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Thermal treatment on sewage sludge by electromagnetic induction heating: Methodology and drying characterization

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ABSTRACT

Thermal drying of sewage sludge is not only an effective way to treat the waste, but also an essential step for further energy utilization. This work focused on drying property of sewage sludge by using electromagnetic induction heating. A novel drying method for sewage sludge was designed. The effects of different electromagnetic-induction media materials, working parameters and conditioning reagents on the efficiency of drying were investigated. Then, the kinetics was analyzed. The change of temperature and heat-transfer was analyzed during the drying process. Experimental results showed that sewage sludge combined with three kinds of induction medias can be efficiently dried by applying electromagnetic induction heating. Fast formation and development of cracks indicated that an increase of drying rates of sludge can be obtained. Considering the release of volatile organic compounds from sludge during drying process, estimated moisture content was used to evaluate the drying effect. A Higher working voltage leaded to a more weight reduction of sludge during a shorter drying time, but a lower voltage prolonged the drying time. It was noted that the estimated moisture rate was very close to the experimental moisture content. Sludge content, forming and induction media significantly affected the drying process. Plate and net media were fitted for thin layer and piled sludge, respectively. However, fiber media seemed to show lower drying rate due to no circuit for induction current. An addition of CaO and sawdust improved the drying process. As a result, few volatile organic compounds released from sludge. For kinetics, three periods (warm-up, constant rate and falling rate period) can be observed and the data fitted linear regression of Lewis drying model very well. The effective moisture diffusivity was influenced by the different induction media and the thickness of sludge. Infrared images showed that outside temperature was higher than central part temperature for all sludge samples. A higher evaporation rate and diffusion of moisture can be obtained from outside part of sludge due to the easy collapse of porous structure.

1. Introduction

Large quantity of sewage sludge (SS) are generated during the operation of waste water treatment plants (WWTP) (Vaxelaire et al., 2000). Many technical ways were conducted on the reduction, harmlessness and resource of sewage sludge, such as dewatering (Liu et al., 2013; Yu et al., 2016), drying (Deng et al., 2009; Kurt et al., 2015; Nazari et al., 2017), pyrolysis (Ma et al., 2017; Wang et al., 2018; Zhang et al., 2014), combustion (Fernandez-Anez et al., 2014; Kijo-Kleczkowska et al., 2015; Liu et al., 2018) and composting (Kulikowska, 2016; Ya-Wei et al., 2017). Generally, it was found that the engineering application, waste to energy or disposal of sewage sludge is constricted due to its higher moisture content (Nazari et al., 2017). Mechanical dewatering devices such as filters or centrifuges are not always sufficient to insure a high dehydration, thus a thermal drying step is often necessary (Chen et al., 2002; Deng and Su, 2014; Vaxelaire et al., 2000). As a result, it is evident that thermal drying plays an important role. Drying treatment on sewage sludge not only reduces the volume of sludge, but also the cost of treatment of the final product. In addition, it increases the concentration of the organic matters which facilitates to be decomposed and burned (Arlabosse et al., 2012; Bennamoun et al., 2013).

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In the drying field, several techniques have been developed. It can be categorized into three main modes: convective drying, conductive drying and finally solar drying. It is possible to combine different drying methods and dryers to realize the drying process of sludge. For the conductive drying methods, the surface of the dryer which delivers the heat to the sludge is heated by heating fluids, such as thermal oil or saturated steam. These heating fluids are mainly heated either by electricity or by a boiler burned with fossil fuel or biomass. In general, the dryers are classified into three main technologies: disc, paddle and thin film dryers (Bennamoun et al., 2013). Drying process is also usually integrated with other treatment technologies, such as dewatering process or incineration process, to efficiently and widely realize the reduction and reutilization of sludge (Deng and Su, 2014).

