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Effects of operation parameters on NO emission in an oxy-fired CFB combustor

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ABSTRACT

Oxy-fuel Circulating Fluidized Bed (CFB) combustion technology, a very promising technology for CO_2 capture, combines many advantages of oxy-fuel and CFB technologies. Experiments were carried out in a 50 kW_{th} CFB facility to investigate how operation parameters influence the NO emission in O_2/CO_2 atmospheres. The simulated O_2/CO_2 atmospheres were used without recycling the flue gas. Results show that NO emission in 21% O_2/79% CO_2 atmosphere is lower than that in air atmosphere because of lower temperature and higher char and CO concentrations in the dense bed. Elevating O_2 concentration from 21% to 40% in O_2/CO_2 atmosphere enhances fuel-N conversion to NO. Increasing bed temperature or oxygen/fuel stoichiometric ratio brings higher NO emission in O_2/CO_2 atmosphere, which is consistent with the results in air-fired CFB combustion. As primary stream fraction increases, NO emission increases more rapidly in O_2/CO_2 atmosphere than that in air atmosphere. Stream staging is more efficient for controlling NO emission in oxy-CFB combustion than that in air combustion. Oxygen staging provides an efficient way to reduce NO emission in oxy-CFB combustion without influencing the hydrodynamic characteristic in the riser.

1. Introduction

Oxy-fuel combustion holds promise for simplifying CO_2 sequestration and management in coal-fired power plants [1–6]. Oxy-fuel technology is currently undergoing rapid development with a number of demonstration projects commencing in the development towards commercialization [7]. Predominantly, current oxy-fuel demonstration projects use PC boilers. However, oxy-fuel combustion using fluidized-bed (FB) and CFB boilers are also being considered. Compared with oxy-fuel pulverized coal (PC) combustion, oxy-fuel combustion in CFB has its particular advantages:

1) With elevated O_2 concentration, the volume of gases flowing through the furnace is reduced largely, which will reduce the furnace size significantly. The reduced furnace size constraints the heat surface arrangement in PC boiler case, but it can be better solved in CFB case by additional surface arrangement in the hot solid loop, such as external heat exchanger, et al. Saastamoinen et al. [8] concluded the volume of furnace of the 60% O_2 case was 38 vol.% of the 21% O_2 case. ALSTOM estimates that oxy-combustion may substantially reduce unit size and cost compared with an air-fired CFB combustion unit (−50% of plant area, −44% of volume, −35% of weight, and −32% of cost).
2) Oxy-fired CFB combustion combines some advantages of oxy-fuel and CFB combustion technology, for example, fuel flexibility, economical furnace desulfurization, low NO_x emission, et al. In oxy-CFB combustor, direct sulfation of limestone will occur due to the high CO_2 partial pressure and the calcium conversion under direct sulfation is usually higher than that under calcination/sulfation due to the better porosity of the product layer, as suggest by many studies [9–12]. So it may be more economical for sulfur capture with sorbents in oxy-fired CFB boilers. For CFB itself, the NO_x emission is quite low for low combustion temperature. And by recycling the flue gas, lower NOx emission in oxy-CFB combustion can be achieved [2].
3) Oxy-fired CFB combustion doesn't need new-designed burner. For oxy-PC combustion, the burner should be redesigned for consideration of safety, high combustion efficiency and low NO_x emission [13]. But in oxy-CFB, the oxygen concentration in the O_2/Recycled Flue Gas (RFG) mixture can be restricted to a low and safe level (21% for instance), and extra pure O_2 can be easily introduced into the combustor through additional O_2 nozzles or O_2 lances.
4) Oxy-fired CFB is easier to realize the transition from air-mode combustion to oxy-mode combustion than oxy-fired PC, because CFB has a large amount of bed material which is inert and can help control the temperature.

At present, some institutes and corporations including US DOE, CANMET, ALSTOM, B&W, FOSTER WHEELER, etc., have done or have planned to do some research work on oxy-CFB combustion. ALSTOM operated their multi-use test facility successfully on coal and petroleum coke combustion in O_2/CO_2 mixture with up to 70% O_2 in the firing zone and there was no evidence of particle agglomeration or defluidization in the furnace. FOSTER WHEELER [14] designed a kind of Flexi-Burn™ CFB boiler which can be capable of on-line switching

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between air and oxy-fuel mode. Also B&W has prepared a preliminary design for 300 MW oxy-fired CFB. Even though, there are still very little published work for us to understand oxy-fuel CFB combustion.

NO_x emission in air-fired CFB has been extensively studied by researchers since 1990s [15–21]. Little thermal-NO_x is produced during the CFB combustion due to the low temperature. Winter [22] summarized the main reaction path of the fuel-N to NO_x, as shown in Fig. 1. The effects of operation parameters on the NO emission in air-fired CFB are summarized in Table 1. However, the relationship between NO emission and operation parameters in oxy-fired CFB has rarely been reported. In the paper, the effects of operation parameter on NO emission during bituminous coal and anthracite combustion process in O_2/CO_2 atmosphere are studied in detail with a 50 kW_{th} CFB combustor.

