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Comparison of entrained flow gasification behaviour of Victorian brown coal and biomass

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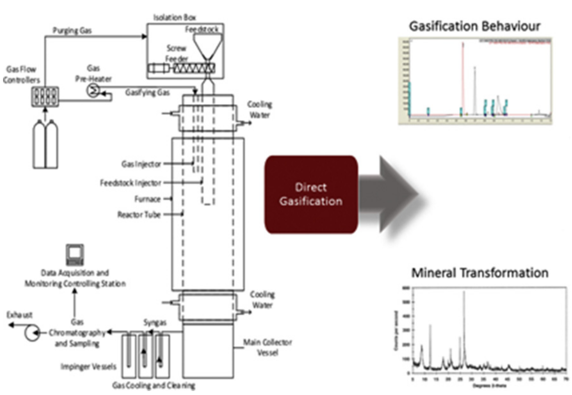
GRAPHICAL ABSTRACT



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ABSTRACT

This study assesses and compares the gasification performance of a Victorian brown coal (Loy Yang) and Pine bark in the temperature range of 1000–1400 °C with CO_2 (10–40% in N_2) as the gasifying agent in a bench-scale atmospheric entrained flow reactor. The effect of temperature and CO_2 concentration in the feed gas on the carbon conversion, syngas composition, and emission of polluting species such as HCN, NH_3 and H_2S has been investigated. In addition, complementary char analysis such as the particle size distribution and char morphology have been performed in order to characterize the fragmentation behaviour. Further, the mineral matter transformation at elevated temperatures has been analyzed through X-ray diffractograms of the chars and comparing with the thermochemical equilibrium predictions. As expected, the carbon conversion increased with increasing temperature and CO_2 concentration. For both the fuels, ~98% conversion was achieved at 1200 °C. The products included the solid residue and the gaseous components such as CO, H_2, CO_2, and CH_4. No tar was observed during the gasification runs. The pollutant gases were in the ppmv range with NH_3 and H_2S negligible amounts being detected for Loy Yang coal and Pine bark, respectively.

1. Introduction

The utilization of coal and its substitution with renewable options has been debated widely over the past few years. However, coal is expected to dominate the world energy market until 2030 and contribute to energy production until the end of 2100 [1–3].

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Gasification is a well-known and a more sustainable utilization option with higher efficiency and significantly lower NO_x and SO_X emissions compared to the traditional combustion process [4,5]. Of the many gasification techniques available, entrained flow gasification dominates the gasification market, accounting for more than 70% of worldwide syngas production, predominantly due to the flexibility of feedstock handling and higher carbon conversion [6,7]. In particular, the feedstock flexibility aspect allows for at least the partial substitution of coal with a renewable carbonaceous fuel such as biomass. However, the 'compatibility' of fuels for co-gasification has to be investigated through fuel specific gasification performance data under industrially relevant conditions in order to enable the design and optimization of the process. In this study, a Victorian brown coal (Loy Yang coal) and a biomass (Pine bark) have been compared in terms of carbon conversion and mineral matter behaviour during entrained flow gasification.

Biomass holds tremendous potential to meet the global energy and chemical needs. The technical potential of biomass for energy is significant and is estimated to be 1500 EJ/year by 2050 [8]. Particularly, biomass derived from forestry, agriculture and municipal wastes and residues is an attractive fuel for gasification owing to large abundance and low cost. Several carbon-rich industrial refuse, for example, the rejects of the local pulp and paper industries, such as wood bark are potential feedstock because of their typically lower ash and sulfur contents.

Entrained flow gasification is an industrially mature technology with several investigations on a variety of coals [9–13]. However, limited data exists on the gasification performance of Victorian brown coal that are one of the largest reserves of lignites in Australia and the world [6]. The investigations of Tremel et al. and Harris et al. on the pyrolysis and gasification behaviour of a German lignite and Australian sub-bituminous coals in an entrained flow reactor demonstrate the influence of the coal property and the gasification conditions on the carbon conversion achieved [14,15]. Similar studies on a variety of biomass by Qin et al. [16] demonstrate the effects of the gasification medium (steam and O_2 mixtures) on the outlet gas quality and carbon conversion.

