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Research article

The porous structure effects of skeleton builders in sustainable sludge dewatering process

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ABSTRACT

Dewatering from sludge is an important sustainable issue in recent years, in this work, we found the unique behavior: Skeleton builder additions can improve the dewatering performance greatly, which related to the different pore structure of skeleton builder. As compared to the coal ash, sawdust and rice husk char are easier to construct porous channels in the sludge body, which is responsible for the discharge of water. the dewatering efficiency can increased from approximately 30%–65% by pipe network effect and interlayer channel effect, a sufficient amount of skeleton builders establish a complete pipe drainage network in the sludge body, allowing the water to be discharged fluently. Moreover, the skeleton builders can cause the sludge body to form a layered structure. Under the combined action of pipe network effect and interlayer channel effect, the deep-dewatering effect increased largely by the addition of skeleton builders.

1. Introduction

Environment and Energy aspects are two main topics in the world (Du et al., 2018; Zhou et al., 2018), but the waste disposal will become an important environmental issue recently, Domestic sewage treatment by bio-methods can produce a large amount of sewage sludge. The key issue of sludge treatment aims at reducing the moisture content efficiently (Ren et al., 2015; Skinner et al., 2015; Zhang et al., 2015). In order to facilitate the subsequent disposal and resource utilization, the general method of mechanical dehydration can reduce the moisture content of sludge to the level of approximately 80%, which is far below the requirements of sludge treatment (Yang et al., 2015), and thus, a deep dehydration is necessary and required. Thermal drying and sludge conditioning as well as mechanical dehydration methods are commonly used in sludge deep dewatering process. However, high energy consumption and serious secondary pollution problems will significantly inhibit its efficient application (Mahmoud et al., 2016; Tang et al., 2018; Zhang et al., 2014); therefore, efficient approach is urgent and raised a wide-spread research interests.

As well known, sludge dewatering mainly contains two important procedures, that is solid-liquid separation at first, and the sequent extrusion for separation water from sludge (Christensen et al., 2015). Recent study shows that the surface adsorption water and internal hydration water can be converted into free-water by series sludge pretreatment (To et al., 2016), thence favoring for the solid-liquid separation. However, in fact, it is difficult to achieve the efficient deep dehydration, because the organic matter content of sludge floc will lead to a high compressibility, and the drainage channels in sludge body will be shut down by the high mechanical pressure during the squeeze process (Collard et al., 2017; Li et al., 2014a). Thus, a dense layer will form on the surface of the sludge body, and deep water separation cannot be discharged completely. Therefore, the use of chemical conditioning can only improve the sludge dewatering performance to some extent (Vega et al., 2015; Zhang et al., 2017c) However, because of the supporting effect of skeleton builder, the porous structure still exist in the sludge body under the great mechanical pressure, so the water can flow out of the sludge body easier. The commonly used skeleton builders by researchers are simple and easy available solid materials, such as powdered coal ash (Cieślik et al., 2015), lime (Hu et al., 2017), sawdust (Deng et al., 2017), wheat grits (Guo et al., 2015), gypsum (Nittami et al., 2015), red mud (Zhang et al., 2014), lignite (Hoadley et al., 2015), rice husk char (Wu et al., 2016b) and so on.

Liu et al. (2017) reported that the addition of sawdust could increase the sludge dewatering rate, and the degree of dewatering effect was also significantly improved with the doses additions. Luo et al. (2013) found that the sludge cake can convert relatively incompressible

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after sawdust conditioning. Sawdust can maintain the permeability of sludge cake by resisting sludge compression during the squeezing process. The permeability of sludge is improved with the increase of sawdust mass ratios gradually. Jeffery et al. (2011) reported biochar has highly enriched carbon skeleton and the surface compared to the biomass material presented a more porous structure. Wu et al. used biochar as a skeleton builder to construct a porous structure in the sludge body, thereby improving the sludge dewatering effect (Wu et al., 2016a). When the amount of treated bio-char was 70% WS, the moisture content of the cake decreased from 76.9% to 70.3%. Powdered coal ash was also a mechanical mixture of various particles. The cool-down PCA mainly consisted of silica-alumina vitreous body and a small amount of carbon granules. the vitreum was constituted by single bead, linked bead body and spongy irregular porous body (Qi et al., 2011). Chen et al. indicated that the addition of unmodified powdered coal ash or sulfuric acid modified powdered coal ash can effectively improve the centrifugal dehydration effect of sludge, but the effect of modified powdered coal was much better than unmodified powdered coal ash (Chen et al., 2010).

Numerous research results reflect that skeleton builder played an indispensable important role on deep-dewatering of sludge (Li et al., 2014b; Liu et al., 2016; Nittami et al., 2015). Nowadays, most of research aims at the behaviors of skeleton builder conditioning, or the effect of adding skeleton builder on sludge dewatering performance (Vega et al., 2015). However, little is known that the channel structure effects of the skeleton builders on dehydration of sludge, it will be an important guideline to efficient deep dehydration in application.

