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Leaching of heavy metals from fast pyrolysis residues produced from different particle sizes of sewage sludge

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ABSTRACT

Pyrolysis residues produced from three particle sizes of sewage sludge using fluidized bed at 500 °C were subjected to toxicity characteristic leaching procedure (TCLP) and diethylenetriamine pentaacetic acid (DTPA) leaching tests to assess the potential release and bioavailability of heavy metals in their pyrolysis residues. Results showed that the smallest particle of sewage sludge produced the highest pyrolysis residue. Most functional characteristics of the pyrolysis residues were similar to those of sewage sludge itself, and some specific functional groups formed after fast pyrolysis. All heavy metals in feedstock sewage sludge were kept in pyrolysis residue except As, and their contents were enriched 2.5–3.5 times in pyrolysis residues. Pyrolysis residues obtained from larger particles of sewage sludge would cause excessive level of Cu and Zn. Although the fast pyrolysis significantly suppressed heavy metals leaching from residues, the leaching pattern of heavy metals was different between pyrolysis residues produced from the three particle sizes of sewage sludge. Specifically, Cu, Zn and As in the pyrolysis residues from the larger particle of sewage sludge were easier to be leached to environment. However, the bioavailability of Cu was highest in the pyrolysis residue derived from the largest particle of sewage sludge; whereas that of Zn and As was highest in the pyrolysis residue derived from the smallest particle of sewage sludge.

1. Introduction

Sewage sludge is a byproduct of the wastewater treatment process and is composed of organic compounds, macro and micronutrients, trace elements, microorganisms and micropollutants [1], which is identified as "a future waste problem" to resolve [2]. Specifically, in China more than 8 million tonnes (dry solid) of sewage sludge are produced annually, and the increase rate is very quick [3].

Pyrolysis can potentially be a method of choice for sewage sludge management [4], particularly compared to the current methods of landfilling and direct agricultural utilization [5]. Because this process can not only produce liquid fuel and chemicals [6], but also reduce the volume of the solid residue [7], eliminate pathogens [8], reduce some toxic compounds [9] in the original sewage sludge.

Fluidized bed pyrolysis, a kind of fast pyrolysis, is the most popular configuration due to its ease of operation and ready scale-up [4], and is being used on a commercial scale in many areas [10]. In a fluidized bed, particle size of the feedstock is one key factor that significantly influences the heat transfer process [11,12]. The choice of particle size coupled with appropriate feed rate could enhance good pyrolysis process by providing adequate supply of energy in the biomass particle size [4]. The particle size of feedstock influences the product yields and characteristics for reason that the feedstock residence time strongly depends on the particle size [4,13–16].

Solid residues are usually the main byproduct of sewage sludge pyrolysis for liquid and gas production, with the yield between 35 and 80 wt%, on a dry basis [17–19]. Application of pyrolysis residues produced from sewage sludge as amendments has potential to improve soil properties [20] and crop yield [21], decrease

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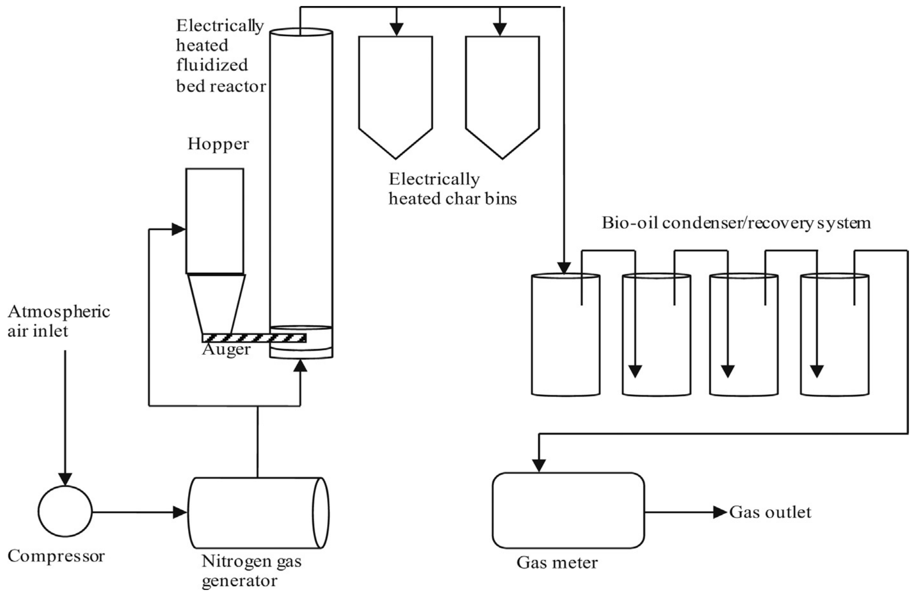

