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Changes of physicochemical properties of sewage sludge during ozonation treatment: Correlation to sludge dewaterability

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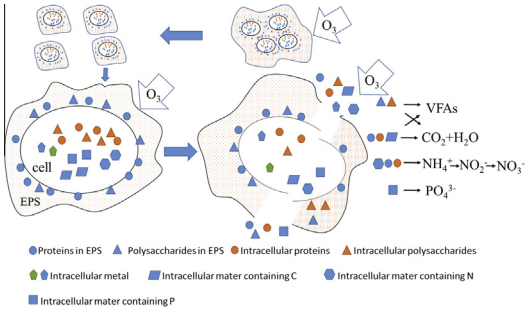
HIGHLIGHTS

- Ozonation influenced settleability, hydrophobicity and dewaterability of sludge.
- The EPS in supernatant increased from 10.72 ± 0.65 mg/L to 607.45 ± 50.47 mg/L during ozonation.
- The proteins/polysaccharides in supernatant increased from 1.40 ± 0.06 to 1.75 ± 0.08 after ozonation.
- The dewaterability was related to the EPS constituent in supernatant and DD_{SCOD}.
- The mechanism involved matter transformations during ozonation was discussed.

GRAPHICAL ABSTRACT

A graphic that explains the actions that ozone can carry out on the sewage sludge including cell lysis, release of intracellular material, oxidation of ammonia, carbon compounds and so on.



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ABSTRACT

The impact of ozonation on physicochemical properties of sewage sludge and the relationships between the physicochemical properties and dewaterability during ozonation were investigated. CST was used to evaluate sludge dewaterability. The results showed that the settleability of sludge was improved after ozonation. The relative hydrophobicity (RH) of sludge flocs decreased from 69.2 ± 4.0% to 50.0 ± 2.4% after ozonation. The dewaterability of sludge was affected by ozonation and depended on ozone dose as CST increased from 25.5 ± 2.4 s to 289.0 ± 25.9 s during ozonation. The SCOD and DD_{SCOD} increased significantly after ozonation, but the increasing tendency of DD_{SCOD} became slow when ozone dose was above 37.8 mg O_3/g SS. The concentrations of polysaccharides and proteins in supernatant increased from 4.46 ± 0.21 mg/L to 220.90 ± 24.87 mg/L and from 6.26 ± 0.28 mg/L to 386.54 ± 32.15 mg/L, respectively. The ratio of proteins and polysaccharides in supernatant increased from 1.40 ± 0.06 to 1.75 ± 0.08 after ozonation. The DD_{SCOD} and constitution of EPS in supernatant played a very important role in changing the dewatering performance of sludge. Microscope images and BET surface area demonstrated that sludge was disintegrated and microbial cells were destroyed by ozonation treatment. The mechanism involved matter transformations during ozonation was also discussed.

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1. Introduction

Sewage sludge generated from wastewater treatment process is a menace to environment. The cost for disposal of excess sludge accounts for 25–60% of the total operating cost of wastewater treatment plant [1]. Sludge minimization is a promising strategy that meets development tendency. It can reduce the cost of sludge disposal and solve the problem of sludge secondary pollution. Lysis–cryptic growth is a strategy to minimize the generation of excess sludge, and the rate-limiting step is lysis process. When disintegration strategies for enhancing lysis are used, cells of microorganism are destroyed and intracellular matter is released. The intracellular matter from cells of microorganism is utilized again resulting in the reduction of overall biomass yield [2]. Numerous chemical and physical methods for disintegrating sludge have been studied in recent years, including thermal hydrolysis [3], mechanical disintegration [4], ultrasonic process [5] and ozonation [6]. In the above methods, ozonation is one of the most promising methods as ozonation can reduce 50–100% of the activated sludge production without toxic by-products [7,8], and the expenditure of the application of ozonation for sludge disintegration is relatively modest, comparing to other methods [6,9]. In Braguglia et al. (2012) [6] study, the specific energy input of ozone was higher than that of ultrasounds when achieving the same level of DD_{SCOD}, while in Salsabil et al. (2010) [9] study, the specific energy input of ozone was lower than that of ozone thermal treatment when achieving the same DD_{SCOD} level.

Many researchers have devoted to using ozonation for disrupting sludge in recent years. Wei et al. (2003) [7] observed that the reduction of excess sludge generation can be achieved by ozonation–cryptic growth. Zhang et al. (2009) [1] reported that the mixed liquor volatile suspended solid content and mixed liquor suspended solid content were decreased by 45.7% and 49.1% after ozonation, respectively. Chu et al. (2009) [10] observed the release of carbon, nitrogen and phosphorus from sludge matrix into the supernatant after ozonation. Yang et al. (2012) [11] observed that the disintegration degree value reached 19.57% at ozone dose of 0.15 g O_3/g DS. Kianmehr et al. (2010) [12] observed the hydrolysis rate of sludge was increased significantly by ozonation. Braguglia et al. (2012) [6] found that ozonation could disintegrate sludge and ozonized sludge (~4000 kJ/kg TS) had the quite high initial soluble COD, the ozonized sludge had significant improvement on the digestion performance, comparing to untreated sludge. Namely the ozonized sludge had an improvement in the organics removal and an enhancement in biogas production in the digester, comparing to untreated sludge.

