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Dynamics of furnace processes in a CFB boiler

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Abstract

With the aim of understanding the dynamics of combustion, this work examines simultaneous fluctuations in fluid dynamic parameters and gas composition measured in a CFB furnace operated with coal as a fuel. The fluid dynamic parameters investigated are pressure and air flow entering the furnace. Gas composition was recorded by a zirconia-cell probe and a gas suction probe connected to a mass spectrometer having a high time resolution (10 Hz). The principal fluctuations detected are around 1 Hz and below 0.3 Hz. The fluctuations below 0.3 Hz mostly originate from variations in the fuel-feed rate. These variations create periods of reducing conditions caused by a momentarily high fuel input accompanied by a pressure rise in the furnace and a reduction of the air feed, which occurs concurrent with the release of an enhanced quantity of volatiles. Modelled pressure fluctuations based on the relation between volatile release and pressure in the furnace give similar pressure fluctuations as the measured pressure fluctuations, with respect to amplitude and characteristic time scale of the fluctuations. There is also a correlation between reducing conditions and the concentration of hydrocarbons.

Keywords: Circulating fluidized bed; Combustion; Gas composition; Dynamics; Hydrodynamics; Fluidization

1. Introduction

During fluidized-bed combustion, constant fuel supply over time and even distribution of fuel over the furnace cross-section are desired to avoid unwanted variations in gas concentration within the furnace. This may be difficult to ensure, particularly during combustion of fuel with a significant content of volatiles, because of rapid devolatilization compared to dispersion in a fluidized bed. It has been reported that large fluctuations between reducing and oxidizing conditions occur during operation with high-volatile fuels in fluidized beds (e.g. Niklasson et al., 2003). Such variations in gas composition retards conversion of gaseous fuel components and displaces it to downstream regions of the furnace, which may influence burn-up and cause undesirable emissions.

In addition to mixing problems related to release of volatiles, the dense fluidized bed present in the bottom part of many designs of CFB boilers could be a source of the changes between reducing and oxidizing conditions. The pressure in such a bed oscillates due to the bubble flow through the bed which may affect combustion. Imperfections associated with large-scale combustion conditions, such as small variations in operation, maldistribution of the fuel over the furnace's cross-section and irregularities in the external solids flow could also be the origin of fluctuations in the gas composition. Pressure variations in the furnace can propagate through the air distributor down into the air-feed system and cause fluctuations in the air feed (e.g. Svensson et al., 1996; Johnsson et al., 2002; Sasic et al., 2004), especially at a low pressure drop across the air distributor, typically found in CFB boilers.

To optimize the performance of boilers and to develop combustion models, it is essential to better understand the origin of the fluctuations in the furnace and the air-feed system. This requires simultaneous information on the fluid dynamic and combustion processes. The related research is hitherto limited to a few works. Stubington and Chan (1990) tried to find a correlation between bubbles and high oxygen concentration in a bed, and Lin et al. (2004) investigated the impact of uniformity of fluidization on the generation of organic pollutants (BTEXs and PAHs). However, both these investigations were concerned with bubbling beds and furthermore, the expected correlations

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were not found in any of these works. Jang et al. (2003) observed that the properties of pressure fluctuations, such as mean pressure and standard deviation, varied depending on the composition of the fuel, but those quantities were not connected to fluctuations in gas concentration.

The present work is an experimental study on the link between fluid dynamic processes and combustion in the furnace of a 12 MW_{th} CFB boiler. The study covers also the influence of the air and the fuel-feed system. The parameters measured include fluctuations of pressure at various locations in the furnace and in the air-feed system, representing the fluid dynamics, and simultaneous variations in local gas concentration, representing combustion processes. In addition, variations in the fuel-feed rate were measured and a conceptual model of the relation between release of volatiles and in-furnace pressure fluctuations is given. A comparison is made with results from similar measurements in a 235 MW_e CFB boiler.

