International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 37664-37667

A Study on Combustion of Torrefied Food Waste Pellets

J. Poudel
Department of Mechanical Engineering, Kongju National University, 1223-24 Cheonan-Daero,
Seobuk Chungnam, 330-717, Republic of Korea, jeeban1985@gmail.com

S.C. Oh
Department of Environmental Engineering, Kongju National University, 1223-24 Cheonan-Daero,
Seobuk Chungnam, 330-717, Republic of Korea, ohsec@kongju.ac.kr

Abstract

In this study, the combustion of torrefied food waste pellet was investigated in a horizontal tubular reactor. The pelletization and the combustion characteristics of the torrefied food waste was studied under air flow in isothermal (850 °C) and non-isothermal (room temperature to 850 °C) conditions. The torrefied food waste was characterized in terms of their higher heating value, energy yield, mass yield, ash content and volatile fraction. The combustion product of the torrefied food waste pellet was characterized in terms of emitted gases.

Keywords: Food waste, torrefaction, combustion, pelletization, higher heating value

Introduction

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]. 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, 4-6]. 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; 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[4-9]. Large potentials of biomass residues and wastes are still available and enable a relevant increase of sustainable bio energy utilization in the future. Combustion is the most important and mature technology available nowadays for biomass utilization. Improvements with respect to efficiency, emissions, and cost are needed for further exploitation. Beside this, alternatives such as gasification also need to be considered and also combinations of different processes are of interest such as gasification as fuel pretreatment for co-combustion.

The food waste (FW) represents a significant and largely underutilized 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[10]. Surprisingly little discussion has been devoted to the issue of FW as a solid fuel. In this research, combustion of readily available cheap feedstock; FW, was carried out in a horizontal tubular reactor after torrefaction and pelletization. State-of-the-art shows that no data has been published regarding the combustion of torrefied FW. Most information regarding the combustion of torrefied 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. To provide a deep insight into the technique of torrefaction and combustion, this study is intended to investigate the effect of torrefaction on the product gas of torrefied product combustion.

Experimental

i. 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 hours. Table 1 shows the properties of the FW samples 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.

ii. Experimental device and procedure

The dried sample was ground for a homogeneous experimental condition. Each torrefaction experiment was carried out with 20 g of sample at atmospheric pressure. The combustion experiment was carried out with 3 g sample with air flow rate of 20 liters/min. The torrefaction sample for combustion experiment was selected from the optimum torrefaction range as defined by Jeeban *et. al.*[11]. The combustion temperature was 850 °C with a heating rate of 30 °C/min. In this study, a horizontal tubular reactor with an internal diameter of 150 mm and a length of 600 mm was used for torrefaction and combustion, as schematically shown in Fig. 1. A prescribed amount of each sample was weighed and put in a crucible. When the reaction temperature reached the required experimental condition, the heating reactor was immediately stopped and the carrier gas was shut down. The product gas during the overall process was measured using a gas analyzer (Greenline MK2, Eurotron Instruments, Chemsford, UK).

For each torrefaction experiment, HHV, volatile fraction, and ash content were measured. The HHV was measured using a bomb calorimeter (Parr Instrument Co., Model 1672, Moline, IL, USA). The mass and energy yields are defined by Eqs. (1) and (2), as used by Bridgeman *et. al.*[9].

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

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

TABLE. 1. The properties of the FW sample used in this study for torrefaction

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

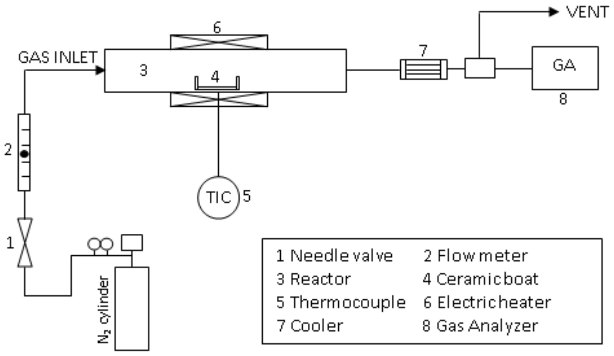


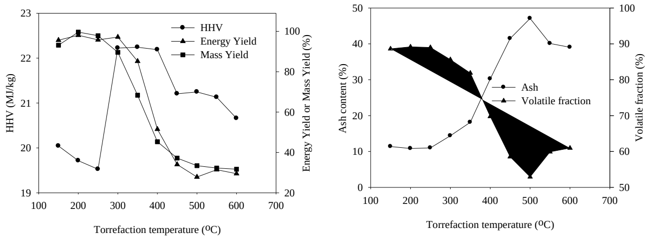
Fig. 1. Schematic diagram of the horizontal tubular reactor used in this study.

