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Short Communication

Possibility of sludge conditioning and dewatering with rice husk biochar modified by ferric chloride

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HIGHLIGHTS

- Positive charge from MRB–Fe surface counteracted negative charge of sludge flocs.
- MRB–Fe effectively improved sewage sludge dewaterability as a skeleton builder.
- Incompressible and permeable sludge cakes were formed through adding MRB–Fe.

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ABSTRACT

Rice husk biochar modified by $FeCl_3$ (MRB–Fe) was used to enhance sludge dewaterability in this study. MRB–Fe preparation conditions and dosage were optimized. Mechanisms of MRB–Fe improving sludge dewaterability were investigated. The optimal modification conditions were: $FeCl_3$ concentration, 3 mol/L; ultrasound time, 1 h. The optimal MRB–Fe dosage was 60% DS. Compared with raw sludge, the sludge specific resistance to filtration (SRF) decreased by 97.9%, the moisture content of sludge cake decreased from 96.7% to 77.9% for 6 min dewatering through vacuum filtration under 0.03 MPa, the SV_{30}% decreased from 96% to 60%, and the net sludge solids yield (Y_N) increased by 28 times. Positive charge from iron species on MRB–Fe surface counteracted negative charge of sludge flocs to promote sludge settleability and dewaterability. Meanwhile, MRB–Fe kept a certain skeleton structure in sludge cake, making the moisture pass through easily. Using MRB–Fe, therefore, for sludge conditioning and dewatering is promising.

1. Introduction

With the increasing of wastewater generation and wastewater treatment efficiency, the growth rate of sewage sludge, which containing over 90% water, is going up. Sewage sludge management is a challenging issue for water industries (Thapa et al., 2009a). Sludge conditioning and dewatering is the paramount important step in the sludge treatment (He et al., 2015; Zhang et al., 2012). Chemical conditioning, such as adding ferric chloride cationic, polyacrylamide and so on to improve sludge dewatering, is commonly used in wastewater treatment plants (Chen et al., 2015). It is noted that chemical addition could enhance sludge dewaterability in certain extent. But due to the high compressibility of sludge with chemical conditioning, the sludge dewatering rate was hindered by the blinding of filtration media and the filter cake (Qi et al., 2011).

In order to decrease the sludge compressibility, physical conditioners used as skeleton builders were investigated. Gypsum, lignite, slag and construction and demolition waste were also used for sludge condition and dewatering (Asakura et al., 2009; Thapa et al., 2009a,b; Zhao, 2002). In these researches, permeable and more rigid lattice structures were formed and the sludge cakes maintained permeable during the compressed filtration, leading to improvement of sludge dewaterability. But adding physical conditioners had little impact on enhancing the sludge dewaterability unless using in together with chemical conditioners (thus it was complicated to find the optimum combination dosing) or using large amounts of physical conditioners (which would greatly increase the sludge solids). Therefore, physical conditioners modification was investigated. Chen et al. (2010) proved that coal fly ash modified by sulfuric acid had much stronger capacity for sludge

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dewatering than raw coal fly ash, and the dosage of coal fly ash modified by sulfuric acid was much less than raw coal fly ash.

In our preliminary study, rice husk biochar was used to improve sludge dewaterability with adding ferric chloride ($FeCl_3$). The specific resistance to filtration (SRF) of sludge decreased by 93.14% and the net sludge solids yield (Y_N) increased by 4.46 times compared with the raw sludge. But the influence of adding rice husk biochar alone in sludge dewaterability was not obvious. Several methods, such as acid and alkali modification, and chemical graft, have been used to modify biochars to enhance biochars adsorption performance for wastewater treatment (Fierro et al., 2009; Jing et al., 2014; Liu et al., 2011; Ma et al., 2014). There is little information on the possibility of modified biochars for sludge dewatering. The challenge of this study is to modify the rice husk biochar by $FeCl_3$ to enhance rice husk biochar capacity for sludge dewatering.

In this paper, the optimal preparation method of rice husk biochar modified by $FeCl_3$ (MRB–Fe) and the possibility of improving sewage sludge dewaterability and settleability with MRB–Fe as skeleton builders were explored. The dosage of MRB–Fe for sludge dewatering was optimized. The changes of zeta potential, the characteristics of raw rice husk biochar (raw RB) and modified rice husk biochar (MRB–Fe), and the microstructure of sludge cakes were investigated to analyze the mechanisms.

2. Methods

2.1. Materials

Sewage sludge was obtained from the sludge thickening tank of a local municipal wastewater treatment plant (WWTP) in Changsha, Hunan, China. A modified oxidation ditch process was used in this WWTP. The sewage sludge was transported to laboratory in an airtight polythene cask and was stored at 4 °C before used. When experiments were carried out, the sewage sludge was firstly kept in a water bath at 20 °C for 30 min (Chen et al., 2010). The main sludge characteristics were: moisture content of 98.4%–98.8%, dry solid (DS) content of 12.05–16.25 g/L, SRF of 1.04×10^{13}–5.13×10^{13} m/kg, Y_N of 0.62–0.98 kg/(m^2·h).

