



## A study on torrefaction of food waste



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### HIGHLIGHTS

- Food waste undergoing torrefaction was investigated.
- Gaseous composition of the product gas from torrefaction was studied.
- The torrefaction range for the food waste was defined considering product gas analysis, the energy yield, and the HHV.
- Food waste showed energy yield values above 80% for torrefaction range, i.e. between 290 and 330 °C.

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### ABSTRACT

Torrefaction of biomass under anoxic condition can produce an energy dense and consistent quality solid biomass fuel for combustion and co-firing applications. This paper investigates the fuel characteristics of food waste at torrefaction temperatures ranging from 150 to 600 °C, for torrefaction residence time varying from 0 to 50 min in a horizontal tubular reactor. The torrefied products were characterized in terms of their elemental composition, energy yield, ash content and volatile fraction. The gaseous products from torrefaction of food waste were also analyzed. Thermogravimetric analysis was carried out in order to obtain the kinetic parameters for the torrefaction reaction of food waste. It was found that the food waste undergoes changes in their physical and chemical properties during torrefaction. The energy and mass yield were also found to decrease with an increase in the torrefaction temperature, whereas the higher heating value increased.

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### 1. Introduction

The world is currently challenged to reduce dependence on fossil fuels and achieve a sustainable, renewable energy supply. Biomass is an important energy source to create a more sustainable society. Biomass is a primary type of renewable energy which is expected to be an important energy source in the coming years. Of the different non-conventional energy sources available (e.g., wind, solar, tidal, and nuclear), biomass is widely available and is considered to be carbon neutral, in that the net carbon emissions resulting from the burning of biomass are zero.

Raw biomass is generally characterized by its high moisture content and volatility, and by its lower higher heating value (HHV) and energy density levels compared to fossil fuels [1]. Biomass has some disadvantages when used as fuel, such as its low HHV, high moisture content, hygroscopic nature, smoke emission during combustion, its heterogeneous and uneven composition, and transport

difficulties [2]. In order to address the above problems, biomass needs to be pretreated to improve its quality for efficient energy conversion. Existing technologies to improve biomass for energy include thermochemical and biochemical processes [3]. Biomass can be exploited to produce energy by different technologies: thermochemical (combustion, gasification), biological (anaerobic digestion, fermentation) or chemical processes (esterification) [2,4]. Recently, the treatment of biomass at low temperatures ranging from 200 °C to 300 °C under an inert atmosphere was found to be effective for improving the energy density and shelf life of the biomass [2,5–7]. This treatment is referred to as ‘torrefaction’, and it has been widely applied to wood and grass biomass over the past few years. The main improvements of torrefied biomass include reduced moisture and an increased energy density; a reduced oxygen-to-carbon (O/C) ratio, which increases the HHV; the strong fibers of the biomass becoming brittle, which improves grindability by reducing the cost and energy required for grinding; and the ignitability and reactivity is improved, which enhances the efficiency during gasification or pyrolysis [5–10]. Torrefaction can be incorporated into a combined drying, torrefaction, and pelletization

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process, with both economic and energy efficiency benefits [11]. However, this process requires a separate plant, the input of the process energy, and the production of gaseous and volatile streams, entailing capital costs, operating costs, and emission control efforts. A balance between these associated costs for fuels which are more grindable and have higher HHV is therefore critical for the future of torrefaction and requires thorough analysis and extensive, reliable data [10].

The food waste (FW) represents a significant and largely under-utilized fraction of municipal solid waste (MSW) in South Korea. It is the main cause of smell and nuisance in MSW and is responsible for most environmental hazards associated with municipal waste management, such as the formation of polluting leachate and methane gas under anaerobic conditions. In light of rapidly rising costs associated with energy supply and waste disposal and increasing public concerns with environmental quality degradation, conversion of FW to energy is becoming a more economically viable practice [12]. Surprisingly little discussion has been devoted to the issue of FW as a solid fuel. Diverted food wastes are primarily treated/managed using biological approaches, including composting and anaerobic digestion. These techniques result in reductions in fugitive greenhouse gas emissions when compared to landfilling and lead to the generation of valuable resources (e.g., fertilizer, methane gas). However, these techniques also impart several operational challenges. Mixed wastes present a critical issue with these techniques.

