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Effects of temperature and composite alumina on pyrolysis of sewage sludge

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ABSTRACT

An interactive dual-circulating fluidized bed system has been proposed in which the pyrolysis of sewage sludge (SS) and incineration of biomass proceed simultaneously, and alumina is used as the bed material and heat carrier. The alumina coated with biomass ash would mix with sewage sludge in the pyrolysis reactor of this device. It is important to know the influence of composite alumina (CA) on the pyrolysis progress. Sewage sludge was pyrolyzed in a fixed bed reactor from 400 to 600°C using CA as catalyst. The effects of temperature and CA additive ratio on the products were investigated. The product yields and component distribution of non-condensable gas were more sensitive to the change of temperature, and the maximum liquid yield of 48.44 wt.% and maximum Useable Energy of Liquid of 3871 kJ/kg sludge were observed at 500°C with 1/5 CA/SS (mass ratio). The gas chromatography–mass spectrometry results showed that the increase of temperature enhanced devolatilization of organic matter and promoted cyclization and aromatization of aliphatics. The presence of CA could strengthen secondary cracking and interaction among primary products from different organic compounds, such as acid–amine condensation, and reduce the content of oxygenated compounds. When the CA additive amount exceeded a certain proportion, the aromatization was clearly strengthened. The effects of CA on decomposition of fatty acids and formation of aromatics were similar to that of temperature. This means that the reaction temperature could be lowered by introducing CA, which has a positive effect on reducing energy consumption.

Introduction

With rapid urbanization, the disposal of sewage sludge generated from wastewater treatment has become a challenge due to its expanding quantity. Pyrolysis is considered to be a promising sludge disposal technology for its advantages of volume reduction, accumulation of heavy metals and stabilization of waste. Furthermore, byproducts obtained from pyrolysis such as char, gas or oil give this technology the potential for commercial application (Caballero et al., 1997; Bridle and Pritchard, 2004; Smith et al., 2009a, 2009b).

Many groups have carried out research on the pyrolysis of sewage sludge in a variety of reactors by changing operating parameters *e.g.*, temperature, particle size, gas residence time, and catalyst (Inguanzo et al., 2002; Kim and Parker, 2008; Piskorz et al., 1986; Park et al., 2008). γ-Al_2O_3, clay, zeolites, Fe_2O_3,K_2CO_3 and CaO have been investigated as catalysts for sewage sludge pyrolysis (Konar et al., 1994; Ischia et al., 2011;

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Beckers et al., 1999; Park et al., 2010a, 2010b; Shie et al., 2003a, 2003b) and the results suggested that a major fraction of the liquid product could serve as a diesel fuel substitute (Konar et al., 1994; Bahadur et al., 1995). Toluene-extracted lipids from sewage sludge were pyrolyzed over activated alumina and it was found that the liquid products were hydrocarbon mixtures (Konar et al., 1994). The presence of sodium and potassium compounds could enhance the reaction rates and improve the quality of pyrolysis liquid products, which would be beneficial for industrial applications (Shie et al., 2003a, 2003b).

An interactive dual-circulating fluidized bed (CFB) system has been proposed in which the pyrolysis of sewage sludge and incineration of biomass, such as straw, would proceed at the same time (Jin et al., 2011). Fig. 1 shows a schematic of the dual-bed reactor in this system. Alumina is used as the fluidized-bed material and heat carrier, which moves between the two CFBs and simultaneously transfers heat from the incinerator to the pyrolysis reactor for thermal decomposition. During the incineration process, alumina would be loaded with biomass ash and form a composite material, which may impact the pyrolysis of sewage sludge. It is important to know the influence of composite alumina (CA) on the pyrolysis process.

In this study, the pyrolysis of sewage sludge using CA as catalyst was studied in a fixed bed reactor to determine the effect of temperature and the CA additive ratio on product yields and components of liquid products.