2. Experiments

Fig. 1 shows the measurement positions in the 12 MW_{th} CFB boiler and the positions of the input of air and fuel. The furnace has a cross-section of 1.7×1.4 m and a height of 13 m and is further described by Leckner et al. (1991). The part of the fuel-feed system investigated in this work consists of a conveyer (scrape feeder) containing densely spaced scrapes, which transport the fuel from the fuel hoppers to a cell feeder and then to the fuel-feed chute, where the fuel is blown into the furnace, assisted by air to improve dispersion. The conveyer is inclined by around 40° as the hopper is situated below the cell feeder. At normal load the interval between discharges of scrapes is around 1 s. The cell feeder, consisting of four cells and rotating with 36 revolutions per minute, distributes the fuel of each scrape into the chute before the discharge of the next scrape into the cell feeder.

The origins of the fluctuations were investigated by altering the solids inventory, corresponding to the different furnace pressure drops: 7.5, 3.0 and 2.0 kPa. Except for the furnace pressure drop all other parameters were kept constant. In the reference case the solids inventory corresponded to the normal operating conditions of the boiler (i.e., with a total pressure drop over the furnace of 7.5 kPa). For the case with the lowest furnace pressure drop (lowest solids inventory) measured, vertical pressure drop profiles indicated that there was hardly any bottom bed present in the furnace (which is the case for normal operating conditions). The boiler was operated at the loads listed in Table 1. In all cases the amount of excess air was 15%. Silica sand was used as bed material, except in the case without a bottom bed (2 kPa) where the bed material was changed to limestone. The fuel was for all cases bituminous coal containing 29% volatiles, 8% moisture, and 9% ash (calculated on coal as delivered). The fuel was ground and the size of the particles was less than 20 mm (size fractions of some samples are given in Table 2).

The fuel feed was stopped during 6 min in the reference case as well as in the case with low bed height to investigate its

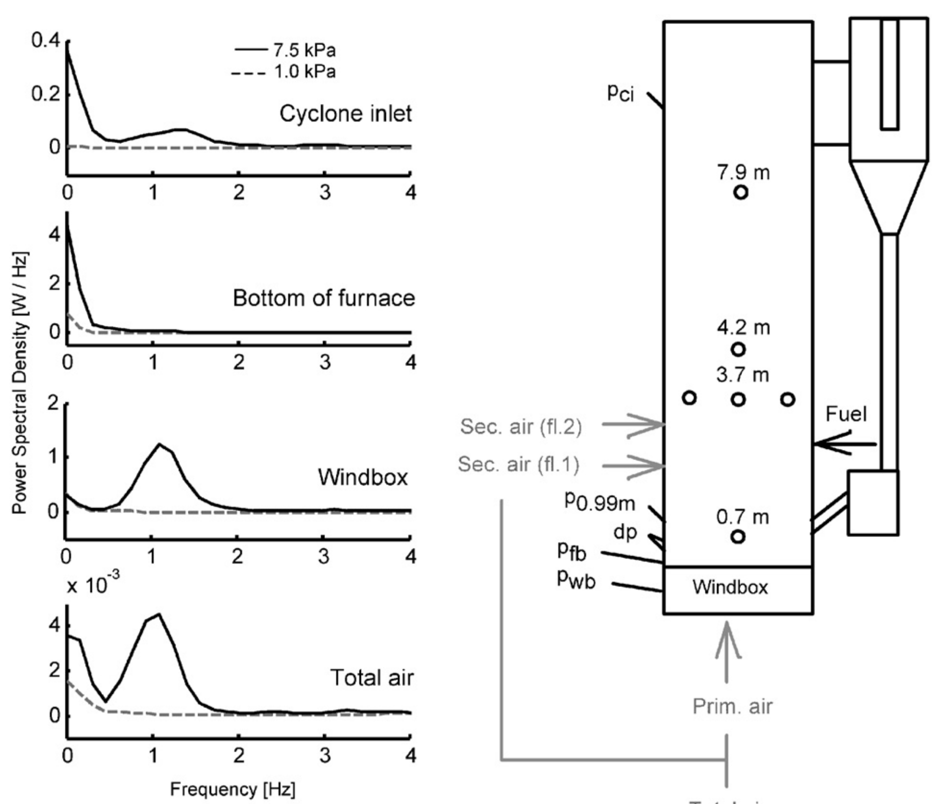

Fig. 1. Examples of power spectral densities at various positions in the furnace in the reference case and the case without a bottom bed.