COMBUSTION OF SINGLE COAL CHAR PARTICLES UNDER FLUIDIZED BED OXYFIRING CONDITIONS

Fabrizio Scala* and Riccardo Chirone
Istituto di Ricerche sulla Combustione - CNR, P.le Tecchio 80, 80125 Napoli, Italy

Summary

Combustion of single coal char particles was studied at 850°C in a lab-scale fluidized bed under simulated oxyfiring conditions. The particle burning rate was followed as a function of time by continuously measuring outlet CO and O_2 concentrations. The significance of carbon gasification by CO_2 was also evaluated at the same bed temperature. Results showed that the carbon burning rate increases with O_2 and char particle size. Particle temperature is approximately equal to bed one up to an oxygen concentration of 2%, being considerably higher for larger O_2. CO_2 gasification of char appears to be not negligible under oxyfiring conditions.

Keywords

Clean coal technologies, CO_2 capture.

Introduction

Production of energy from fossil fuel combustion results in the emission of greenhouse gas species, with the most significant fraction being CO_2. The constant increase in emissions has resulted in the development of new technologies that can accommodate capture and sequestration of CO_2. Oxyfiring technology can produce an almost pure CO_2 outlet stream, by using pure oxygen instead of air for fuel combustion.[1] Flue gas is partly recycled back into the furnace to control the combustion temperature. In this way the costs of CO_2 separation from the flue gas can be substantially reduced. Although most of the research activity in oxyfiring has concentrated on pulverized coal boilers, recently the application of this technology to circulating fluidized bed (CFB) boilers has been examined.[2-6] CFBs appear to be particularly suited for oxyfiring conditions because of the fuel flexibility and better temperature control (which allows to reduce the amount of recycled flue gas). The feasibility of CFB coal oxyfiring has been successfully demonstrated in pilot-plant tests, and no particular technological barrier appears to exist for implementing this technology in the near-term.
However, a number of issues still need to be addressed in more detail to obtain a more fundamental understanding of the changes between oxyfiring and conventional air-fired combustion.[1] One of these issues regards the combustion characteristics of coal in an O_2/CO_2 atmosphere. For example, it has been suggested that under these conditions carbon gasification by CO_2 might contribute significantly to the char mass loss.[1]

Experimental

An electrically heated stainless steel bubbling fluidized bed reactor 40mm ID was used for the experiments. A stainless steel probe was inserted from the top of the column to convey a known fraction of the exit gas directly to the gas analyzers. A NDIR analyzer was used for on-line measurement of CO and a paramagnetic analyzer for O_2 in the exhaust gases. The bed material consisted of 180g of 500–600μm quartz sand, corresponding to an unexpanded bed height of 0.1m. Further details of the apparatus can be found elsewhere.[7]
A Snibston bituminous coal was used as the test fuel. The fuel particles were first devolatilized by dropping them in the fluidized bed with N_2 at 850°C. After 5min, char particles were retrieved from the bed and machined into almost spherical particles with an average size of ~6-7mm. The experiments were performed in the fluidized bed at 850ºC, atmospheric pressure, with a fluidization velocity of 0.3m/s. An inlet gas mixture of CO_2 and O_2 was introduced with O_2 concentrations of: 0, 1, 2, 4.5 and 8 % (v/v). Each test consisted in the injection of one char particle, of known mass and diameter, in the fluidized bed and in the continuous measurement of CO and O_2 concentrations at the outlet. Some combustion tests were performed with a thin (250μm OD) thermocouple inserted inside the particle to measure its temperature during combustion.

* To whom all correspondence should be addressed

Results and discussion

In Fig. 1 the measured curves of CO and O_2 at the exit of the bed are shown for a typical combustion test. The absence of peaks or changes in the slope of the CO curve reveals that no particle fragmentation occurred in the test.

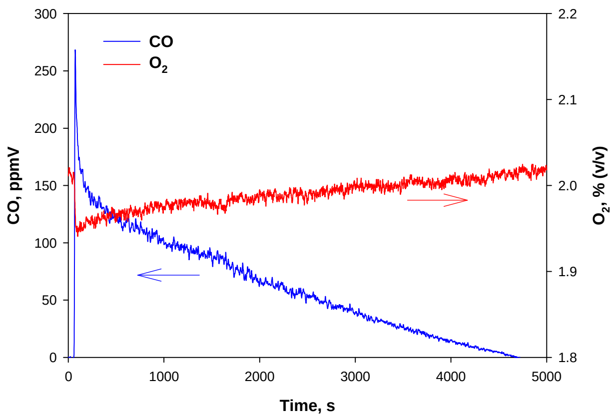

Fig. 1) CO and O_2 concentration profiles during a typical oxyfiring char combustion test, O_2=2% (v/v);

