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Economical evaluation of sludge reduction and characterization of effluent organic matter in an alternating aeration activated sludge system combining ozone/ultrasound pretreatment

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HIGHLIGHTS

- AAMA + $O_3/US_{2\#}$ system was economically feasible that can give a 14.04% saving of costs.
- 55.08% sludge reduction was achieved in AAMA + $O_3/US_{2\#}$ system compared with $AAMA_{1\#}$.
- Less humic substance and soluble microbial products were generated from AAMA + $O_3/US_{2\#}$.
- NH_4^+-N removal and TTC-ETS activities showed significant positive correlations.
- Appropriate sludge lyses recycling gave rise to the improvement in microbe activity.

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ABSTRACT

An ozone/ultrasound lysis–cryptic growth technology combining a continuous flow anaerobic–anoxic–microaerobic–aerobic (AAMA + O_3/US) system was investigated. Techno-economic evaluation and sludge lyses return ratio (r) optimization of this AAMA + O_3/US system were systematically and comprehensively discussed. Economic assessment demonstrated that this AAMA + O_3/US system with r of 30% (AAMA + $O_3/US_{2\#}$ system) was more economically feasible that can give a 14.04% saving of costs. In addition to economic benefits, a 55.08% reduction in sludge production, and respective 21.17% and 5.45% increases in TN and TP removal efficiencies were observed in this AAMA + $O_3/US_{2\#}$ system. Considering the process performances and economic benefits, r of 30% in AAMA + $O_3/US_{2\#}$ system was recommended. Excitation–emission matrix and Fourier transform infrared spectra analyses also proved that less refractory soluble microbial products were generated from AAMA + $O_3/US_{2\#}$ system. Improvement in 2,3,5-triphenyltetrazolium chloride electron transport system (TTC-ETS) activity in AAMA + $O_3/US_{2\#}$ further indicated that a lower sludge lyses return ratio stimulated the microbial activity.

1. Introduction

Conventional activated sludge (CAS) process, which involves the transformation of dissolved and suspended organic contaminants into biomass during sewage treatment process (Mohammadi et al., 2011), is widely used for the municipal and industrial wastewater treatment, domestically and internationally. However, one significant disadvantage to CAS process is the high generation of waste activated sludge (WAS) during sewage treatment process. The management and disposal costs of the WAS account for up to 60% of the whole operation expenses (Lin et al., 2012), and the restrictive economic, environmental and legal regulations have imposed restrictions on the conventional sludge treatment methods, e.g. land application, incineration and land filling (Yang et al., 2011). In view of the environmental burden and the expensive costs, the solution of this increasing WAS problem has become one of the most stringent challenges in sewage treatment field (Li et al., 2013). Therefore, a profound research effort on exploiting and developing new methods for WAS minimization is urgently needed.

The mechanisms for in-situ activated sludge reduction technologies are commonly classified into four groups (Guo et al., 2013): chemical or/and physical lysis–cryptic methods combining with the activated sludge processes; uncoupling metabolism; worms' predation; and improved/novel developed processes. In recent

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Nomenclature

AAMA + O_3/US system	anaerobic–anoxic–microaerobic–aerobic combining ozone/ultrasound system
BNPR	biological nitrogen and phosphorus removal
CAS	conventional activated sludge
COD	chemical oxygen demand
DO	dissolved oxygen
DPAO	denitrifying phosphate-accumulating organisms
EEM	excitation–emission matrix
EfOM	effluent organic matters
FTIR	Fourier transform infrared spectroscopy
MLSS	mixed liquor suspended solids
NH_4^+-N	ammonia nitrogen
O_3	ozone
PAO	phosphate-accumulating organisms
r	sludge lyses return ratio
SBR	sequencing batch reactor
SMP	soluble microbial products
TC	total cost
TN	total nitrogen
TP	total phosphorus
TS	total solids
TTC-ETS	2,3,5-triphenyltetrazolium chloride electron transport system
US	ultrasound
WAS	waste activated sludge