The use of steam and oxygen for gasification in an industrial setting is cost intensive. On the other hand, the use of air lowers the cost, however, the product gas is dilute with nitrogen resulting in a lower heating value. Instead, the utilization of CO_2 as a gasifying agent reduces carbon footprint and the heat requirement for phase change compared to steam gasification [17]. Recently, Billaud et al. investigated the CO_2 gasification performance of sawdust in a lab-scale entrained flow gasification rig [18]. For the char samples used in their study, a temperature of 1200 °C was required. Tanner et al. investigated the entrained flow gasification of German lignite and Victorian brown coal, and suggest that ~100% carbon conversion was achieved at 1400 °C [19]. However, the gasification conditions required in large scale gasification would be governed by both the carbon conversion and the mineral matter behaviour. The mineral composition would affect the slag formation temperature in the gasifier [20]. This, in fact, reinforces the need for fuel specific experimental data at industrially relevant gasification conditions.

In this paper, the comprehensive assessment of entrained flow gasification performance of Loy Yang coal and pine bark is presented. The Loy Yang brown coal is currently used for mine-mouth power generation in conventional pf boilers. The pine bark is a reject from the paper mills. Both these solid fuels are currently assessed for entrained flow gasification with a view of producing chemicals and liquid fuels. The comparison between the fuels is drawn in terms of carbon conversion, syngas composition, emission of syngas contaminants such as H_2S, HCN, and NH_3; mineral matter characteristics and their transformation as a function of temperature. The results from this study contribute to the overall objective of the feasibility analysis of the co-gasification of the biomass along with Victorian brown coals to be undertaken later.

2. Experimental

2.1. Sample selection and preparation

In this study, Loy Yang coal from Loy Yang mine in Victoria, and Pine bark (*Pinus Radiata*) sourced from Norske Skog were selected as the coal and biomass subject. In this paper, Loy Yang coal and Pine bark with henceforth be referred to as LY and PB respectively. These fuels have been selected for comparison due to their similar carbon and ash contents. Both samples were firstly air-dried and ground and then sieved to a particle size of 90–106 μm using a Tyler sieve shaker machine. A range of fuel characterization such as the proximate, ultimate analysis, ash fusibility, and composition have been carried out and are presented in Table 1.

2.2. Apparatus and procedure

The gasification tests were conducted on the HELENA (High temperature, electrically heated, entrained flow apparatus), shown in Fig. 1. The HELENA, located at Monash University Clayton, was custom designed to mimic industrial gasifier residence times; a detailed description of the capabilities and process parameter ranges of the apparatus is covered by Tanner et al. (2016) [19]. At atmospheric pressure, the furnace of HELENA is heated to the desired temperature at a rate of approximately 1 °C/min using the temperature control panel. The slow heating rate preserves the condition of the alumina reactor tube and the molybdenum disilicide heating elements. The cooling water system is turned on prior to heating and remains switched on throughout the duration of the experiment. The impingers (gas cleaning and cooling section) and the solids collector are air-blown, cleaned with water and dried prior to use to ensure accurate ash collection and weighing. The gasifying agent was pre-heated to 500 °C and the Varian

Table 1
Proximate, ultimate and ash fusibility analysis of fuels.

Parameter	Loy Yang	Pine Bark
Moisture (oven dried, wt%)	1.0	5.0
Proximate analysis (dry basis, wt%)		
Volatile matter	50.63	59.78
Fixed carbon	35.33	23.91
Ash	14.02	16.30
Ultimate analysis (dry basis, wt%)		
C	57.38	53.47
H	3.89	5.47
N	0.14	0.15
S	0.12	0.13
O	24.44	24.49
Ash fusibility (reducing atmosphere) (°C)		
Deformation	1250	1148
Sphere	1400	1166
Hemi-sphere	1440	1218
Flow	>1500	1236
Ash composition (dry basis, wt%)		
SiO_2	38.6	60.69
Al_2O_3	36.7	14.38
Fe_2O_3	5.64	6.78
CaO	1.26	6.18
MgO	7.85	2.74
Na_2O	6.33	1.12
K_2O	0.59	5.47
TiO_2	2.19	0.90
SO_2	0.04	0.69
P_2O_5	0.28	0.97
BaO	0.05	0.03