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Influence of AAEM species in coal and biomass on steam co-gasification of chars of blended coal and biomass

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ABSTRACT

This study investigated effects of blending ratio and alkali and alkaline earth metallic (AAEM) species in the feedstock on char reactivity and producer gas composition in steam co-gasification of chars of blended coal and biomass. Experiments were conducted on a bench-scale fixed bed gasifier in which lignite was used as coal and radiata pine was used as biomass. The blending ratios of lignite to pine (L/P) were, respectively, 0:100 (pure pine), 20:80, 50:50, 80:20 and 100:0 (pure lignite). Lignite and radiata pine were first separately ground to fine particles which were then blended based on pre-set ratios. After this, the blends were pelletized and charred at 900 °C. In order to investigate the effect of AAEM in the coal, experiments were also performed using blended pine and acid-washed lignite from which most of AAEM species were effectively removed. The co-gasification operation temperature was 950 °C. From the experimental results, it was found that the ratios of H_2/CO, H_2/CO_2 and CO/CO_2 in the producer gas were nonlinearly related to L/P ratio in the lignite blended chars; however, these gaseous ratios were linearly correlated to the L/P ratio in co-gasification of acid-washed lignite blended chars. In addition, by removing the AAEM species in lignite, yields of H_2 and CO_2 were reduced while CO yield was increased. The char reactivity of acid-washed lignite and pine blends was decreased and this decrease became more significant with increase in coal to biomass blending ratio.

1. Introduction

Gasification technology has attracted increasing attention due to its advantages of high conversion efficiency and flexibility in application of the producer gas for generation of electricity or synthesis of liquid fuels. The producer gas yield and composition are affected by a number of factors such as type of gasification reactors (fixed bed, fluidised bed), fuel type (biomass, coal or their blends), gasification agent (steam, oxygen or air) and operation conditions (temperature, pressure). Among these factors, the fuel type has the most significant impact.

Gasification technology can effectively process blended coal and biomass to take the advantages of each individual feedstock [1–7]. From an environmental point of view, the addition of biomass to coal reduces CO_2 emissions and pollution caused by sulphur and ash contained in coal, as biomass is known to be CO_2 neutral and has low contents of sulphur and ash. On the other hand, costs for transportation and handling of a large quantity of low density biomass for a large scale plant are high. Therefore, blending of biomass with a proportion of coal provides a promising opportunity to build a large scale gasification based energy plant. New Zealand has in-ground coal reserves of more than 15 billion tonnes [8], which are distributed throughout the country. In the meantime, New Zealand has about 2 million tonnes of wood residues per annum generated from log harvesting and wood processing [9].

The gasification process can be divided into two stages including an initial fast pyrolysis process (or devolatilization) followed by subsequent reactions between char and gases and reactions among gases generated from the first fast pyrolysis stage [10]. Char reactions are the rate-dominant reactions for overall gasification process [11,12]. The diversity in fuel properties makes the mechanism of co-gasification more complicated than gasification of pure fuel. Therefore, it is important to understand and quantify the char reactivity during the co-gasification process.

Recently, extensive studies have been conducted on co-gasification of coal-biomass blends, and various types of biomass and coals have been tested using different types of gasification

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reactors [3,4,6,13–27]. It has been found that gasification rate was increased with increase in biomass proportion in the blends, which was attributed to the high surface area in the porous biomass char and the inherent alkali metals (K, Na) and alkaline metals (Mg, Ca) in the biomass [28–32]. However, an opposite trend was reported by Fermoso et al. [33] who used blended Spanish bituminous coal and chestnut wood as biomass.

Furthermore, conflicting results have been reported in literature on the synergetic effect in co-gasification of coal and biomass. Some studies demonstrated presence of the synergetic effects [22,24,26,34–37] while others could not find such effect [30,38–40]. These conflicting results may be attributed to the blending method and different contents of AAEM species in coal and biomass tested [41,42]. The AAEM species may act as a catalyst to enhance char reactivity after the initial stage of gasification (devolatilization or fast pyrolysis) which promotes conversion of solid char into gaseous products [43–50]. It is known that different types of coals and biomass contain different species and contents of alkali (K and Na), alkaline earth (Ca and Mg) and transition (Fe) metals. In general, these AAEM species exit in three different forms [51]: as salts in biomass (e.g. NaCl or KCl), as carboxylates in coal (-COOM, where M is AAEM) and as a part of mineral matter (e.g. silicates) [52–57]. These different AAEM species may play a different role in the co-gasification. However, only limited studies have reported the catalytic effect of AAEM species in the co-gasification of coal-biomass blended char [58,59].

