ARTICLE IN PRESS

Fuel xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Coal combustion characteristics on an oxy-fuel circulating fluidized bed combustor with warm flue gas recycle

Lunbo Duan *, Haicheng Sun, Changsui Zhao, Wu Zhou, Xiaoping Chen

Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China

HIGHLIGHTS

- Oxy-fuel CFB combustion with warm flue gas recycle.
- Oxy-transition is quite safe.
- SO_2 concentration is high while its emission is low.
- NO emission is much lower under oxy-mode than air-mode.

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form 22 May 2013
Accepted 10 June 2013
Available online xxxx

Keywords:
Oxy-fuel
CFB
Warm flue gas recycle
SO_2 emission
NO emission

ABSTRACT

More than 100-h steady warm flue gas recycle operation was carried out on a 50 kW_{th} oxy-fuel circulating fluidized bed (CFB) combustor burning three kinds of fuel. The results demonstrate the good safety benefit of oxy-CFB operation, especially in the oxy-transition process. A slightly higher oxygen concentration, ranging from 22.2% to 23.4% for different fuels in oxy-fuel operation, can bring equivalent or higher carbon burnout than air combustion. SO_2 concentration in ppm unit is higher in flue gas while the SO_2 emission in mg/MJ unit is lower than air combustion. The desulfurization efficiency of limestone can reach 80% in oxy-fuel combustion in this test. The higher Ca utilization rate burning coal in oxy-fuel combustion than that in air combustion may be associated with the high moisture content in the flue gas. Fuel nitrogen conversion ratio in oxy-fuel is much lower than in air combustion, and it looks like higher volatile content in fuel leads to a bigger reduction of NO in the recycle flue gas.

1. Introduction

Oxy-fuel combustion is commonly considered as one of the most promising technologies for carbon dioxide capture from coal-fired power plants due to its advantages in both technical and economical areas. The concept of oxy-fuel combustion is the removal of nitrogen from the oxidizer to carry out the combustion process in oxygen and, in most concepts, recycled flue gas to lower the flame temperature. Some reviews [1–4] have been published to describe the oxy-fuel combustion in detail over very extensive areas including fundamental findings, industrial development status and work need to be done. At present, the main researches involved are oxy-fuel pulverized coal (PC) combustion. At the same time, oxy-fuel CFB combustion has begun to gain more and more attentions [5–12].

Oxy-fuel CFB combustion has its particular advantages over oxy-PC combustion. First, Oxy-fuel CFB boiler can burn a wide variety of fuel. Particularly as suggested by Jia et al. [8], it can be CO_2-negative when burning biomass in oxy-fuel CFB combustor. Second, Oxy-fuel CFB is more accessible to realize zero-emission for coal-fired power plants due to in situ sulfur removal and low NOx emission in CFB combustors. Third, Oxy-fuel CFB can adopt higher O_2 concentration and smaller boiler size by arranging heat absorption surface in the solid recycle system [5]. Fourth, Oxy-fuel CFB permits 100% wet flue gas recycle while Oxy-PC must use dry flue gas to transport the coal powder. It can omit heat exchanger in the flue gas recycle train and recover energy.

Till now, Boiler manufactures like ALSTOM [12] and FOSTER WHEELER [6], research institute like Canmet Energy [8] and VTT Technical Research Centre of Finland [13], and Universities like Lappeenranta University of Technology in Finland [13], University of Utah [14] in USA and Southeast University [9–11] in China have done some work on Oxy-fuel CFB combustion.

This paper presents some results on a 50 kW_{th} oxy-fuel CFB combustor with warm flue gas recycle located at Southeast University, China.

2. Experimental

The warm-recycle oxy-CFB system is shown in Fig. 1. It consists of coal feeding system (a screw feeder to feed coal-limestone

---

* Corresponding author. Tel./fax: +86 25 83793453.
E-mail address: duanlunbo@seu.edu.cn (L. Duan).

0016-2361/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2013.06.016

Please cite this article in press as: Duan L et al. Coal combustion characteristics on an oxy-fuel circulating fluidized bed combustor with warm flue gas recycle. Fuel (2013), http://dx.doi.org/10.1016/j.fuel.2013.06.016

mixture into primary zone), combustion system (a typical CFB combustor, 5.2 m from air distributor to the centerline of furnace outlet, 122 mm ID in primary zone and 150 mm ID in secondary zone), flue gas treatment system (a gas cooler to cool the flue gas to lower than 200 °C and a well-sealed bag filter to remove particles and keep the outlet temperature of flue gas above its dew point), warm flue gas recycle system (a recycle fan and a RFG preheater to ensure the RFG temperature higher than its dew point), oxygen supply system (oxygen supply from an oxygen manifold and oxygen injection to RFG and secondary zone separately), CO_2 supply system (supply CO_2 to the loop seal for solid recirculation, to screw feeder for gas seal and to oxygen pipe for purging, the total CO_2 flowmeter is about 2–5 Nm^3/h), and measurement and control system (includes valves, thermocouples, pressure sensors, flowmeters, $O_2/CO_2/H_2O/CO/SO_2/NOx$ analyzers, sampling systems for fly ash, mercury, SO_3 and chlorine).

