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Syngas production by catalytic in-situ steam co-gasification of wet sewage sludge and pine sawdust

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ABSTRACT

The catalytic in-situ co-gasification of wet sewage sludge (WSS) and pine sawdust (PS) for syngas production was studied. The thermogravimetric analysis showed that weight loss and the maximum weight loss rate of the sample increased with the increasing of PS content and the co-gasification behavior has obvious synergistic or coupling effects. The in-situ co-gasification process was performed in a lab-scale reactor to investigate the influences of PS content, catalyst and catalytic temperature on product yields, gas composition and gasification performances. The results indicated that the maximum dry gas yield (1.23 N m^3/kg), H_2 yield (14.44 mol/kg) and carbon conversion efficiency (84.56%) were obtained in presence of NiO/MD catalyst with 40% PS content in the blends and 900 °C catalytic temperature. The proposed direct catalytic co-gasification of wet sewage sludge and pine sawdust process may be a promising way to produce syngas using WSS.

1. Introduction

With the widespread use of biological wastewater treatment, a huge amounts of sewage sludge as an unescapable by-products are produced from these processes which known to contain complex components [1,2]. In recent years, there are more than 3080 municipal wastewater treatment plants working in China which generate about 20 million tons of sewage sludge every year [3,4]. Moreover, the sewage sludge yield during the next years would maintain continued growth due to the development of population and rapid urbanization. As the legislation on waste discharge to the environment is more and more restrictive, the conventional disposal methods, such as landfilling, incineration, composting for farmland use, and dumping into sea are becoming increasingly limited [3].

Gasification of sewage sludge technology is indisputably considered as a promising, convenient, and effective alternative to dispose sewages sludge, which can convert the sludge into combustible gaseous products by reducing its volume, eliminating the pathogens and immobilizing the heavy metals in the inorganic matrix [5–7]. However, due to high moisture content (containing 80 wt.% water), wet sewage sludge (WSS) from the wastewater treatment plant is subjected to pre-drying process before gasification, and then steam is introduced into the sewage sludge gasification process as an oxidizer in order to enhance syngas yield. From the point of energy consumption, both processes are illogical and increase the cost of disposal considerably.

Co-gasification of two different materials mixture has received great attention in recent years due to its high energy conversion efficiency, operational stability, friendly environmental effect and economic advantages [8–10]. Co-gasification, widely used in coal and biomass gasification, does not only reduce the emissions of greenhouse gases but also have a positive impact on the emission of anther pollutants, such as SO_x and NO_x [11–14]. Since coal is fossil fuel and limited to its shortage, sewage sludge which is regarded as the residue generated from municipal wastewater treatment plants and contains high levels of organic matters and proteins, is a good alternative. Sewage sludge has some characteristics, namely high moisture content, ash, density and viscosity, low heat value. Biomass contains lower ash, and it can be made into high heat value pyrolysis products. In the process of pyrolysis, the biomass is low energy density, low ash melting point and slagging easily. In addition, biomass is low density that will tend to float and fly, which is inconvenient to storage and transportation [15]. If the two materials are mixed in appropriate proportion, it

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may resolve their problems and compensate their weakness each other. Pinto et al. [16] indicated that gas product of sewage sludge co-gasified with straw pellets contained lower concentrations of NH_3 and H_2S than pure sewage sludge gasification due to the low N and S content in straw pellets. Zhang et al. [17] have carried out the kinetic analysis of the co-pyrolysis of sewage sludge mixed with rice straw and concluded that synergistic effect accelerated the release of volatile matter after rice straw adding. However, co-processing of sludge with biomass to produce combustible gases still has been shortly reported.

Tar handling is one of the major barriers to commercialization of gasification technologies. Traditional tar removal methods are either physical process (scrubbers, filters, cyclones, activated carbon, etc.) or thermal–chemical process (thermal cracking or catalytic reforming) [18]. Among these, catalytic reforming is considered as a technically and economically interesting approach for gas cleaning. Various types of catalysts have been studied on tar removal in biomass gasification. Metal oxide catalysts demonstrated high catalytic activity in tar removing during biomass gasification process, such metals including Al [19], Mo [20], Ni [21], Co [22], Pt [23], and so on. Li and his collaborators [24,25] developed nano-NiO/γ-Al_2O_3 and tri-metallic catalyst Nano-NiLaFe/γ-Al_2O_3 for tar removal and H_2 gas production in biomass or municipal solid waste (MSW) gasification. However, at present the mostly studies are focused on a single material gasification, little available research could be found on tar catalytic reforming during co-gasification of sewage sludge mixed with biomass.