Using the data from these curves it was possible to determine the variation of the particle diameter with time. Figure 2 reports the carbon burning rate as a function of the particle diameter for the oxyfiring combustion tests at different O_2 inlet concentrations. Results show that the combustion rate increases as the concentration of O_2 in the bed increases. This result can be expected both in the case of kinetically controlled and diffusion controlled combustion. However, the combustion rate increases almost linearly with the particle diameter, indicating that diffusion of oxygen through the particle boundary layer is likely to control (at least partially) the burning process, as it is the case during air combustion.[7]

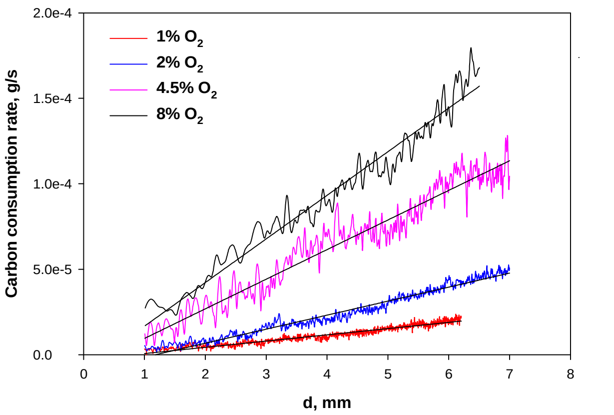

Fig. 2) Carbon consumption rate as a function of particle diameter during oxyfiring char combustion tests at different O_2 concentrations, T = 850°C.

Some of the combustion tests were performed with a thermocouple inserted in the char particle to measure its temperature during the test. For oxygen concentrations larger than 2% the error done by considering that the char particle has the same temperature as the bed can be larger than 10°C (up to 60°C at 8% O_2 inlet concentration).
Another series of tests was performed at 850°C with 100% CO_2 inlet flow to quantify how important is gasification reaction during the tests. The typical outlet CO concentration measured during a gasification test is shown in Fig. 3. The gasification test clearly shows a much longer reaction time with respect to the combustion ones.

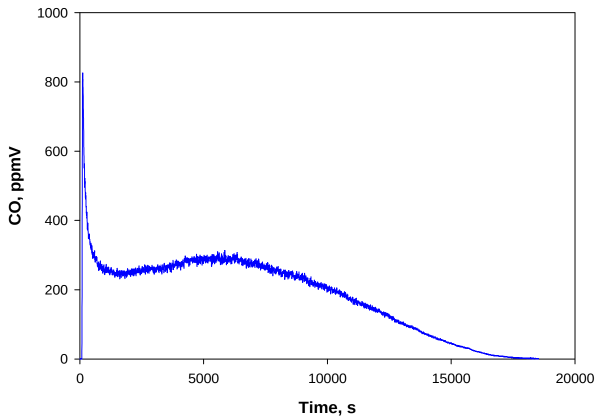

Fig. 3) CO concentration profile during a typical char gasification test, CO_2 = 100% (v/v).

By comparing the measured carbon consumption rates in both types of tests, it is noted that the gasification rate at 850°C is always lower than the combustion rate and that it is less dependent on the actual char particle mass, denoting a significant contribution of intrinsic kinetics resistance. Nevertheless, the gasification rate under high CO_2 bulk concentrations at 850°C is not negligible, contrary to what happens under typical air combustion conditions.[7]

References

(1) Buhre, B.J.P.; Elliott, L.K.; Sheng, C.D.; Gupta, R.P.; Wall, T.F. *Prog. Energy Combust. Sci.* **2005**, *31*, 283-307.
(2) Jukkola, G.; Liljedahl, G.; Nsakala, N.; Morin, J.; Andrus, H. *Proc. 18th Int. Conf. Fluidized Bed Combustion*, Toronto, Canada **2005**, paper #78104.
(3) Czakiert, T.; Bis, Z.; Muskala, W.; Nowak, W. *Fuel Process. Technol.* **2006**, *87*, 531-538.
(4) Saastamoinen, J.; Tourunen, A.; Pikkarainen, T.; Hasa, H.; Miettinen, J.; Hyppanen, T.; Myohanen, K. *Proc. 19th Int. Conf. Fluidized Bed Combustion*, Vienna, Austria **2006**, paper #49.
(5) Jia, L.; Tan, Y.; Wang, C.; Anthony, E.J. *Energy Fuels* **2007**, *21*, 3160-3164.
(6) Eriksson, T.; Nuortimo, K.; Hotta, A.; Myohanen, K.; Hyppanen, T.; Pikkarainen, T. *Proc. 9th Int. Conf. Circulating Fluidized Beds*, Hamburg, Germany **2008**, pp.819-824.
(7) Scala, F. *Proc. Combust. Inst.* **2009**, *32*, 2021-2027.