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Pulverized coal combustion in air and in O_2/CO_2 mixtures with NO_x recycle

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Abstract

This paper presents experimental results of a 20 kW vertical combustor equipped with a single pf-burner on pulverised coal combustion in air and O_2/CO_2 mixtures with NO_x recycle. Experimental results on combustion performance and NO_x emissions of seven international bituminous coals in air and in O_2/CO_2 mixtures confirm the previous findings of the authors that the O_2 concentration in the O_2/CO_2 mixture has to be 30% or higher to produce matching temperature profiles to those of coal-air combustion while coal combustion in 30% O_2/70% CO_2 leads to better coal burnout and less NO_x emissions than coal combustion in air. Experimental results with NO_x recycle reveal that the reduction of the recycled NO depends on the combustion media, combustion mode (staging or non-staging) and recycling location. Generally, more NO is reduced with coal combustion in 30% O_2/70% CO_2 than with coal combustion in air. Up to 88 and 92% reductions of the recycled NO can be achieved with coal combustion in air and in 30% O_2/70% CO_2 respectively. More NO is reduced with oxidant staging than without oxidant staging when NO is recycled through the burner. Much more NO is reduced when NO recycled through the burner (from 65 to 92%) than when NO is recycled through the staging tertiary oxidant ports (from 33 to 54%). The concentration of the recycled NO has little influence on the reduction efficiency of the recycled NO with both combustion media—air and 30% O_2/70% CO_2.

Keywords: NO_x recycle; Pulverized coal combustion; Coal combustion in O_2/CO_2

1. Introduction

With conventional coal-air combustion, NO_x recycle is an alternative approach for the control of NO_x emissions from combustion [1]. It uses regenerable sorbent to adsorb NO_x in the flue gas from a combustor followed by desorption, producing a highly concentrated NO_x-laden stream. This stream is then sent back to the same combustor or to a separate combustor, where the NO_x is reduced in the flame and NO_x formation is inhibited. Obviously, the reduction efficiency of the recycled NO_x in the combustor decides the effectiveness of the NO_x recycle approach to reduce NO_x emissions. Previous investigations, such as Zhou et al. [1] who carried out their experiments on a 1.76 MW cyclone furnace, on NO_x recycle with conventional coal-air combustion found that the NO_x recycle location had a significant effect on the reduction efficiency of the recycled NO_x. New investigations on the reduction of the recycled NO_x with pf burners and other combustors will improve our understandings on the fate of the recycled NO_x in practical power plant boilers.

Coal combustion with oxygen and recycled flue gases is one of the encouraging methods to tackle CO_2 emissions from coal-fired power plants. The recycled flue gases are mixed with pure oxygen, produced by air separation, to form the oxidant. This reduces or completely eliminates nitrogen from the combustion oxidant and hence produces flue gases with a high concentration of CO_2 (up to 95%), which can be directly injected into the oceans and used for enhanced oil recovery [2]. The recycling flue gases will affect not only the coal combustion performance but also the formation of pollutant emissions, such as NO_x, SO_2 and CO. In addition, when flue gases are recycled back to the combustor, minor species in the flue gases, such as NO_x and SO_2, are also recycled. Therefore, it is environmentally of interest to know the fate of the recycled pollutants under

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conditions of coal-O_2/flue gas recycling combustion. There have been a limited number of investigations on the reduction of recycled NO_x in coal combustion with O_2 and recycled CO_2 [3–5].

Okazaki and Ando [3] studied NO_x reduction mechanism in coal combustion with recycled CO_2. Their tests were carried out with a flat CH_4 flame burner laden with anthracite particles, with the maximum temperature being fixed at 1450 K and the initial O_2 concentration at 21%. They concluded that more than 50% of the recycled NO was reduced to N_2 in the combustion zone of coal volatile matter. More recently, Hu et al. [4,5] reported their investigations on the reduction of recycled-NO_x in coal combustion with O_2/recycled flue gas under high initial O_2 concentrations (60–100%). They carried out their experiments on a bench-scale, quasi-one-dimensional, electrically heated combustor (28 mm id) and found that the reduction efficiency of the recycled NO_x increased with both the equivalence ratio and the recycling ratio of flue gas (the ratio of flue gas in inlet gas). The reduction efficiency for the recycled NO_x reached as high as 80% at the fuel equivalence ratio of 1.4 [5].

