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Self-heating co-pyrolysis of excessive activated sludge with waste biomass: Energy balance and sludge reduction

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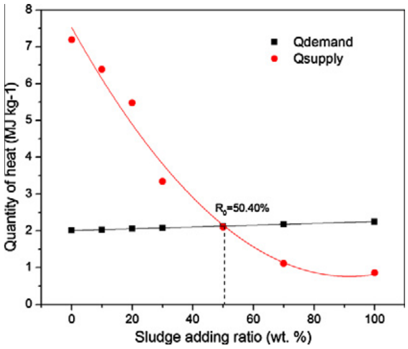
HIGHLIGHTS

- ▶ Proposed a self-heating co-pyrolysis technology for activated sludge reduction.
- ▶ Indicated no obvious synergistic effect between similar H/C molar ratio feedstocks.
- ▶ Determined the marginal sludge adding ratio for self-heating run of the system.

GRAPHICAL ABSTRACT

The treatment of huge excess sludge brought about severe environmental and economic problems. Co-pyrolysis of sludge and waste biomass, such as sawdust and rice husk, would bring about some merits, such as the reduction of floatation of biomass in reactor, the improvement of pyrolysis airflow, and the production of higher heating value oil to keep the self-heated run of co-pyrolyzing reactor. The sludge adding ratio, a key factor influenced the self-heating run of the reactor, was calculated. The synergistic effect between two feedstocks was studied.



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ABSTRACT

In this work, co-pyrolysis of sludge with sawdust or rice husk was investigated. The results showed that the co-pyrolysis technology could be used to dispose of the excessive activated sludge without external energy input. The results also demonstrated that no obvious synergistic effect occurred except for heat transfer in the co-pyrolysis if the co-feeding biomass and sludge had similar thermogravimetric characteristics. The experimental results combined with calculation showed that adding sawdust accounting for 49.6% of the total feedstock or rice husk accounting for 74.7% could produce bio-oil to keep the energy balance of the co-pyrolysis system and self-heat it. The sludge from solar drying bed can be further reduced by 38.6% and 35.1% by weight when co-pyrolyzed with rice husk and sawdust, respectively. This study indicates that sludge reduction without external heat supply through co-pyrolysis of sludge with waste biomass is practically feasible.

1. Introduction

Activated-sludge method is the most widely used technology in the urban wastewater treatment process for its low cost and universality (Sarkar et al., 2010). However, the treatment of huge excess sludge brought about severe environmental and economic problems (Hong et al., 2009; Murray et al., 2008). In the past decades, many technologies were developed to dispose of the excess sludge, mainly including landfilling, land application, and incineration. Landfilling is widely used in past decades, but it is commonly undesirable due to limitations in land volume and restrictive legis-

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lation (Kim and parker, 2008; Cao et al., 2010). Land application may lead to the accumulation of toxic substance, such as heavy metals, in the soil (Vasseur et al., 1999). Incineration is an effective way for sludge reduction and stabilization of the organic material in sludge (Werther and Ogada, 1999). But the incineration of sludge needs additional input of fuel (e.g., coal) because the sludge has low heating value, which increases the cost of sludge disposal. In addition, the incineration in high temperature would produce toxic organic compounds or volatile heavy metals (Mondala et al., 2009).

Fast pyrolysis is an environmentally benign technology, and it can thermochemically decompose organic matter of sludge into bio-oil and bio-char at moderate temperature (400–600 °C) in inert atmosphere (Bridgwater, 2003). Considering the high ash content and density of activated sludge (Fonts et al., 2009), co-pyrolysis of sludge with biomass potentially possesses some advantages, such as reduction of floatation of biomass in pyrolysis reactor and improvement of pyrolysis airflow (Zhang et al., 2009). In addition, due to the high heating value of biomass, the heating value of bio-oil from co-pyrolysis would be elevated so that bio-oil can supply enough energy for self-heated run of co-pyrolysis reactor.

Co-pyrolysis of sludge and biomass has attracted many concerns in the past several decades. These studies are mainly focused on bio-oil production, pollutant emission, and heavy metal distribution in co-pyrolysis products (Samanya et al., 2012; Ren, 2012; Zhang et al., 2011). However, some issues existing in co-pyrolysis process of sludge and biomass are inconsistent. For instance, Fairous et al. (2011) studied the bio-oil yield from fast pyrolysis of sludge and rice waste in a fluidized-bed reactor and found that the bio-oil yield of co-pyrolysis is in the range of that of sludge and rice waste pyrolysis alone, which suggested that there is no obvious synergistic effect between sludge and rice waste biomass. Promoting NH_3 and HCN formation by co-pyrolysis of sludge and cotton stalk may also indicates synergistic effect occurred to some extent (Ren, 2012). Zhang et al. (2009) studied the co-pyrolysis of sludge and rice straw through the curves of thermogravimetry (TG) and differential thermogravimetry (DTG) and found that obvious synergistic effect occurred in co-pyrolysis process. More importantly, little information is known about the energy balance which determines the economical feasibility of the co-pyrolysis technology. Thus, the systematic study about co-pyrolysis of sludge and biomass is important for the practical application of the co-pyrolysis technology.

