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Modelling of particle radiation in oxy-fuel flames

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1. Introduction

In oxy-fuel firing, the recycling conditions will determine flue gas flow rates, residence time, mixing conditions, gas composition and combustion temperature, parameters which have implications on the design of new oxy-fuel boilers. Unlike N_2, which is transparent to thermal radiation, both CO_2 and H_2O emit and absorb thermal radiation. High concentrations of these gases therefore increase the emissivity of the oxy-fuel flue gas with subsequent effects on the radiative heat transfer. The relative importance of gaseous radiation compared to particle radiation depends on the type of fuel, but also on the combustion conditions. Even when gaseous fuels are burnt there can be a significant influence of soot radiation in the high temperature flame region. Pulverized coal flames include various particle types that participate in the radiative heat transfer. In the literature, there is limited information on the role of gaseous versus particle radiation in oxy-fuel flames, under gas and coal-fired conditions. The aim of this work is therefore to discuss the particle and gaseous radiation in air and oxy-fuel flames; both scattering and non-scattering particles are included in the analysis. This paper compares measured profiles of total intensity with modelled gas and particle radiation, for air-fired and oxy-fired cases applying dry flue gas recycling with propane and lignite as fuels.

2. Methodology

The experiments of the present work were carried out in the Chalmers 100 kW oxy-fuel test unit (see Andersson et al., 2008a, b for details). The radiation modeling is based on measured profiles of temperature and concentrations of H_2O and CO_2. The amount of particles present in the flames is obtained by fitting modeled intensity profiles against intensity profiles measured against a cool non-emitting background. The geometry considered in the modeling is an infinitely long cylinder where the distribution of species and temperature is assumed to have a radial symmetry. The discrete transfer method with a S_6 scheme is used to calculate the radiative intensity. For gas radiation a statistical narrow-band model is applied. The parameters used in the model were presented by Soufiani and Taine (1997). Particle radiation is modeled as non-scattering soot in the propane flames, while in the lignite flames it is modeled as

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either soot or as scattering coal particles. Particle properties are calculated for each narrow band and the transmissivity of each band is given by the product of the gas transmissivity and the particle transmissivity.

3. Results

Figure 1 presents radial profiles of intensity measurements by the narrow angle radiometer together with modelled intensities in the air and OF 27 propane flames, 384 mm from the burner. The modelled profiles include gas radiation intensity, total radiation intensity, and profiles of soot radiation based on the fitted soot concentrations and measured temperatures. There is a significant increase in the radiation emitted by the oxy-fuel flame (Fig. 1b), although the temperature measurements (Andersson et al., 2008a), show that the temperatures, corresponding to the radiation data in Fig. 1, are slightly lower in the OF 27 case compared to the air-fired case. Thus, the increased intensity level in the OF 27 flame compared to air combustion has other explanations. In the OF 27 flame it is seen that the increase in CO_2 concentration results in an increased gas radiation. By comparing measured total radiation (soot and gas radiation), with modelled gas radiation it is also evident that the soot radiation increases drastically in the OF 27 flame. It is also seen that for typical flame temperature conditions, as in the present measurements, the CO_2 absorbs a fraction of the flame emission when the temperature decreases towards the combustor wall. Thus, the increased CO_2 fraction in the OF 27 flame does not significantly increase the amount of heat transferred to the combustor wall (0.8m in Fig. 1), while the increased soot radiation has a strong impact on the heat transfer conditions in the OF 27 flame.

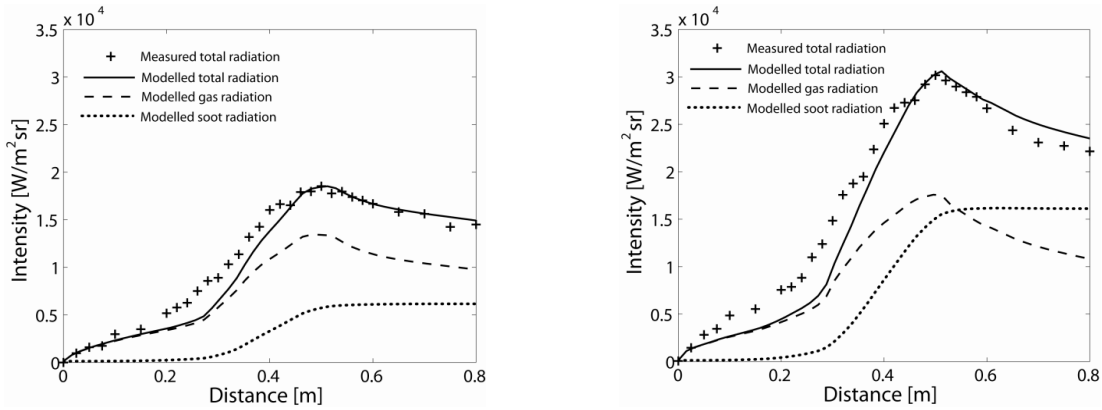

Figure 1. Measured total radiation intensity with the narrow angle probe and modelled total gas and soot radiation intensity in (a) air-fired conditions and (b) OF 27 conditions. The fuel is propane and the measurements were performed at a distance of 384 mm from the burner.

