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Effect of gamma-ray irradiation on the dewaterability of waste activated sludge

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HIGHLIGHTS

- The optimum absorbed dose for improving WAS dewaterability is 1–4 kGy.
- Disintegration degree, EPS content and particle size could affect dewaterability.
- Low-dose irradiation and CPAM co-conditioning showed minimal synergistic effect.

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ABSTRACT

The effect of gamma-ray irradiation on waste activated sludge (WAS) dewaterability was investigated with irradiation doses of 0–15 kGy. Time to filter (TTF_{50}), specific resistance of filtration (SRF) and water content of sludge cake were measured to evaluate sludge dewaterability. Soluble chemical oxygen demand (SCOD), soluble extracellular polymeric substances (EPS) concentration and sludge particle size were determined to explain changes in sludge dewaterability. The optimal irradiation dose to obtain the maximum dewaterability characteristics was 1–4 kGy, which generated sludge with optimal disintegration (1.5–4.0%), soluble EPS concentration (590–750 mg/L) and particle size distribution (100–115 μm diameter). The combination of irradiation and cationic polyacrylamide (CPAM) addition exhibited minimal synergistic effect on increasing sludge dewatering rate compared with CPAM conditioning alone.

1. Introduction

Biological treatment of wastewater produces large quantities of waste activated sludge, which generally contains over 95% water, and treatment and disposal of WAS represent a bottleneck in wastewater treatment plants in China. Increasing amounts of WAS and strict regulations regarding sludge treatment and disposal have motivated researchers to develop new processes for reducing sludge production. Sludge dewatering is an important process in wastewater treatment system because it reduces sludge volume, facilitates transportation and is beneficial to downstream treatments.

The dewaterability of WAS can be enhanced through several pre-treatment methods, such as chemical (He et al., 2015), mechanical (Yu et al., 2009; Feng et al., 2009), ionized (Sawai et al., 1990; Xiang et al., 2016) and combined techniques (Dogan and Sanin, 2009). Gamma-ray irradiation is a promising technology for sludge dewatering treatment. This method is advantageous because its water radiolysis reaction is produced within 10^{-7} s and exhibit minimal environmental impact compared with other methods; moreover, the reaction can efficiently and rapidly change or destroy flocs and cellular structure by numerous highly reactive radical species (oxidizing hydroxyl radical ·OH, reducing hydrated electron e_{aq}^{-} and hydrogen radical ·H, and the G-value is 2.7 molecules/100 eV, 2.6 molecules/100 eV, and 0.6 molecules/100 eV, respectively), as shown in Eq. (1) (Park et al., 2009). The water radiolysis reaction is predicted to occur upon irradiation of WAS, which has high water content; furthermore, ·OH, e_{aq}^{-} and ·H destruct the sludge structure and change the dewaterability of the sludge phase. In addition, pathogens in sludge can be killed by irradiation due to damages of genetic materials, so irradiation can be used for hygienization of sludge simultaneously (Wang and Wang, 2007).

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$$H_2O \overset{100eV}{\Longrightarrow} [2.7]OH\cdot + [2.6]e^-_{aq} + [0.6]H\cdot + [2.6]H_3O^+ + [0.7]H_2O_2 + [0.45]H_2 \quad (1)$$

Dewaterability is mainly influenced by sludge disintegration degree, concentration of soluble extracellular polymeric substances and particle size distribution. Although dewaterability can be improved by gamma-ray irradiation, their relationship remains unclear (Sawai et al., 1990; Thomas et al., 1997; Daniel et al., 2004; Xiang et al., 2016). Thus, further studies must be performed to identify the optimal dewatering condition and confirm the relationship between irradiation dose and sludge structure variation.

In this study, the effects of individual irradiation and irradiation cooperating with cationic polyacrylamide (CPAM) addition on sludge dewaterability were investigated. Time to filter (TTF_{50}) and specific resistance of filtration (SRF) were measured to investigate dewatering rate, and water content of the sludge cake was evaluated to determine dewatering content. Sludge disintegration degree, soluble EPS content and particle size distribution were also assessed to explain the mechanism involved in dewaterability. This study provides additional knowledge to elucidate the mechanism of sludge dewaterability by gamma-ray irradiation and a basis for practical applications.

2. Materials and methods

2.1. Test materials

Sludge was obtained from a wastewater treatment plant in Wuhan, China, which adopts the A_P/O (anaerobic–oxic) process. WAS was obtained from a secondary settling tank, then immediately transferred to the laboratory and stored in plastic containers at 4 °C prior to use. The physicochemical characteristics of the sludge were measured by standard methods (SEPA, 2002) and are shown in Table 1.