In this work, three kind of commonly used skeleton builders, sawdust, rice husk carbon (RHC) and powdered coal ash (PCA) were investigated systematically. Series experiments, including the sludge conditioning by chemical agent, skeleton builders combined with chemical agent, as well as the corresponding dehydration effect tests were performed to prove the different sludge dewatering process, i.e., solid-liquid separation process and water discharge process. Microcosmic observation and analysis were carried out on the filter cake obtained in each of the above experiments and three kind of skeleton builders, in order to get the channel structure form in the sludge constructed by the skeleton builders. Then, contrasting with dehydration effect of different skeleton builders, function mechanism of skeleton builder for sludge dewatering was preliminary discussed in this paper.

2. Materials and methods

2.1. Materials

The pre-dewatered sewage sludge was obtained from Qinhuangdao third sewage treatment plant, and the moisture content was approximately 80%–85%. The three kinds of skeleton builders used in this experiment of sawdust, rice husk char (RHC) and powdered coal ash (PCA) was kindly provided by JIJIANG Water filters Co., China. The chemical conditioners used in this experiment were CTAB (analytic grade) and CPAM (analytic grade) respectively.

2.2. Experiment section

2.2.1. Chemical reagent condition and dehydration experiment

Two kinds of chemical conditioning agent were used in the experiments for conditioning. The dose of CTAB was 0 g, 0.9 g, 1.2 g, and 1.5 g, and the dose of CPAM was 0 g, 0.5 g, 0.65 g, and 0.75 g respectively. The above doses were well dissolved in 50 ml of deionized water with 200 g of sludge addition. Stirring for at least 15 min was necessary to ensure the reaction completely. Finally, the mixture was put into mechanical filter-press equipment and pressed for 20 min under 1.3 MPa.

2.2.2. The hybrid condition and dehydration experiment

In the previous section, the optimal amount of CTAB and CPAM can be obtained. The optimal amount of CTAB and CPAM was combined with sawdust, rice husk and powdered coal ash to perform joint conditioning and dehydration experiments. The dosage of the skeleton builders was 0 g, 5 g, 10 g, 15 g, 20 g, and 25 g respectively.

2.3. Analysis method

Specific surface area of RHC and PCA was measured using BET specific surface area analyzer (Model ASAP 2020) by N_2-BET method. The particle size distribution of PCA was measured by BT-9300H type particle size distribution analyzer and that of sawdust was measured by Malvern laser particle size analyzer. In addition, the microscopic structure of cake and the micro-shape of skeleton builders were observed by Field Emission Scanning Electron Microscopy (FE-SEM).

Dewatering rate is defined as the ratio of the amount of the water lost before and after press exerting. Considering the moisture content of cake (After skeleton builder conditioning) is seriously affected by the moisture content of the skeleton builder and the amount of use, so it is difficult to examine the sludge dehydration effect, while dewatering rate is an suitable parameter for it with the following equations.

① The calculative equation of sludge dewatering rate of raw sludge and that conditioned by chemical conditioners alone was as follow:

$$D = \frac{W_1 - W_2}{W_1 \times P_1} \times 100\% \quad [1]$$

Where P_1 is assigned to the moisture content of the sludge before dewatering (%), W_1 is the amount of the sludge (g), W_2 is the amount of the filter cake (g), and D reflects the sludge dewatering rate (%).

② The calculative formula of sludge dewatering rate conditioned by skeleton builder alone and by chemical conditioners combined with skeleton builders was as follow:

$$D = \frac{W_1 + W_J - W_2}{W_1 \times P_1} \times 100\% \quad [2]$$

Where W_J is the quality of skeleton builder (g), others are the same as the above.

3. Results and discussion

3.1. The properties of the three kinds of skeleton builders

The moisture content, specific surface area, and pore distribution of sawdust, RHC and PCA had been determined with the results of Table 1 and Fig. 1. It can be found that the lowest moisture content is attached onto RHC with the value of 1.03%, comparatively, that of sawdust can obtain a highest value of approximately 5.52%. As for the surface areas, an ultrahigh surface areas of 489.6 m^2/g can be attached, which is equal to 30 times greater than PCA samples. Whereas the pore size of

Table 1
The main pore structure parameters of three skeleton builders.

	Moisture content (%)	BET specific surface area (m^2/g)	Average pore size (nm)	Pore volume (cm^3/g)	Particle size D50 (μm)[a]	Particle size D90 (μm)[a]
Sawdust	5.52 ± 0.2	–	–	–	689.8	1250.4
RHC	1.03 ± 0.2	489.6	4.21	0.663	408.7	834.8
PCA	2.76 ± 0.3	16.7	8.41	0.0263	38.1	89.2

[a] The definitions of D 50 and D 90 have been added in supporting information.