Evaluation and Characterisation of the Temperature of a Coal-fired Flame through CFD Modelling and Practical Measurements

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The work presented is concerned with the temperature evaluation and characterisation of a coal-fired flame on a 3 MW_{th} Combustion Test Facility. The flame temperature is measured by a two-colour based imaging system and a suction thermocouple probe. The temperature is also estimated using complementary CFD modelling. The results are compared and evaluated so as to achieve an understanding of the pulverised coal flame.

Introduction

Information on spatial variations in both particle and gas temperature of a pulverised coal flame plays an important part in the in-depth understanding of combustion processes and emission formation. A number of techniques have been developed and used for measuring and predicating the flame temperature, those including physical probes such as thermocouples, vision-based monitoring systems, and computational modelling [1]. The validation of the results obtained using different techniques is therefore necessary for the reliable evaluation and characterisation of the combustion process. As part of European Interreg IIIa project - Combustion Optimisation through Advanced Modelling and Measurements, a study has been carried out to evaluate and characterise the temperature of a coal-fired flame on a 3MW_{th} coal Combustion Test Facility (CTF). The flame temperature is measured by a two-colour based flame imaging system and a suction thermocouple probe. A complementary CFD model of the flame has also been established. The results are compared and evaluated.

Methodology

Temperature measurement- The solid phase temperature of the flame was measured using a flame imaging system, which is capable of measuring the two-dimensional temperature distribution of the flame based on the two-colour pyrometry [2]. In this study, the optical probe/camera of the system was installed at a view window of the furnace sidewall close to the burner so the whole root of the flame was visualised.

The gas temperature of the fame was measured using a suction thermocouple (Pt-PtRh) prevented by radiation ceramic protection tubes. Up to 44 measurement points along three measurement lines across the flame zone were taken. Please note that the locations of the two types of the measurements are different. The solid phase temperature was measured on an integrated volume in a vertical plane along the burner axis whilst the gas temperature was taken along lines in a horizontal plane. A CFD model of the flame was created to link the two types of measurements.

CFD Modelling- The CFD model of the flame was developed using the CFD finite-volume code Fluent. The turbulence is modelled using the Reynolds Stress Model. The gas phase combustion of the volatile phase was only controlled by the turbulence with a probability density function model using equilibrium. The displacement of particles in the flow is obtained through a Lagrangian method. The devolatilisation kinetic is calculated with the two competing rates. The char burnout is determined with a diffusion model. The radiation is calculated with the P-1 model.

The boundary conditions were obtained by modelling the air inlet conditions. The wall heat flow was calculated from the cooling loops. The properties for the coal devolatilisation were obtained using a flat flame burner [2].

Experimental

Experiments were undertaken on the $3MW_{th}$ CTF run by *CEntre de Recherche sur le CHARbon* (CERCHAR) at Mazingarbe, France. The CTF is a pilot pulverized fuel fired furnace, having a cylindrical water-cooled combustion chamber fitted with a low-NO_x horizontal swirl burner. The coal used in the test is a high volatile bituminous coal from Freyming, France. During the test, the furnace load was $3.6MW_{th}$. The burner was set with a swirl number of 1.27 and a stoichiometry in the quarl of 0.57 (fuel-rich). The global stoichiometry after the stabilisation air introduction is oxidant.

Results

Fig. 1 shows the typical example of instantaneous and averaged temperature profiles of the solid phase of the flame obtained by the imaging system. The averaged temperature profile is computed over a total of 60 instantaneous images recorded for a selected periods of 6 minutes under a stable test condition. Fig. 2 illustrates the gas temperature measured using the thermocouple probe, plotted over the temperature mapping computed based on the CFD modelling results.

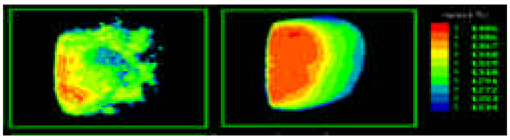

Fig. 1. Instantaneous and averaged temperature profiles of the solid phase of the flame.

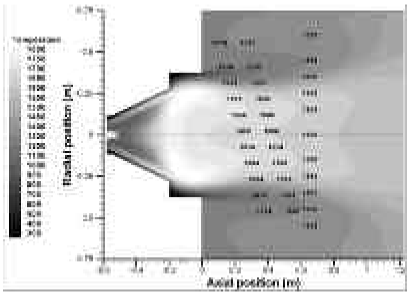

Fig. 2. Gas phase temperature of the flame plotted over the temperature CFD modelling results.

In the comparison between the maximum gas phase temperature (measured by the thermocouple) and the solid phase temperature (measured by the imaging system) of the flame, a good agreement has been found in the root region of the flame (particularly where close to the burner quarl). A suggested hypothesis is that the imaging system measured the temperature of soot in the root region as the small size of soot allows it to be in equilibrium with gases and compensate the energy lost by radiation [2].

Fig. 3 shows a comparison between measured (by the thermocouple) and modelled temperatures for the measurement lines (Fig. 2) across the flame sections. Significant differences between the measured and modelled temperatures at some measuring points are evident. The flame model with its infinitely fast kinetics may give an over predicted temperature. The lack of a soot model may also contribute to the error in the modelled temperature.

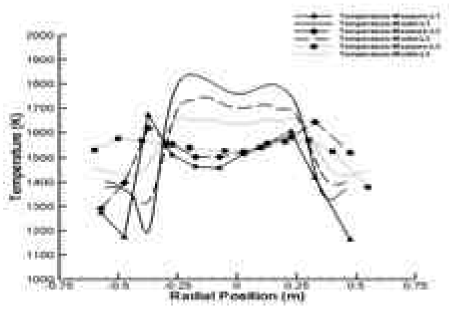

Fig. 3. Measured and modelled temperatures for the measurement lines.

Conclusions

Evaluation and characterisation of a coal-fired flame temperature have been conducted on a 3 MW_{th} CTF through practical measurements and CFD modelling. A good agreement between the maximum gas phase temperature and the solid phase temperature of the flame has been found in the root region of the flame. This suggests the measured temperature by the imaging system is probably the temperature of soot particles rather than the coal particles. The results from CFD models show the main structures of the flow but with some errors linked to the numerical approximations. However, the coal volatile composition is complex and industrial installation can be of a greater size; consequently, the computational time for a realistic model including kinetics to represent properly species with kinetics, would be far too long using traditional Arrhenius laws.

References

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