



2nd Oxyfuel Combustion Conference

Experimental research of the oxy-fuel combustion in a circulating fluidized bed

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Keywords: oxy-fuel combustion; circulating fluidized-bed (CFB), hard coal, ignition, devolatilization, fragmentation

1. Introduction

Nowadays, greenhouse gases emissions from coal-fired systems, particularly CO₂, become more and more important. Oxy-fuel combustion is one of the promising options for power generation with carbon dioxide capture. This technology can reduce significantly emissions of NO_x and improve the thermal efficiency of the combustion process through the reduction of flue gas volume. In the oxy-fuel combustion, coal particles are burnt in a mixture of pure oxygen and recycled flue gas. Because nitrogen is eliminated from the oxidizing gas, the flue gas leaving the combustion chamber is highly enriched in CO₂ which means that the combustion process takes place in an O₂/CO₂ environment. Partial recycling of flue gas helps to control the flame temperature in the combustion chamber. Extensive studies in both pilot-plant and lab scales have pointed out the pronounced influence of gas composition (air versus O₂/CO₂) on coal combustion performance. The heat transfer and temperature distribution in a furnace are greatly affected by the large specific heat capacity of CO₂. Coal ignition is delayed in O₂/CO₂ in comparison to in O₂/N₂ with the same O₂ concentration. To match the flame/particle temperature in air, a large amount of O₂ in CO₂, typically around 30%, is required. Oxy-fuel combustion has now been well studied for pulverized coal combustion, but to date has received relatively little attention for oxy-fuel circulating fluidized bed combustion (CFBC). Work in this field has been conducted by: Foster Wheeler Energia Oy and VTT, ALSTOM, CANMET and Czestochowa University of Technology.

In the present work, oxy-fuel CFB combustion tests were conducted in a 12-kW bench-scale CFB combustor. The main objective of this study was to investigate the combustion behaviour of three Polish and one South African

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bituminous coal particles, in air and O₂/CO₂ mixtures, in terms of particle temperature profiles, fragmentation, ignition time, devolatilization time and the total combustion time.

2. Experimental

Oxy-fuel combustion tests were conducted in a 12-kW bench-scale CFB combustor shown schematically in Fig. 1. The bench-scale CFBC consists of a combustion chamber (1), a cyclone (2) a downcomer (3) and a loop seal (4). The electrically-heated rectangular combustion chamber (riser), 680×75×35 mm, is the main component of the unit. The front wall of the riser is made of transparent quartz through which the combustion process can be directly observed. Particles of silica sand between 100 and 400 μm, with $d_{50}=210$ μm, constitute the inert bed. Total mass of circulating solids is 0.3 kg. The gases to make up gas mixtures are supplied from cylinders (11) to a mixer (16) and then transferred via a preheater (8) directly into the combustion chamber. Flow rates of gases are controlled by valves (16) and measured by rotameters (15). During combustion tests, the superficial gas velocity was kept at a constant level of about 5 m/s. The temperature was held at 850°C by means of microprocessor thermoregulators (11). S-type thermocouples (T1–T3) measured the temperature at three different levels inside the combustion chamber with an accuracy of ±2°C. A spherical coal particle (5) was introduced into the combustion chamber and positioned in the bed. Temperatures on the surface and inside coal particle were measured by S-type thermocouples. The thermocouples were connected via a card (9) to a computer (10) in order to record the temperature measurements.

The experiments were carried out in air (base case) and mixtures of O₂/CO₂ with oxygen concentrations in the range from 20% to 60% vol. Video and digital cameras were used to record the progress of combustion.

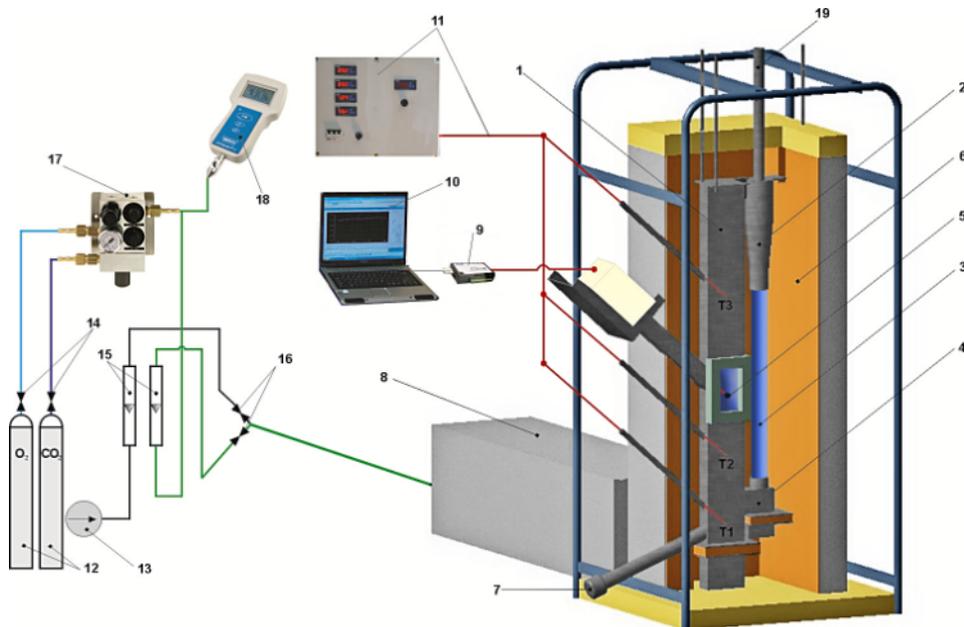


Fig. 1. Schematic diagram of the experimental apparatus for oxy-CFB combustion

1-combustion chamber, 2-cyclone, 3-downcomer, 4-loop seal, 5-coal particle, 6-insulation, 7-drain valve, 8-preheater, 9-card, 10-computer, 11-temperature measurement and control system, 12-gas cylinders, 13-air compressor, 14-pressure regulators, 15-rotameters, 16-valves, 17-mixer, 18-gas analyser, 19-ventilation duct, T1–T3-S-type thermocouples