Based on the technologies mentioned above, many researches have been conducted on thermal drying characteristics and mechanism. Factors such as sludge type, drying temperature, air velocity, relative humidity, time, moisture content, additive, and emission, which are affecting the drying process, have been well studied and reported in previous researches (Ali et al., 2016; Arlabosse and Chitu, 2007; Deng and Su, 2014; Horttanainen et al., 2017; Hsu et al., 2010; Li et al., 2012; Tuncal, 2010; Vega et al., 2015; Weng et al., 2015; Zerlottin et al., 2013). Among these studies, five main kinds of heat sources were directly used in sludge drying process. These heat sources, such as heating oil, hot air, high-pressure steam, solar and microwave, are usually generated from electric resistance heating, hot-blast furnace, boiler, solar power panel and microwave oven respectively. It is known that electromagnetic induction (EMI) is an efficient, fast and energy saving heating method which has been widely used in scientific research and industrial field (Bayerl et al., 2014; Bera and Babadagli, 2015; Norambuena-Contreras and Garcia, 2016; Sadeghia et al., 2017). Induction-heating has been carried out for three sewage sludges from the food processing factories and showed a potential for biomass energy resource (Tsai et al., 2009a,b,c). At the meantime, Tsai et al. have investigated the pyrolysis of bio-oil from sewage sludge by induction-heating and the level of polycyclic aromatic hydrocarbons in pyrolysis bio-oil (Tsai et al., 2009a,b,c). These three literatures have focused on the pyrolysis in food-processing sludge and proved that induction-heating can be used as heat source in a process of pyrolysis. A patent (Kim and Jung, 2006) introduced a method for induction heating drying sludge by using a mesh convey belt as induction media. It was like one of medias used in this work. The plate and fiber which were used as induction medias during EMI heating have been not reported. Generally, EMI heating becomes very popular because of its non-contact, pollution-free and fast distribution of thermal energy within the object of interest. Using EMI heating method to thermally treat sewage sludge during the drying process has not been reported.

In this work, a novel sludge drying method based on electromagnetic induction heating was firstly established. Then the studies were carried on to characterize the fundamental behavior of the sludge during drying process. The influencing factors, such as working voltage, electromagnetic induction media, moisture and sludge content, induction time and additives, were discussed. Kinetics models for EMI drying process were fitted; finally, the drying effect and mechanism were evaluated and interpreted, respectively.

2. Materials and methods

2.1. Materials

Mixed sewage sludge used in this work was collected after mechanical dewatering with cationic polymeric flocculants as conditioner from Luobuzui wastewater treatment plant in Wuhan, China. Raw sludge samples were stored at 4 °C in a refrigerator. The moisture content, pH and lower heating value of raw sludge sample were 84%, 6.9 and 6.08 MJ/kg. The content of carbon, hydrogen, nitrogen, sulfur and oxygen of raw sludge sample from ultimate analysis were 12.48%, 1.48%, 1.95%, 0.41% and 10.28%, respectively. Al_2O_3 and SiO_2 were the main inorganic chemical compounds of dry based raw sludge. Three iron media materials were used in this work. Seen from Fig. 1, three media materials are remarked as electromagnetic induction fiber (EMI-F), electromagnetic induction plate (EMI-P) and electromagnetic induction net (EMI-N), respectively. Among these media materials, EMI-F and EMI-N are defined as inner induction media which are mixed and formed with sludge. EMI-P is defined as outer induction media which is regarded as a container with a thin layer of sludge in it. Quicklime used in this study was passed through a screen of 0.5 mm, and the content of free-CaO was above 60%. Wood sawdust was used in this work and collected from local wood processing plant. The characteristics of different sewage sludge samples are listed in Table 1.

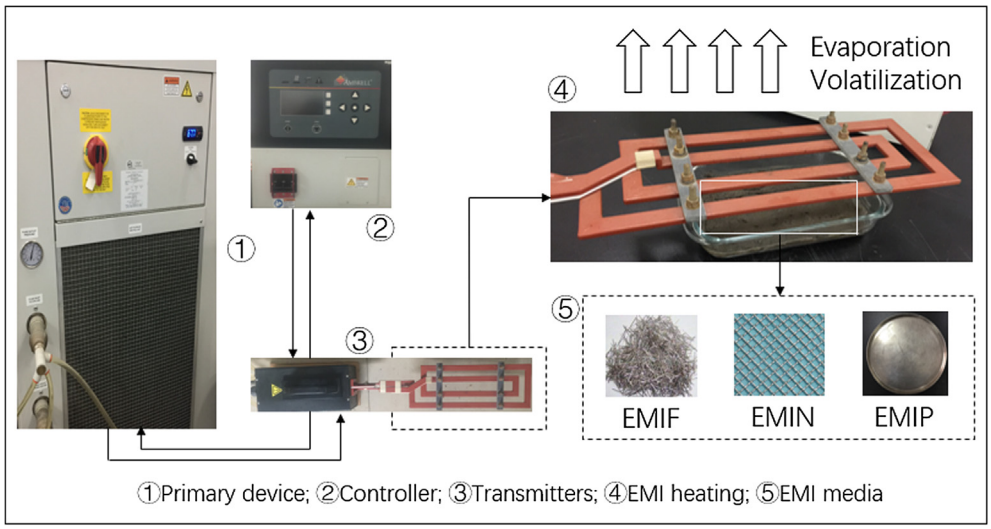

Fig. 1. Experimental installation and flow of electromagnetic induction heating method.