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Experimental study on agitated drying characteristics of sewage sludge under the effects of different additive agents

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ABSTRACT

Drying experiments of dewatered sewage sludge (DSS) were conducted on a agitated paddle dryer, and the effects of additive agents, i.e., CaO, pulverized coal (PC), heavy oil (HO), and dried sludge ("DS" through back mixing) on the agitated drying characteristics of DSS were investigated. The results indicated that CaO can significantly increase the drying rate of DSS. The drying rate at CaO/DSS (mass ratio) = 1/100 was 135% higher than that of CaO/DSS = 0. Pulverized coal has no obvious effect on drying rate, but the increase of PC/DSS can promote breaking up of sludge lump. Heavy oil was found to be slightly effective in improving the drying rate of DSS in the examined experimental range of HO/DSS = 0–1/20. It is also found that HO can reduce the torque of the dryer shaft, due to its lubrication effect. Back mixing of DS was found to be effective in alleviating the unfavorable effect of the lumpy phase by improving the mixing effect of the paddle dryer. There was a marked increase of drying rate with an increase of the DS/DSS in the experimental range of DS/DSS = 0–1/3.

Introduction

Sludge management is still an important problem in China and many parts of the world. Presently, tens of millions of tons of dewatered sewage sludge (DSS) are annually generated in China from municipal and industrial wastewater treatment plants (MIWTPs) (Dai, 2012). Most of the sludge from MIWTPs was directly or indirectly applied to agricultural land or disposed by landfilling (Uggetti et al., 2010). For sludge treatment, usage, and disposal, low moisture content is usually required. Mechanical solid–liquid separation 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).

Amount of studies have been conducted on thermal drying mechanism of drying process, and its drying kinetics have been studied using comprehensive models for heat and mass transfer (Deng et al., 2009a, 2009b; Yan et al., 2009; Tao et al., 2006, 2008; Vaxelaire et al., 2000). Important factors affecting the performance of the drying process, including drying temperature, air velocity, relative humidity, formation of crusts, and sludge moisture content, have been well studied and reported in previous research (Li et al., 2012; Arlabosse and Chitu, 2007; Tuncal, 2010; Hsu et al., 2010). Drying is an important intermediate treatment process preparing for other sludge disposal methods. For instance, sludge drying-incineration is an important method for sludge disposal (Werther and Ogada, 1999). Sludge drying-incineration can reduce sludge to a mass of ash that is less than 20% of its original volume and eliminate some environmental and health problems by destroying pathogens and toxic organic chemicals. However, desulfurizing agents (CaO, $Ca(OH)_2$, $CaCO_3$, etc.) are often necessary for sludge incineration due to high sulfur content of DSS (Deng et al., 2009b). Auxiliary fuels (coal, heavy oil, biomass, etc.) are also important for maintaining a stable combustion condition during sludge incineration process (Liu et al., 2011). For sludge drying-incineration system, it is technically and economically feasible to introduce desulfurizing agent or auxiliary fuels (regarded as "additive agents" for drying system) into the drying process, given that these additive agents have positive effect on sludge drying. However, few reports focusing on the effects of additive agents on the drying characteristics of DSS can be found.

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Table 1 – Proximate and ultimate analysis of DSS and pulverized coal (PC). [a]

Species	Value of DSS (wt.%)	Value of PC (wt.%)
Ash	54.7	37.9
Volatile	37.4	6.7
Fixed carbon (FC)	6.1	54.1
Carbon in volatile and FC	25.2	54.1
Hydrogen in volatile and FC	3.9	2.5
Nitrogen in volatile and FC	2.6	1.2
Sulfur in volatile and FC	1.6	0.3
Oxygen in volatile and FC	9.3	2.6

[a] On a dry basis.

Table 2 – Ultimate, physical and chemical analysis of heave oil.

Species	Value
Carbon	86.1 wt.%
Hydrogen	9.5 wt.%
Nitrogen	0.7 wt.%
Sulfur	1.3 wt.%
Oxygen	2.4 wt.%
Density	955 kg/m^3
API (American Petroleum Institute)	16.1°API
Viscosity	2.4°E
Flash point	110°C
High heating value	41.6 MJ/kg
Moisture content	0.9 wt.%

In this study, the agitated drying characteristics of DSS were studied, and the effects of four additive agents, i.e., CaO, pulverized coal (PC), heavy oil (HO), and dried sludge (through back mixing), on the drying characteristics of DSS were investigated. The advantages and disadvantages of different additive agents on drying system were discussed.

