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Co-gasification of biosolids with biomass: Thermogravimetric analysis and pilot scale study in a bubbling fluidized bed reactor

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HIGHLIGHTS

- Switchgrass ash rich in potassium catalyzed and enhanced co-gasification reactions.
- Biosolids minerals interacted with biomass minerals and inhibited gasification.
- Increasing the feedstocks biosolids proportion adversely affected gasification.
- No more than 25 wt% biosolids in the fuel feed is recommended.

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ABSTRACT

This work studied the feasibility of co-gasification of biosolids with biomass as a means of disposal with energy recovery. The kinetics study at 800 °C showed that biomass, such as switchgrass, could catalyze the reactions because switchgrass ash contained a high proportion of potassium, an excellent catalyst for gasification. However, biosolids could also inhibit gasification due to interaction between biomass alkali/alkaline earth metals and biosolids clay minerals. In the pilot scale experiments, increasing the proportion of biosolids in the feedstock affected gasification performance negatively. Syngas yield and char conversion decreased from 1.38 to 0.47 m^3/kg and 82–36% respectively as the biosolids proportion in the fuel increased from 0% to 100%. Over the same range, the tar content increased from 10.3 to 200 g/m^3, while the ammonia concentration increased from 1660 to 19,200 ppmv. No more than 25% biosolids in the fuel feed is recommended to maintain a reasonable gasification.

1. Introduction

In wastewater treatment plants (WWTPs), the solids in wastewater are separated, dewatered, and treated to meet the pollutant and pathogen (bacteria and viruses that cause diseases) requirements of local environmental protection agencies. The solids are called biosolids, composed mainly of water, organic matter and ash.

According to the US Environmental Protection Agency (EPA, 1999), 60% of biosolids were being used in land application in 1999, while 40% were incinerated, landfilled, or disposed in other ways. Spreading of biosolids on land is controversial, as the public in some areas opposes application of biosolids because of the concern of perceived risks and odor concerns (Petersen and Werther, 2004). Incineration is often criticized because of secondary pollutants (Chun et al., 2011). Landfilling requires large area and sealing of the site boundary, so this method is also problematic (Seggiani et al., 2012).

The above disposal methods are therefore far from perfect, and becoming less and less acceptable. Gasification of biosolids is an advantageous disposal method in many aspects compared to other disposal methods. During gasification, pathogens and pollutants are gasified or degraded at high temperatures. Thus, gasification can eliminate treatment processes such as the stabilization, digestion and composting, thereby reducing biosolids treatment costs. Also, for land applications, the public is worried about odors and risks, whereas gasification does not appear to worry the public. Compared to incineration, gasification is more efficient in terms of energy and causes less gas emission concern (Petersen and Werther, 2004; Saw et al., 2011). In addition, incineration extracts energy only in the form of heat, whereas the syngas produced from gasification has wider applications such as being burned in gas engines or converted to hydrogen and organic chemicals.

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Thermochemical conversion of fossil fuels and biomass mixtures has been investigated elsewhere (Habibi et al., 2012; Masnadi et al., 2015a,b; Masnadi, 2014; Masnadi et al., 2014). It is also likely to be necessary to mix biosolids with biomass like wood pellets before feeding to gasifiers. Several synergistic benefits might be achieved by biomass/biosolids co-feeding: (1) biosolids from WWTPs contain high moisture contents compared to other gasification feedstocks. For example, the moisture content of biosolids from Vancouver WWTPs is ~70% according to a Greater Vancouver Sewerage and Drainage District Quality Control Annual Report (2011). Mixing biosolids with drier biomass can effectively reduce the average moisture content of the feedstock. (2) Biosolids usually have high ash content, typically ~35% (i.e. Saw et al., 2011; Leckner et al., 2004; Nipattummakul et al., 2010). Co-gasifying biosolids with biomass of low ash content like wood pellets reduces the overall ash content in the feedstock. On the other hand, co-gasification of biosolids with fossil fuels does not seem to be feasible because of blend high ash content causing significant bed agglomeration (Dai et al., 2008). (3) The addition of biomass to an energy generation system lowers the CO_2 footprint for that process. (4) Some components, such as alkali and alkaline earth metals (AAEM) in the biomass, may act as catalysts, promoting gasification of biosolids (Habibi et al., 2012). (5) Co-feeding may help to overcome some of the feeding difficulties commonly associated with biosolids feeding (Dai et al., 2012).

In this work, co-gasification of biosolids and biomass was first studied in a thermogravimetric analyzer (TGA) at 800 °C in order to help understand the interactions between the fuels and their kinetic behavior. Next, pilot scale bubbling fluidized bed co-gasification of biosolids (0%, 10%, 25%, 50%, and 100% by weight) mixed with wood pellets was investigated. Results are presented showing measured syngas composition, syngas yield, char conversion, tar content and ammonia concentration. For 50% biosolids by mass in the fuel, bed temperature was varied from 720 to 830 °C in steps of ~30 °C to investigate the influence of bed temperature on gasifier performance.

