Spectroscopy of Infrared Emission Characteristics of Thermal Power Plant Boiler Coal Ash Deposits

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Abstract: Thermal radiation characteristics of ash deposits on a coal combustion boiler of an electric power plant are investigated. Normal emittance spectra in 2.5-25 μm wavelength region and total normal emittance are measured on four kinds of ash at 600~1100K in heating and cooling processes. Ash layers are opaque for infrared radiation in the heating process of the powder. Emittance increases with an increase of wavelength and temperature, irrespective of chemical composition. Total emittance decreases with an increase of temperature. Emittance of sintered layers is higher after the sintering. In an ash layer, semi-transparency occurs with the sintering. The results are summarized from a thermal engineering aspect to determine a quantitative direction for evaluating the thermal radiation characteristics in safety design of a boiler system.

Keywords: Thermal radiation, Spectroscopic measurement, Emittance, Ash deposit, Pulverized coal combustion boiler furnace

1 Introduction

Normal emittance spectra in 2.5-25 μm region and total normal emittance are measured on four kinds of coal ash deposits at 600~1100K during heating and cooling. The results are discussed and a quantitative direction is suggested for evaluating the thermal radiation characteristics in safety design of boilers.

2 Experimental

Materials of specimens are bulk pieces of broken ash layers sampled at 4 points in a Yugoslav power plant boiler furnace shown in Table 1. Because of large mm-order inhomogeneity in the pieces, powdered specimens are prepared. Table 2 shows the chemical composition. Size of the specimen powder particles is of 10~500μm, more than 50% lie in 100~300μm diameter range.

Table 1: Specification of ash specimens

	position in furnace	structure	color		density kg/m^3
			bulk	powder	
1	10m, inclined wall	s-granular	brown	pink	1378
		i-layer	dark red		
2	30m, rear wall	s-granular	brown	brown	1469
		i-layer	black		
3	46m, su-per heater	s-layer	violet	pink	898
		i-layer	dark red		
4	10m, inclined wall	s-granular	violet	brick red	999
		i-granular	dark red		

(s-specimen surface, i-inner part of the specimen)

Table 2: Chemical composition of ash specimens (wt.%)

	No.1	No.2	No.3	No.4
$CaSO_4$	48.17	25.95	73.44	0.53
CaO	4.71	18.90	4.5	10.94
Al_2O_3	3.08	3.39	2.55	24.21
FeO	29.45	35.33	5.66	10.39
SiO_2	7.42	9.48	7.36	44.32

Figure 1 shows a schematic diagram of the experimental set-up. Specimen powders are set in stainless steel vessels of 1, 3 and 5 mm in depth to form specimen layers. Temperature of the layers is measured by a K-thermocouple of 0.1mm in diameter whose hot junction set at 0~0.5mm depth in the layer. The specimen is radiation heated from the backward by SiC heaters.

The specimen layer is heated to 1100K and cooled down at a heating/cooling rate of 2 K/min and above 500K at every 100K an optical measurement is made.

Emittance of specimen layers is measured by comparing radiation emitted from the specimen surface with that from a blackbody, accounting for the ambient radiation. The spectrophotometer for the infrared spectral measurement is of a Fourier transformation type, measuring a spectrum in the infrared region of λ=2.5~25μm, where λ is the wavelength of radiation. Total radiation fluxmeter used for the total emittance measurement is a modified-type radiation pyrometer.

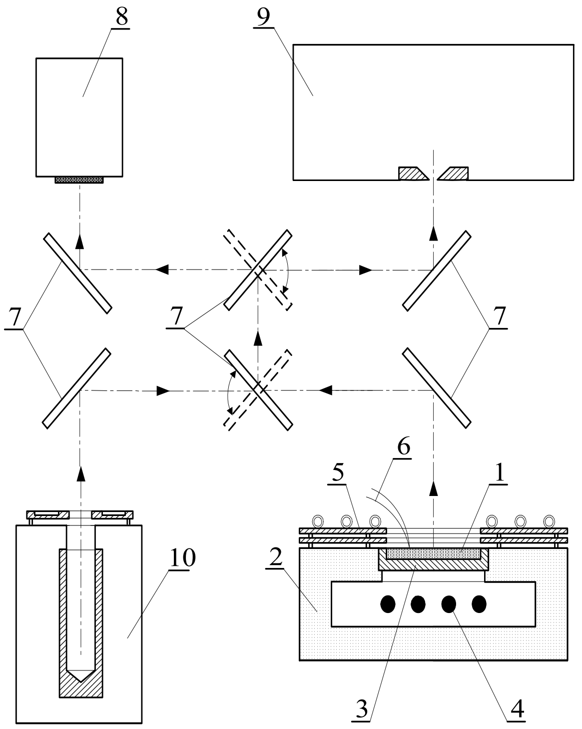

Fig. 1: Schematic diagram of the experimental set-up (1. specimen, 2. oven, 3. vessel, 4. heaters, 5. radiation shield, 6. thermocouple, 7. mirror, 8. fluxmeter, 9. spectrophotometer, 10. blackbody)

3 Discussion of results

Figure 2 shows thickness dependence of the measured spectral emittances ε_N at λ=3.75 and 12.5 μm of ash layers. The data are for specimens 1~4 of thickness t=1~5mm at 1000K in the heating and cooling processes.

