JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

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JES JOURNAL OF ENVIRONMENTAL SCIENCES

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Q1 Experimental continuous sludge microwave system to enhance dehydration ability and hydrogen production from anaerobic digestion of sludge

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ARTICLE INFO

Article history:
Received 26 February 2017
Revised 22 August 2017
Accepted 22 August 2017
Available online xxxx

Keywords:
Sludge
Microwave
Dehydration performance
Conditioning
Continuous
Anaerobic digestion

ABSTRACT

Dehydrating large amounts of sludge produced by sewage treatment plants is difficult. Microwave pretreatment can effectively and significantly improve the dewaterability and hydrogen production of sludge subjected to anaerobic digestion. The aim of this study was to investigate the effects of different microwave conditions on hydrogen production from anaerobic digestion and dewaterability of sludge. Based on an analysis of the electric field distribution, a spiral reactor was designed and a continuous microwave system built to conduct intermittent and continuous experiments under different conditions. Settling volume, capillary suction time, particle size, and moisture content of the sludge were measured. The results show that sludge pretreated in continuous experiments has equally remarkable dehydration performance as intermittent experiments; the minimum moisture content was 77.29% in the intermittent experiment under a microwave power of 300 W and an exposure time of 60 sec, and that in the continuous experiment was 77.56% under a microwave power of 400 W and an exposure time of 60 sec. The peak measured by differential scanning calorimeter appeared earliest under a microwave power of 600 W and an exposure time of 180 sec. The heat flux at the peak was 4.343 W/g, which is relatively small. This indicates that microwave pretreatment induced desirable effects. The maximum yield of hydrogen production was 7.967% under the conditions of microwave power of 500 W, exposure time of 120 sec, and water bath at 55°C. This research provides a theoretical and experimental basis for the development of a continuous microwave sludge-conditioning system.

Q4 Introduction

In 2014, more than 3500 sewage treatment plants were built and put into operation in China, which provided new daily treatment capacity of 140 million m^3 (Qu et al., 2014). Sludge, a by-product of sewage treatment, contains not only organic matter, nitrogen, phosphorus, and potassium; but also biodegradable substances, heavy metals, salts, pathogens, and parasites. It is difficult to dehydrate and has problematic biochemical properties. Because a large quantity of sludge is produced on a daily scale, covering a wide area, if not handled properly, it will cause serious secondary pollution of the environment (Hu et al., 2005; Wang et al., 2014). In order to facilitate its transport and resource recovery, sludge needs to be conditioned using physical, chemical, and biological

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http://dx.doi.org/10.1016/j.jes.2017.08.016
1001-0742/

Please cite this article as: Zhou, C., et al., Experimental continuous sludge microwave system to enhance dehydration ability and hydrogen production from anaerobic digestion of sludge, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.08.016

methods (Yuan et al., 2007; Zhu et al., 2010). Currently a relatively novel pretreatment method, microwave technology, has drawn attention because it can effectively improve sludge dehydration performance, decrease processing time, and reduce the usage of reagents (Eskicioglu et al., 2007; Fu et al., 1999; Yu et al., 2009). Through microwave pretreatment, pathogens can be effectively killed and biosolids can be cracked. Organisms in sludge are broken down into ammonia and phosphate that can be used as fertilizer for plant production. Moreover, microwave pretreatment can also assist in the extraction and digestion of heavy metals in pyrolysis sludge, as well as in the stabilization of metal ions in soil or sludge (Hong et al., 2004; Kuo et al., 2005; Menendez et al., 2002; Tang et al., 2010; Tyagi and Lo, 2013). Sludge contains rich organic substances such as proteins, carbohydrates and fat, so transforming this organic matter into available energy is another effective way of recycling resources (Liao et al., 2005).

Anaerobic digestion is among the top methods for sludge disposal, and is used not only to reduce environmental pollution, but also to produce renewable energy from waste (Lu et al., 2013). In the most common anaerobic sludge treatment process, fermentation and hydrogen production from sludge is an intermediate stage. With careful control at this hydrogen production stage, it is possible to obtain clean energy and pretreat sludge simultaneously (Chen et al., 2007).

