The Radiative Properties and Thermal Effects of Ash Clouds and Deposits In Pulverised Fuel Fired Furnaces

by

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I hereby certify that the work embodied in this thesis is the results of original research and has not been submitted for a higher degree to any other University or Institution

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Abstract

A theoretical and experimental study was undertaken on the radiative properties of solids suspended in furnace gases and those of the solid deposits formed on the furnace wall during pulverised coal combustion. Experiments included measurement of the absorption indices of coal, char, ash and slag particles, and the emittance of their deposits, both real time and ex-situ, to assess the effects of particle size, physical state, iron and unburnt carbon (UC), devolatilisation and heating. Theoretical studies included formulation of mathematical models for spectral radiative heat transfer involving particulates and gases, and for the spectral emittance of opaque and semi-transparent ash deposits. These codes considered both isothermal and non-isothermal fields, particle size, composition and concentration variables and evaluation of the effect of UC on radiative heat transfer and emittance of ash clouds.

A technique was proposed to measure the absorption index of the particulate samples. The technique, after calibration with known samples, was applied to three different coal samples, char prepared from each of these at several burnout levels, and fully burnt ash from each of these. In ash samples, the level of UC had a significant effect on the absorption index. Using these data the evolution of total emissivity of single coal particles with burnout was examined. A marked increase in emissivity was predicted during the initial stages of burnout followed by a decrease during the later stages. The effect of UC on net heat transfer across a plane parallel slab of particles was examined. Rapid decrease was observed up to 10% UC content, after which the rate of decrease was predicted to decrease. The effect of UC distribution in ash was examined qualitatively by calculating the hemispherical emittance of a slab of flyash particulates considering two cases: all particles have the same UC content, or the UC content was concentrated only in the large particles. The significant difference in emittance between the two cases suggest that it is not sufficient to specify only the bulk UC content of the flyash, rather how the UC is distributed relative to the particle size.

A model was developed to predict the spectral normal and hemispherical emittance of opaque and semi-transparent particulate deposits. A significant effect of particle size and composition on spectral emittance of particulate deposits was predicted. The presence of large particles and particles having high iron content were found to make deposits more emissive at wavelengths up to 5 μm. Calculations indicate that the apparent emittance of a non-isothermal deposit could be significantly different from the isothermal emittance if there is a substantial temperature gradient across it and the material is weakly absorbing. Results of calculations performed for two types of deposits (one heated from bottom and the other heated from top), indicate that care must be taken in experimental design and data

interpretation for accurate prediction of emittance from such measurements. The approximate thickness required for opacity (1% transmission) of ash deposits was calculated using the model developed and found to vary between 80 μm and 1 mm depending on the type of material and particle size in the deposit, consistent with measurements reported in literature. The emittance of smooth slag layers was predicted to be of grey character, insensitive to both the real and the absorption index and exceed 0.9, a value supported by recent published measurements.

Speculations on the variation in the deposit properties as they build are presented with results of preliminary experiments to examine these speculations. Calculations were performed to assess the effects of conductive and radiative properties on exit gas temperature, wall flux and efficiency of a power station furnace. For a moderately reflective layer, both these effects are found to be significant whereas for unreflective deposits, conductive effects are found to be more significant. Comparison with an industrial measurement supported the predicted effects.

Spectral emittance measurements using slag particles showed the effect of particle size being limited primarily to the wavelengths below 6 μm, supporting model predictions. Heating of the particles at temperatures above 1000°C resulted in higher emittance values. At a particular temperature, emittance measured during the cooling cycle was found to be higher than the emittance measured during the heating cycle indicating possible irreversible structural transformations. Spectral emittance measured on slag particles having different iron contents indicated the effect to be limited to wavelengths below 5 μm with particles having higher iron content recording higher emittance. Spectral emittance measured on particles of muffle burnt ash and the particles of the same ash after melting to a slag showed differences with the slagged ash recording significantly higher emittance. The effect of devolatilisation on emittance of coal particles was measured; it was observed that with devolatilisation emittance increases to about 0.85 before decreasing to values about 0.7 with char combustion. Spectral emittance of char samples was measured as a function of ash content with char having lower ash content recording higher emittance.

Few studies have reported the importance of the inclusion of dependent effects in radiation calculations on the emittance of ash deposits. All studies are limited to either very small particles or very large particles and the experiments are either transmission or reflection measurements. Measurements were conducted using particle sizes relevant to radiative heat transfer in furnaces, and also involving *two* independent sets of measurements, transmission and reflection, on the same sample. Measured emittances were significantly higher than the values predicted assuming independent effects only thus showing the importance of

dependent effects. Additional experiments using a wider range of samples and particle sizes are recommended to quantify the extent of dependent effects.

The study provides the theoretical and experimental confirmation of the difference in nature between the spectral emittance of particulate and slagged deposits and thus show the importance of the physical state on emittance of deposits rather than the chemical composition. The results provide the necessary background for deposit monitoring using pyrometric measurements with consequent effects on the calculation of devolatilisation rates and heat transfer as well as the inclusion of this spectral character in radiative transfer. All the effects (size, dependent, thermal, physical state etc.) on emittance of particulate deposits are found to be limited primarily to the wavelength region below 6 μm.