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Physicochemical, structural and combustion characterization of food waste hydrochar obtained by hydrothermal carbonization

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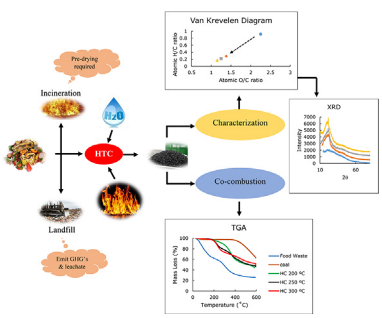
GRAPHICAL ABSTRACT



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ABSTRACT

A solid carbon-rich product hydrochar, was prepared using hydrothermal carbonisation of food waste at temperatures of 200, 250 and 300 °C. To acquire detailed insight into physicochemical and structural properties, hydrochar samples were characterised using a range of techniques. The carbon content and higher heating value of food waste increased considerably from 39 to 73% and 15 to 31 MJ/kg corresponding to the heating temperature. The blends of hydrochar and coal prepared in three different ratios (5%, 10% and 15%) exhibited different thermal behaviour. The overall results of co-combustion study showed that the activation energy of hydrochar samples decreased from 56.78 KJ/mol to 29.80 KJ/mol with increase in temperature. Hydrochar prepared at 300 °C with coal blending ratio of 10% exhibited the lowest activation energy of 19.45 KJ/mol. Additionally thermal gravimetric analysis of the samples showed that high temperature carbonization can increase the combustion properties of hydrochar.

1. Introduction

As the world energy crisis looms, alternative sustainable green energy option has been the main focus in many parts of the world. The burgeoning world population coupled with shortage of fossil fuel based energy could result in catastrophic situation with shortage of energy required in diverse sectors in the future. This high requirement of energy has forced researchers to seek other means of producing energy from renewable sources to fulfil energy demand (Mafakheri & Nasiri, 2014).

Biomass is the leading source of energy in rural areas for many centuries (Liu & Balasubramanian, 2012). Biomass provides about 10–14% of total energy consumption of the world while coal, gas and electricity provide 12–14%, 14–15% and 14–15% respectively (Saqib et al., 2015). All non-fossil biological materials are the source of bioenergy. As a matter of fact, bioenergy has the ability to solve the global

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energy crisis. The increase in production of renewable energy must not result in the increase of carbon dioxide CO_2 emission. Hence, renewable and natural forms of energy should be preferred over the traditional fossil fuel sources which have been declining rapidly.

The production of high carbon material from renewable resources has great potential for research in diverse sectors including application in large range of technologically key applications, including energy production (White et al., 2009). However, the main disadvantages of using such materials for energy production are their high production cost, use of expensive metal catalysts, fossil-based precursors and with high-temperature processing units. Besides these drawback, high carbon material obtained from biomass are likely to play the main role in the production of biofuels (Lehmann, 2007).

Recently it has been widely accepted that food waste is an untapped resource having a great potential for energy generation. This accomplishment has motivated the basic research on technologies associated with recovery of valuable fuels from food waste, in order to reduce depletion of natural resources, environmental burden on its disposal, and minimize its risk to human health (Pham et al., 2015).

Food waste is a type of organic waste that is produced from different sources like household, restaurants and processing plants, contributing a large section of municipal solid waste (Kiran et al., 2014). Worldwide, the amount of food waste generated is increasing at a steady rate. According to Food and Agricultural Organization (FAO) about 1.3 billion tonnes of edible food per year are wasted (Ross et al., 2012). Food waste requires proper management in order to reduce risk to human health and environment (Kim et al., 2011). Food waste contains high moisture content and decomposes very easily (Zhang & Jahng, 2012).

Various researchers have used hydrothermal carbonization (HTC) method for conversion of food waste like dog food, orange and olive waste, fish meat and restaurant leftover into value added products (Hwang et al., 2012; Kang et al., 2001; Kaushik et al., 2014; Pellera et al., 2012). Hydrothermal carbonisation is a favourable chemical process that transforms lignocellulosic biomass into an value-added products such as hydrochar (solid product), bio-oil and gases (Libra et al., 2011). However, the properties and distribution of these products are greatly dependent on the HTC reaction conditions. Unlike incineration, HTC can be used to process wet feedstock, as the dehydration process takes place in the presence of water (Funke & Ziegler, 2010). Moreover, hydrochar is easily filterable from the reaction solution and hence, no further drying is required. HTC is a suitable method to convert food waste into useful products as compared to other thermal theologies which required pre-thermal drying.