Previous studies have experimentally studied the effect of microwaves on the characteristics of sludge. Several research teams (Eskicioglu et al., 2009; Hong et al., 2006; Park et al., 2004) proved that microwave pretreatment is capable of cracking sludge flocs and biological cells, and thereby capable of releasing organic matter and transforming them into their soluble phase. Liang et al. (2012) applied microwave radiation to condition sludge, and discovered that microwave can significantly improve the dehydration performance of sludge under appropriate conditions. Zhou et al. (2013a, 2013b) carried out research on microwave conditioning of sludge and found that dehydration performance of sludge exhibited significant changes after microwave conditioning, affecting qualities such as soluble chemical oxygen demand, particle size of sludge, and viscosity. Wojciechowska (2005) applied microwave to condition sludge and found the specific resistance to filtration of mixed sludge and anaerobic digested sludge, was reduced by 27% and 26%, respectively. Eskicioglu et al. (2008) found that at 90°C, dehydration performance of sludge was improved by about 40% (pretreatment with microwave at 90°C for 10 min), and that the capillary suction time (CST) of sludge with total solid content of 5.8% was significantly decreased. Water distribution and the mechanical dehydration performance of sludge are closely associated, and can be used directly to measure the degree of difficulty of mechanical dehydration: the larger the volume of bound water, the more difficult the mechanical dehydration (Colin and Gazbar, 1995). The relationship between temperature and heat flow (related to the thermal transition temperature of internal materials) was determined using differential scanning calorimeter (DSC). This technique is used for measuring thermal effects of samples under temperature control programs, and is widely used for studying thermal properties, phase transition, and crystallization kinetics of a wide variety of organic, inorganic, polymeric, metallic, semiconductor, pharmaceutical, and biological materials. Although the application of the DSC for moisture testing of sludge is still relatively rare, its excellent performance has made it widely used in studies of crude oil, high-concentration oil–water emulsions, and drilling (Clausse et al., 2005; Dalmazzone et al., 2006, 2010; Garti et al., 2000; Le Parlouer et al., 2004; Kovalchuk and Masalova, 2012; Zhu et al., 2011). The DSC has also been applied in the food industry (Chen et al., 2010). In this study, the DSC was used to measure the bound water content of sludge to characterize its dehydration performance (Zhou et al., 2014).

Carrère et al. (2010) reviewed studies on the effect of different pretreatment methods on anaerobic fermentation of sludge. Pino-Jelcic et al. (2006) and Hao et al. (2011) found that the amount of biogas produced from sludge increased when the sludge was pretreated using microwave radiation. Shen et al. (2009) compared the effect of heat pretreatment, microwave pretreatment, and chloroform pretreatment on the anaerobic fermentation of organic waste, and found that the microwave pretreatment is the most suitable method for improving hydrogen production from anaerobic reaction.

Current microwave sludge pretreatment research has been focused on the use of intermittent microwave conditioning, research based on continuous microwave conditioning is still relatively rare. Because the production of sludge in sewage treatment plants is continuous, it is necessary to develop a continuous microwave conditioning device for sludge, if this conditioning apparatus is to be used at industrial scale. Based on previous work on intermittent microwave conditioning, a continuous microwave conditioning device was created for these experiments. It was used to compare the effects of intermittent and continuous microwave conditioning on dehydration performance of sludge. Additional experiments were performed to assess the effects of microwave pretreatment on hydrogen production from anaerobic digestion.

1. Method

1.1. Design of continuous microwave conditioning system

To obtain the device needed for continuous sludge conditioning, a main reactor was designed and resonant-cavity was numerical simulated. According to the characteristics of the processing materials and microwave conditions, a continuous conditioning system was established, as shown in Fig. 1. It included four

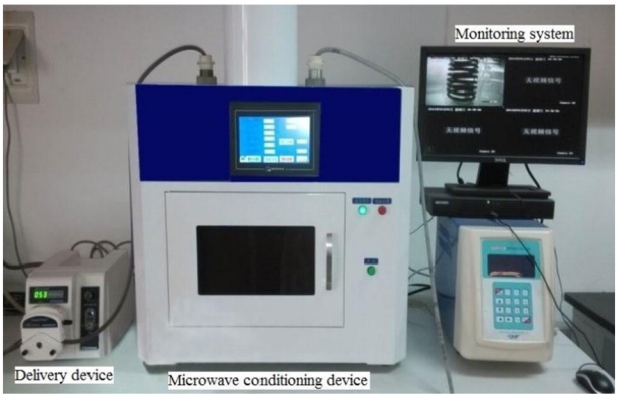

Fig. 1 – Continuous microwave sludge conditioning system.

Please cite this article as: Zhou, C., et al., Experimental continuous sludge microwave system to enhance dehydration ability and hydrogen production from anaerobic digestion of sludge, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.08.016