Figure 2 presents experimental data reported by Andersson et al. (2008b) including total intensity measurements together with radiation modeling results of the lignite flame for both air and OF 25 conditions at a distance of 384 mm from the burner inlet. The radial temperature profiles of air and OF 25, measured in the same probe port as the radiation data almost coincide with differences less than 20 K in most positions. The gas radiation calculations reveal that the additional CO_2 content in the OF 25 flame give a noticable contribution to the gaseous radiation compared to air-fired conditions, but, also, that this has little or no influence on the measured total intensity. The explanation is found in the radiative contribution by particles. In Figs 2a-b, the modelled particle radiation is assumed to be radiation emitted by non-scattering soot particles. The results show that the similarity in the intensity profiles between air and OF 25 is due to the fact that the particle radiation dominates the flame radiation, which reduces the influence of increased CO_2 radiation in the O_2/CO_2 environment. As a comparison to the results in Figs 2a-b, calculations based on scattering particles are presented in Figs 2c-d. The scattering particles are approximated

as coal-particles with an average diameter of 40 µm, which is the average particle diameter of the fuel. As the particle projected surface area is fitted to obtain a good agreement between measured and modelled total intensity, the total intensity is not affected by a change in particle type. The aim is instead to illustrate how the contribution of particle radiation is affected by the physical properties of the particles. As seen, for scattering particles, the radiative contribution is reduced compared to non-scattering soot particles. Thus, in this case the particle radiation becomes less dominant; it is still the major contributor to the emitted flame radiation, but the relative contribution by the gaseous radiation becomes more important. It is obvious that further work is required to increase the knowledge on coal-derived soot as well as on particle radiation characteristics in oxy-fuel flames.

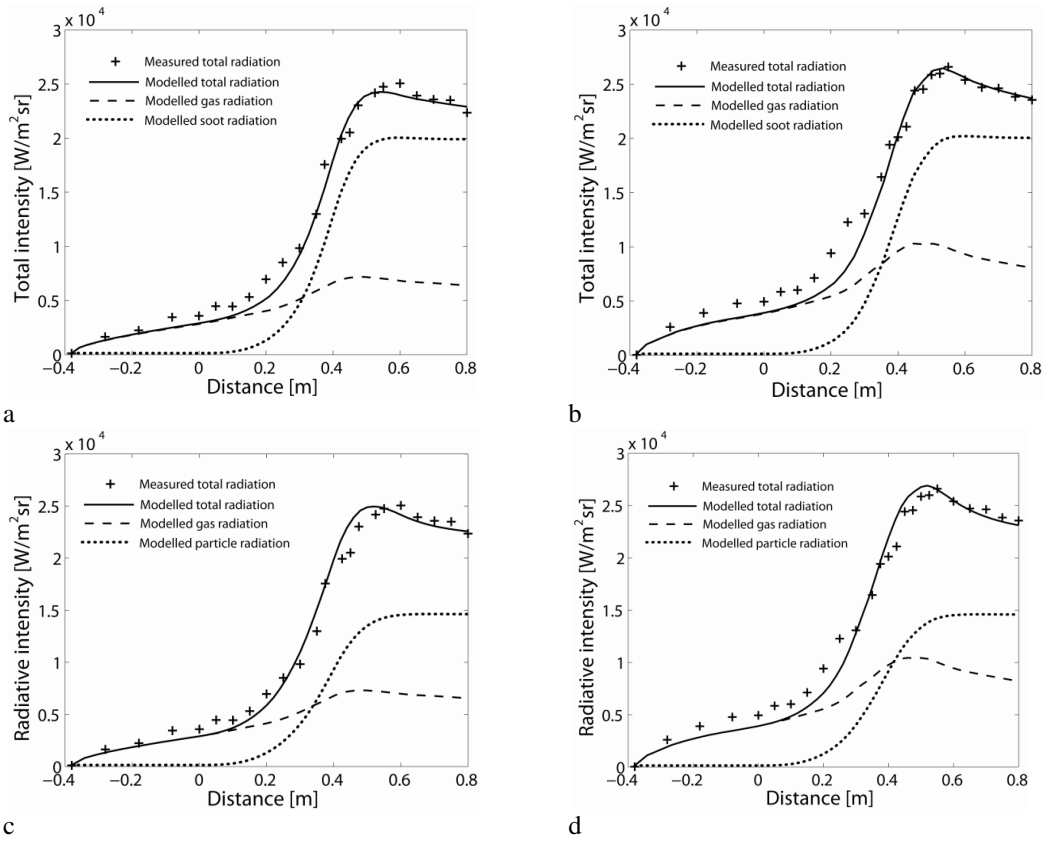

Figure 2. Comparison of radiation intensity measurements and modelling results in (a, c) air-fired and (b, d) OF 25 conditions, during combustion of lignite. The measurements are performed at a distance of 384 mm from the burner. The extension of the radiative path by the opposite probe port is indicated by the line (-0.38m to 0 m) and the furnace walls are located at the radial distances 0 and 0.8 m. The modelling results include total intensity, gas and non-scattering soot radiation in (a) and (b) and total, gas and coal particle (scattering) radiation in (c) and (d) respectively.

4. References

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