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Hydrogen production by sewage sludge gasification in supercritical water with a fluidized bed reactor

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ABSTRACT

In this work, gasification of sewage sludge in supercritical water was investigated in a fluidized bed reactor. Effect of operating parameters such as temperature, concentration of the feedstock, alkali catalysts and catalyst loading on gaseous products and carbon distribution were systematically studied. The results showed that the increase of temperature and the decrease of feedstock concentration were both favorable for gasification, and the addition of catalyst enhanced the formation of hydrogen better. The K_2CO_3 catalyst could better enhance gasification efficiency and the catalytic activity of different catalysts for hydrogen production was in the following order: KOH > K_2CO_3 > NaOH > Na_2CO_3. The maximum molar fraction and yield of hydrogen reached to 55.96% and 15.49 mol/kg respectively with KOH at 540 °C. Most carbon in feedstock existed in gaseous and liquid products, and alkali catalysts mainly promoted the water-gas shift reaction rather than steam reforming.

1. Introduction

Due to the increasing price and decreasing amount of fossil fuels, energy obtained from biomass and biomass wastes has received much attention in recent years. Biomass and biomass wastes always contains much water and they must be dried first so that they can be used in conventional thermochemical gasification process. However, a large amount of energy is consumed when the biomass and biomass wastes are dried. In order to avoid the drying process, hydrothermal gasification has attracted more attention because water can be used as a reaction medium so that wet biomass do not need to be dried. Among the hydrothermal gasification processes, supercritical water gasification (SCWG) is a promising technology. The supercritical water ($T_c \geq 374$ °C, $P_c \geq 22.1$ MPa) has special physical and chemical properties, such as high diffusion rates, low viscosity and low dielectric constant [1]. These unique features make it a better solvent for the dissolution of various organic matters so that the reactions can be carried out in a homogenous condition and can be promoted better.

Hydrogen as a clean energy source is gained increasing attention. It is expected to play a key role in future source of energy by replacing fossil fuels. The production of it from SCWG of model compounds, biomass, biomass waste and industrial wastewater have been widely studied [2–9]. However, not all organic matters in feedstock can be easily converted to hydrogen or carbon dioxide. Instead, tars and chars will be generated as the final products, which will block the reactors. High yield of hydrogen can be only obtained when reaction temperature is above 600 °C. Some problems such as

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Table .1 – Properties of sewage sludge sample.

Water content (wt.%)[a]	Proximate analysis (wt.%)[b]			Ultimate analysis (wt.%)[b]					LHV(MJ/kg)
	VM	FC	Ash	C	H	N	S	O[c]	
84.0	61.63	9.41	28.96	38.18	3.40	4.67	1.05	23.74	14.63

a Water content = 100% – dry matter content.
b On a dry basis.
c By difference (O% = 100% – ash% – C% – H% – N% – S%).

high cost and corrosion of the reactor are also caused because of the high reaction temperature. In order to suppress the formation of tars and chars, moderate reaction temperature and enhance the formation of hydrogen, numerous catalysts have been widely investigated on the process of SCWG. Among them, the alkali catalysts (KOH, NaOH, K_2CO_3 and Na_2CO_3) are widely employed because of low cost and high activity whenever the reactions are happened in batch or continuous system [7,10–12].

In recent years, utilization of sewage sludge formed during wastewater treatment process is popular. Sewage sludge containing 80 wt.% ~ 98 wt.% water is composed of various organic matters and inorganic matters. Due to the high moisture content, treatment of sewage sludge in supercritical water is an attractive utilization approach.

The gasification of sewage sludge in supercritical water has been investigated by some researchers [13–19]. However, experiments on SCWG of sewage sludge are still limited. Moreover, all of them were only carried out in batch reactors or miniature scale continuous reactors (2 g/min). There are also only two reports on catalytic gasification of sewage sludge in supercritical water with miniature scale continuous reactors [14,15]. On the other hand, there are no systematic reports on the suitability of alkali catalysts for the application. In order to obtain more information and further determine the feasibility of sewage sludge gasification in supercritical water, studies on the sewage sludge gasification in supercritical water with a bench-scale continuous flow fluidized bed reactor were carried out and the alkali catalysts were used in these experiments. To our knowledge, it is the first time to study the SCWG of sewage sludge with fluidized bed reactor and it is also the first time to systematically study the suitability of alkali catalysts for SCWG of sewage sludge with continuous reactors. Effects of reaction temperature, concentration of the feedstock, alkali catalyst type, and catalyst loading on gasification of sewage sludge are investigated.

2. Experimental

2.1. *Materials*

The sewage sludge was obtained from the Beishiqiao wastewater treatment plant in Xi'an, Shaanxi, China. The main properties of sewage sludge were listed in Table 1.

The alkali catalysts including NaOH, KOH, K_2CO_3 and Na_2CO_3 were purchased from Tianjin Hongyan Chemical Reagent Factory and they are anhydrous reagent. Sodium carboxymethyl cellulose (CMC) was purchased from Shanghai Shanpu chemical Co. Ltd. All these reagents were analytical pure. The deionized water was used to dilute the sludge to desired concentration.

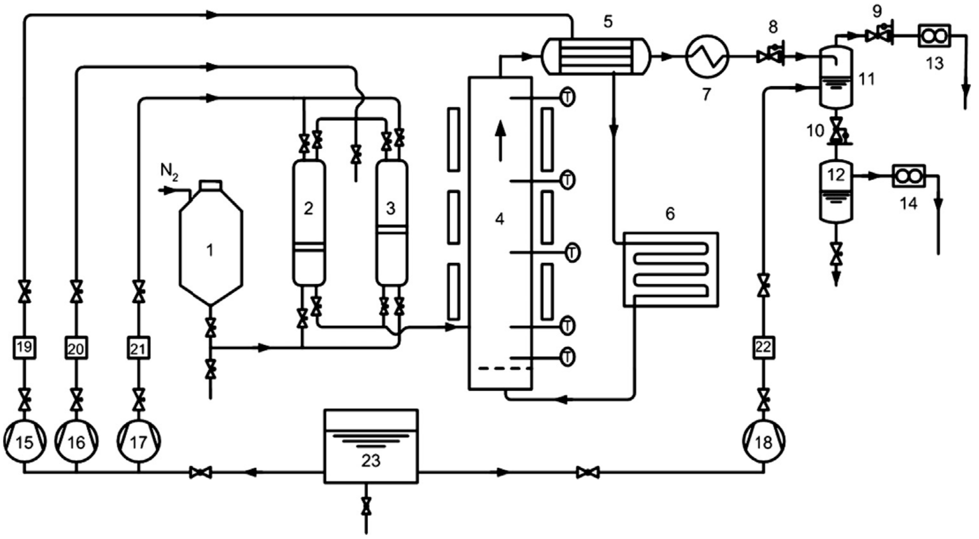

Fig. 1 – Scheme of system for hydrogen production from sewage sludge in supercritical water with a fluidized bed reactor: 1 feedstock tank; 2,3 feeder; 4 fluidization bed reactor; 5 heat exchanger; 6 pre-heater; 7 cooler; 8,9,10 back-pressure regulator; 11 high pressure separator; 12 low pressure separator; 13,14 wet test meter; 15,16,17,18 high pressure metering pump; 19,20,21,22 mass flow meter; 23 water tank.