1. Materials and methods

1.1. Materials

A kind of mechanically dewatered sewage sludge (DSS) which was produced from aeration basins using anaerobic/oxic wastewater treating system was sampled from a municipal sewage treatment plant in Hangzhou city of Zhejiang province. The moisture content of DSS was 4.7 kg moisture/kg dry solid (DS). DSS samples were stored in a refrigerated container at 4°C before experiments. The principal characteristics of DSS are listed in Table 1.

Four kinds of additive agents, i.e., calcium oxide (CaO), HO, PC, and DS were respectively introduced during DSS thermal drying process. CaO is an analytical reagent with an average diameter of 50.2 μm. HO was produced from pyrolysis of scrap tire at 600°C, the ultimate, physical and chemical analyses of HO were shown in Table 2. The average diameter of PC was 40.2 μm. The proximate and ultimate analysis of PC is shown in Table 1 as well. Dried sludge was produced from thermal drying of DSS and was back mixed with DSS before drying in the back mixing experiments.

1.2. Experimental procedures

Fig. 1 shows the experimental set-up of the DSS drying system. The system is mainly composed of a glass cylindrical vessel (8 cm in diameter) placed in an oil bath, used as the heating unit of the dryer. A mixing shaft with six paddles was driven by an electric motor. The distance between paddles and hot surface was 1 mm. The dryer was run batch-wise. The drying rate was measured by condensing the water vapor in a water-cooled condenser and continuously measuring the condensate mass flow during the entire experiment. The drying rate (R) was calculated by the following equation:

$$R = (W_i - W_{i+1})/((t_{i+1} - t_i) \times W_{DS})$$

where, R (kg H_2O/(min kg DS)) is the drying rate; t_i and t_{i+1} are the drying time, min; W_i (kg) and W_{i+1} (kg) are the mass of sludge sample at the drying time of t_i and t_{i+1}, respectively; and W_{DS} (kg) is the mass of dried sludge sample.

Sludge temperature was measured by inserting a thermocouple 2 cm into the product. The torque at the stirrer was measured by a torque dynamometer. Scrapers are both necessary for improving the mixing effect of the paddles, and for producing a dried sludge product in a granular form. In order to study the effect of different additive agents on the drying characteristics of the DSS, the additive agents and DSS were premixed at different

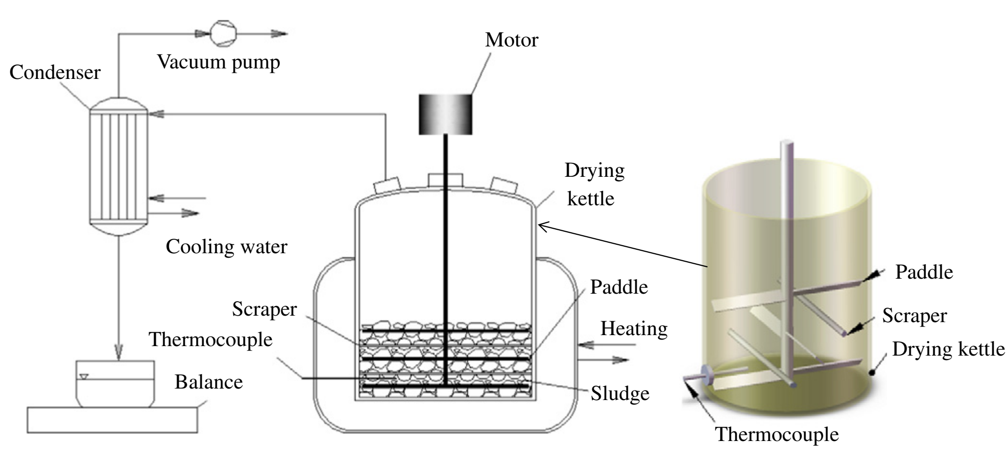

Fig. 1 – Schematic diagram of experimental set-up.