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# Torrefaction of landfill food waste for possible application in biomass co-firing

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## ABSTRACT

Greenhouse gas emissions and municipal solid waste management have presented challenges globally. This study aims to produce a high-quality biochar with properties close to bituminous coal from landfill food waste (FW). FW was analyzed by proximate and ultimate analyses to determine its fuel properties and elemental composition before torrefaction. Temperature was varied from 200 to 300 °C at a constant residence time of 40 min and 10 °C/min heating rate. Calorific value, mass yield, energy yield and energy density were computed and used to determine the quality of the resulting biochar. Quality of raw food waste was also determined by elemental analysis. Thermal evolution was then investigated using hyphenated Thermogravimetric Analysis (TGA) and Fourier Transform Infra-Red Spectrometry (FTIR). Torrefaction was done at 225 °C, 275 °C and 300 °C. The calorific value was upgraded from 19.76 MJ/kg for dried raw food waste to 26.15 MJ/kg for torrefied food waste at the appropriate conditions which were 275 °C, 40 min and 10 °C/min. The higher heating value was comparable to that of bituminous coal from Anglo Mafube in South Africa. Elemental analysis of biochar showed an increase in carbon content with temperature due to loss of oxygen containing volatiles. This agreed with TG curves and FTIR spectra which confirmed release of H<sub>2</sub>O, CO and CO<sub>2</sub>. This resulted in a more hydrophobic solid fuel with high energy density. Food waste can therefore be upgraded to a biochar with similar fuel properties as pulverized coal used in coal fired boilers.

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## 1. Introduction

Municipalities across the world are facing waste disposal problems. Annual generation of Municipal solid waste (MSW) is over 2 billion tons (Amoo and Fagbenle, 2013). The amount of MSW generated is expected to keep increasing due to rapid development, industrialization as well as population growth, which is projected to reach 9.5 billion by 2050 (Pham et al., 2015). Sadly, this increase in MSW will not be complemented by an increase in size and number of landfill sites as land is limited. As a result, landfill sites have either reached or are about to reach their capacities. Organic portion of this MSW is problematic in landfills as it contributes to greenhouse gas emissions and health problems (Hartmann and Ahring, 2006). According to the Intergovernmental Panel on Climate Change (IPCC, 2006), food waste forms a greater part of MSW (25–70%) (Wu et al., 2012).

Anaerobic respiration of the FW results in release of CO<sub>2</sub> and high concentrations of methane (40–70%v/v) which are greenhouse gases. Methane is more problematic than CO<sub>2</sub> as its negative effects on global warming are 20–25 times more compared to those of CO<sub>2</sub> (Hartmann and Ahring, 2006).

Waste management needs to be improved in order to solve these waste disposal problems. The ultimate solution is to avoid disposal of food waste at landfill sites.

On the other hand, fossil fuel combustion is increasing carbon dioxide emissions at 2.23% per annum and this trend is ongoing (Wu et al., 2012). South Africa aims to reduce CO<sub>2</sub> emissions by 34% in 2020 and 42% in 2025. This is to be achieved by reducing emissions from coal-fired power plants by 90% (Alton et al., 2014).

It is desirable to reduce the amount of coal combusted by co-firing it with food waste as this diverts FW from landfills whilst producing renewable energy. However, FW as collected from the landfill is heterogeneous, wet, fibrous and bulky. This lowers its heating value and makes it difficult and uneconomic to store and transport. Moreover, mixing it with pulverized coal will lower

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combustion efficiencies, increase toxic gas emission and cause fouling in combustion chambers. Torrefaction can improve FW fuel properties thereby enabling its co-firing with coal. During torrefaction, moisture content is reduced as unbound moisture is eliminated through evaporation with increase in temperature to 200 °C. With an increase in temperature from 210 to 250 °C, light volatiles like CO<sub>2</sub>, CO and H<sub>2</sub>O are emitted (Anca-Couce et al., 2016). These volatiles are emitted due to the degradation of hemicellulose and light aliphatic compounds which are more sensitive to temperature than the other biomass constituents. Heavier volatiles are released during degradation of cellulose, protein and carbohydrate compounds as temperature is increased to 300 °C. These include methane, formic acid, acetic acid and aromatics (Anca-Couce et al., 2016; Chen et al., 2015). The overall effect is reduction of O/C and H/C ratio which in turn results in enhancement of carbon. Carbon enhancement increases heating value and reduces bulk density of biomass. Emission of volatiles causes restructuring of the constituents of biomass making it less fibrous thereby improving its grindability and hydrophobicity (Bilgic et al., 2016).

Different types of biomass have been torrefied with the results showing excellent enhancement of fuel properties especially the heating value and grindability (Wu et al., 2012; Arias et al., 2008; Chen et al., 2013; Ciolkosz and Wallace, 2011; Liu and Han, 2015; Poudel et al., 2015; Van der et al., 2011). Heating value and grindability are the most important properties for co-firing biomass with pulverized coal in coal fired power plants. These properties should be close to those of sub-bituminous and bituminous coal to enable co-firing without jeopardizing power output and costs.