2. Methods

2.1. Materials

Nexterra Systems Corp. of Vancouver, Canada, provided biosolids from a WWTP in Baltimore, USA. Two types of Canadian biomass samples were considered, wood pellets and switchgrass. The wood pellets were provided from a local supplier by Highbury Energy Inc. of Vancouver, BC. The switchgrass from Manitoba has been identified as having potential as an energy crop for Eastern Canada (Madakadze et al., 1996).

Ash analysis were performed by Acme Labs in Vancouver, BC. Key properties of the biosolids and biomass samples are provided in Table 1. Biomass samples have much more oxygen than biosolids, whereas biosolids contain much more nitrogen (6.6% dry and ash free) than biomass samples. Although the wood pallets contain the highest calcium oxide content in its ash (21.4 wt%) which can catalyze gasification, its catalytic effect may not be significant because of the very low ash weight proportion (only 1.1%). The switchgrass has a higher ash content (6.3 wt%) and is rich in calcium and potassium (15.3 and 13.1 wt% oxides in its ash, respectively), and is expected to have the greatest catalytic effect on gasification. The biosolids ash also contains a high proportion of calcium (10.36 wt% oxide) which can enhance the fuel reactivity during gasification. The biosolids sample is also rich in phosphorous which is from the treated sewage sludge (Habibi, 2013). It has been reported that phosphorous lowers the ash melting point during co-gasification (Coda, 2004).

Table 1
Proximate, ultimate, and ash analysis of biosolids, wood pellets and switchgrass used.

Material	Biosolids	Wood pellets	Switchgrass
Water content (%)	9.2	5.9	6.0
Proximate (dry)			
Volatile (%)	82.3	83.6	76.9
Ash content (%)	10.9	1.1	6.3
Fixed carbon (%)	6.8	15.4	16.8
Higher heating value(kJ/kg, dry)	22,100	19,300	19,600
Ultimate (dry and ash free)			
Carbon (%)	55.1	47.8	47.9
Hydrogen (%)	8.6	6.4	6.2
Oxygen (%)	29.1	44.6	45.0
Nitrogen (%)	6.6	0.3	0.8
Sulfur (%)	0.6	0.9	0.1
Ash analysis			
SiO_2	23.27	25.32	52.10
Al_2O_3	10.37	4.41	0.50
TiO_2	2.42	0.22	0.03
Fe_2O_3	16.65	4.04	0.96
CaO	10.36	21.44	15.28
MgO	2.95	13.63	5.94
K_2O	1.98	8.92	13.11
Na_2O	0.49	1.36	0.40
P_2O_5	27.05	1.50	5.05
LOI[a]	4.46	19.16	6.63

[a] LOI, loss on ignition.

The deformation and flow temperatures of biosolids were measured and are 1136 and 1290 °C, much lower than for wood pellets, 1420 and 1450 °C respectively (Wilk et al., 2011). To prevent agglomeration and sintering, the temperature was kept below 1100 °C.

2.2. TGA experimental setup

A Thermax500 high-pressure TGA was used for the kinetic study, as shown elsewhere (Masnadi, 2014). CO_2 gasification of the different fuels was performed to compare their gasification rates at atmospheric pressure. In laboratory scale experiments (e.g. thermogravimetric analysis), CO_2 is often used for kinetic studies. Catalysts which are active for the CO_2 gasification have similar reactivity with steam (Pullen, 1984).

The inlet gases were introduced from the bottom of the reactor. The outlet gases passed through a tar and moisture removal bucket. Fuel samples were loaded into a hemispherical quartz basket, 17 mm ID and 20 mm in height, connected to a load cell via a thin metal wire. A non-metal basket was chosen to minimize catalysis by the basket during the experiments.

During the experiments, the weight of sample and temperature were monitored. For pyrolysis, the reactor was heated from room temperature to 800 °C at a heating rate of 25 °C/min and then maintained at 800 °C for half an hour. During this period, the carrier gas was nitrogen at a flow rate of 500 N mL/min. The purpose of pyrolysis was to yield 15 mg of char for gasification based on single fuel char yields. Masnadi et al. (2014) reported that mixing raw fuels before pyrolysis results in the same char yield as making char from each individual fuel. After the pyrolysis, the char samples were subjected to CO_2 gasification. Hence, nitrogen was switched to CO_2 with the temperature maintained at 800 °C throughout the gasification period. The experiments continued until the gasification was complete, i.e. until the weight of sample was no longer decreasing. The TGA experiments were replicated three times to verify the reproducibility of the data. At a 95% confidence level, the measurements for each case were found to be