Results and Discussion

i. Energy yield, Mass yield, HHV, volatile fraction, and ash content

The torrefaction of biomass is usually performed at temperature of around 300 °C, and the thermal treatment at higher temperature is referred to as pyrolysis. The relationship between HHV, the energy yield and the mass yield with respect to the torrefaction temperature is shown in Fig. 2 (a). The HHV of the sample shows a trend to decrease till 250 °C. This decrease of HHV, although undesirable is less compared to the overall heating value. The HHV increased to 22.25 MJ/Kg on increasing the torrefaction temperature to 300 °C which remains constant till 400 °C. The sharp increase shows the inception of the torrefaction within this region. A further increase in the torrefaction temperature resulted in a decrease of the HHV. This is actually due to the pyrolysis reaction that occurred at a higher temperature.

The energy yield is a useful measure during this process. Here, the energy yield decreased steadily from 95 to 25% with an increase in the torrefaction temperature. The energy yield in the torrefaction range corresponds to the mass yield. The mass yield of the torrefied products at a temperature up to 300 °C showed a decrease in mass nearly identical to that of the raw material. This indicates that the extent of torrefaction for the FW up to 300 °C was negligible compared to these values at higher temperatures. There are two main causes in the decrease of mass of torrefied products. One is moisture loss, with the other being thermal decomposition to form volatile gaseous products such as H_2O, CO, CO_2, acetic acid and other organics[12]. The decrease in mass during torrefaction at a lower temperature torrefaction is thought to be mainly caused by the loss of moisture. The variations in the volatile fractions and ash contents are shown in Fig. 2(b). The volatile fraction content gradually decreased while the ash content increased with the torrefaction temperature.



(a) (b)

Fig. 2. (a) The HHV, energy yield, mass yield, and (b) ash and volatile fraction contents of torrefied FW as a function of the torrefaction temperature.

ii. Combustion of FW pellets

The sample for torrefaction was selected from the optimum torrefaction range of torrefaction temperature between 290 and 330 °C as obtained from Fig. 2(a). The sample was then well grinded and then converted into pellets.

The combustion of the torrefied FW pellets was conducted in isothermal and non-isothermal conditions. Fig. 3 shows the characteristics of gas emission during non-isothermal combustion of torrefied FW pellets. The combustion experiment was carried out from room temperature to 850 oC. Fig. 3 (a), (b), (c) and (d) show the emission of CO, NOx, C_xH_y and CO_2, respectively. The emission of CO and NOx started at around 500 seconds (310 °C) while the emission of CO_2 incepted at a little higher combustion time of around 620 seconds (370 °C). However, the hydrocarbon is emitted at higher temperature of 450 °C at 770 seconds. This finding was attributed to the fact that compounds with oxygen are emitted at temperatures lower than those for hydrocarbon gases for non-isothermal combustion.

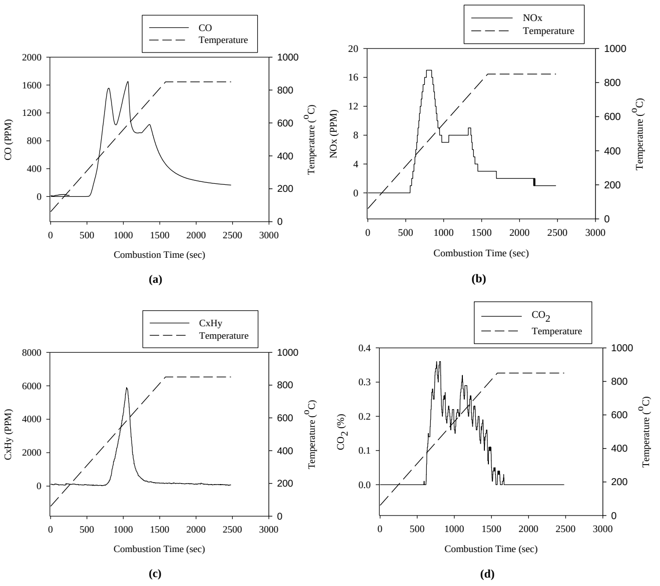


Fig. 3. Characteristics of the gas emission during non-isothermal combustion of FW up to 850 °C from room temperature.

Fig. 4 shows the characteristics of the gas emission during isothermal combustion of the torrefied FW pellets. The isothermal temperature was fixed at 850 °C. Fig. 3 shows the emission characteristics of CO, NOx, hydrocarbon and CO_2. The complete combustion of the torrefied FW pellet takes almost 250 seconds for the complete combustion. The inception of the emission of all the gases begins quickly below 50 seconds and completes at around 250 seconds. However there is no emission of the hydrocarbons at this isothermal combustion for 250 seconds. This finding was attributed to the fact that hydrocarbon gases for isothermal conditions are not emitted even when the emission of compounds with oxygen is completed.

