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Interaction of earthworms-microbe facilitating biofilm dewaterability performance during wasted activated sludge reduction and stabilization

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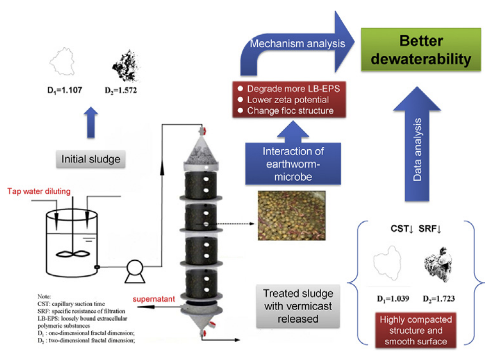
HIGHLIGHTS

- Interaction of earthworms-microbe greatly improves sludge dewaterability.
- Excess sludge floc was more compact and smoother after vermifilter treatment.
- More hard-to-remove water was released in vermifilter.
- Reduction of EPS was facilitated in vermifilter.

GRAPHICAL ABSTRACT



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ABSTRACT

Sludge dewaterability was chemically and morphologically explored during sewage sludge treatment by vermifiltration. The results, with a conventional biofilter (BF, no earthworms) as a control, demonstrated that the capillary suction time(CST) and specific resistance of filtration(SRF) of vermifilter (VF, with earthworms) treated sludge were 64.9 ± 1.7 s and (23.1 ± 1.3) × 10^{12} m/kg,16.8% and 36.0% lower than that of the BF, respectively. Additionally, the VF could efficiently decompose loosely bound extracellular polymeric substances (LB-EPS), releasing more water trapped inside biofilm. Furthermore, the VF enable to reduce the electrostatic repulsive forces between particles, verified by 9.61 ± 0.19 mV of the absolute value of zeta potential, 19.6% lower than that of the BF. Notably, based on scanning electron microscopy (SEM) analysis, the fractal dimension (D_f) of sludge floc structure stated that more small and loose sludge flocs tended to aggregate into bigger inorganic particles. Therefore sludge flocs with highly compacted structure and smooth surface can transform part of vicinal water and water of hydration into easier-removed interstitial water, improving the dewaterability.

1. Introduction

As global urbanization proceeded, sewage sludge treatment and disposal has posed environmental, economic and political challenges for municipal WWTPs, especially for small towns and countryside areas due to high cost of sludge management (Salihoglu and Salihoglu, 2016; Tomei et al., 2016).Reducing the cost of sewage sludge (e.g. disposal, transport, and storage) is closely related with both the volume to be treated and the moisture content (Kamil Salihoglu et al., 2007).

Although several mechanical, physical and chemical methods were available for improving sludge reduction and stabilization, including ultrasonic, thermal and ozone pre-treatment (Wei et al., 2003; Conrardy et al., 2016), most of which required for greater amounts of capital and higher operational costs (Hendrickx et al., 2009; Gorgec et al.,

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2016). Accordingly, it is stated that vermifiltration, involving the interaction of earthworms and microbes, is a newly conceived novel technology to treat excess sludge in an ecological, economical and acceptable way for rural areas. Zhao et al. (2010) advocated firstly to employ vermifiltration to treat sewage sludge, which demonstrated that it not only enabled to reduce volatile suspended solids (VSS) in the range of 56.6– 66.6% but notably offered a polishing process to improve sludge dewaterability during excess sludge treatment. When it comes to the improved sludge dewaterability by earthworms in vermifiltration, the activities of earthworms were firstly and significantly considered, including their burrowing, humus formation, casting activities and also affect organic matter localization. Earthworms, well known as ecosystem engineer, have to ingest and egest large amounts of feeding because of their low assimilation to create feeding porosity and stable aggregates (Schrader and Zhang, 1997). Therefore, earthworm casts (vermicompost) have generally been assumed to be more stable than the parent feeding aggregates.

Waste activated sludge (WAS) flocs are complex and heterogeneous and the characteristics involving size distribution, micro-structure, and surface properties varying from wastewater compositions and operational conditions determine the dewatering process easy or not (Wilén et al., 2003). Notably, highly bounded water of extracellular polymeric substances (EPS) in sludge flocs was closely related with sludge dewatering performance. When it comes to EPS, the absolute value of zeta potentials of the EPS-poor bacteria strains are relatively low compared with those of the EPS-rich strains (Tsuneda et al., 2003). And lower absolute value of zeta potential can make more smaller size particles aggregating closely to form bigger ones with more compacted structure (Li et al., 2016). Additionally, results found that the increased mean flock size were beneficial to the settling properties (Zhao et al., 2010). As for the morphological aspects, previous research also found that the fragmented and porous flocs with more compacted structure and smoother margin, presents better dewaterability. And all these structure characteristics are beneficial to reduce the interstitial water within the sludge markedly and lower the water absorption on sludge surface, and they also can increase the sludge settling velocity and decrease the compacted volume.