In the heating process, while the specimen layer keeps the powder state, ε_N does not depend substantially on t for all the specimens and at both of the shorter and longer wavelengths. That is, in a state of powder the 1mm thick layer is opaque enough. Measured emittance ε_N of the layers can be taken as true emittance as the property value.

Figure 3 shows emittance spectra of ash layers of specimens No.1~4 of t=5mm at 600~1100K in the heating process. Absorption of infrared active gases is observed clearly. Particularly, the reliability of data in the 4.3μm region of CO_2 is low. Therefore, data at λ=4~5μm are omitted from the following discussion.

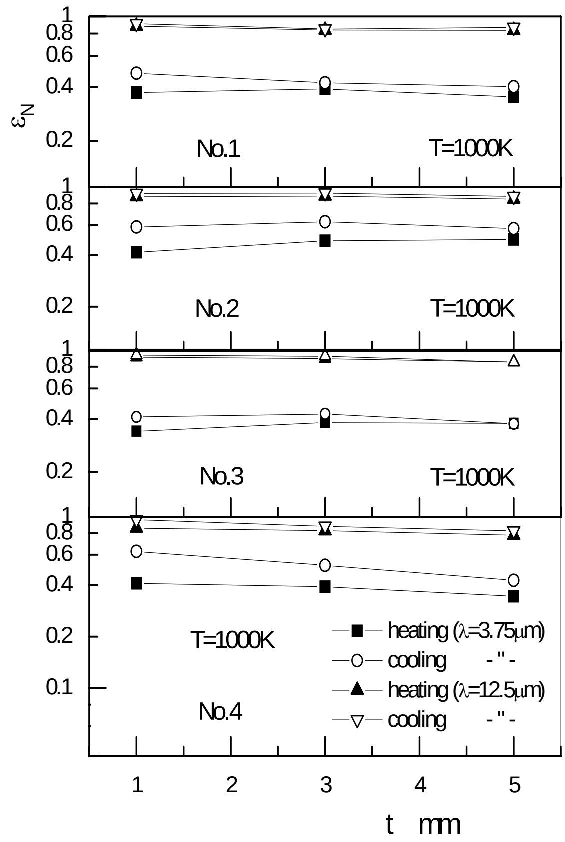

Fig. 2: Ash layer ε_N vs. t

Emittance of ash increases with an increase of wavelength over the spectral region of measurement. The temperature dependence is distinct in the shorter wavelength region. Data for specimen No.2 containing 35% FeO are than those of the other three specimens in this region.

Above 1000K the ash layers are sintered and fused. In the cooling process, emittance of specimen No.4 decreases with an increase of the layer thickness. It is considered that radiation absorption of the layer is weak, and that radiation emitted from the specimen vessel at higher temperature is measured with that from the upper specimen layers in the thinner layers. This tendency is coincident with that in measured values of total emittance ε_N^{total}.

