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Review

Investigation of combustion and co-combustion characteristics of raw and thermal treated bamboo with thermal gravimetric analysis

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ABSTRACT

The thermal behaviour and chemical characteristics of the bamboo species, *Bambusa multiplex* (BM), sourced from South Africa were investigated using thermogravimetric analysis (TGA). Torrefaction and low-temperature carbonization conditions were applied to samples of this plant at temperatures between 250 °C and 380 °C. The burning profiles for the raw and thermally treated bamboo samples co-fired with coal A at different ratios of coal inclusion were examined. The raw BM was found as the easiest to ignite fuel probably due to possessing the highest volatile matter content.

Considerable differences in fuel characteristic were found between the raw and thermally treated BM samples. Raw BM was found to have a calorific value of 17.60 MJ/kg, whereas, torrefied and low temperature carbonized BM produced fuels of 23 MJ/kg and 28 MJ/kg, respectively. Further results attained in this investigation on basis of combustibility, has shown the relatively low ignition temperatures and highly reactive potential of torrefied bamboo samples.

Contents

1. Introduction

Biomass is defined as a biological and sustainable material originated from plants in a woody and non-woody form, respectively. Bamboo is known as a woody biomass, which has shown positive prospect as a future energy source due to its fast growth rate, strength and high quality fuel physiochemical properties such as

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low ash content, high calorific value, and low alkalis index [1]. The increasing investigation on biomass such as bamboo for power generation solely, or co-fired with coal, is as a result of increase in the global outcry to reduce fossil fuel dependence. With many techniques available for converting biomass or co-firing it with coal to generate energy, biomass still faces different shortcomings, such as different physiochemical properties, varied combustion characteristics, difference in energy density when blended with coal, high grindability and handling cost, low energy yield and high moisture and volatile components [2–4].

Thermal pre-treatment of biomass is a process used to increase the energy yield of biomass, eliminate biodegradation, and improve grinding and handling properties along with homogenization for combustion and co-firing with coal. The application of this technique was found by Park and Jang [4] to have a major influence on the chemical and physical properties of raw biomass. Investigation on the thermal pre-treatment and decomposition of the *Bambusa multiplex* (BM) utilized in this research will provide a better understanding of its combustion reactivity as a co-fired fuel or a solely fired fuel. However, low burning rate and low flame temperatures of biomass, which results in poor flowability, poor blending and a reduction in thermal efficiency and capacity of existing boiler units are additional challenges facing biomass as co-fired fuel [5,6]. Nevertheless, it is proposed that some of the aforementioned limitations should be addressed through the thermal treatment of the raw bamboo leading to the production of a biomass with high valuable and renewable energy source.

The impact of different pre-treatment methods such as torrefaction, carbonization and pelletisation in achieving high quality biomass that could be co-fired with coal to attain high quality co-firing combustion characteristic, low CO_2 and NO_2 emissions have been investigated by many researchers [3,7,8]. Torrefaction is known to facilitate the homogenization of biomass through the decomposition of hemicellulose, which is the most reactive component of the polysaccharides or lignocellulosic constituents of biomass. With the torrefaction of biomass, an investigation conducted by Brzdekiewicz et al. [9] on the effect of biomass substitution at different weight blends in a coal firing boiler on temperature and gas components has shown similar flue gas temperature distributions for all composition of fuels tested. The same authors also found a significant reduction in the NOx emissions for torrefied biomass relative to coal as a result of the lower nitrogen content of biomass, and more so, due to the conversion of nitrogen in biomass volatiles to NH_3 [10].

Phanphanich and Mani [3] reported a ten-fold reduction in energy required for grinding pine chips torrefied at 300 °C and a six-fold reduction for torrefied logging residues compared to untreated biomass. The authors also showed that the energy required in grinding woody biomass torrefied between 275 and 300 °C could be improved by 23–78 kWh/t, similar to energy used in grinding coal (i.e. 7–36 kWh/t). A reduction of about 85% in power utilized in grinding torrefied willow was also reported by Svoboda [11]. Studies have also shown that the energy and mass yield from the low carbonization of biomass is different to that obtained during torrefaction. The investigation conducted by Park et al. [12] on different biomasses supported the fact that pyrolysis at low temperature between 400 and 500 °C improved fuel characteristics such as increased calorific value, higher fixed carbon and lower volatile matter. This increased the product's characteristics towards that of coal on the H/C vs. O/C diagram. This significant improvement in fuel characteristics was reported to be as a result of the decomposition of cellulose and hemicelluloses constituents in the biomass at this low carbonization temperature.

The species of bamboo utilized in this investigation (*Bambusa multiplex*) i.e. BM, was acquired from the Western Cape region of South Africa. *Bambusa multiplex* has a slender culm, a height within the range of 7–15 m, an internode of about 15–30 cm and it is utilized for construction and crop supports. Two other potential bamboo species planted in South Africa have also been identified for future combustion and co-combustion tests based on the data obtained from the preliminary investigation conducted on these two species, as depicted in Fig. 1. However, to date there has been very little conducted on the potential of bamboo grown in Southern Africa for power generation. For this reason, this research set out to test the torrefaction and low carbonization thermal treatment process on BM, and thereafter to investigate the effectiveness of different torrefaction and carbonization temperatures on the fuel basic characteristics including calorific value, carbon content, nitrogen and volatile matter content. In addition, the combustion profiles of both torrefied and carbonized biomass, along with biomass/coal blends at different ratios using differential thermogravimetric (DTG) techniques were evaluated.

2. Experimental

2.1. Materials and thermal treatment

Bambusa multiplex bamboo samples (referred to as raw BM) and coal were utilized as the raw biomass material and co-fired fuel in this investigation respectively. The bamboo culms were divided into different sections representing the leaves, top, middle and bottom of the stem and the root as shown in Table 1. The samples were

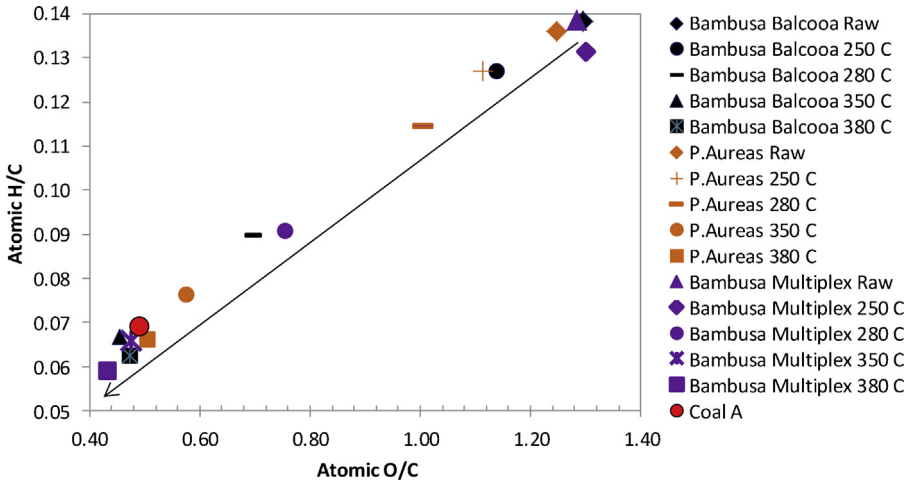

Fig. 1. Van Krevelen plot on coal, raw and thermal treated bamboo species.