3. Results

Results of proximate and petrographic analyses reveal that ash and inertinite (maceral that is less reactive than vitrinite) contents in the South African are much higher than those in Polish coals. Therefore, it can be expected that the combustion behaviour of these coals may differ significantly. Thus, the main objective of our study was to investigate the combustion behaviour of these coals, in air and O₂/CO₂ mixtures, in terms of particle temperature profiles, ignition time, devolatilization time and the total combustion time. Therefore the combustion behaviour of these coals was different in air and O₂/CO₂ mixtures. Combustion in air proceeded at ~50°C higher centre temperatures and was slightly shorter in time compared to combustion in O₂/CO₂ mixture with 21% vol. O₂. Larger heat capacity of CO₂ compared to that of N₂ also retards the ignition of volatiles in O₂/CO₂ mixtures with 21% O₂. These trends are consistent with those found in the literature. However, when the concentration of oxygen in O₂/CO₂ mixtures is larger than 30%, the ignition time decreases with increasing O₂ content. Surface and centre temperatures increase significantly with increasing O₂ concentration. The devolatilization time decreases with increasing O₂ concentration for Polish coals and increases for South African coal. The total combustion time decreases with increasing oxygen concentration for all coals tested. Figure 2 shows images of particles of A and D coals at different stages of combustion.

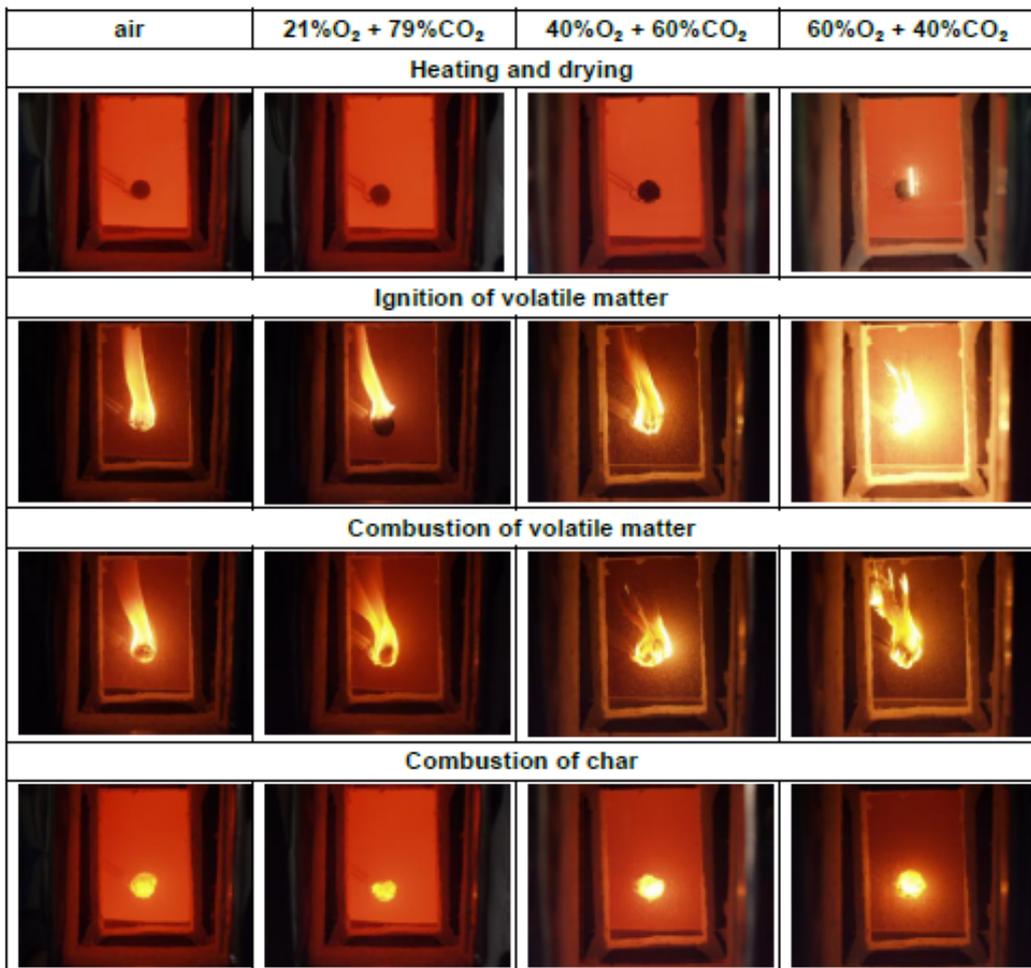


Fig. 2. Visualisation of 10-mm Polish coal particle in CFBC in air and O₂/CO₂ mixtures