Previous studies mainly focused on the disintegration of sludge cells, while little is known on the changes of physicochemical characteristics of sewage sludge during ozonation treatment and the relationships between the physicochemical properties and sludge dewaterability when sludge was exposed to ozone. This was important for understanding the internal mechanism for ozonation–cryptic growth strategy. Therefore, the objective of this research was to study: (1) the influence of ozonation on the physical characteristics of sewage sludge; (2) the influence of ozonation on the chemical characteristics of sewage sludge; (3) the influence of ozonation on the chemical speciation of heavy metals (Cu and Zn) in sludges; (4) the relationships between the physicochemical properties and dewaterability; (5) mechanism involved matter transformations during ozonation.

2. Methods

2.1. Sludge and ozonation

Sewage sludge used in this research was collected from the secondary sedimentation tank of Harbin Wenchang sewage treatment plant, China. The collected secondary biological sludge sample was screened to remove big debris and then precipitated for 5 h to thicken sludge and stored at 4 °C until use in 48 h. The sludge had a total solid concentration of 19,412 ± 463 mg/L. Sludge characteristics are presented in Table 1.

Table 1
Fundamental characteristics of sewage sludge.

Parameter	Value
pH	6.84
VSS (mg/L)	10,869 ± 254
TSS (mg/L)	19,412 ± 463
VSS/TSS	0.56 ± 0.037
SCOD (mg/l)	54 ± 4.3
SCOD/TCOD (%)	0.267 ± 0.033
Water content (%)	98.49 ± 0.01

A scheme of the sludge ozonation system is presented in Fig. 1, composing of an ozone generator, ozonation sludge reactor and excess ozone absorption. Ozone was generated from pure oxygen by an ozone generator (Jiujiu, DHS-1-G). The yield of the ozone generator at fixed O_2-injecting flux was measured by iodometric method. The sludge was ozonized in a polymethyl methacrylate cylindrical reactor with the height of 1300 mm and the diameter of 70 mm, with 3000 ml effective volume (Fig. 1). Ozone was continuously distributed into the sludge sample by a microporous diffuser in the bottom of the reactor, which was stirred with an electric blender to break the foam produced during ozonation. The amount of excess ozone leaving the reactor was also measured by iodometric method through ozone quantitative absorption bottle and then the exhaust gas was discharged into the atmosphere. To study physical and chemical properties of sewage sludge after ozonation, 3000 ml sludge sample was inoculated into the ozonation sludge reactor. 100 ml sludge mixture was taken every 10 min from the reactor, and at the same time 100 ml fresh sludge was returned to the reactor to ensure that the reaction system is constant. Nine kinds of sludge samples were collected in this study. The first kind of sludge sample was sewage sludge; the second kind of sludge sample was obtained when sewage sludge was treated with ozone at the dosage of 6.3 mg O_3/g SS for 10 min; the third kind of sludge sample was obtained when sewage sludge was treated with ozone at the dosage of 12.6 mg O_3/g SS for 20 min; the fourth kind of sludge sample was obtained when sewage sludge was treated with ozone at the dosage of 18.9 mg O_3/g SS for 30 min; the fifth to ninth kinds of sludge sample was obtained when sewage sludge was treated with ozone at the dosage of 25.2 mg O_3/g SS, 31.5 mg O_3/g SS, 37.8 mg O_3/g SS, 44.1 mg O_3/g SS and 50.4 mg O_3/g SS for 40 min, 50 min, 60 min, 70 min and 80 min, respectively. Ozone consumption was calculated as the quantity of ozone entering the ozonation sludge reactor minus the quantity of ozone leaving the reactor: $(ozone_{in} - ozone_{out})$/mixed liquor suspended solid, where $ozone_{in}$ is ozone yield multiplied by ozone bubbling time, $ozone_{out}$ is the quantity of ozone leaving the reactor, and mixed liquor suspended solid is the weight of sludge to be treated. Experiments were conducted in triplicate at ambient temperature.

2.2. Physicochemical characteristics indices

The physical characteristics of sludge includes mixed liquor suspended solid, mixed liquor volatile suspended solid, particle size, pH, diluted SV_{30} (DSV_{30}), diluted sludge volume index (DSVI), RH, CST and conductivity; The chemical characteristics includes SCOD, DD_{SCOD}, PO_4^{3-}-P, NH_4^+-N, NO_3^--N, the polysaccharide and protein concentration in sludge and supernatant; Heavy metals (Cu and Zn) in sludge have four kinds of chemical speciation, namely acid

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