There are few studies on torrefaction of FW for possible application in power generation. Food waste at landfills is either compacted or used to make compost. These two methods of dealing with food waste do not aid in the reduction of greenhouse gas emissions from coal usage. On the other hand, torrefaction studies have mainly focused on use of wood, agricultural residues, sewage sludge and microalgae. This cannot aid in reducing pressure at landfill sites. This study can therefore help reduce carbon emissions whilst reducing pressure at landfill sites. To the authors' knowledge, there is no published literature on torrefaction of South African FW with the aim to co-fire and/or substitute coal in coal fired boilers.

## 2. Materials and methods

### 2.1. Materials

A representative food waste sample was collected from Marie Louis landfill site located on Dobsonville road in Soweto in the west of Johannesburg CBD. This community was chosen because it represents a typical South African municipality with high, medium and low density suburbs as well as informal settlements and hostels. It is serviced by PIKITUP which collects waste from an estimated 112405 service points, 659 illegal dumping sites, 16004 informal settlement units and 5 hostels with an estimated total population of 7604. It collects about 1231.525 tonnes/month of waste. This information was obtained from the depot's fact sheet in consultation with the depot manager.

Food waste was collected during a waste composition study at Marie Louis landfill site. The study was conducted in November 2015 for a period of 5 days. It was done per ASTM D 5231-92-2008. Food waste was separated from the 52 samples of organic waste during the composition study. It was manually mixed and homogenized. A sample was then kept for characterization and the torrefaction study. About 300 g were set aside for moisture content analysis. The rest of the sample was oven dried at 105 °C

for 24 h (Amoo and Fagbenle, 2013). The dry sample was crushed using a cone crusher before it was pulverized. It was then sieved and only particles which passed through 750 µm were collected and sealed in a plastic for further studies (Poudel et al., 2015). This size range was chosen as it ensures a uniform and effective heat transfer during torrefaction, and hence eliminates the effect of particle size. Proximate and ultimate analysis was done and the results presented in Table 1.

Moisture content (MC), Volatile content (VC) and Ash content (AC) were determined using American standards ASTM E1358-97, E872-82 and E1534-93 respectively. Fixed carbon was then calculated from the difference. Elemental composition was determined using a Thermo scientific flash 2000 CHNS-O analyzer fitted with an auto sampler and quartz reactor.

The Higher Heating value of raw and torrefied biomass was measured using an e2k combustion calorimeter. The calorific value was determined per BSI standard EN 14918 using e2k combustion calorimeter, in which 0.50 g of biochar was completely combusted under a pressurized O<sub>2</sub> atmosphere (3000 kPa).

### 2.2. Equipment and procedure

#### 2.2.1. Torrefaction equipment

The torrefaction experiment was carried out in an Elite Lenton (TSH12/38/500.2216E) tube furnace. It consists of a cylindrical cavity surrounded by heating coils that are embedded in a thermally insulating matrix. It uses molybdenum di-silicide heating elements. The furnace was connected to a nitrogen line to flash air and create an inert environment in the tube. Nitrogen flowrate was controlled using a Multi Gas Controller 647C. The experiment setup is shown in Fig. 1.

A Perkin Elmer TG-IR-GCMS Interface TL 9000 thermogravimetric analyzer (TGA) coupled to a Fourier Transform Infrared Spectrometer (FTIR) was used to study the thermal evolution of FW during torrefaction. Volatiles released passed through a heated line at 250 °C to avoid condensation before analysis by the FTIR.

#### 2.2.2. Procedure

A rectangular crucible was filled with approximately 3 g of FW sample measured to the nearest 0.01 g. The sample was carefully put at the centre of the quartz reactor before inserting the reactor in the furnace. Nitrogen flowrate was adjusted to 150 ml/min, heating rate was adjusted to 10 °C/min and temperature was set to 200 °C for the first run. Torrefaction temperature was varied from 200 °C to 300 °C in 25 °C increments keeping heating rate at 10 °C/min and residence time at 40 min. The residence time and heating rate were chosen after studies on influence of residence time and heating rate were conducted and appropriate conditions obtained. These results were reported elsewhere. The torrefied product was allowed to cool to room temperature in a nitrogen

**Table 1**  
Properties of raw food waste.

Food waste (Current work)		Food waste (Poudel et al., 2015)
Moisture (%. wet)	62.15	79.00
Ash (%. db.)	5.41	2.30
Volatile (%. wet)	15.30	18.70
Fixed carbon (%)	17.14	
Calorific value (MJ/kg)	19.76	19.52
Element	%	
C	45.32	47.57
H	6.22	6.76
N	2.00	2.61
S	0.00	0.01
O	46.47	36.19

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