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Response of biodegradation characteristics of unacclimated activated sludge to moderate pressure in a batch reactor

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HIGHLIGHTS

- Process of TOC, DO, CO_2 concentration of off-gas and EPS were monitored.
- Effect of pressurizing was evaluated by degradation rate.
- Application of pressurizing under high organic load is reasonable and practicable.
- More oxygen expenditure leads to more EPS consumption.

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ABSTRACT

This study was aimed to investigate the effect of moderate pressure on unacclimated activated sludge. Process of organic degradation, variation of carbon dioxide (CO_2) concentration of off-gas and characteristics of extracellular polymeric substances (EPS) of activated sludge were analyzed using pressure-atmospheric comparative experiments in bench-scale batch reactors. It was found that moderate pressure increased the degradation rate more dramatically when the biological process ran under a higher organic load with much more oxygen demand, which illuminated that applications of the pressurized method to high concentration organic wastewaters would be more reasonable and practicable. High oxygen transfer impetus increased utilization of oxygen which not only promoted the biodegradation of organics in wastewater, but also led to more EPS consumption in activated sludge. CO_2 concentration of off-gas was lower in the earlier stage due to CO_2 being pressed into the liquid phase and converted into inorganic carbon (IC). More CO_2 emission was observed during the pressurized aerobic process 160 min later. EPS in pressurized reactor was much lower, which may be an important way of sludge reduction by pressurized technology.

1. Introduction

Activated sludge process has been widely used in biological wastewater treatments. Microorganisms such as aerobic bacteria play a big role in aerobic activated sludge process dealing with organic pollutants in wastewater by the biochemical reactions of microbes (Cote et al., 1995; Onken and Liefke, 1989). Treatment effectiveness is mainly dominated by the concentration of dissolved oxygen (DO) in aeration tank. Low DO concentration causes a decline in water quality due to the low growth rate of bacteria. Filamentous bacteria in the sludge also tend to breed when DO concentration is low, which cause sludge bulking (Liao et al., 2011). Therefore, the concentration of DO in the activated sludge process should be high to provide adequate oxygen for microorganisms within the sludge (Holenda et al., 2008).

There are many ways to improve oxygen transfer impetus and increase DO concentration in the liquid phase, including pressurization, pure oxygen aeration and deep shaft technology (Onken and Liefke, 1989; Shammas and Wang, 2009; Mueller et al., 2002). Pressurized method can accelerate oxygen transfer rate through increasing oxygen partial pressure, maintaining high DO concentration of about 10–14 mg L^{-1} in the reactor (Ho and Tan, 1988). Compared with conventional activated sludge, pressurized

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technology not only achieves high oxygen transfer impetus, but also has a small area and low cost (Berktay and Ellis, 1997). Pure oxygen aeration uses pure oxygen with oxygen-containing volume fraction of more than 90% to replace air during aeration process. It can increase the oxygen transfer rate and maintain the DO concentration in the bioreactor at high level, ranging from 6 to 10 mg L^{-1} (Zupančič and Roš, 2008; Calderón et al., 2012). In deep-shaft process, hydrostatic pressure is used in the deep well to increase oxygen transfer efficiency, resulting in low power and land requirement. The rate of DO transfer depends on the depth of deep well (Boon and Thomas, 1998). It has been widely used in high concentration wastewater treatments (Irwin et al., 1989; Hait and Mazumder, 2011).

In terms of pressurized method, some studies focus on the moderate pressure processing technology, e.g. biological wastewater treatment. Microorganism under moderate pressure is not significantly damaged (Onken and Liefke, 1989). In moderate-pressurized process, DO concentration and oxygen transfer rate increase with the increase of total air pressure (Ellis et al., 1992; Jin et al., 2010). The method has been reported to be successfully used in high concentration industrial wastewater biological treatment, which consumes large amounts of oxygen, such as wastewater composed of pesticide with high concentration (Jin et al., 2010). Filamentous growth and sludge bulking can also be prevented due to very high DO concentration by pressurizing (Ho and Tan, 1988). There are other types of sewage being investigated, such as wastewater generated from drilling operation or from the canning of sour vegetables, cotton textile wastewater, tannery wastewater etc (Lu et al., 2010; Krauth and Staab, 1993; Krauth, 1996).

