

## A Study on Combustion of Torrefied Corn Stalk Pellets

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### Abstract

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

**Keywords:** Corn stalk, torrefaction, combustion, pelletization, higher heating value

### Introduction

Owing to the increasing impact of traditional energy usage on global climate patterns and the environment, stakeholders are turning their attention to renewable energy sources. 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]. 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.

A considerable amount of corn stalk waste is produced annually, as corn is one of the most common staple crops worldwide [10]. Surprisingly little discussion has been devoted to the issue of corn stalk as a solid fuel. In this research, combustion of readily available cheap feedstock; corn stalk, 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 corn stalk. Most information regarding the combustion of torrefied corn stalk remains to be studied. Very little research has been done to investigate the possibility of using complex biomass like corn stalk 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

Corn stalk sample used in this study was collected after harvesting from a farm located in Cheonan, South Korea. 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 corn stalk samples used in this study. The moisture content of the raw corn stalk sample was 13.2%, with 2.1% ash content. The final moisture content of the corn stalk was 0% which was used for the torrefaction process. The HHV of the dried sample was determined to be 18.49 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].

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

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

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

Elements (wt%, dry)	C	44.79
	H	5.48
	N	0.34
	O	44.3
	S	0.04
	Cl	0.06
	Others	4.99
Moisture (% , wet)		13.2
Volatile fraction (% , wet)		84.7
Ash (% , wet)		2.1
HHV (MJ/kg, dry)		18.49

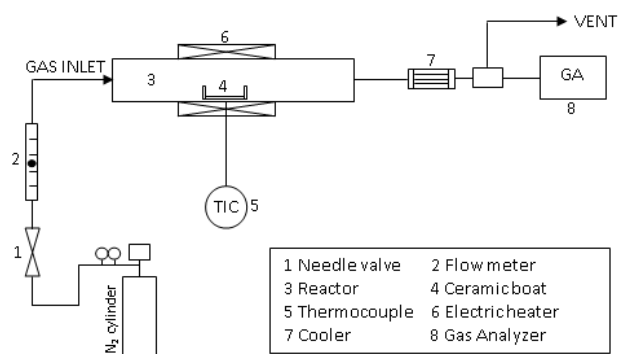


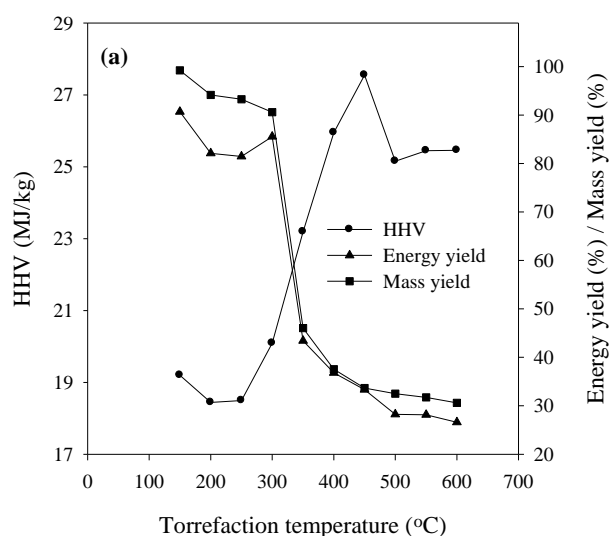
Fig. 1. Schematic diagram of the horizontal tubular reactor used in this study.

## 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 all samples increased with the torrefaction temperature. The increase in the HHV up to 450 °C is due to the removal of oxygen and hydrogen. A further increase in the 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 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 corn stalk 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<sub>2</sub>O, CO, CO<sub>2</sub>, 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.



