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A Study on Combustion of Torrefied Sewage Sludge

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Abstract

Torrefaction is a treatment which serves to improve the properties of biomass in relation to thermochemical processing techniques for energy generation. In this study, the torrefaction of sewage sludge, which is a non-lignocellulosic waste was investigated in a horizontal tubular reactor under nitrogen flow at temperature ranging from 150-600°C. The torrefied sewage sludge products were characterized in terms of their energy yield, ash content and volatile fraction. The energy and mass yields decreased with an increase in the torrefaction temperature. The pelletization and the combustion characteristics of the torrefied sewage sludge was studied in isothermal and non-isothermal conditions.

Keywords Sewage Sludge, Torrefaction, Energy yield, Mass yield, pelletization, combustion

Introduction

The global problems associated with the intensive use of fossil fuels have increased interest in the use of renewable fuels worldwide where biomass is widely available at low cost. However, a pre-treatment process is required to convert biomass into a hydrophobic solid product with an increased energy density[1].The treatment of biomass at lower temperatures ranging from 200-300 °C under an inert atmosphere was known to be effective for improving the energy density and shelf life of the biomass[2-4]. 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, 6].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.

One of the materials which can be converted into fuel is sewage sludge (SS)[7]. SS is a waste generated from wastewater treatment plants. Municipal wastewater treatment can be considered as a continuous activity also in the future. It is organizationally, technically, and economically hardly possible to prevent or strongly reduce the amount of municipal wastewater. This means that the produced amount of sewage sludge will not change significantly in the future [8].In its dry form, SS could be considered a special type of renewable fuel, due to the high quantity of organics of sufficiently high calorific value, similar to that of brown coal [9]. There is therefore increased interest in utilization of SS, resulting also from limited reserves of fossil fuels, limited global security of energy supplies and environmental and climatic regulations on CO_2 emissions.

The effect of the operational conditions of SS torrefaction on the properties of the products obtained is investigated in the present work. The combustion characteristics of the pellets is also studied in isothermal and non-isothermal conditions. Different torrefaction temperatures were tested in a lab-scale horizontal tubular reactor.

Experimental:

SS obtained from wastewater treatment plant in Cheonan, Koreawas used as the raw material in this study. After collection, each sample was homogeneously mixed and dried at 105 ^{o}C for 24 hours. Table 1 shows the properties of the SS sample used in this study.The moisture content of the raw SS was 82.2%, with 2.6% ash content. The HHV of the dried sample was determined to be 19.86 MJ/kg. Most of the compositions of “others” in Table 1 are inorganic components.

The dried sample was ground for a homogeneous experimental condition. Each experiment was carried out with 20 g of sample at atmospheric pressure. The sample weight for the combustion experiment was taken as 3g with the air flow rate of 20 litres/min. The combustion temperature was 850 ^{o}C with a heating rate of 30 ^{o}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, as schematically shown in Fig. 1.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). The ash content was determined by the standard method developed by National Renewable Energy Laboratory (NREL) [10]. The emitted gas during the torrefaction of SS was measured using a gas analyzer (Greenline MK2, Eurotron Instruments, Chelmsford, UK).The mass and energy yields are defined by Eqs. (1) and (2), as used by Bridgeman *et al.*[6].

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

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

Table.1:The properties of the SS sample

Elements (wt. %)^a	C	46.93
	H	6.83
	N	7.40
	O	23.23
	S	0.54
	Cl	0.07
	Others	15.0
Moisture (%)^b		82.2
Volatile fraction (%)^b		15.2
Ash (%)^b		2.6
HHV (MJ/kg, dry)^a		19.86