CPAM (50% cationic degree and 12 million molecular weight) was applied as sludge conditioner to improve dewaterability after irradiation pre-treatment. CPAM solution (1000 mg/L) was prepared by completely dissolving powered polyelectrolyte in distilled water. The resulting solution was incubated for 12 h prior to use.

WAS was concentrated by settling at 4 °C for 12 h to investigate the co-conditioning effects on sludge with larger concentration. Thicken waste activated sludge (TWAS) was obtained with total solids (TS) of 27000 mg/L.

2.2. Irradiation

^{60}Co-source was designed and built by Hubei Provincial Nuclear Agriculture Sciences Research Institute. The radioactivity of the source is approximately 1.4×10^{16} Bq. The sludge samples were irradiated in 1 L sealed plastic bottles with a dose rate of 6.7 Gy/min under atmospheric pressure and ambient temperature (around 25 °C). The absorbed doses were measured using a silver dichromate gamma-dosimeter. Irradiation was performed in batch system with doses of 1–15 kGy (for 2.5–37.5 h).

2.3. Analytical methods

Vacuum filtration method was conducted to assess sludge dewaterability. A total of 100 mL of sludge was poured into a 7 cm standard Buchner funnel fitted with a pre-wetted filter paper. A constant vacuum pressure of 0.03 MPa was applied to WAS and TWAS for 10 and 60 min, respectively. After the filtration, no additional water could be removed from the sludge within 15 s. Filtrate volume and filtration time were recorded to assess the SRF of the sludge. The water content of sludge cake trapped through filter paper was measured by gravimetric method. TTF_{50} (s) is defined as the time required to collect half of the sludge sample volume during vacuum filtration (Meeroff et al., 2004; He et al., 2015).

Sludge particle size was examined using laser diffraction particle size analyser (Beckman Coulter LS 13 320, USA), which could detect particle sizes within 0.04–2000 μm. Results were expressed according to specific surface area and dp90, which is defined as the cut-off diameter at which 90% of particles (by volume) have diameters equal to or lower than the value of dp90.

After the sludge samples were irradiated and centrifuged at 4500 rpm and 4 °C for 30 min (TGL-185 centrifuge, China), the supernatant was filtered through a 0.45 μm filter membrane. Soluble chemical oxygen demand (SCOD) and soluble EPS of the sludge samples were measured. Sludge disintegration degree DD_{SCOD} (%) was defined by the following equation: $DD_{SCOD}(\%) = (SCOD\text{-}SCOD_0)/TCOD_0$, where $SCOD_0$ and $TCOD_0$ indicate the initial soluble chemical oxygen demand and total chemical oxygen demand, respectively (Chu et al., 2011, 2010). A pre-set volume of supernatant was heated at 105 °C to measure soluble EPS concentration through gravimetric method (Pei et al., 2007). Soluble proteins (< 0.45 μm) were determined by Coomassie brilliant blue G-250 method, with bovine serum albumin (BSA) as standard. Soluble polysaccharides (< 0.45 μm) were analysed measured by anthrone method, with glucose as standard.

Each experimental measurement was replicated three times to minimise systematic errors. The average values for each replicate were obtained.

3. Results and discussion

3.1. Dewaterability of sewage sludge with gamma-ray irradiation

3.1.1. Waste activated sludge conditioned with gamma-ray irradiation

The TTF_{50} and SRF results of WAS after irradiation are shown in Table 2. TTF_{50} considerably decreased from 144 s in the untreated sludge (0 kGy) to 100 s in sludge with 1 kGy irradiation but increased gradually with increasing irradiation doses. The shorter filtration time implied the easier removal of water from the sludge.

Table 1
Physicochemical characteristics of raw waste activated sludge.

Parameter	Average
pH	7.45
Total solids (TS, mg/L)	11,470
Volatile solids (VS, mg/L)	5820
Total suspended solids (TSS, mg/L)	10,410
Volatile suspended solids (VSS, mg/L)	5190
Soluble chemical oxygen demand (SCOD, mg/L)	214.24
Total chemical oxygen demand (TCOD, mg/L)	8899.20

Table 2
TTF_{50} and SRF of WAS after gamma-ray irradiation.

Dose (kGy)	TTF_{50} (s)	SRF ($\times 10^{11}$ m/kg)
0	142	3.62
1	100	2.58
2	105	2.56
4	109	3.09
6	112	3.14
10	110	3.14
15	144	3.15