The aim of this study is to investigate the performance of catalytic in-situ steam co-gasification of wet sewage sludge and sawdust mixture in a bench scale reactor. NiO supported on modified dolomite (MD) acted as catalyst. The effects of PS content in the blends and catalytic temperature on gasification performances are investigated.

2. Experiment and methods

2.1. Materials

The wet sewage sludge (WSS) (77.32 wt.% moisture content) used in this study was produced in a Wuhan urban wastewater treatment plant located in Hubei province, China. The dehydrated sewage sludge was collected and stored in a refrigerator as original material. Pine sawdust (PS) was from a furniture factory in Wuhan City, Hubei Province, China. The pine sawdust was naturally dried for a period of 7 days and then shredded into size of about 5 mm. The characteristics of two raw materials were presented in Table 1. Prior to each experiment, the WSS was blended with PS to obtain mixtures with different mixing ratios. The PS content added in blends was 0%, 20%, 40%, 60%, 80% and 100% in the tests, respectively.

2.2. Thermogravimetric analysis (TGA)

The Diamond TG/DTA (Thermal Gravity/Differential Thermal Analysis) integrated with thermal analyzer (Diamond TG/DTA, PerkinElmer Instruments) was used to investigate the pyrolysis characteristics of the samples. All the TGA tests were performed in high purity nitrogen (99.99%) with a flow rate 100 ml/min. The test temperature was ranged from ambient temperature to 1273 K at a heating rate of 20 K/min. The mass of each sample (particle size: 0.3–0.5 mm) used in each experiment was 10 ± 0.1 mg.

2.3. Catalyst

The modified dolomite (MD) was calcined in air at 900 °C for 4 h named as calcined MD, and the MD was prepared as follows: firstly, the natural dolomite was milled in a ball mill to pass a 320 mesh (0.045 mm) screen; then the dolomite powder, calcium aluminate cement and calcium citrate were mixed together at a mass ratio of 7:2:1 and reconciled with the right amount of water, which were formed into spherical granularmaterial with the diameter of about 12 mm via extrusion molding; finally, the shaped samples were dried at 105 °C for 7 h, followed by calcination at 400 °C for 2 h.

The incorporation of precursor of NiO into modified dolomite (MD) was performed by deposition–precipitation method, using the aqueous solution of $Ni(NO_3)_2{\cdot}6H_2O$ and $CO(NH_2)_2$ and the modified dolomite (MD). After deposition–precipitation reaction, the catalysts were dried at 105 °C overnight and then calcined at 900 °C for 4 h in air atmosphere. The NiO loading amount in MD was 6.09 wt.%. Table 2 shows the content of metal oxide and physical properties of NiO/MD catalyst.

2.4. Apparatus and procedure

The apparatus used in this study mainly consisted of a fluidized bed gasifier (800 mm of effective height, 100 mm i.d.), catalytic reaction bed (1000 mm of effective height, 88 mm i.d.) and associated auxiliary equipments, as shown in Fig. 1. Feedstock was continuously fed into the gasifier by a two-stage feeder which designed for preventing the air into the reactor. The catalytic bed filled with 1 kg of NiO/MD catalyst was employed for tar elimination. During the whole process, catalytic bed temperature was maintained constant at 800 °C for every trial and the gasification fixed bed temperature was varied at 600, 700, 800 and 900 °C.

At the start-up of each test, when the desired temperatures of gasifier and catalytic bed reached, mixture feedstock was continuously fed into the gasifier with the rates of 5–10 g/min. Meanwhile, the nitrogen was injected into the gasifier to fluidize the feedstock at speed of 0.37 m/s. The volatile gasification products flowed out the gasifier and passed through the catalytic bed. Subsequently produced gas stream flew into the cyclone followed by a cooling system and gas purification unit. The condensable gases converted into bio-oil, which then was captured by the collector. The non-condensable gases were collected with a tedlar sampling bag and the volume of gas produced was measured by a gas flow meter. Solid residues in gasifier were collected and weighted, which recorded as char fraction directly. It took 20 min for the test to reach a stable state and ensure the reliability of test data. Each experiment was repeated three times and the data reported in this

Table 1
Properties of wet sewage sludge (WSS) and pine sawdust (PS) sample.

Sample	Proximate analysis (wt.%)				Ultimate analysis (wt.%)					LHV (MJ/kg)
	VM[a]	FC[a]	Ash[a]	M[c]	C	H	N	S	O[b]	
WSS	15.60	15.90	68.50	78.00	12.99	2.54	2.37	0.05	16.30	14.89
PS	82.18	16.13	1.69	4.54	46.36	5.75	2.26	0.32	43.62	16.91

[a] Dry basis.
[b] By difference (O% = 100% − Ash% − C% − H% − N% − S%).
[c] Wet basis.