

Experiments on lignite combustion in a circulating fluidized-bed reactor

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Abstract:

In this study, a circulating fluidized bed (CFB) (0.15 m i.d. and 5.4 m high) was used to investigate the combustion characteristics, including riser temperature, major pollutant emissions (CO, SO₂ and NO) and combustion efficiency, of Thai lignite. The combustion experiments were carried out at different excess air ratios ($\alpha_0 = 0.97-1.50$). The experimental results from combustion tests demonstrate that either or both the resulted change in the riser temperature in the CFB riser and the O₂ availability for combustion affected the combustion efficiency (E_c) and formation of CO, SO₂ and NO. The combustion efficiency varies between 96.0-97.4% depending on the excess air ratio.

Keywords: Circulating fluidized bed; Coal; Combustion; Pollutant emissions

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1. Introduction

Low rank coals are largely available in the world and have low price compared to high rank coals and other commercialized fuels. However, these coals have undesirable properties, e.g. excessive moisture content, high emission formation due to high sulfur content, etc. Circulating fluidized bed (CFB) boilers offer several advantages over the low velocity bubbling fluidized bed (BFB) or other boiler technologies for utility application. With relatively high operating velocity, CFB gives a higher gas throughput per unit area, a more compact size and possibility for large capacity (> 100 MWe) (Koornneef et al., 2007). Despite various attractive features of low-quality coal combustion, major challenge on the optimal operation of a CFB boiler involves the control of SO₂ and other pollutant emissions. Therefore, a combustion study on Thai lignite was carried out in a lab-scale CFB facility developed at JGSEE laboratory. The objective of this work was to investigate the effect of excess air ratio, which is one important operating condition, on performance of lignite combustion in terms of combustion efficiency (E_c) and major pollutant emissions (CO, SO₂ and NO).

2. Experiment

2.1 Fuel and bed material

In the experiments, Thai lignite was used as fuel with properties given in Table 1. The bed material was silica sand (95% Si; 2,670 kg/m³ particle density) with the mean particle size of 474 μ m.

Table 1 The properties of Thai lignite

Proximate analysis (wt%, as-received basis)		Ultimate analysis (wt%, dry ash free basis)	
Moisture	12.3	Carbon	61.8
Volatile matters	38.1	Hydrogen	5.2
Fixed carbon	34.2	Oxygen	29.7
Ash	15.4	Nitrogen	1.8
		Sulfur	1.5

2.2 Apparatus

Experiments were carried out in a circulating fluidized bed facility shown schematically in Fig.1. The detailed configuration of the device has been published elsewhere (Chovichien et al., 2013). In

brief, the CFB consists of a riser (0.15 m i.d. × 5.4 m high), an internal cyclone with a standpipe (0.1 m i.d. × 3.6 m high) and an L-valve (0.10 m i.d. × 0.17 m long). At the exit of CFB locates a dust cyclone to capture fly ash entrained in the flue gas. The reactor is made of casting steel and insulated with layers of refractory and ceramic wool.

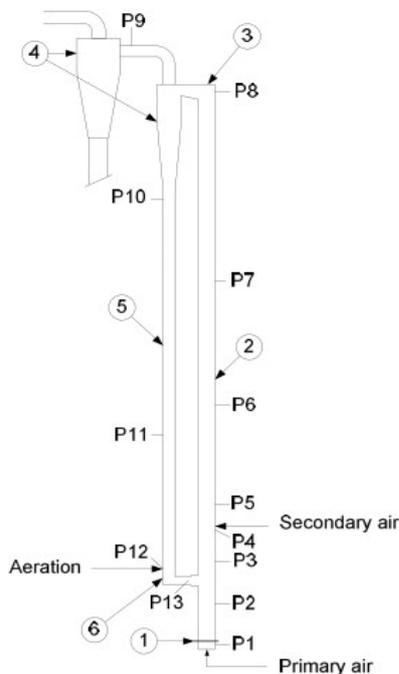


Fig. 1 Schematic diagram of the CFB reactor: (1) air distributor; (2) riser; (3) riser exit; (4) cyclones; (5) standpipe; (6) L-valve. P# = pressure transmitters.

2.3 Experimental procedure

Tests were carried out to study the effect of excess air ratios (α_0) on the combustion efficiency and emissions. Two ranges of excess air ratio were performed: 0.97-1.05 (low excess air) and 1.37-1.50 (high excess air). Only primary air was supplied. The feed rate of lignite was 10 or 15 kg/hr. The concentrations of O₂, CO, CO₂, SO₂ and NO in the flue gas were measured at the cyclone exit by a gas analyzer (TESTO 350XL) and reported based on 7% O₂ basis. The combustion efficiency was calculated using the heat-loss method (Basu et al., 2000) shown as Eq. (1):

$$E_c = 100 - (q_{uc} + q_{ic} + q_h) \quad (1)$$

where q_{uc} is heat loss due to unburned carbon; q_{ic} is heat loss due to incomplete combustion; and q_h is heat loss due to convection and radiation from the reactor exterior.

3. Results and discussion

3.1 Effect of (low-range) excess air on riser temperature and combustion characteristics

The effect of low excess air ratio on combustion efficiency and emission of CO and SO₂ is shown in Fig.2. It can be seen that the higher α_0 reduced the averaged riser temperature from 825 to 780°C. However, the higher α_0 above the stoichiometric volume of combustion air reduced CO emissions and increased the combustion efficiency. The results suggest that, within this range of α_0 , the effects of increasing mean O₂ concentration were more significant and promote more complete combustion in the reactor.