None of the above mentioned investigations on the fate of the recycled NO_x in coal combustion with O_2/CO_2 was carried out with a combustor equipped with pf burner(s). Investigations with a combustor equipped with pf burner(s) should produce more reliable results that may be applied to a power plant boiler. In addition, the initial O_2 concentration in the inlet gas should include the range (30–42%) that will likely produce matching temperature profiles to those of conventional coal-air combustion [6–9]. Miyamae et al. [6] reported that 42% O_2 in CO_2 was required to produce equivalent adiabatic flame temperature to coal-air combustion according to their calculations. Croiset et al. [7,8] found coal combustion in 35% O_2/65% CO_2 could produce equivalent flame temperature to coal-air combustion in their 0.3 MW vertical combustor. Our previous paper [9] reported our experimental results on the comparisons of combustion performance and NO_x emissions between coal combustion with air and coal combustion with various O_2/CO_2 mixtures in a 20 kW down-fired combustor (190 mm id×3 m). It concluded that an initial O_2 concentration in CO_2 of 30% or higher was required to produce matching temperature profiles to those of coal-air combustion under the investigated conditions. It was also concluded that coal combustion in 30% O_2/70% CO_2 produced less NO_x than coal combustion in air. No NO_x recycling experiments had been done at that stage. In this paper, experimental results on NO_x recycling with both coal-air combustion and coal-O_2/CO_2 combustion will be reported. The results with coal-air combustion will be particularly of interest to the NO_x recycle approach as one of the NO_x control methods [1], while the results with coal-O_2/CO_2 combustion will reveal the likely fate of the recycled NO_x with coal-O_2/recycled flue gas combustion. New results with combustion of various coals in air and O_2/CO_2 mixture will be introduced first to complement our previous paper [9] and followed by results with NO_x recycle.

2. Experimental

Details of the 20 kW vertical coal combustor (190 mm id×3 m) and the experimental procedures had been described in the previous paper [9]. Here only the essential and new information is presented.

The non-swirling primary oxidant carrying coal particles mixes with swirling secondary oxidant near the entrance to the burner quarl. Further down the combustor a tertiary oxidant can be added to simulate the air staging/OFA or low-NO_x burners combustion. In the following sections of this paper, 'staging' will be used to indicate that a portion of the secondary oxidant is added as the tertiary oxidant.

Seven international bituminous coals have been tested with their analyses shown in Table 1. All of these pulverized coals were supplied from a UK commercial power plant. Experimental conditions are almost the same as reported in the previous paper [9] and given in Table 2. On each testing day, the combustor is heated by natural gas combustion for about 2 h before coal combustion starts. Every test always starts with conventional coal-air combustion and after stabilization and measurements of coal-air combustion, which takes about 2 h, the combustion air is changed over to the mixtures of O_2/CO_2 with continuous coal feeding. The stabilization and measurements with coal-O_2/CO_2

Table 1
Coal analyses (% as received)

Coal	Proximate analysis				Ultimate analysis			
	Moisture	Volatile	Ash	Fixed carbon[a]	C	H	N	O+S[a]
UK Bit 1	2.6	29.4	11.4	56.6[a]	70.6	4.6	1.6	9.2
US Blend	3.4	31.6	11.6	53.4	69.6	4.50	1.4	9.5
Polish Blend	1.6	30.6	11.1	56.7	72.0	4.6	1.3	9.4
South African	3.6	25.6	10.9	59.9	69.4	4.2	1.8	10.1
Colombian	3.5	33.1	6.0	57.4	72.9	5.1	1.6	10.9
Australian	2.0	29.6	11.9	56.5	69.9	4.4	1.6	10.2
UK Bit 2	5.3	28.4	22.3	44.0	64.2	4.6	1.2	2.4

[a] By difference.