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Key parameters for the radiative emittance of ashes of solid fuels

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Abstract

The knowledge of the emittance of solid fuel ashes is important for the radiative energy balance in boilers and, hence, crucial for their design. This paper summarizes the most important effects on emittance based on own experiments and makes references to literature. Experimental results will be presented on the spectral emittance of typical minerals (SiO_2, $CaCO_3$, $MgCO_3$, $SrCO_3$, $CaSO_4$, $MgSO_4$, Fe_2O_3) contained in solid fuels ashes, extended by exemplary measurements on natural ashes (coal). The normal emittance is measured in a temperature range between 500 and 1000 °C in the wavelength range from 1.6 to 12 µm in a radiation test rig. The influence of physical surface structure and chemical-mineralogical composition on emittance is discussed. The results show that sizes of ash particles influences emittance. Emittance is increasing with particle size. Surface sintering as well as Fe in the ash also increases emittance. Surface fusion can either increase or decrease emittance based on ash composition. Sulfates and carbonates, typical for ashes under oxyfuel conditions, show characteristic spectral emittance bands. These bands vanish when the sulfates and carbonates being converted to the corresponding oxides at elevated temperatures. These characteristic bands can also be detected in natural ashes which consist of a variety of mineral components.

Keywords: emittance; solid fuels; radiative heat transfer; boiler

Nomenclature

S	detected radiance signal
T	temperature

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x	particle diameter
RT	room temperature
Greek Symbols	
ε	emittance
$\bar{\varepsilon}$	total emittance
λ	wavelength
Subscripts	
BB	blackbody
λ	spectral dependence

1. Introduction

The heat transfer in the furnaces of solid pulverized fuel boilers is dominated by radiation. In pulverized fuel flames typically particle radiation is more important than gas radiation, and, hence, radiative properties of fuel and ash particles are of importance [1]. Flame radiation determines the wall heat flux to the heat transfer surfaces (water walls) of the boiler. The emittances of the ash layers, which are deposited at the wall, determine how much of the heat is absorbed or reflected. Therefore, the knowledge of ash emittance is crucial for a correct furnace energy balance.

Emittance of ashes is dependent on two parameters: physical surface structure and chemical-mineralogical composition. An example of the influence of physical surface structure are the findings of Gwosdz et al. [2]. They reported from power plant commissioning experiences that thin wall ash layers of very small dust particles can effectively reflect radiation. As a result of radiation reflection an increase of furnace exit temperature up to 125 °C has been detected. The reflectivity of very fine ash particle layers is mainly an effect based on scattering with the ratio of particle diameter/radiation wavelength being the dominant factor; the chemical composition of the particle is of less importance. The physical effect of the influence of particle size on emittance can be derived based on Mie-Theory [3,4]. Further physically based effects can be expected when the surface structure changes due to thermal load. Surface sintering [5,6] and surface fusion [7] influence emittance, examples will be shown in the current paper.

The second important effect on emittance is the chemical composition of the ash. This composition can be rather complex being a mixture of many minerals. The radiation interference of the minerals is unknown, i.e. it is unclear whether the emittance of a natural ash layer can be derived by superimposition the radiation characteristics of pure, single minerals. The situation is even more complex because minerals can transfer under thermal load or new minerals can be formed, a fact which makes emittance predictions of natural ashes difficult. However, the examples that will be shown in the current paper will give at least emittance trends and characteristics of typical mineral classes, especially oxides, sulfates and carbonates, which are also found in natural ashes. Special attention will be paid to the spectral characteristics of the sulfates and carbonates, because the background of the examinations presented in the current paper is oxyfuel combustion. In oxyfuel combustion nitrogen is replaced by CO_2 for flame temperature control and the massive flue gas recycling leads to an accumulation of SO_2 in the furnaces. Therefore, oxyfuel ashes may contain larger amount of sulfates and carbonates, as indicated by Scheffknecht et al. [8] and Kull et al. [9].

The current paper will present examples of emittance measurements which highlight the two important effects, physical surface structure and chemical composition, on normal radiative spectral and spectrally averaged emittance. The standard temperature range examined is typically between 500 and 1000 °C, which reflects typical ash layer temperatures on the water walls of boiler furnaces.

2. Experimental

The test rig consists of a Fourier transform infrared (FT-IR) spectrometer and an electrical heating unit that includes both, the sample holder as well as the reference radiator, a black body. The samples are typically prepared as powders of defined particle size fraction. Radiation of the heated sample (22 mm diameter, 2 mm thickness) and the black body is guided to a FT-IR spectrometer via a gold coated off-axis parabolic mirror. Radiation is measured perpendicular to the sample surface, i.e. normal emittance is determined. Thermal radiation is detected in the range from 1.6 µm to 12 µm. The sample surface temperature is determined by two thermocouples (type K, 0.25 mm