^{a}*dry basis*
^{b}*wet basis*

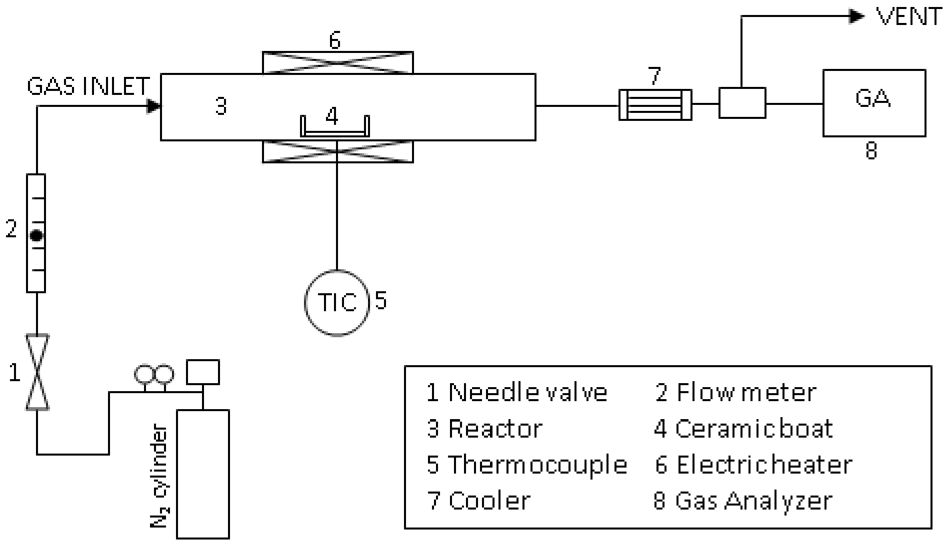

Fig. 1:Schematic diagram of the horizontal tubular reactor used in this work.

Results and Discussion:

Energy yield, Mass yield, HHV, volatile fraction, and ash content:

The relationship between the HHV, the energy yield and the mass yield with respect to the torrefaction temperature is shown in Fig.2 (a). The increase in the HHV up to 350°C is due to the removal of oxygen.A further increasein the torrefaction temperature resulted in a decreaseof the HHV. This is due to the pyrolysis reaction that occurred at a higher temperature. Furthermore, since SS is non-lignocellulosic which contains thermally degradable organic components, it easily breaks down with increase in torrefaction temperature which results into the decrease of the HHV. The torrefaction of SS at temperaturehigher than 350 °C has negative impact on its HHV. So, to minimize this loss, the pre-treatment of SS using torrefaction technology should be done at temperature below it.

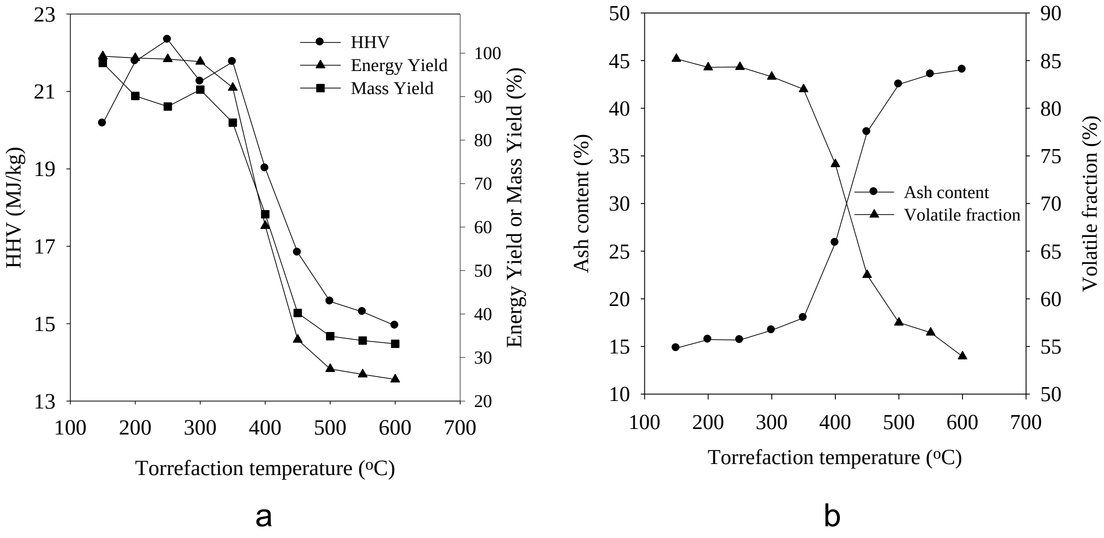

Fig. 2: (a) The HHV, energy yield, mass yield, and (b) ash content and volatile fraction contents of torrefied SS as a function of the torrefaction temperature.

The energy yield is a useful measure during this process. It can be calculated from the mass yields, as described by Bridgeman *et al*[6]. Here, the energy yield decreased steadily from 98% 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 productsat a temperature up to 300 °C showed that the mass after thermal treatment is nearly identical to that of the raw material.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.

Combustion of SS pellet:

The combustion of the pelletized torrefied SS was conducted in isothermal and non-isothermal conditions. Fig. 3 shows the characteristics of the gas emission during isothermal combustion of the pelletized torrefied SS. The isothermal combustion temperature was fixed at 850 ^{o}C. Fig. 3 shows the emission characteristics of CO_2, HCL, NO_x and SO_2.The emission of CO_2, NO_x and SO_2 starts at around 30 seconds and rises to peak and then are totally emitted by 250 seconds at 850 ^{o}C.The chlorine present in the SS is removed earlier than other components in the form of HCL owing to the lower chlorine content as can be seen in Table 1.