2.2. Preparation of MRB–Fe

Raw rice husk biochar (RB) (80–250 μm) was prepared in an airtight crucible with limited supply of air at 500 °C for 2 h in a muffle furnace which was the optimal preparation condition in preliminary study. $FeCl_3$ with a concentration of 1, 2 and 3 mol/L was used for rice husk biochar modifying respectively. The rice husk biochar of 10 g was firstly soaked in 500 ml of hydrochloric acid (1 mol/L) for 24 h, after which the rice husk biochar was filtered, cleaned and dried in the oven. Then the rice husk biochar, which was soaked in $FeCl_3$ solution (solid–liquid ratio is 1:10), was placed into an ultrasonic cleaner (KQ2200V) at 30 °C for 0.5, 1 and 1.5 h, respectively. Lastly, the rice husk biochar was filtered and dried in the oven and milled. The particle size of MRB–Fe was distributed within a range of 80–250 μm.

2.3. Sludge conditioning and dewatering

MRB–Fe was added into 200 ml sewage sludge. After mixing at rapid agitation (350 r/min, 30 s), followed by slow agitation (40 r/min, 3 min), 100 ml of the conditioned sludge was poured into a 100 ml measuring cylinder and settled for 30 min to measure the sludge settleability. The sludge settleability was evaluated with SV_{30}%. And 100 ml of the conditioned sludge was put into a 9 cm Buchner funnel under a pressure of 0.03 MPa for sludge dewaterability analysis. The sludge dewaterability was evaluated with SRF, Y_N and moisture content of sludge cake. After the sludge filtration, a sludge cake was formed. The microstructure and coefficient of compressibility of sludge cakes, and zeta potential of sludge supernatant were tested to verify the conditioning mechanisms. Each experiment was repeated twice or more, and the average value was used to evaluate the performance of sludge conditioning and dewatering.

2.4. Analytical methods

A standard Buchner funnel test apparatus with a 9 cm Buchner funnel and qualitative filter paper was used for SRF determination (Chen et al., 2010). The sludge solids obviously increase with the addition of MRB–Fe in this study, so the sludge dewaterability should not be evaluated only with SRF. Relative effectiveness of sludge conditioners could be better evaluated with Y_N, when the sludge solid increased. The Y_N expresses the amount of sludge solids filtered per unit area and unit time, and was also used to evaluate the sludge filterability in this study (Rebhun et al., 1989). And the Y_N was calculated according to Rebhun et al. (1989).

The sludge cake was harvested after 6 min for dewatering through vacuum filtration, and dried to constant weight at 105 °C to measure solid content of sludge cake. The moisture content of sludge cake was measured by gravimetric method. SV_{30}% was measured by volumetric method. The MRB–Fe and raw RB were characterized by ESEM (Quanta 200, America) and EDS (EDAX genesis xm-2, USA). The Zeta potential was analyzed by Zetasizer Nano analyzer (ZEN3600, England). The microstructure of sludge cakes was characterized with the ESEM. The coefficient of compressibility of sludge cakes was measured according to Qi et al. (2011).

3. Results and discussion

3.1. Optimization of MRB–Fe preparation condition

Fig. A.1 shows the effect of MRB–Fe preparation condition on sludge dewatering. The MRB–Fe dosage was 30% DS (300 g rice husk flour was added to each 1 kg sludge DS). Raw sludge and the same dosage raw RB were used as controls. Lower SRF and higher Y_N indicated higher sludge dewaterability (Chen et al., 2010). Fig. A.1 shows that the dewaterability of sludge conditioned with MRB–Fe was significantly superior to that of raw sludge or sludge conditioned with raw RB. And the lowest SRF and the highest Y_N were reached with a $FeCl_3$ concentration of 3 mol/L and an ultrasound time of 1 h. The sludge SRF decreased from 10.40×10^{12} m/kg to 1.13×10^{12} m/kg and the Y_N increased from 0.98 kg/(m^2·h) to 14.56 kg/(m^2·h), compared with raw sludge. The iron content increased with the increase of $FeCl_3$ concentration. Ultrasound of a suitable time could benefit iron species covering on the MRB–Fe surface (Chen et al., 2014). The sewage sludge could be flocculated by iron species to improve its dewaterability (Chen et al., 2015).

3.2. Effect of MRB–Fe dosage

The sludge was conditioned with MRB–Fe (prepared with a $FeCl_3$ concentration of 3 mol/L and an ultrasound time of 1 h). Fig. 1 indicates the effect of MRB–Fe dosage on sludge dewatering and settling. By contrast, the effect of raw RB dosage on sludge dewatering was also performed. Lower SV_{30}% value indicated higher sludge settleability (Chen et al., 2010). When the MRB–Fe was used, the sludge SRF, moisture content of sludge cake and SV_{30}% decreased with the increase of MRB–Fe dosage. The sludge Y_N increased with the increase of MRB–Fe dosage, and the highest