years, sludge reduction by cell lysis–cryptic growth has aroused much public concern and interest (Lan et al., 2013; Lin et al., 2012; Zuriaga-Agustí et al., 2012). According to the previous investigations, this technique can be realized by means of various treatment methods including thermal, microwave, alkaline, ultrasonic, and ozone oxidation pretreatments, which these pretreatments combining the existing bio-reactors (e.g. CAS, membrane bio-reactor, sequencing batch reactor (SBR) and etc.) used so far at lab, pilot and real scales have already achieved many positive results (Ma et al., 2012; Yang et al., 2013). Zuriaga-Agustí et al. (2012) reported that dosing 2.5 mg chlorine dioxide/g TS in a SBR achieved 43.4% reduction in excess sludge production, while results demonstrated that this technology severely deteriorated effluent quality. Lan et al. (2013) achieved a 42.4% sludge reduction in a SBR under 70 MPa disruption pressure of high-pressure-homogenization, and this lysis–cryptic growth system was found imposed negligible changes in the sludge activity. Dytczak et al. (2007) combined an ozonation stage with a SBR, results found that 20% returned ozonated sludge had no negative impact on the effluent quality of the SBR process. Ma et al. (2012) proposed a continuous operated lysis–cryptic growth system combining ultrasonic and alkaline technologies. Results indicated that 56.5% reduction in excess sludge could be achieved in this pilot-scale lysis–cryptic growth system. Lin et al. (2012) reported a combination of ultrasonic and chlorine dioxide processes. When combined the ultrasonic + chlorine dioxide technology with a SBR, 55% reduction in excess sludge was observed by recycling 70% ultrasonic + chlorine dioxide disrupted sludge. However, obvious disadvantages induced by the ultrasonic + chlorine dioxide technology were the increases in effluent phosphorus and nitrogen concentrations. Based on the previous investigations, although most studies have already demonstrated the ability of sludge reduction by using different sludge lysis–cryptic growth technologies combining bio-reactors, few literatures have paid attention to the worsening of the effluent quality (Yan et al., 2009; Lin et al., 2012). As is well-known, substandard discharging high levels of nitrogen and phosphorous are widely recognized as potential causes of the eutrophication. The breakthrough of water turbidity, oxygen depletion and algae blooms caused by eutrophication would permanently harm human health and severely damage the environment (Amini et al., 2013). Thus, the development of sludge lysis–cryptic growth technologies combining bio-reactors aiming at achieving simultaneous excess sludge reduction and superior biological nitrogen and phosphorus removal (BNPR) efficiency will become the focal points in the future study.

Focusing on the application of sludge lysis–cryptic growth technologies, ultrasound (US) and ozonation (O_3) are potentially regarded as the wonderful tools (Lin et al., 2012; Yang et al., 2013). US pretreatment, recognized as an effective and promising pretreatment, has been proved little negative impact on environment (Guo et al., 2011). Whereas when the US pretreatment is devoted to the WAS, a large proportion of US energy will be absorbed by the liquid (Xu et al., 2010), thus the application of ultrasound sludge lysis–cryptic growth technology might be limited by coupling the lysis step in the bio-reactors. To solve this problem, a combined ozonation and US pretreatment has been proved to lower the US energy consumption and enhance the WAS disruption (Yang et al., 2013). However, to our knowledge, there has been few literature study on this O_3/US pretreatment coupling with bio-reactors. In order to provide a comprehensive basis for practical application, comprehensive researches on the application of the combined O_3/US pretreatment for process performances are necessary.

In this study, an O_3/US lysis–cryptic growth technology combining an alternating anaerobic–anoxic–microaerobic–aerobic system (AAMA + O_3/US system) was investigated. The objectives of this study are (1) to evaluate the economic assessment of the combined O_3/US pretreatment time in this AAMA + O_3/US system, (2) to optimize the impacts of different O_3/US sludge lyses return ratios on the performances of sludge reduction and BNPR, (3) to analyze the effects of effluent organic matters (EfOM) composition by excitation–emission matrix (EEM) and fourier transform infrared spectra (FTIR) spectra, and (4) to investigate the relationship between the activities of microorganisms and the performances of nutrient removal during sewage treatment process. It is expected that the results obtained in this study can provide a comprehensive basis for the future investigation of an O_3/US pretreatment-based wastewater treatment and sludge reduction system.

2. Methods

2.1. Waste activated sludge

The waste activated sludge taken from the secondary setting tank of Harbin Wenchang sewage treatment plant was used in this study. Before the experiments started, the seeded sewage activated sludge was screened through a sieve to separate large debris from the activated sludge, and then, the waste activated sludge was settled and washed two or three times to remove any residuals in the supernatant.

2.2. Pretreatment experiments

To prepare the O_3/US sludge lyses, sludge samples discharged from the corresponding continuous flow systems were pretreated by a combined O_3/US apparatus. For the combined O_3/US apparatus