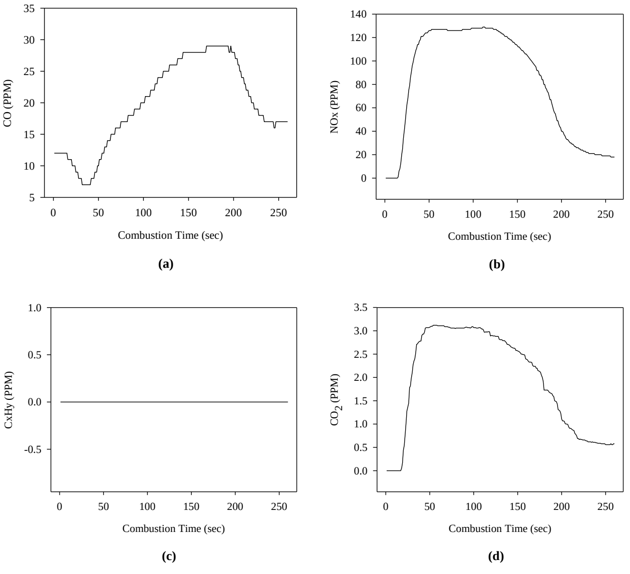


Fig. 4. Characteristics of the gas emission during isothermal combustion of FW at 850 °C

Conclusion

The combustion of torrefied FW pellets was studied to investigate the effects of the isothermal and non-isothermal combustion conditions on the characteristics of the emitted gases. The HHV increased to 22.25 MJ/Kg on increasing the torrefaction temperature to 300 °C which remains constant till 400 °C. The sharp increase shows the inception of the torrefaction within this region. A further increase in the torrefaction temperature resulted in a decrease of the HHV. The emission of CO and NOx started at around 500 seconds (310 °C) while the emission of CO_2 incepted at a little higher combustion time of around 620 seconds (370 °C). However, the hydrocarbon is emitted at higher temperature of 450 °C at 770 seconds. This finding was attributed to the fact that compounds with oxygen are emitted at temperatures lower than those for hydrocarbon gases for non-isothermal combustion. However for isothermal combustion of the torrefied FW pellets, the complete combustion of the torrefied FW pellet takes almost 250 seconds for the complete combustion. The inception of the emission of all the gases except hydrocarbon gases begins quickly below 50 seconds and completes at around 250 seconds. However there is no emission of the hydrocarbons at this isothermal combustion range. This finding was attributed to the fact that hydrocarbon gases for isothermal conditions are not emitted even when the emission of compounds with oxygen is completed.

Acknowledgment

This subject is supported by Korea Ministry of Environment (MOE) as “Waste-to-Energy Technology Development Project”.

References

[1] Werther, J., Saenger, M., Hartge, E., Ogada, T., Siagi, Z., 2000, “Combustion of agricultural residues” Prog Energy Combust Sci., 26 (1) pp.1-27.

[2] Uemura, Y., Omar, W. N., Tsutsui, T., Yusup, S. B., 2011, "Torrefaction of oil palm wastes” Fuel., 90 (8) pp.2585-2591.

[3] Goyal, H., Seal, D., Saxena, R., 2008, “Bio-fuels from thermochemical conversion of renewable resources: a review” Renew Sustain Energy Rev., 12(2) pp. 504-17.

[4] Couhert, C., Salvador, S., Commandre, J., 2009, “Impact of torrefaction on syngas production from wood” Fuel., 88(11) pp. 2286-90.

[5] Arias, B., Pevida, C., Fermoso, J., Plaza, M., Rubiera, F., Pis, J., 2008, "Influence of torrefaction on the grindability and reactivity of woody biomass” Fuel Process Technol., 89 (2) pp. 169-175.

[6] Deng, J., Wang, G., Kuang, J., Zhang, Y., Luo, Y., 2009, “Pretreatment of agricultural residues for co-gasification via torrefaction” J Anal Appl Pyrol., 86(2) pp. 331-7.

[7] Li, H., Liu, X., Legros, R., Bi, X. T., Lim, C., Sokhansanj, S., “Torrefaction of sawdust in a

fluidized bed reactor" Bioresour Technol., 103(1) pp.453-8.

[8] Chen, W., Kuo, P., 2010, "A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by a thermogravimetry" Energy., 35(6) pp. 2580-6.

[9] Bridgeman, T., Jones, J., Shield, I., Williams, P., 2008, "Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties" Fuel., 87 (6) pp. 844-856.

[10] Zhang, R., El-Mashad, H. M., Hartman, K. Wang, F., Liu, G., Choate, C., Gamble, P., 2007, "Characterization of food waste as feedstock for anaerobic digestion" Bioresour Technol., 98(4) pp.929-35.

[11] Jeeban, P., Tae-In, O., Sea C. O., 2015, "A study on torrefaction of food waste" Fuel 140(1) pp. 275-81.

[12] Sadaka, S., Sharara, M. A., Ashworth, A., Keyser, P., Allen, F., Wright, A., 2014, "Characterization of Biochar from Switchgrass Carbonization" Energies., 7(2) pp. 548-67.