VERIFICATION OF PRECISE PREDICTIVE EXPRESSION OF EMITTANCE SPECTRA FOR POWDERY COAL ASH

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KEYWORDS Boiler, Pulverized coal, Thermal design, Coal ash, Emittance

ABSTRACT. The calculation expression for the emittance spectra has been derived by fitting it to the measured emittance spectra of powdery coal ash to improve the accuracy of a calculation tool for pulverized coal-fired boilers. The expression is composed of two terms. The first corresponds to the former expression, which stands for the effect of five major metallic oxides that occupy a composition of 85% in coal ash. The second stands for the effect of other five metallic oxides. The extra second term was found to improve the calculation accuracy of emittance spectra. The expression has widespread predictability for powdery coal ashes, whose fuel ratio (=mass ratio of fixed carbon to volatile matter in coal) ranges 0.6—2.4 (-).

INTRODUCTION

In the thermal design of pulverized coal-fired boilers, estimation of the thermal energy transferred from combustion gases to heat-transfer tubes is crucial. The high predictability of powdery coal-ash emittance contributes to improving the accuracy with which absorbed radiation can be estimated in the thermal design of the tubes arranged in pulverized coal-fired boilers.

Measurements of coal-ash emittance have clarified a qualitative trend that coal-ash emittance depends on the physical state and the chemical composition of coal ash [1–3]. Moreover, methods have been proposed for predicting coal-ash emittance [4–5]. Their prediction methods were, however, limited to specific coal ash samples or a few brands of coal ashes. Therefore, we have proposed the predictive expression of emittance spectra applicable to more brands of coal ash derived by fitting it to the measured emittance spectra of the five major metallic oxides [6]. The major metallic oxides that compose 85% of coal ash were expected to be predominant over other compositions on coal-ash emittance. The derived expression, however, has 0.050–0.170 (-) uncertainty in emittance corresponding to up to 22% uncertainty in thermal energy estimated with the calculation tool for pulverized coal-fired boilers. The uncertainty of the expression has to be reduced more.

In the present research, the emittance spectra of ten brands of coal ash were measured to investigate the effect of the chemical composition of powdery coal ash, especially minor composition. The objective is to improve a predictive methodology for emittance spectra of the powdery coal ash by investigating the effect of the minor metallic oxides.

METHODOLOGY

Experimental methodology The experimental setup for the emittance measurements was composed of the sample-heating system and optical-measurement system [4, 8, 9]. The setup was configured so that the emittance of samples could be accurately measured as to the proportion of radiation from the samples to the reference radiation from the black body. Ten brands of coal ash, whose raw coal ranges from 0.6—2.4 (-) in their fuel ratio, which mostly covered coals combusted in industrial boilers were measured. The experimental facility was located at the University of Bochum in Germany*.

Fitting methodology We derived the calculation expression for powdery coal-ash emittance by fitting it to the measured emittance spectra of ten brands of powdery coal ashes. The expression is composed of the following two terms:

$$\varepsilon(\lambda) = \varepsilon_1(\lambda) + \varepsilon_2(\lambda) \tag{1}$$

The first term $\varepsilon_1(\lambda)$ stands for the effect of the five major metallic oxides: SiO_2, Al_2O_3, CaO, Fe_2O_3, and MgO [6].

$$\varepsilon_1(\lambda)= \begin{cases} A+B\cdot\lambda & (2\leqq\lambda(\mu m)<4) \quad (2) \\ E_0+E_1\cdot(\lambda-4)+E_2\cdot(\lambda-4)^2+E_3\cdot(\lambda-4)^3 & (4\leqq\lambda(\mu m)\leqq 8) \quad (3) \\ C+D\cdot\lambda & (8<\lambda(\mu m)\leqq 16) \quad (4) \end{cases}$$

A, B, C, and D in expressions (2) and (4) are independent constants on λ, and E_0, E_1, E_2, and E_3 are constants determined by A, B, C, and D by connecting smoothly lines (2) and (4).

The second term $\varepsilon_2(\lambda)$ stands for the effect of the minor metallic oxides of TiO_2, Na_2O, K_2O, SO_3, and P_2O_5.

$$\varepsilon_2(\lambda)= \begin{cases} F+G\cdot\lambda & (2\leqq\lambda(\mu m)<4) \quad (5) \\ J_0+J_1\cdot(\lambda-4)+J_2\cdot(\lambda-4)^2+J_3\cdot(\lambda-4)^3 & (4\leqq\lambda(\mu m)\leqq 8) \quad (6) \\ H+I\cdot\lambda & (8<\lambda(\mu m)\leqq 16) \quad (7) \end{cases}$$

$\varepsilon_2(\lambda)$ was derived by the similar fitting procedures to $\varepsilon_1(\lambda)$. Instead of linear function for the fitting functions, the hyperbolic tangent function was employed to calculate the coefficients in the expressions (5) and (7) as the following representative expressions:

$$A = A_{SiO2}\cdot x_{SiO2} + A_{Al2iO3}\cdot x_{Al2O3} + \ldots \tag{8}$$

$$F = F_{TiO2}\cdot k_{TiO2}\mathrm{Tanh}(x_{TiO2}/k_{TiO2}) + F_{Na2O}\cdot k_{Na2O}\mathrm{Tanh}(x_{Na2O}/k_{Na2O}) + \ldots \tag{9}$$

A_{SiO2}, A_{Al2O3}, F_{TiO2}, F_{Na2O}, kT_{iO2}, and k_{Na2O} in expressions (8) and (9) are independent constants on x_{SiO2}, x_{Al2O3}, x_{TiO2}, and x_{Na2O}.

