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Effect of short-term salinity shock on unacclimated activated sludge with pressurized aeration in a sequencing batch reactor

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ABSTRACT

This study was aimed to investigate the effect of short-term salinity shock on unacclimated activated sludge with pressurized aeration. The activated sludge cultured with fresh wastewater under atmospheric pressure was transferred into a pressurized sequencing batch reactor (SBR) under 0.3 MPa gage pressure and exposed to saline wastewater with different salt concentrations. Another reactor was running in atmospheric environment as control reactor, with the same operation parameters except for the pressure. Substrate removal rate, specific oxygen uptake rate (SOUR) and soluble microbial products (SMP) were determined to reveal the influence rule at different salinities. The results indicated that for activated sludge without salt-resistant acclimation suffering a low strength salinity shock (below 2.0%), pressurized aeration could increase substrate removal rate and serve a positive function. SOUR of pressurized activated sludge was significantly higher than that of the control one ($p < 0.05$). Concentrations of SMP in effluent from the pressurized reactor were also lower than that from the control reactor at 1.0% salinity. However, when activated sludge suffered high strength salinity impacts (2.5%, 3.0%), pressurized aeration would further deteriorate the treating effects, accompanied with lower SOUR and higher SMP concentrations compared to the conventional aeration method.

1. Introduction

Activated sludge process is an effective and economical treatment which was widely used to degrade organic pollutants. The technology is also preferred in the disposal of saline wastewater, even though increased and changed salinities have significant negative impacts on microorganisms in activated sludge [1]. Many biochemical processes, associated with specific microbe populations, have been reported to be suppressed in saline wastewater, e. g. anammox treatment with anammox sludge [2], biological denitrification with denitrifying bacteria [3], phosphorus removal with phosphorus accumulating organisms (PAOs) [4], and methane production with methanogens [5]. Typical impacts are higher density, viscosity and osmotic pressure of the solution at higher salinity [6,7]. Higher density and viscosity will retard the sedimentation of activated sludge and thus lead to an increase of turbidity of effluent from secondary sedimentation tank. The diffusivity will also be reduced by the increasing viscosity, which will further impede the mass transfer of oxygen in the mixed liquor. The osmotic pressure of the water increases approximately 8 bar for every 10 g L^{-1} of NaCl [6]. Increasing osmotic pressure would induce cell dehydration and plasmolysis due to the outward flow of intracellular water, and even result in death of microorganisms which do not have the capability of increasing the intracellular ion concentration (mainly potassium) or accumulating organic solutes called "compatible solutes" [8].

Fluctuations of salinity in wastewater depend on the treated raw materials and on single wastewater streams that may change frequently in many industrial production processes [9]. Rapid change of salinity has more impact on biological treatment than gradual shift [7,10]. A response to rapid change of the salinity is the release of cellular materials, resulting in an increase of soluble chemical oxygen demand (COD) [11]. Li et al. [12] found that a rapid increase of salinity leads to an accumulation of soluble microbial products (SMP) and reduces effluent quality. Windey et al. [13] also reported that a shock loading of 30 g L^{-1} will sharply

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decrease microbial metabolic activity. Massive swings in salinity of many industrial wastewaters seriously affect biological treatment, even for microorganisms that have been successfully acclimated to a steady salinity [14].

Some biological processes improve treating efficiency by enhancing the solubility of oxygen with pressure, e. g. pressurized activated sludge process and deep-shaft process. The pressurized activated sludge process promotes oxygen transfer rate by increasing total air pressure [15]. In deep-shaft process, hydrostatic pressure is used in the deep well to increase oxygen transfer efficiency [16]. The moderate pressures which were exerted in these processes do not reportedly result in any damage to the microorganisms [17]. Some high concentration organic wastewaters have been treated effectively by pressurized technology, such as pesticide wastewater, wastewater from canning of sour vegetables, pickled mustard tuber wastewater and tannery wastewater [18–21]. Even though these high concentration industrial wastewaters treated by pressurized technologies are always accompanied with sharp fluctuations of salinity, little work has been conducted to study the salinity shock on activated sludge under moderate pressure.