2. Experimental

2.1. 50 kW_{th} oxy-fuel CFB apparatus description

The investigation was conducted in a 50 kW_{th} CFB apparatus, as shown in Fig. 2. The system is equipped for various types of measurements and has facilities that make it possible to vary parameters independently and in a wide range. The height of the combustor is 4200 mm with three sections, primary zone of 800 mm, transition zone of 200 mm and secondary zone of 3200 mm. The inner diameter of the primary zone is 122 mm and the inner diameter of the secondary zone is 150 mm. The combustor is equipped with three zones of external heaters to minimize the heat loss and to help control the temperature. Six sensors for temperature and pressure measure, one on the wind box and five along the riser height are installed to measure the temperature and pressure profiles during the test. The coal and sorbent are premixed and supplied gravimetrically at an elevation of 700 mm from the bottom distributor. The primary stream is introduced through air nozzles in the bottom distributor and the secondary stream can be injected through two separate points with the elevation of 800 mm and 1000 mm, respectively. The inner diameter of the bottom distributor is 122 mm, which is the same as that of the primary zone. 12 air nozzles with an ID of 10 mm are fixed in the distribution plate by refractory material. The hot solid from the cyclone is fed back to the dense zone at an elevation of 200 mm. The flue gas is cooled by a heat exchanger, dedusted by a bag filter and then measured on-line with a gas analyzer. In this study, the O_2/CO_2 mixture from gas bottles (O_2 purity>99.9%; CO_2 purity>99%) was used to simulate the oxy-fuel combustion with completely cleaned recycle flue gas. Parameters including atmosphere, temperature, pressure, oxygen/fuel stoichiometric ratio, primary stream fraction (volume proportion of the primary stream to the total streams) and

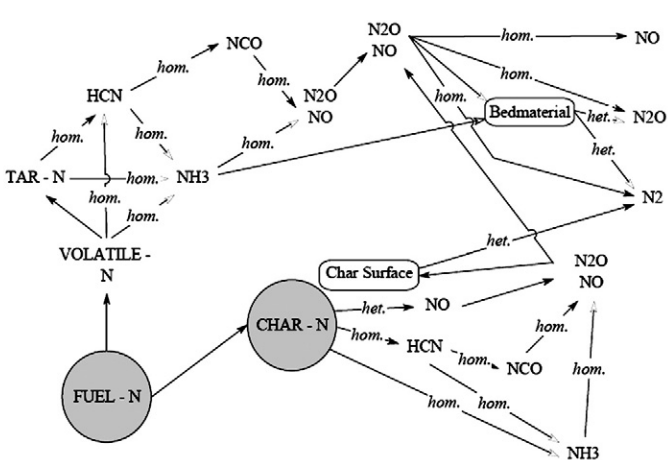

Fig. 1. The main reaction paths of fuel-N to NO, N_2O and N_2 [22].

Table 1
Effects of operation parameters on the NO emission in air-fired CFB ("↗" means increase and "↘" means decrease in the table).

Parameter	Temperature	Volatile	Fuel-N	Excess air ratio	Primary air fraction	Limestone addition	SO_2
Tendency	↗	↗	↗	↗	↗	↗	↗
NO emission	↗	↗	↗	↗	↗ or ↘	↗ or ↘	↘

oxygen concentration in different streams were adjusted to different values to investigate their effects on NO emission. Each test run lasted stably for 4 h. All the data including temperature, pressure, gaseous emissions were collected on-line and the arithmetic average values were used in the paper.

2.2. Fuels

Two typical Chinese coals (bituminous coal and anthracite) are selected and sieved as the coal samples. The ultimate and proximate analyses are listed in Table 2. The particle size range of the coal samples is 0–4 mm. The mean diameter of bituminous coal is 0.545 mm and that of anthracite is 0.829 mm. No sorbent were used in this study.

3. Results and discussion

3.1. Effect of atmosphere on NO emission

The effect of atmosphere on NO emission is shown in Fig. 3. In this paper, four atmospheres including air, 21% O_2/79% CO_2, 30% O_2/70% CO_2 and 40% O_2/60% CO_2 were studied. The overall oxygen/fuel stoichiometric ratio is kept as 1.2 and the primary stream fraction is kept as 0.7 in the tests. Compared with that in air atmosphere, NO emission in 21% O_2/79% CO_2 atmosphere is lower. Zhao et al. [19], Reidick and Kremer [21] studied the NO emission profiles along the riser in air-fired CFB combustor and found that the most important zone of NO formation is the oxygen-rich regime directly above the bottom nozzle plate. The NO formation is mainly from fuel nitrogen which will release first as NO precursors such as NH_3, HCN, NHCO, etc. Then the precursors will be oxidized to NO by O and OH radicals. The NO emission is dependent on O and OH radicals rather than O_2 in CFB

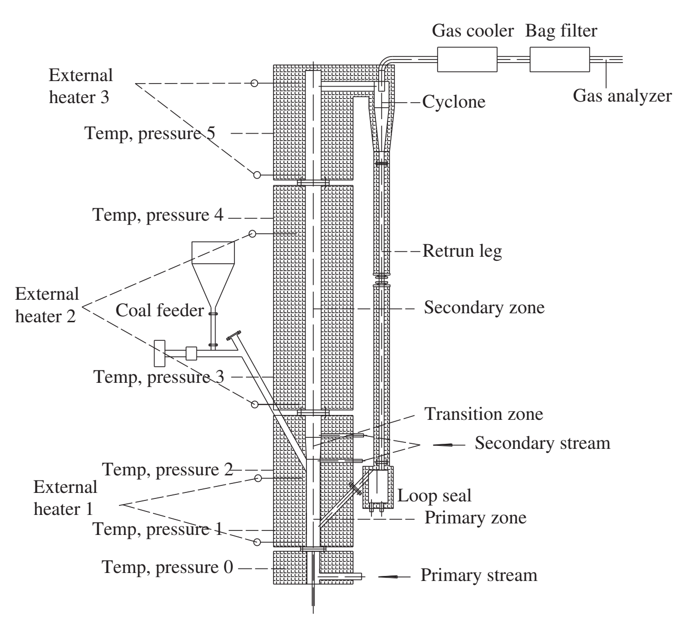

Fig. 2. 50 kW_{th} CFB setup diagram.