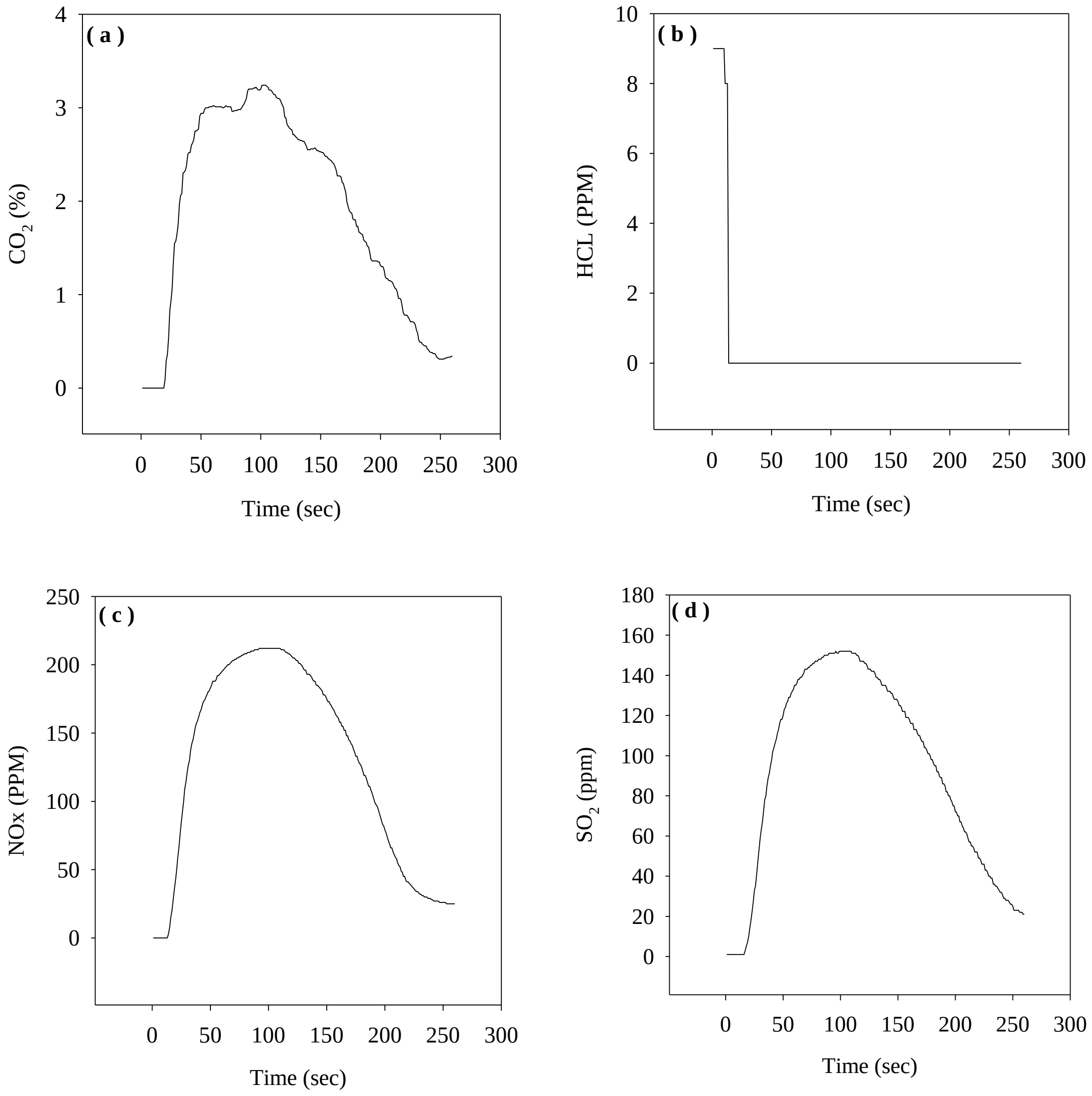

Fig. 3: Characteristics of the gas emission during isothermal combustion of SS at 850 ^{o}C.

Fig. 4 shows the characteristics of gas emission during non-isothermal combustion of SS. The emission of all the gases except SO_2 begins at temperature slightly higher than 300 °C while SO_2 emission begins at temperature around 700 °C. Generally, the NO_x content of the emission gas comprises of Thermal NO_x and Fuel NO_x. The higher NO_x content in the isothermal combustion is the result of simultaneous emission of the Thermal NO_x and Fuel NO_xdue to the exposure in higher temperature.