SO₂ emission was found to be reduced at higher α_0 . It is known that most of sulfur is released from the organic and inorganic structures of coal during the devolatilization process, followed by a rapid

conversion to SO₂ during the combustion of volatiles. Both pyrolysis and combustion steps are temperature dependent. Therefore, the SO₂ concentration tended to be lower at the higher α_0 , under which the temperature of the riser was lower.

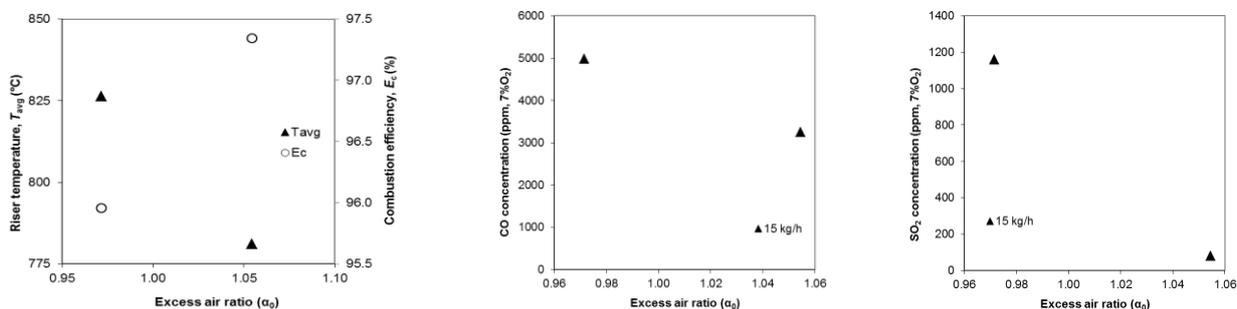


Fig. 2 Effect of low excess air ratio on the riser temperature, combustion efficiency (E_c), concentrations of CO and SO₂ for Thai lignite combustion.

3.2 Effect of (high-range) excess air on riser temperature and combustion characteristics

As shown in Fig.3, in the relatively high range of α_0 (1.37-1.50), the increasing α_0 was also found to reduce the riser temperature from 760 to 620°C. In this case, however, CO emission increased and E_c dropped slightly. The reduction in the riser temperature had more significant impact on the combustion efficiency of the CFB unit than the increasing O₂ availability. SO₂ emission also reduced in response to the reduced riser temperature. On the other hand, NO emission increased. The increase in NO was mostly contributed by the increasing O₂ concentration during NO formation from volatile-N and char-N oxidation.

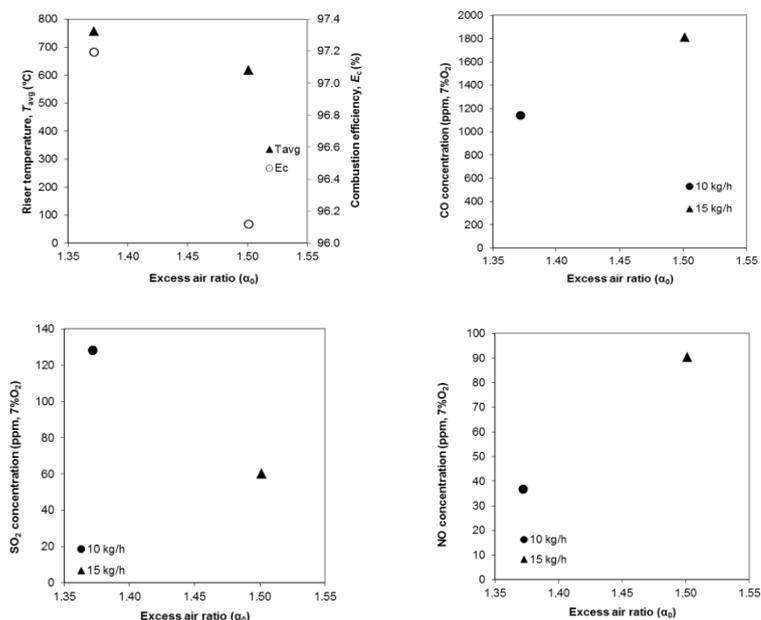


Fig. 3 Effect of high excess air ratio on the riser temperature, combustion efficiency (E_c), concentrations of CO, SO₂ and NO for Thai lignite combustion.

4. Conclusion

The effect of excess air ratios (α_0) on the combustion efficiency and emissions of CO, SO₂ and NO of Thai lignite combustion in a circulating fluidized bed (CFB) reactor was investigated. At the lower range of α_0 (0.97-1.05), the combustion efficiency and CO emissions were closely dependent on the O₂ availability for combustion. Increasing α_0 increased the combustion efficiency and

reduced CO emissions, despite the reduction of temperature in the riser. SO₂ emissions were more influenced by temperature and found to decrease when temperature decreased. As α_0 was further increased to the high α_0 range (1.37-1.50), the combustion efficiency and CO emissions became more temperature dependent. Although with higher O₂ availability for combustion, the combustion efficiency dropped and CO emissions increased. SO₂ emissions decreased as temperature decreased, but NO emissions are favored by the higher O₂ availability at high α_0 . Overall, the results suggest that the CFB reactor could operate well with Thai lignite. Under the range of α_0 studied, the optimum α_0 seemed to be achieved at 1.05, at which the combustion efficiency reached the maximum at 97.4% and all emissions were at minimum levels. The resulting temperature in riser was at around 780°C.

5. References

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