The system permits the warm-recycle test, that is, the temperature of the whole recycle flue gas line is controlled higher than 180 °C to ensure the moisture will not condense in the recycle loop. The data acquisition system and on-line heat-mass balance calculation based on Programmable Logic Controller (PLC) are installed to facilitate the process control.

The facility was started up in air-combustion with spend bed material from previous tests. When the combustion and operation reached stability, a 4-h air combustion test was carried out before the system was transited from air-mode to oxy-mode. After the transition was completed with stable operation, a 16-h oxy-combustion test was conducted for each fuel. The overall oxygen concentration during the oxy-mode is between 21–25% and is the same in both the primary and secondary oxidants. If the overall oxygen concentration is higher than 28% or is lower than 20%, the oxygen injection will be cut off and the air intake from the inlet of RFG fan will be started up consequently. The primary oxidant fraction was 0.7 in all the test conditions. In both air-mode and oxy-mode, the heat input was kept constant. The coal screw feeder frequency was stable to ensure the same heat input, and was corresponding to 5–8 kg/h coal feed in all the tests.

The ultimate and proximate analysis of fuel is listed in Table 1. An American bituminous coal, a Chinese bituminous coal and a Chinese petroleum coke were used in the test. All fuels were sieved to less than 6 mm. One Chinese limestone was used in the test and its composition is listed in Table 2 and the particle size of limestone is 0–1 mm.

During all the test runs, the CFB riser was operated under small positive pressure, and the zero gauge pressure point was controlled at the outlet of the cyclone. The main air ingress part is the flue gas pass section, including bag filter, recycle fan and preheater. By monitoring the O_2 concentration at furnace outlet and the outlet of RFG preheater, it can be seen the gas tight of the whole system is quite good, as shown in Fig. 2.

3. Results and discussion

3.1. Oxy-transition behavior

Former study [8] has demonstrated the quick and smooth oxy-transition from air combustion to oxy-fuel combustion. In this paper, an interesting oxy-transition experience will be presented to demonstrate the strong safety behavior of oxy-CFB operation. First, the RFG fan was switched onto recycle the flue gas. At the same time, the O_2 was injected into the flue gas. The O_2 concentration after oxygen injection (C3 in Fig. 3) was kept constant by adjusting the amount of injected oxygen. Suddenly, we cut off the oxygen injection while kept coal feeding stably. As a result of oxygen loss, air intake from the RFG fan inlet was carried out automatically. We kept this oxygen loss for 5 min and then injected again. During this process, the O_2 and CO_2 concentrations are shown in Fig. 3. There is a sharp oxygen and CO_2 concentration drop because of the air

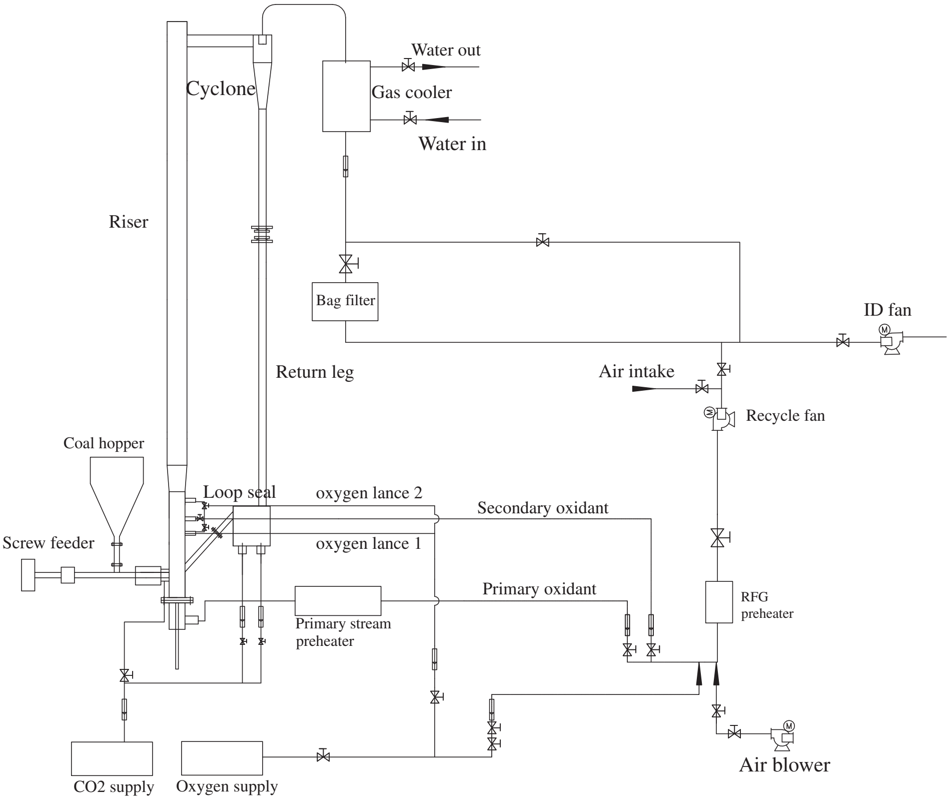

Fig. 1. Oxy-fuel CFB system with warm flue gas recycle.

Please cite this article in press as: Duan L et al. Coal combustion characteristics on an oxy-fuel circulating fluidized bed combustor with warm flue gas recycle. Fuel (2013), http://dx.doi.org/10.1016/j.fuel.2013.06.016