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Torrefaction of waste biomass for application in energy production in South Africa

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ABSTRACT

Power producing plants are major emitters of greenhouse gases that lead to global warming and climate changes. In the past two to three decades, attention has been drawn to organizations such as these reduce their dependence on coal reserves which are depleting and focus on producing clean energy i.e. for every ton of fuel produced, 100 kg or more should be made from clean energy. This has made torrefaction to gain interest as it improves energy content of biomass, a renewable and clean energy source, to levels equal to and sometimes above that of coal. The benefit of this is that, torrefied biomass could be co-fired with coal thereby reducing greenhouse gases and global warming.

In this study, the effect of different parameters were investigated on two abundant sources of biomass in South Africa. There parameters were temperature, oxygen content, heating rate and residence time. It was observed that a temperature range between 275 and 300 °C under inert conditions with a heating rate of 10 °C/min and residence time between 20 and 40 min were required to achieve the best biomass with properties comparable to those of coal. This made it possible to co-fire the biomass with coal for energy production at different proportions.

1. Introduction

Majority of power used in household and industries in South Africa come from Eskom. Eskom power generating plants use energy from steam, combustion gases or expanding gas to convert heat energy into mechanical energy using rotary machines (Eskom website, 2016). However, a large amount of waste heat energy contained in the flue gases from combustion of fossil fuels mainly composed of CO_2, NO_x, SO_x and water vapour are released into the atmosphere. These gases are hazardous to the environment and ways of limiting the emissions of such gases need to be implemented (Eskom website, 2016).

To reduce the amount of hazardous gases, biomass, that has undergone torrefaction, can be used to replace a small amount of coal. The gases emitted from torrefied biomass combustion are part of the carbon cycle as biomass is produced from CO_2 absorbed from the atmosphere during photosynthesis (Basu, 2010). Of late, Eskom has shown a

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strong interest in utilising torrefied biomass in existing large-scale combined heat and power (CHP) plants to co-fire with coal without having to change the design (Creamer, 2012; Rycroft, 2015; Stafford, 2014; Yende, 2017). Biomass is considered to be one of the most important renewable fuels. However, in its natural occurring form it has low energy density when compared to that of fossil fuels like coal and diesel. As a result, biomass has low utilization efficiency when it is directly consumed as a fuel. To overcome this disadvantage, studies have shown that the energy density of biomass can be enhanced by thermal/physical treatment processes. These treatments include compression, pelletization and torrefaction. Torrefaction occurs when thermal heat is carefully applied to biomass under controlled thermodynamic conditions causing chemical, physical and mechanical changes to the biomass. The temperature range required is between 200 and 300 °C and the process should occur under inert conditions, at low heating rates and low residence time (Basu, 2010; Chew and Doshi, 2011; Chen et al., 2013). Torrefied biomass can be co-fired with coal and the net CO_2, NO_x and SO_x emissions will be reduced thereby reducing environmental damage. The blending process results in negligible changes in synergistic effects between coal and torrefied biomass (Chen and Kuo, 2011). Currently, researchers are mostly focused on the compositional changes of solid biomass, along with the product distribution (Prins et al., 2006). The volatiles released during this process can be burned in a combustor, and the flue gases collected and used to preheat raw biomass.

Some research on biomass torrefaction parameters has led to the conclusion that slow heating rate has an effect on torrefaction, typically the heating rate should be significantly slow (<50 °C/min) to allow maximization of solid yield of the process (Batidzirai et al., 2013; Tran et al., 2013). Studies to evaluate the thermal behaviour of biomass in both oxidizing and inert atmospheres have been carried out by a number of authors. Most of these researchers have shown that in oxidative environment, the thermal reactivity of biomass is greatly enhanced. This is due to the acceleration of mass loss in the first stage of torrefaction (Chen and Kuo, 2011).

Biomass is mostly composed of cellulose, hemicellulose and lignin (Chen et al., 2015; Galletti and Antonetti, 2012). During torrefaction of biomass, the thermal decomposition of biomass happens through chemical reactions coupled with heat and mass transfer depending on the temperature range. Within the temperature range of 100–260 °C, hemicellulose is chemically most active, but its major degradation starts from around 200 °C. Cellulose and lignin will start degrading at higher temperatures. Lignin starts degrading from around 275 °C, whilst cellulose starts degrading from 330 °C (Batidzirai et al., 2013). At 300 °C biomass begins to change colour to brown and give off additional moisture, CO_2 and large amounts of acetic acid with some phenols that have low energy values (Tran et al., 2013). In addition, torrefaction yield can vary between 24% and 95% of the original raw biomass weight. Usually, biomass with higher hemicellulose content will result in lower yield while biomass with lower hemicellulose gives higher yield (Chew and Doshi, 2011). This is due to the fact that during torrefaction, hemicellulose is mostly decomposed as it is active within the range 200–300 °C.

Due to large biomass requirements, the chosen raw biomass should be able to meet the demand and that is why different biomasses have been investigated. In South Africa, marula seeds and blue gum wood are some of the abundant raw biomasses that can be used to investigate the effect of the torrefaction process for application in power generation companies. In this study these biomasses abundant in South Africa and some parts of the world, were investigated for possible use in co-firing coal-fired boilers for electricity production. Different parameters were varied to determine their impact on the torrefaction process.

2. Experimental method

2.1. Biomass

The investigation was conducted on two South African biomasses, marula seeds and blue gum wood (Fig. 1).

2.1.1. Marula trees

Marula (*Sclerocarya birrea*) is a medium-sized tree, native to the following countries: South Africa, Malawi, Namibia, Niger, Botswana, Gambia, Zambia, Zimbabwe, Sudan, Swaziland, the Democratic Republic of Congo, Ethiopia, Kenya, Tanzania (including Zanzibar), Angola and Uganda. Marula is also present in Madagascar (possibly introduced) and has been introduced into Mauritius and Reunion. It has been grown as an experimental crop in Israel and has been introduced into Australia and India (Directorate Plant Production, 2010; Mng'omba et al., 2012; Neya, 2006).

It is a single stemmed tree with a wide spreading crown characterised by a grey mottled bark. The fruits are used to

Fig. 1 – Marula seeds (left) and Blue gum tree wood (right) used for torrefaction studies.