The objective of this study was to experimentally examine the synergetic effects in steam co-gasification of chars of blended lignite (coal) and radiata pine (biomass), and to investigate the effect of AAEM species present in the coal on the producer gas composition and char reactivity.

2. Experiments and materials

2.1. Materials

Lignite (coal) and radiata pine wood (biomass) were selected from New Zealand as solid fuels for the experiments. Lignite is a typical low rank coal and radiata pine is the most common plantation wood species in New Zealand [60].

Before the experiments, each solid fuel was ground through a ring mill and sieved to powders with particle size of less than 0.5 mm. Then the fine particles of pine and lignite were thoroughly mixed with coal-to-biomass mass blending ratios being 100:0 (pure coal), 80:20, 50:50, 80:20 and 0:100 (pure wood), respectively. After that, the mixture was compressed under a pressure of 1.6 MPa in a mould to produce cylindrical pellets of around 20 mm in length and 8 mm in diameter. The pellets were finally placed in an oven at 900 °C for 7 min to remove the volatile components and, in this way, chars of various blends were produced. It is found that char yield was high for pure lignite (41%) and low for pure pine wood (18%) while the char yields for the blended lignite and pine were linearly related to the composition of lignite and pine in the blend (Table 1).

In order to investigate the effect of AAEM in the lignite on gasification performance, separate experiments were conducted in which most of the AAEM species were removed with acid washing. In the acid washing, the lignite particles were treated by continuous stirring for 15 min in a 1 M hydrochloric acid (HCl) solution at room temperature [61]. The acid-washed powder was then filtered and washed repeatedly with distilled water until the washing gave no indication of chloride in treatment with silver nitrate solution. Finally, the washed lignite powders were dried and mixed with pine particles at pre-set blending ratios. The mixtures were then pelletized and charred in the same way as mentioned above. Char yields for the blended washed lignite and pine biomass also followed the linear relationship with the blending ratio although the char yield for the washed lignite was slightly higher (44%) than the pure lignite. The proximate analysis results of two types of coal-biomass blended chars in the present study are presented in Table 1.

It is expected that the acid-washing would change the char structure and reduce the concentrations of AAEM species in the lignite. Shakirullah et al. [62] performed experiments to demineralize coal using various acids including ethylenediaminetetraacetic acid (EDTA), citric acid, hydrochloric acid (HCl) and nitric acid (HNO_3), and examined the surface structure changes using Scanning Electron Microscopy (SEM). They found that the coal surfaces were changed significantly for some acids (such as citric acid) but the surfaces for HCl treated coal seemed to be intact.

In order to investigate the removal of AAEM species in the lignite with acid washing, X-ray fluorescence (XRF) analysis were conducted in this study to determine the major elements present in ash for selected solid fuels. The results are given in Table 2.

Table 2
XRF analysis results of the major elements (wt%) present in the ash for selected solids.

Samples	100L:0P	50L:50P	0L:100P	50AWL:50P	100AWL:0P
SiO_2	24.8	31.8	20.5	40.2	45.8
Al_2O_3	3.7	1.3	4.7	0.5	1.7
Fe_2O_3	15.1	12.0	2.7	2.9	3.3
CaO	30.1	26.3	24.4	4.2	2.5
MgO	4.3	6.4	9	2.8	1.1
Na_2O	0.4	0.4	1.8	1.2	0.1
K_2O	0.1	3.2	21.5	15.3	0.1
TiO_2	0.2	0.1	0.3	0.2	0.1
Mn_3O_4	0.4	0.4	1.9	0.2	0.1
SO_3	20.3	15.8	3.5	30.6	44.9
P_2O_5	0.1	1.8	5.1	0.5	0.1

Table 1
Char yields and proximate analysis of coal-biomass blended chars (dry basis).

Lignite (L)/Radiata pine (P)	100L:0P	80L:20P	50L:50P	20L:80P	0L:100P
Char yield (%)	41	36	29	23	18
Fixed Carbon (wt% db)	81.1	83.6	87.4	91.8	96.0
Volatiles (wt% db)	6.0	5.4	4.3	3.2	2.1
Ash (wt% db)	12.9	11.0	8.3	5.0	1.9
Acid washed Lignite (AWL)/Radiata pine (P)	100AWL:0P	80AWL:20P	50AWL:50P	20AWL:80P	0AWL:100P
Fixed Carbon (wt% db)	86.0	88.2	89.4	92.5	96
Volatiles (wt% db)	6.4	5.6	4.9	3.6	2.1
Ash (wt% db)	7.6	6.2	5.7	3.9	1.9