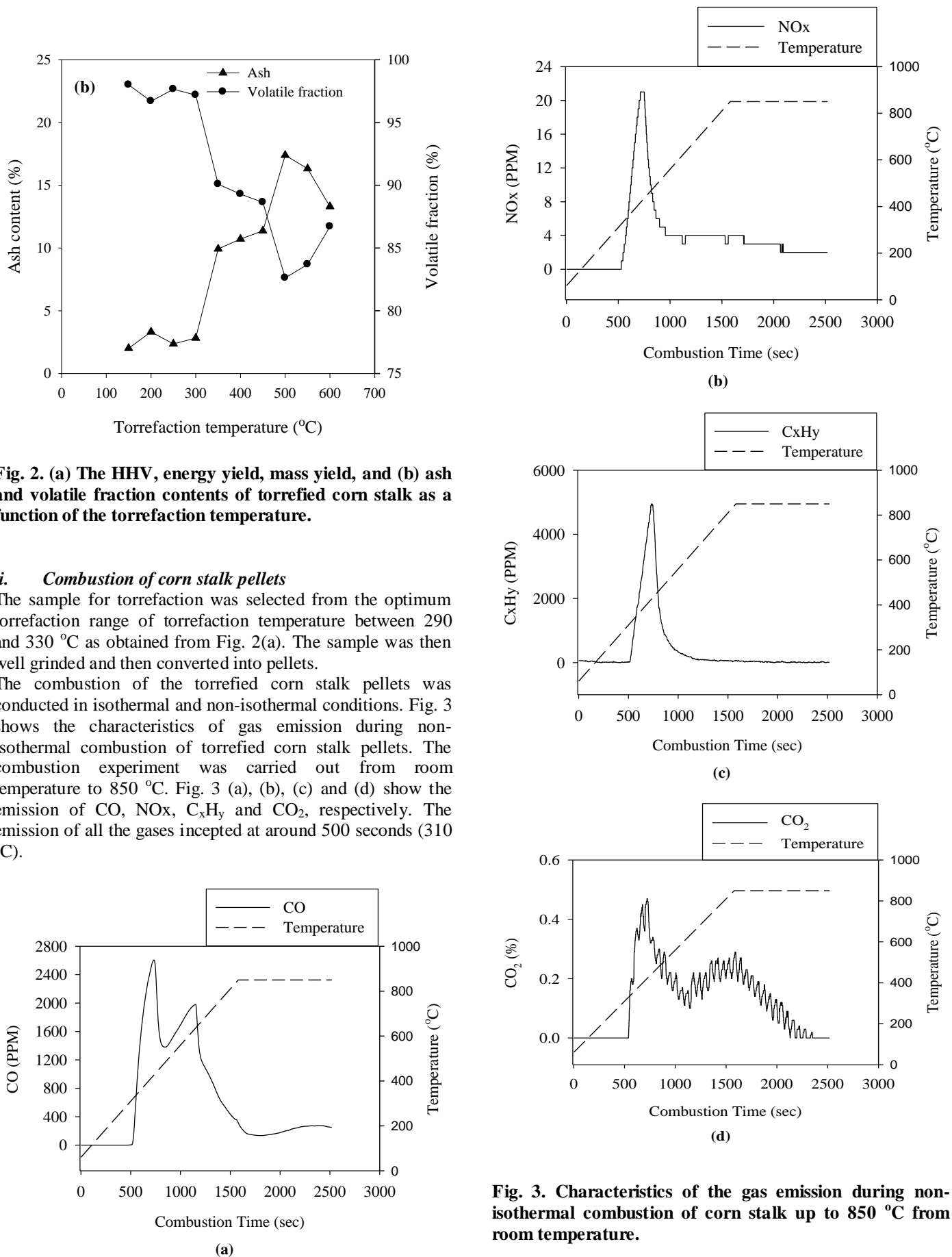
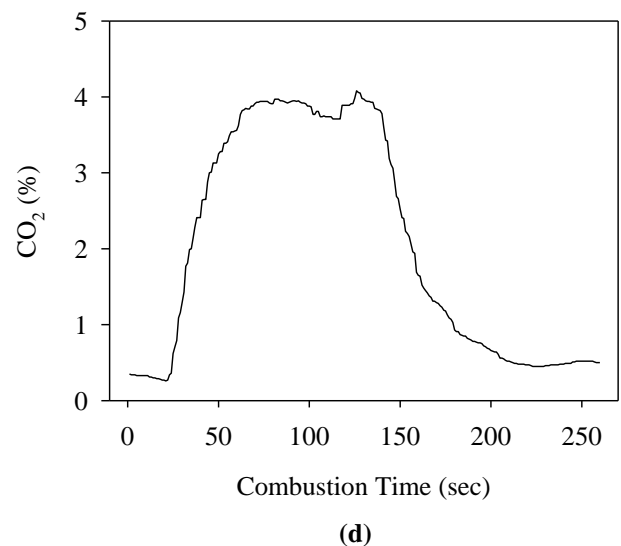
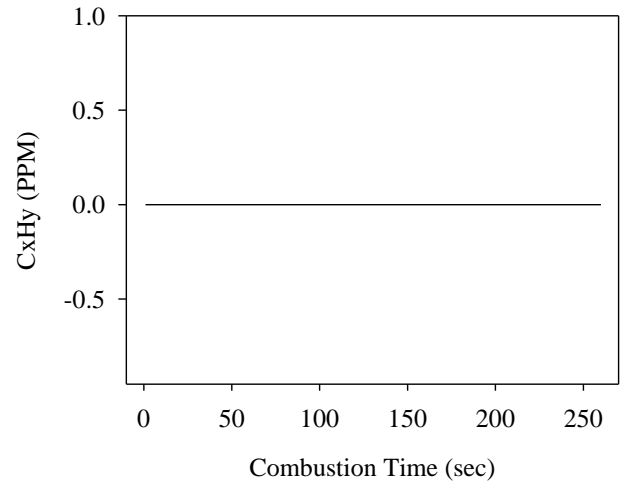
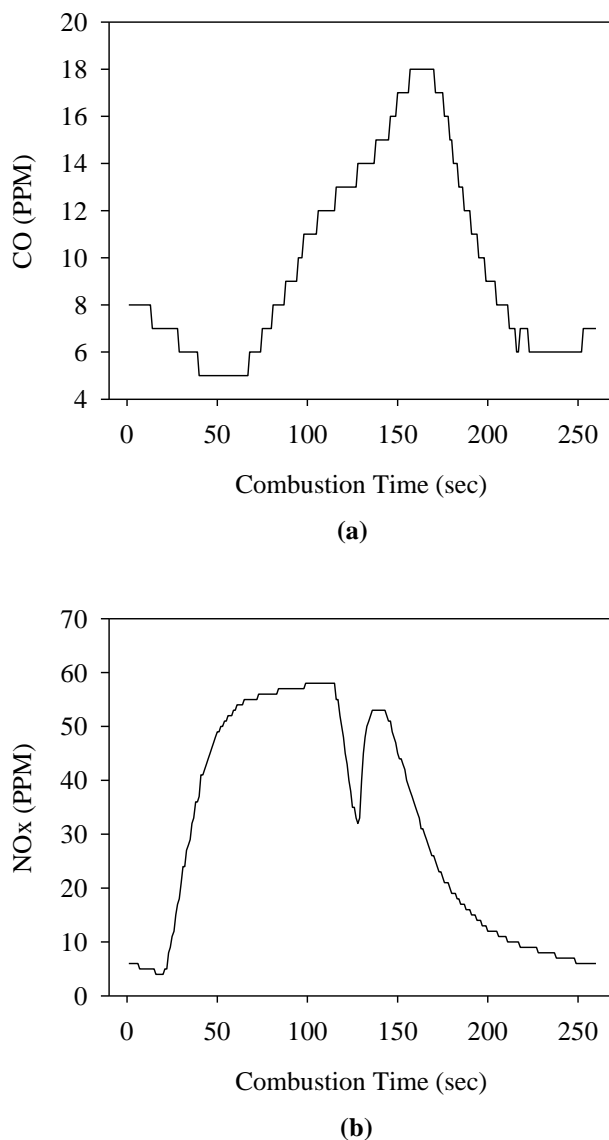


Fig. 4 shows the characteristics of the gas emission during isothermal combustion of the torrefied corn stalk pellets. The isothermal temperature was fixed at 850 °C. Fig. 3 shows the emission characteristics of CO, NO<sub>x</sub>, hydrocarbon and CO<sub>2</sub>. The complete combustion of the torrefied corn stalk pellet takes almost 250 seconds. 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 corn stalk at 850 °C**

### Conclusion

The combustion of torrefied corn stalk 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 28 MJ/Kg on increasing the torrefaction temperature to 450 °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 all the gases for non-isothermal combustion inceptioned at a combustion time of around 500 seconds (310 °C). However for isothermal combustion of the torrefied corn stalk pellets, the complete combustion of the torrefied corn stalk 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. 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

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