Therefore, the objective of this study was to systematically assess the dewaterability improved by the interaction of earthworms-microorganisms during excess sludge treatment based on the sludge floc characteristics, including: (1) Physical properties (settleability, zeta potential); (2) Chemical constituents of polymeric substances (EPS and its composition); (3) Morphological aspects (size distribution, scanning electron microscopy (SEM) and fractal dimension analysis), which will significantly offer a reference for the practical application of vermifiltration.

2. Material and methods

2.1. Initial sludge and earthworms

The experiment was conducted in Tongji University, Shanghai city, China. The initial sludge was taken from the secondary sedimentation tank of a domestic WWTP (Quyang WWTP, Shanghai) near Tongji University. The sludge was screened with 10 mesh screens to remove impurities like gravel of large size, hair, etc. Then the sludge was diluted to a constant organic loading of approximately 1.19 kgVSS/($m^3 \cdot$d) using tap water in an equalization tank before it was pumped to the filters. The characteristics of the initial sludge were listed in Table 1.

The earthworm, *Eisenia fetida* was inoculated into the vermifilter at an initial earthworm density of 32 gL^{-1} (fresh weight basis) (Xing et al., 2011; Zhao et al., 2010). The initial adult earthworms were obtained from a farm and the earthworms with well-developed clitella and an appropriately average weight of 0.28 g were chosen.

2.2. Filter media

The ceramic pellets selected as filter media has the advantages of stable chemical properties, hard strength and micro-porous surface and thus large specific surface area with strong adsorption capacity. Additionally, ceramic pellets have spherical surface with 10–20 mm in diameter sand proper specific weight, avoiding damages on the body wall of earthworms.

2.3. Vermifilter design and operation

Two sets of cylinder shaped reactors were established in parallel, naturally ventilated. Each contained four layers, 20 cm in diameter and 25 cm in depth of each layer (Fig. 1). One reactor was defined as VF (vermifilter, with earthworms), while the other one, BF (conventional biofilter, no earthworms) as a control. The reactors consisted of three parts: water distributor area, filter material area and drainage area. A layer of plastic fiber was placed on the top of the filter bed to ensure even influent distribution. And in the filter material area, each layer was packed with ceramic pellets in working filter bed which are hospitable for earthworms and microorganisms. The two sets were operated continuously for 8 months after about 30-day acclimation. Details about the design and operation parameters of each set were listed in Table 2.

2.4. Analysis methods

2.4.1. CST and SRF

Sludge dewaterability was evaluated by CST and SRF (Feng et al., 2009). Triton CST apparatus model 200 with a 1.8 cm diameter cylinder and Whatman No. 17 filter paper were used to measure CST value. A standard Buchner funnel apparatus with a 9 cm funnel was used for the SRF determinations. A 100 mL sludge sample was filtered at an applied vacuum pressure of 1500 mm Hg. The filtrate quantity was collected as a function of time. The supplemental illustrations for CST and SRF measurement have been tested (Scholz, 2005).

2.4.2. EPS extraction

A heat extraction method (Li and Yang, 2007) was modified to extract LB-EPS and TB-EPS from the activated sludge. A sludge suspension was first dewatered by centrifugation in a 50 mL tube at 4000 g for 5 min. The sludge pellet left in the centrifuge tube was then diluted with the 70 °C, 0.05% NaCl solution to its original volume of 50 mL. The sludge suspension was then sheared by a vortex mixer for 1 min, followed by centrifugation at 4000*g* for 10 min. The organic matter in the supernatant was regarded as the LB-EPS of the biomass. While the sludge pellet left in the centrifuge tube was resuspended in 0.05% NaCl solution at room temperature to its original volume of 50 mL. The sludge suspension was heated to 60 °C in a water bath for 30 min, and the sludge mixture was then centrifuged at 4000*g* for 15 min. The supernatant that was collected was regarded as the TB-EPS extraction of the sludge.

Table 1
Characteristics of initial sludge.

Item	Moisture content (%)	Volatile content (%)	pH	TCOD (mg L^{-1})	SS (mg L^{-1})	VSS/SS (%)
Value	99.1– 99.5	54.8– 82.3	6.8– 7.3	4200– 9000	4000– 7500	52.1– 82.9

Note: TCOD – Total chemical oxygen demand; SS – Suspended solids;
VSS – Volatile suspended solids.