In this work, an approach for sludge reduction and stabilization was proposed by co-pyrolysis of a typical agricultural waste (rice husk) and forestry waste (sawdust) with excess sludge. The objectives of this work are to investigate: (1) the effect of sludge adding ratio on product distribution in the co-pyrolysis process; (2) the energy balance values for co-pyrolysis of sludge with two types of biomass; and (3) the performance of sludge reduction with different sludge adding ratio and biomass.

2. Methods

2.1. Materials

Dewatered sewage sludge was collected from WangTang Municipal Wastewater Treatment Plant in Hefei, China and air dried before use. The sawdust and rice husk were obtained from a local timber treatment plant and Anhui Yineng Bio-energy Co., Ltd in Hefei, China, respectively. The three kinds of raw materials were dried in an oven at 105 °C for 24 h, then pulverized by a rotary cutting mill and screened into fractions with particle size below 125 μm (120 mesh). Finally, they were stored in a glass desicator for further use. The proximate and ultimate analysis results of the three kinds of materials are shown in Table 1. All reagents used in this study are of analytical grade purity.

2.2. Fast pyrolysis experiments

In the co-pyrolysis experiments, a vertical fixed-bed reactor which had been described in our previous work (Liu et al., 2011) was used, in which feedstocks with different sludge weight ratios (0%, 10%, 20%, 30%, 50%, 70% and 100%) were pyrolyzed.

During pyrolysis process, approximately 4 g of feedstock was firstly placed in the feeder. After the pyrolysis temperature in the reactor was reached, the reactor was swept by a nitrogen flow of 400 mL min^{-1} for 20 min to ensure an inert atmosphere. A few minutes later, the nitrogen flow rate was adjusted to 160 mL min^{-1}, and then the feedstock was rapidly feeded and decomposed in 1–2 s in the pyrolysis region. The pyrolysis vapor was streamed out by the nitrogen flow and the condensable components were condensed by cold ethanol to obtain bio-oil. While the incondensable part (denoted as biogas) was discharged into air after the stream was bubbled through a gas-washing bottle. The reactor was moved out of the heater once the pyrolysis was finished, and still kept in nitrogen atmosphere until cooled to ambient temperature. The produced biochar and bio-oil were collected and weighed to calculate their yields. The biogas yield was calculated by difference. Each pyrolysis experiment was conducted twice.

2.3. Analytical methods

The non-isothermal TG method was used for the thermal stability analysis and the proximate analysis of sludge and biomass. Determination of both moisture content and volatile matter content was conducted using a method described by Munir et al. (2009). Ash content of biomass was measured by the gravimetric method prescribed in ASTM D 3174-04, and fixed carbon content was obtained by difference. In the TG analysis process, approximately 10 mg of sample was placed into a TG analyzer (SDT Q600, TA Co., USA), in which the temperature is raised from ambient temperature to 900 °C at 10 °C min^{-1} in nitrogen atmosphere of 100 mL min^{-1}.

Moisture content of bio-oil was measured by Karl-Fischer titration (ZKF-1, Shanghai Super Scientech Co., Ltd, China) using dichloromethane/methanol (3:1, v/v) as solvent. Each test was conducted in triplicate. The carbon, hydrogen, and nitrogen contents in raw material and products (bio-oil and biochar) were measured on a Vario EL cube elemental analyzer (Elementar Analysensysteme GmbH, Germany). Based on the elemental composition, higher heating values (HHV) and lower heating values (LHV) were calcu-

Table 1
Physicochemical characteristics of feedstocks.

	Sludge	Sawdust	Rice husk
Proximate analysis (wt.%, as received)			
Volatile matter	38.87	80.72	67.15
Fixed carbon	5.43	16.07	14.68
Ash	54.31	0.88	13.66
Moisture	1.39	2.33	4.51
Ultimate analysis (wt.%, on dry basis)			
C	22.17	49.68	41.25
H	3.77	6.07	5.52
N	4.02	0.25	0.99
O^{diff}.	14.97	43.10	37.93
molar ratio H/C	2.04	1.47	1.61
Higher heating value (calculated, as received)			
HHV(MJ kg^{-1})	9.33	19.64	16.09