However, studies of moderate pressure are mainly focused on the promoting effect of pressurized biological process on removal of pollutant. Although moderate pressures have been demonstrated to be no damage to activated sludge (Onken and Liefke, 1989), the integrated affection of pressure, DO concentration and oxygen transfer rate on activated sludge still need more in-depth studies. The objective of this study was to investigate the effect of moderate pressure on unacclimated activated sludge by pressure-atmospheric comparative tests under batch operation. Changes of organic degradation and sludge characteristics were revealed when activated sludge in atmospheric circumstance was suddenly pressurized, focusing on the process of organic degradation, variation of sludge activity, EPS within the sludge etc.

2. Materials and methods

2.1. Experimental materials

Simulated wastewater was used as experimented sewage with the composition as follows: CH_3COONa: 500 mg L^{-1}, Glucose: 250 mg L^{-1}, NH_4Cl: 170 mg L^{-1}, KH_2PO_4: 20 mg L^{-1}, $NaHCO_3$: 40 mg L^{-1}, $CaCl_2$: 40 mg L^{-1}, $MgSO_4 \cdot 7H_2O$: 164 mg L^{-1}. The characteristics of the raw simulated sewage within bioreactors were: chemical oxygen demand (COD): 350–450 mg L^{-1}, ammonia nitrogen (NH_3–N): 40–50 mg L^{-1}, total phosphorus (TP): 4–5 mg L^{-1}, pH: 6.5–7.5, total organic carbon (TOC): 150–250 mg L^{-1}. We denoted the sewage mainly by TOC concentration. Activated sludge was obtained from a sewage treatment plant and acclimatized by the simulated sewage under the normal environment before experiment.

2.2. Bioreactor

A schematic diagram of the experiment was shown in Fig. 1. Pressurized bioreactor was made of steel with 200 mm in diameter, 300 mm in height and 8.2 L in its effective volume. Atmospheric contrast bioreactor with plexiglas columns had same structure and dimensions as the pressurized device. Perforated pipe diffusers with a diameter of 20 mm were used to aerate the sludge.

When the two bioreactors ran, sludge and simulated sewage were firstly pumped into the pressurized bioreactor (2) and the contrast one (1) until the liquid level reached the inlet sludge valves (3). Then, the air entered contrast bioreactor from the perforated pipe (8) with air pump, and the aeration rate was controlled by the rotameter (9). The entering gas in the pressurized bioreactor was with air compressor, and the aeration rate was controlled by both outlet air valve (10) and rotameter (9). The aeration rates of the pressurized reactor and the contrast one were both controlled at 80 L h^{-1}. The initial concentrations of TOC was 150–250 mg L^{-1} (except for Fig. 2 (a)) under batch operating conditions. The mixed liquor suspended solids (MLSS) concentration were 1900–2200 mg L^{-1}, and MLSS concentrations of both reactors were same. At the end of the batch operation, all of the mixture was drained from the effluent valves (6), and the two bioreactors were properly washed so that the next experiment could be operated. All experiments were performed at ambient temperature (24 ± 2 °C).

2.3. Analytical methods

Wastewater samples were collected simultaneously from the two reactors for TOC and DO analysis. The concentrations of TOC and DO were measured with a TOC analyzer (TOC-V_{CPH}, SHIMADZU, Japan) and a dissolved oxygen meter (HI 9146, HANNA, Italy) respectively.

Sludge samples were collected simultaneously from the pressurized device and the contrast one, for analysis of MLSS. MLSS was assayed according to the standard method (SEPAC, 1989).

Microscopic morphology of sludge was observed by a scanning electron microscope (JSM-7600F, Japan). CO_2 samples of off-gas were assayed using a professional detector (GT901-CO_2, Haochi Co., China).

2.4. EPS extraction and analysis

We used low temperature heating to extract EPS in the sludge. It is believed that the heating method is convenient, with a relatively higher extraction yield and lower cell lysis (D'Abzac et al., 2010). During the experiment, samples were taken out from the pressurized device and the contrast one, respectively. Firstly, the samples were centrifuged at 4000 r min^{-1} and sustained for 10 min. Then, supernatant was drained before the samples were supplied to the original volume with 0.9% NaCl solution. The supernatant was centrifuged at 4000 r min^{-1} for 10 min before discarding. Afterwards, the cleaned sludge was suspended in the 0.9% NaCl solution and added to the original volume. Using a vortex mixer (XW-80A, Kexi Co., China), the samples were shaken violently for 1 min and then put into the heated water bath (HH.2, Kexi Co., China) at 80 °C continued for 5 min. Finally, the samples were centrifuged at 4000 r min^{-1} for 60 min and the supernatant were collected for EPS analysis.

Two parts of EPS were assayed, including extracellular polysaccharide (ECP_C) and extracellular proteins (ECP_P). ECP_C was determined by the method of phenol-sulfuric acid, using glucose as