1. Experimental

1.1. Materials

The sewage sludge (SS) was obtained from a wastewater treatment plant in Jurong, China. Before the pyrolysis, the sludge was pre-dried at 105°C to constant weight and screened to obtain particles with a diameter from 0.25 mm to 0.6 mm. The proximate and ultimate analyses of the dried sewage sludge are as follows: ash content 58.28 wt.%, volatile matter content 39.85 wt.%, fixed carbon 1.87 wt.%, C 16.23 wt.%, H 2.57 wt.%, N 3.44 wt.% and O 19.48 wt.% The higher heating value is 9831 kJ/kg.

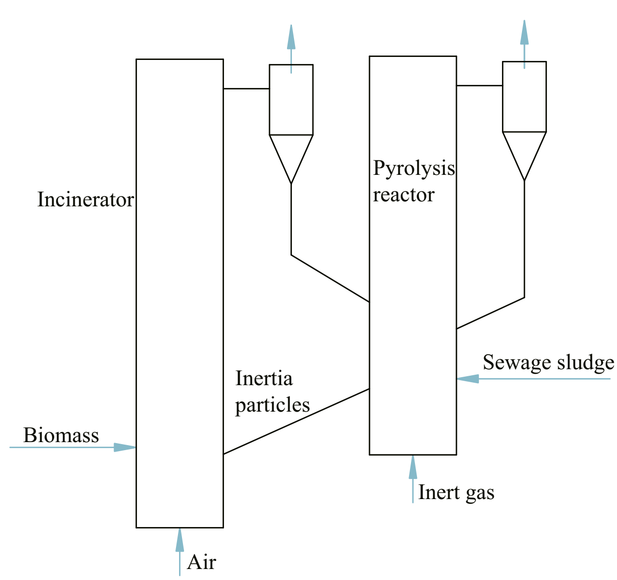

Fig. 1 – Schematic of the dual-circulating fluidized bed (CFB) reactor.

Composite alumina (CA) was a complex material formed by alumina particles (with diameters between 0.3–0.5 mm) in a biomass-fed fluidized bed at around 850°C. The X ray fluorescence (XRF) results of alumina and composite alumina are given in Table 1. The proportion of metals such as K, Ca, Na and Mg in the composite alumina increased rapidly compared with alumina, which indicated that the alumina has a good effect on coating biomass ash. The sample was made by mixing sewage sludge and composite alumina in predetermined ratios. The particle sizes of these two materials were similar so it was easy to get a well-mixed sample.

1.2. Fixed bed reactor

The fixed bed pyrolysis system is shown in Fig. 2. The reactor is made up of a stainless steel tube with a diameter of 50 mm and a length of 1000 mm, which is heated by an external electrical furnace. A stainless steel boat loading 35 g mixed sample was first placed in the non-heating zone of the tube. Then N_2 (99.999% purity) was introduced into the reactor with a flow rate of 500 mL/min. When the temperature reached the set point, the boat with sample was pushed into the heated area of the tube to allow the pyrolysis to progress for 50 min. The pyrolysis gas passed through a condenser, a filter and a drier successively, from which liquid and non-condensable gas (NCG) were separated and collected respectively. The primary gas compounds such as CO_2, CO, H_2 and CH_4 were tested online. When the experiment finished, the char and the liquid product were collected and weighed. The non-catalytic pyrolysis was studied over a wide temperature from 300 to 900°C in a previous work, and the results showed that a medium temperature is favorable to the generation of liquid product (Sun et al., 2013a, 2013b). Thus the sewage sludge pyrolysis temperature was selected in the range 400 to 600°C in this study.

1.3. Analysis

The ultimate analysis was carried out in a Vario EL-III elementar (ELEMENTAR Analysen-systeme GmbH, Hanau,

Table 1 – X-ray fluorescence (XRF) of alumina and composite alumina (wt.%).

	Al_2O_3	SiO_2	TiO_2	Fe_2O_3	CaO	K_2O	P_2O_5
Alumina	79.24	13.964	3.371	2.398	0.361	0.271	0.191
Composite alumina	57.14	21.43	2.304	2.845	4.565	1.571	2.39
	Cr_2O_3	V_2O_5	SO_3	MgO	MnO	Na_2O	Cl
Alumina	0.067	0.061	0.047	0.019	0.01	–	–
Composite alumina	0.0605	0.095	0.621	4	0.103	2.7	0.124