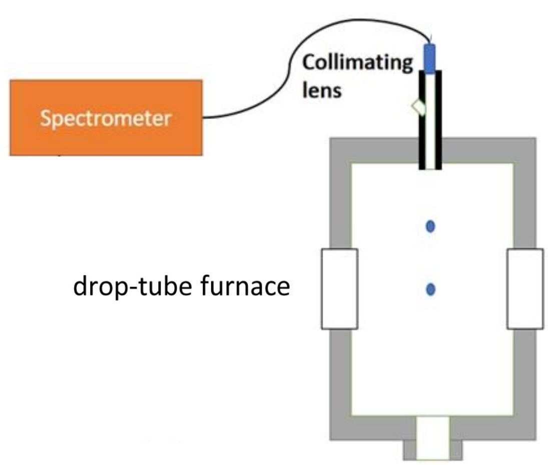

Figure 1. Schematic of the experimental setup

The coal particles used in this research is a Pittsburgh #8, HVA with a sieve size of 75-90 µm. All the particles were burned in air, one at a time, in an electric drop-tube furnace heated to 1400 K.

Results and Conclusions

The spectrometer records particle temperatures every 15 ms. The measured values in Fig.2 are the peak temperature points in the volatile flame and char combustion in every single particle.

Temperatures are in the range of 2100-2200 K (averaging 2136 K over 10 particles), as shown in Fig. 2. The measured spectral emissivities of these envelope flames are in the range of 0.05-0.12, averaging 0.8. The emissivity curve of the volatile flames is rather flat, denoting only a small deviation from graybody behavior in the wavelength range of 600 nm to 1000 nm. The spectrometer recorded burning char temperatures in the range of 1750-1850 K, with an average of around 1779 K. The measured volatile flame temperature agrees with the results of Levendis et al. [1]. The spectral char emissivities were measured to be 0.4 to 0.5, with an average of around 0.43 and with limited departure from graybody in the wavelength domain of 600 -1000 nm . Such spectral emissivity values are in line with those measured by Graeser et al. [3] (0.4-0.5), albeit at a higher wavelength range, but at similarly elevated temperatures.

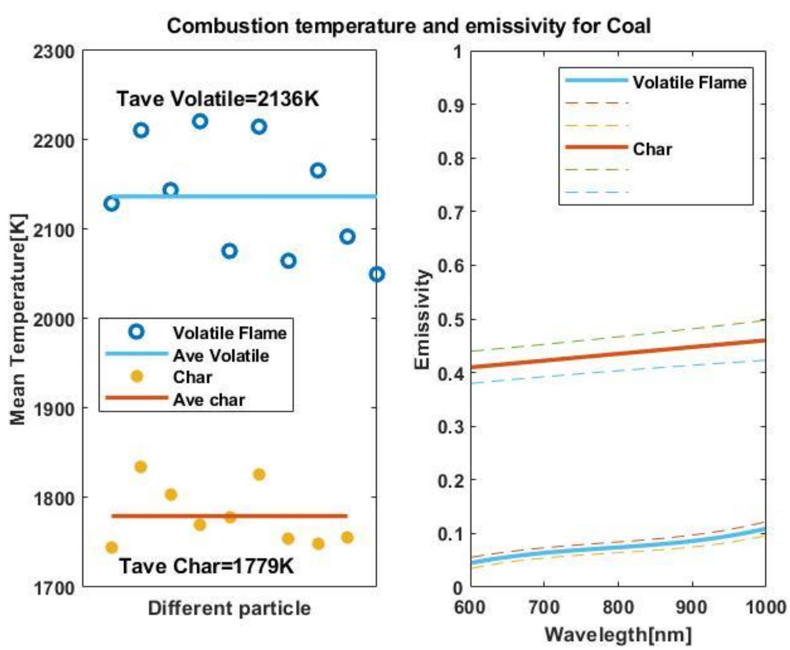

Figure 2. Combustion temperature and emissivity of volatile and char for different single bituminous coal particles from spectrometric measurements

The emissivity curve of the char is rather flat, denoting a small deviation from graybody behavior in the wavelength range of 600 nm to 1000 nm.

References

[1] Y.A. Levendis, K. Joshi, R. Khatami, A.F.J.C. Sarofim, Flame. Combustion behavior in air of single particles from three different coal ranks and from sugarcane bagasse. 2011;158(3):452-65.

[2] P. Graeser, M.J.F. Schiemann. Char particle emissivity of two coal chars in oxy-fuel atmospheres. 2016;183:405-13.

[3] P. Graeser, M.J.F. Schiemann. Emissivity of burning bituminous coal char particles–Burnout effects. 2017;196:336-43.

[4] W. Yan, A. Panahi, Y.A.J.E.T. Levendis, F. Science. Spectral emissivity and temperature of heated surfaces based on spectrometry and digital thermal imaging–Validation with thermocouple temperature measurements. 2020;112:110017.