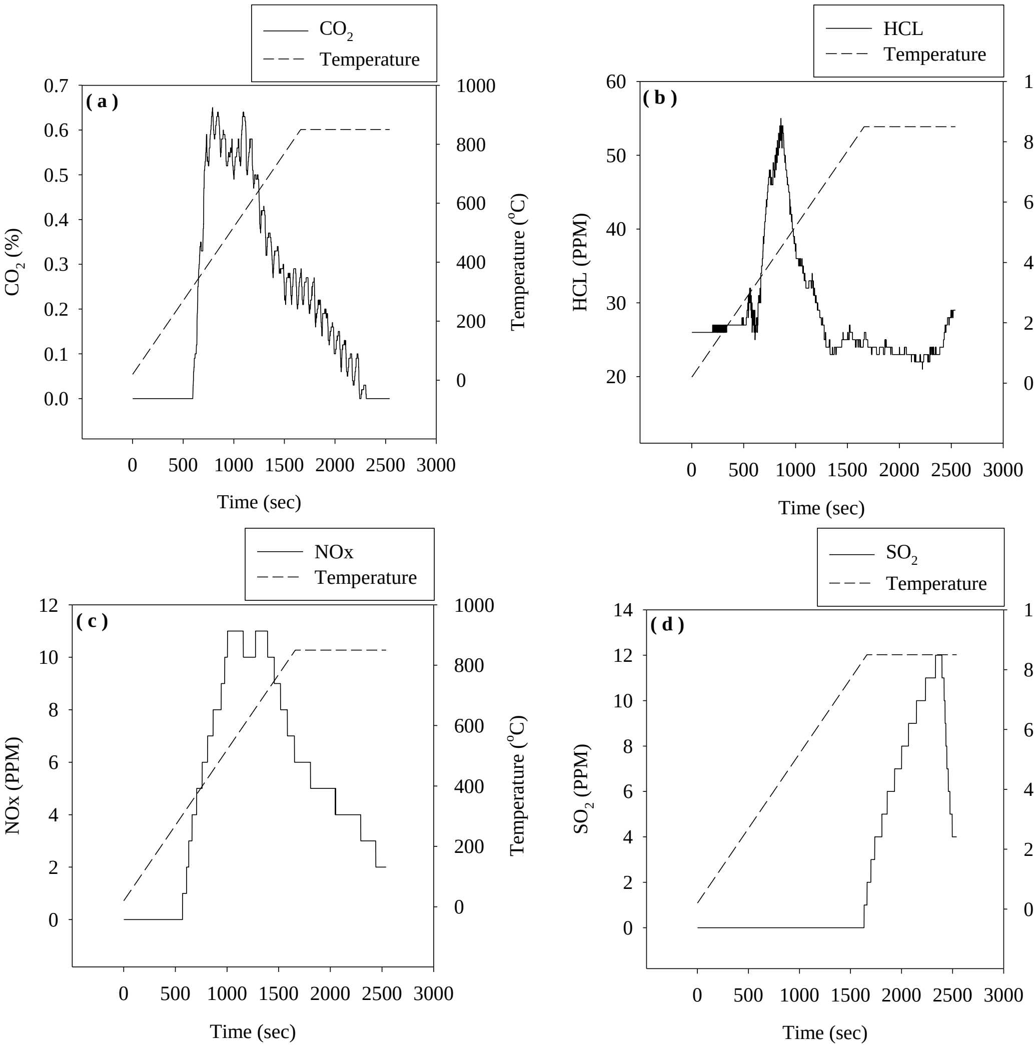

Fig. 4: Characteristics of the gas emission during non-isothermal combustion of SS.

Conclusions:

SS is non-lignocellulosic which contains thermally degradable organic components.It easily breaks down with increase in torrefaction temperature which results into the decrease of the HHV. The torrefaction of SS at temperature higher than 350 °C has negative impact on its HHV. So, to minimize this loss, the pre-treatment of SS using torrefaction technology should be done at temperature below it.The combustion of the pelletized torrefied SS was conducted in isothermal and non-isothermal conditions.The isothermal combustion temperature was fixed at 850 ^{o}C.The emission of CO_2, NO_x and SO_2 starts at around 30 seconds and rises to peak and then are totally emitted by 250 seconds at 850 ^{o}C. The chlorine present in the SS is removed earlier than other components in the form of HCL owing to the lower chlorine content. In the case of non-isothermal combustion, the emission of all the gases except SO_2 begins at temperature slightly higher than 300 ^{o}C while SO_2 emission begins at temperature around 700 ^{o}C.

Acknowledgements

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