Fig. 1. Schematic diagram during fast pyrolysis of sewage sludge by fluidized bed unit.

the greenhouse gas emission [3], and for permanently sequester carbon [21,22]. But on the other hand, the majority of heavy metals originally contained in sewage sludge remain in its pyrolysis residues [18,22–25], except the volatile elements Hg and Cd [16,25]. Thus a risk assessment of potential soil and groundwater contamination should always be considered prior to the land application of pyrolysis residues produced from sewage sludge. The results from extraction and leaching experiments showed that heavy metals in sewage sludge-derived pyrolysis residues were significantly lower than those in sewage sludge itself [17,25]. The study from pot experiment also detected insignificant bioaccumulation of the trace metals present in the cherry tomato (*Lycopersicon esculentum*) fruits using wastewater sludge-derived pyrolysis residue [21].

Zhai et al. [16] employed three particle sizes of sewage sludge and three heating rates to study the pyrolysis process. They found that the mass loss was about 65 wt% of the total sludge mass at all experiment by means of the thermogravimetric analysis. However, less attention has been given to the effect of particle size on properties of the 35 wt% of pyrolysis residue, especially on its heavy metals. It is still unknown that whether the heavy metal contents in pyrolysis residue produced from different sewage sludge particles are distinct as well, and what is their potential environmental effects, which limit the reasonable treatment and land application security for sewage sludge-derived pyrolysis residues. Determining levels of heavy metals distributed in pyrolysis residues obtained from different particle size of sewage sludge and their forms by means of leaching test seems to offer valuable references for its risk assessment on environment and living organisms.

In this study, we mainly focused on Cu, Zn, Ni, Pb, Cd, Cr, and As in different particle sizes of sewage sludge and their fast pyrolysis residues as these heavy metals are common in sewage sludge, toxic to living organisms at high level and major metal pollutants in water bodies and soil environment around the world [26]. The specific objectives of this study were to: (1) determine the effect of particle size of sewage sludge on heavy metal distribution in its fast pyrolysis residues; (2) identify the potential leaching of heavy metals in pyrolysis residues produced from different particle size of sewage sludge; and (3) evaluate the feasibility of sewage sludge-derived pyrolysis residues for land application or reuse in view of the mobility and bioavailability of heavy metals.

2. Materials and methods

2.1. Fluidized bed pyrolysis

2.1.1. Feedstock preparation

The feedstock sewage sludge (SS) for the fast pyrolysis used in this study was obtained from the domestic waste after treatment at the Wastewater Treatment Plant, located in College Station, TX, USA. Then SS was activated and centrifuged for dewatering followed. Based on related work [16,27], some preparations were conducted before fast pyrolysis. First, SS was dried in an oven at 105 °C for 24 h. Then the dry SS was cracked from the original size (irregular clusters of the order of centimeters) into the size of around 1 mm using mallet. After that, the ground dry SS was shaken using Fisher Standard Brass Test Sieve (Fischer Scientific Company, MA, USA) to pass through 20 mesh (d = 0.830 mm) and 60 mesh (d = 0.180 mm). Therefore, three particle sizes of SS were obtained, i.e., >0.830 mm (SS1), 0.180–0.830 mm (SS2) and <0.180 mm (SS3). The samples were then kept in a desiccator for future use.

2.1.2. Fast pyrolysis experiment

The fast pyrolysis of SS1, SS2 and SS3 was conducted by the bench-scale fluidized bed setup in the Bio Energy Testing and Analysis (BETA) Laboratory of Texas A&M University (Fig. 1). The moisture content of the feedstock was ensured to be less than 10% prior to use to the pyrolysis process. Fluidization of SS was accomplished through the introduction of N_2 gas produced by the N_2 gas generator. The purpose of our whole project is to select the optimized fast pyrolysis conditions for bio-oil production using SS. The essential features of a fast pyrolysis process for producing liquids are moderate temperatures and short vapor residence time [28]. Usually, the reaction temperature is carefully controlled around 500 °C to maximize the liquid yield for most biomass, and vapor residence times of typically less than 2 s to minimize secondary reactions. According to the previous results in our lab, the reaction conditions in this study were selected in view of the optimized bio-oil yield, i.e., temperature of 500 °C and vapor residence time of 1.95 s. Pyrolysis residues of sewage sludge (SSC) were accumulated in the char bins of the unit, and collected after enough cooling in each running. Pyrolysis residues obtained from SS1, SS2