Though there have been a few studies on HTC and associated solid products, the detailed chemistry behind the conversion of biomass into high carbon products during HTC is still yet to be understood. Therefore, it is important to understand the different reaction mechanism of HTC by analysing the chemical properties of the solid char. Hwang et al. (2012) conducted hydrothermal carbonisation of dog food to recover solid fuel from waste and reported the carbon content of hydrochar obtained being more than 75%. Orange waste and olive pomace were used as feedstock to prepare an adsorbent using HTC and pyrolysis. The olive pomace based adsorbent prepared by pyrolysis showed higher adsorption capacity, while orange waste based adsorbents prepared by pyrolysis and HTC processes showed similar adsorption capacity (Pellera et al., 2012). According to Parshetti et al. (2014) food waste can be converted into hydrochar which can act as an important adsorbent for different pollutants. In another study, restaurant leftover food was hydrolysed enzymatically before HTC (Kaushik et al., 2014). The hydrochar produced via enzymatic pre-treatment showed calorific and carbon content values ranged from 17.4 to 26.9 MJ/kg and 43.7% to 65.4%, respectively. While hydrochar with no pre-treatment displayed calorific and carbon content values of 15.0–21.7 MJ/kg and 38.2% to 53.5%, respectively. The overall results shows that enzymatic pre-treatment of food waste before HTC can improve the quality of hydrochar and bio-oil.

Many researchers have investigated co-combustion of coal with different biomasses like textile dyeing sludge and sugarcane bagasse, sewage sludge, corn stalk and pine sawdust, pine wood and bamboo (Huang et al., 2018; Liang et al., 2017; Ullah et al., 2017; Xie et al., 2018; Zhou et al., 2016). Others have studied only on specific materials like paper and wheat straw (Vamvuka et al., 2009; Wang et al., 2009). However, to the best of our knowledge, there has been no systematic investigation on the co-combustion of hydrothermally converted food waste with coal. Hence, the objectives of this work are (1) to convert food waste into hydrochar by HTC process and (2) to evaluate the physiochemical, structural and combustion properties of food waste hydrochar for its energy generation via co-combustion with coal.

2. Materials and methods

2.1. Feedstock

In this study, all food products were purchased from the local grocery store and a standard food waste was prepared. Given food waste composition varies from place to place therefore, a standard food waste recipe was prepared in order to keep composition constant. Different kinds of food waste used in this study are summarized in Table 1. All the components of food waste were weighted in an equal proportion and were homogenously mixed with a food grade blender as previously done by Komilis and Ham (2006). Food waste was stored in a sealed container at 4 °C before the HTC. For the co-combustion study, low-rank coal of sub-bituminous rank was obtained from the Solid Energy New Zealand.

2.2. Hydrothermal carbonisation

Hydrothermal carbonization of food waste was carried out in a 1L high-pressure batch reactor (Amar Equipment Pvt Ltd, India) at different temperatures (200 °C, 250 °C and 300 °C) with a constant reaction time of 1 h. In a single run, 100 g of food waste was dispersed in 300 mL of de-ionized water. The reactor was pressurised to 30 bar using N_2 gas and was stirred at 600 rpm. The reactor was sealed and heated to the desired temperature followed by cooling for quenching the reaction. The reactor was then opened at room temperature (23 ± 2°) and the solid (hydrochar) and liquid (water and bio-oil) products were carefully separated by means of filtration. The hydrochar was washed with deionised water to remove impurities, dried in an oven at 105 °C for 2 h, weighed and stored in a sealed container until further analysis.

2.3. Characterisation of hydrochar

The moisture content, volatile matter and ash contents of food waste and hydrochars were measured using ASTM D1762-84 standard methods. The elementary analyses of organic elements present in food waste and hydrochars were determined using an elemental analyser (Thermo Flash 2000). Briefly the samples were placed in a tin capsule which were dropped in a quartz tube containing tungsten oxide and copper as a catalyst heated at 1020 °C. The helium as carrier gas was enriched with pure oxygen temporarily as the samples were dropped into the tube.

The energy density, yield and higher heating value (HHV) were

Table 1
Different types of food waste used in this study.

S. No	Vegetables	Fruits	Meat	Staple food
1	Onion skin	Banana	Chicken	Rice
2	Potato peel	Orange	Fish	Potato
3	Carrot peel	Apple	Beef	Bread
4	Tomato	Lemon	Pork	Pasta
5	Cabbage	Banana	Lamb	Noodle