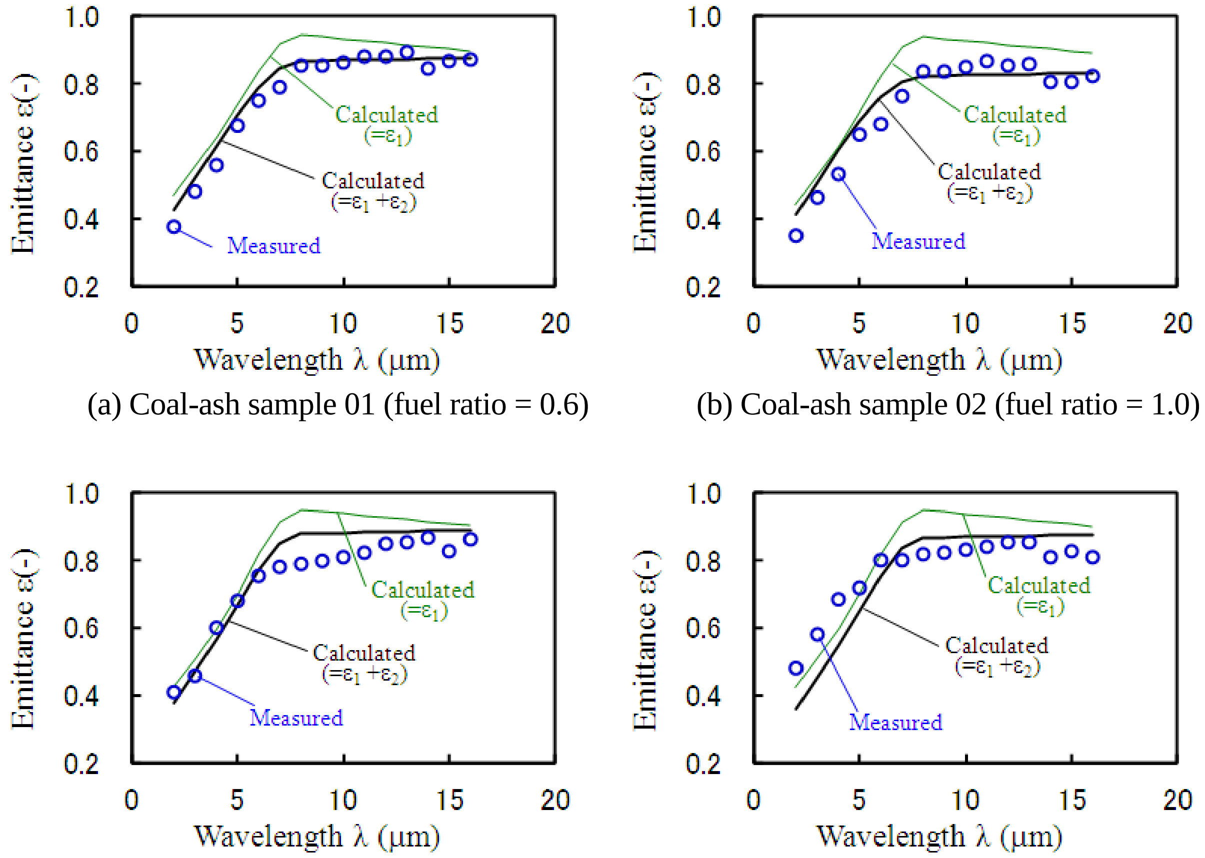
The hyperbolic tangent function was employed to avoid numerical divergence of the expression caused by the protruding irregularity in mass fraction of minor metallic oxide.

RESULTS AND DISCUSSION

Figure 1 shows the emittance spectra of coal-ash samples, which represent the ten brands of coal whose fuel ratio range is 0.6—2.4 (-). The calculated emittance spectra (ε_1 and ε_1+ε_2) are compared with the measured emittance spectra. The calculated ε_1 deviates upward from that measured in the range of 5—10 (μm). On the other hand, the upward deviation was not observed in the calculated

***ACKNOWLEDGEMENTS** The emittance measurements in this research were entirely conducted by the University of Bochum. The authors are grateful to Dr. Fabian Greffrath and Prof. Scherer for these important measurements.

$\varepsilon_1+\varepsilon_2$. Consequently, the minor metallic oxides improve calculation accuracy from 0.05—0.17 (-) to 0.03—0.06 (-) in the root-mean-square deviation. The accuracy corresponds to less than 10% uncertainty in estimating thermal energy with the calculation tool for pulverized coal-fired boilers.



(a) Coal-ash sample 01 (fuel ratio = 0.6)

(b) Coal-ash sample 02 (fuel ratio = 1.0)

(c) Coal-ash sample 06 (fuel ratio = 2.1)

(d) Coal-ash sample 05 (fuel ratio = 2.4)

Figure 1. Verification of the calculation expression for emittance spectra

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