In this research, torrefaction of readily available cheap feedstock; FW, was carried out in a horizontal tubular reactor in the presence of nitrogen gas. State-of-the-art shows that no data has been published regarding the torrefaction of FW. Most information regarding the torrefaction of FW remains to be studied. Very little research has been done to investigate the possibility of using complex biomass like FW in terms of energy. Dhungana et al. [13] conducted a study regarding the torrefaction of complex non-lignocellulosic biomass. But, no particular study was observed so far which considered the heat treatment experiment of FW. Most information regarding the torrefaction of FW remains to be studied. To provide a deep insight into the technique of torrefaction, this study is intended to investigate the effect of torrefaction temperature and residence time upon the properties of FW as a solid fuel.

## 2. Experimental

### 2.1. Materials

FW sample used in this study was collected from the university cafeteria in South Korea which comprised of a mixed composition of vegetables, grains, and meats. The raw waste was screened to remove coarse contaminants. After collection, each sample was homogeneously mixed and dried at 105 °C for 24 h. Table 1 shows the properties of the raw food sample used in this study. The moisture content of the raw food sample was 79%, with 2.3% ash content. The final moisture content of the FW was 0% which was used for the torrefaction process. The HHV of the dried sample was determined to be 19.52 MJ/kg. Most of the “Others” components in Table 1 are inorganic materials.

### 2.2. Experimental device and procedure

The dried sample was ground for a homogeneous experimental condition. Each experiment was carried out with 20 g of sample at atmospheric pressure. In this study, a horizontal tubular reactor with an internal diameter of 150 mm and a length of 600 mm was used for torrefaction, as schematically shown in Fig. 1. A prescribed amount of each sample was weighed and put in a crucible.

**Table 1**  
The properties of the FW sample used in this study.

Elements (wt.%, dry)	C	47.57
	H	6.76
	N	2.61
	O	36.19
	S	0.01
	Cl	0.88
	Others	5.98
Moisture (% wet)		79.0
Volatile fraction (% wet)		18.7
Ash (% wet)		2.3
HHV (MJ/kg, dry)		19.52

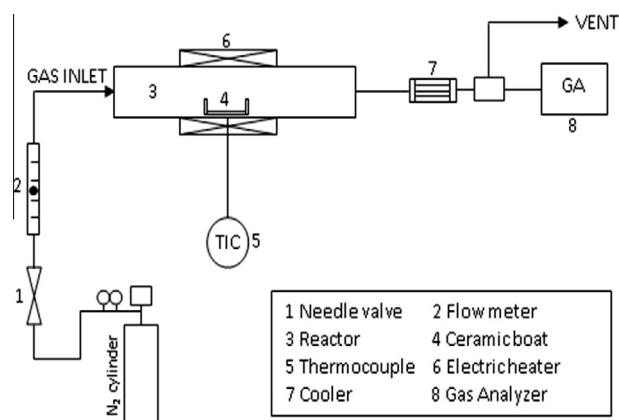
After flushing the reactor with nitrogen (2 l/min), the temperature of the reactor was raised to different desired temperatures ranging from 150–600 °C at a constant heating rate of 10 °C/min using an electric heater. When the reaction temperature and torrefaction residence time reached the required experimental condition, the heating reactor was immediately stopped and the carrier gas was shut down. The torrefied sample was then instantly removed and was weighed. The product gas during the overall process was measured using a gas analyzer (Greenline MK2, Eurotron Instruments, Chemsford, UK).

For each experiment, the moisture content, HHV, volatile fraction, and ash content were measured. The HHV was measured using a bomb calorimeter (Parr Instrument Co., Model 1672, Moline, IL, USA). For the ash content, a prescribed amount of the sample was weighed in a crucible and calcined in an electric furnace at 600 °C for 3 h, after which the final weight was measured. Elemental analyses of the feedstock and torrefied sample were done by an elemental analyzer (Thermo Fisher Scientific Inc., Thermo FLASH 2000, Hudson, NH, USA). The mass and energy yields are defined by Eqs. (1) and (2), as used by Bridgeman et al. [10].

$$\text{Mass yield } (Y_{\text{mass}}) = \frac{\text{mass after torrefaction}}{\text{mass of raw sample}} \times 100\% \quad (1)$$

$$\text{Energy yield } (Y_{\text{energy}}) = Y_{\text{mass}} \times \frac{\text{HHV (torrefied sample)}}{\text{HHV (raw sample)}} \times 100\% \quad (2)$$

To obtain the kinetic parameters of torrefaction reaction, a thermogravimetric analysis (TGA) of the FW was also conducted using a thermogravimetric analyzer (TA Instruments, Q50, New Castle, DE, USA). The sample was studied at various heating rates ranging from 10 to 30 °C/min and at temperatures ranging from ambient to



**Fig. 1.** Schematic diagram of the horizontal tubular reactor used in this study.

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