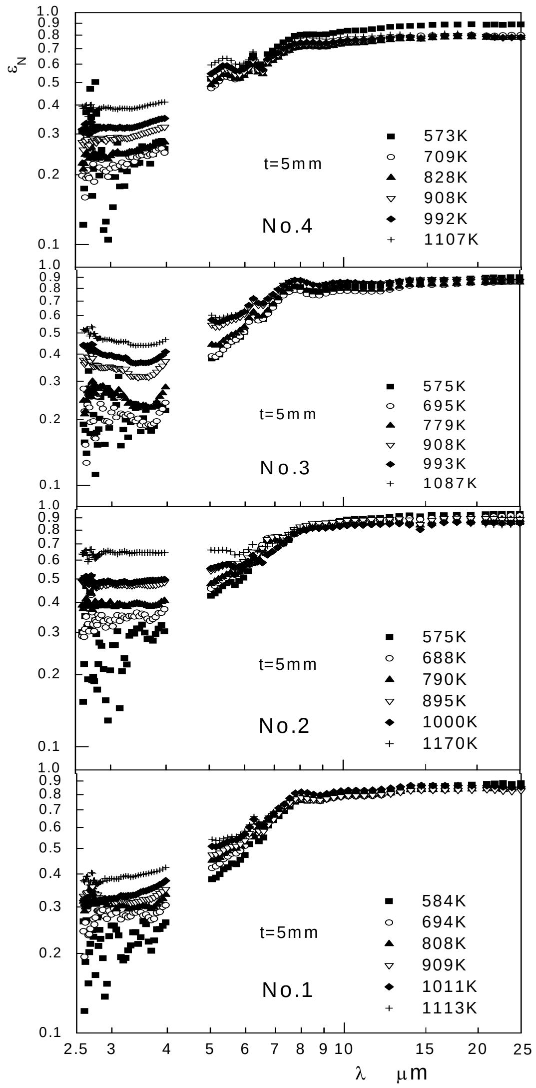

Fig. 3: ε_N spectra of ash layers in heating process

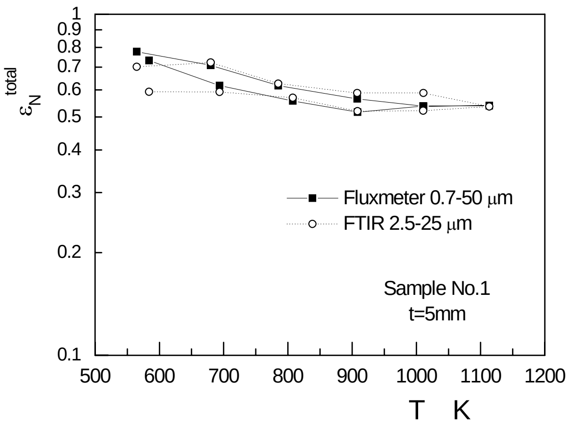

Fig. 4: ε_N^{total} in heating and cooling processes

Figure 4 shows the temperature dependence of measured total emittance ε_N^{total} of specimen No. 1 of t=5mm in the heating and cooling processes at 600~1100~600K. The figure also shows integrated emittance values derived from spectral measurements. Data for the other three specimens show a similar behavior. There is an obvious hysteresis as discussed.

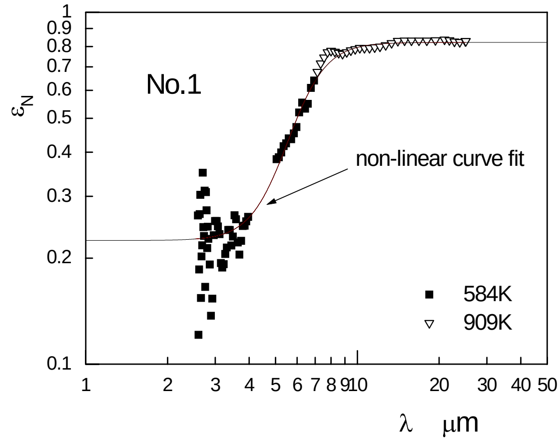

Fig. 5: Evaluated emittance spectrum of an ash layer

For safety design of boiler furnace, it is important to evaluate the maximum and the minimum energy flux possible in the boiler walls. Maximum flux is evaluated by using Planckian distribution for the blackbody. The minimum flux should be evaluated on the basis of the knowledge on spectra of the minimum emittance possible. It is true that the emittance used in the traditional radiation energy exchange calculation using configuration factors is hemispherical emittance, and is not the normal emittance ε_N of the present measurement. But directional characteristics of emittance are weak [1], the values of emittance ε_N are considered to be near to those of hemispherical emittance.

We choose the lowest value of emittance among the values for different temperatures at each wavelength. Discrete experimental points in Figure 5 are obtained for specimen No.1. For the actual engineering applications, it is desirable that the spectrum is described in a form of a continuous function of wavelength of radiation. Then, we propose the following function to correlate the experimental points,

$$\varepsilon_N=\{\varepsilon_{min}+\varepsilon_{max}(\lambda/\lambda_m)^p\}/\{1+(\lambda/\lambda_m)^p\} \quad (1)$$

where ε_{min}, ε_{max}, λ_m and p are parameters for Equation (1). Experimental points in Figure 5 are analyzed by a best-fit analysis technique to determine the values of the four parameters. Table 3 shows the determined values of the four specimens. Figure 5 shows an example of a spectrum of the minimum emittance calculated by Equation (1) with the values in Table 3 for the case of specimen No.1 by a solid line.

Table 3: Parameters for evaluation of emittance spectra

	ε_{min} (-)	ε_{max} (-)	λ_m (μm)	p (-)
No.1	0.22461	0.82144	6.14911	6.69333
No.2	0.26123	0.85515	6.12821	6.23025
No.3	0.21181	0.84162	5.99631	7.48352
No.4	0.21674	0.76272	5.19129	7.54929

For each zone of the boiler furnace, appropriate experimental results should be used, i.e. for samples obtained from deposits taken at different levels in the furnace. The obtained data are applicable to the safety design of the furnace where the samples are taken from as well as for the design of other furnaces with similar geometry and combusting similar type of coal. This is interesting from the practical viewpoint, showing thus the applicability of property research results in the engineering practice.

4 Concluding remarks

- The ash powder layers are opaque for infrared radiation, true emittance can be measured on the layers. The emittance increases with an increase of wavelength of radiation. It increases with an increase of temperature of the layer at shorter wavelengths in particular. The emittance spectrum does not depend on chemical composition of the ash strongly.
- At temperatures higher than 1000K the ash powder layers are sintered and fused and solid layers of higher mass density are formed. The emittances are higher than those before the sintering. A kind of ash layer changes to be semi-transparent absorbing. The tendency is remarkable at shorter wavelength region.
- Total emittance of the ash layers decreases with an increase in temperature.
- In safety designs of thermal engineering systems including ash layers whose chemical/physical states are not clarified well, the emittance spectra are recommended to be evaluated by using the Equation (1) with constants in Table 3.
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