The aim of this work was to investigate the effect of short-term salinity shock on activated sludge with pressurized aeration. The activated sludge cultured with fresh wastewater under atmospheric pressure was transferred into a pressurized sequencing batch reactor under 0.3 MPa gage pressure and exposed to saline wastewater with different salt concentrations. Another reactor was running in atmospheric environment as control reactor. Both reactors ran with the same operation parameters except for the pressure. Since industrial wastewaters were always accompanied with frequently fluctuations of salinity, this study is intended to reveal the positive or negative effect of moderate pressure on resistant ability of unacclimated activated sludge suffering short-term salinity shock.

2. Materials and methods

2.1. Wastewater

Synthetic fresh wastewater were prepared as experimental wastewater. Each liter contained 1000 mg CH_3COONa, 170 mg NH_4Cl, 20 mg KH_2PO_4, 40 mg $NaHCO_3$, 40 mg $CaCl_2$ and 164 mg $MgSO_4{\cdot}7H_2O$. The main quality indicators of the synthetic fresh wastewater were: total organic carbon (TOC) 240–300 mg L^{-1}, COD 650–750 mg L^{-1}, ammonia nitrogen (NH_3-N) 40–50 mg L^{-1}, total phosphorus (TP) 4–5 mg L^{-1} and pH 6.5–7.5. We indicated the concentration of organic matter by the parameter TOC to eliminate the disturbance of chlorine ion on COD measurement [6]. Different dosages of sodium chloride were added into the fresh wastewater to prepare different concentrations of saline wastewater ranging from 0 to 3.0%.

2.2. Activated sludge

Activated sludge obtained from a municipal wastewater treatment plant in Nanjing, China was cultured with the fresh wastewater in a 150 L plastic container under atmospheric pressure. The fresh wastewater culture process had four cycles per day. Each cycle (6 h) consisted of 0.5 h feeding, 3 h aeration, 1 h settling, 0.5 h decanting and 1 h idle. The fresh wastewater culture process ran over 2 months and the effluent TOC concentrations stabilized at approximately 25 mg L^{-1}. Main running parameters during the fresh wastewater culture process are shown in Table 1.

Table 1
Main running parameters of the fresh wastewater culture process.

Parameter	Unit	Value
Volume	L	150
Exchange volume ratio	L/cycle	75
Aeration rate	L h^{-1}	300
DO	mg L^{-1}	~6.0
SRT	d	15
Influent	–	Fresh water

2.3. Bioreactor

The effective volume of the pressurized reactor was 8.2 L. The control reactor had the same shape and size as the pressurized reactor. The overall dimensions of both reactors were described by Xu et al. [22]. Both reactors ran in sequencing batch mode with the reaction time of 90–300 min, depending on the salinity of the wastewater which will significantly influence biodegradation rate. Firstly, activated sludge and saline wastewater (0–3.0%) were pumped into the two reactors. Then, the compressor and the air pump respectively transported the air to the pressurized reactor and the control reactor, with the same aeration rate of 80 L h^{-1}. The gage pressure of the pressurized reactor was controlled at 0.3 MPa. Table 2 summarizes the main operating parameters of the experiments. All experiments were conducted at ambient temperature (25 ± 2 °C).

2.4. Analytical methods

TOC was determined by a TOC analyzer (TOC-V_{CPH}, SHIMADZU, Japan) and DO by a dissolved oxygen meter (HI 9146, HANNA, Italy). Mixed liquid suspended solids (MLSS) was analyzed according to the standard method [23]. CO_2 concentrations of the exhaust from the reactors were measured by a professional detector (GT901-CO_2, Haochi Co., China). Oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR) were determined according to Vidal et al. [24]. The determination methods of the concentrations of polysaccharides and proteins in SMP were based on Li et al. [12]. T-text was used to test the significance of results and $p < 0.05$ was considered to be statistically significant.

3. Results and discussion

3.1. TOC removal rate of activated sludge

The Monod equation is generally accepted as the basis of the activated sludge models due to its advantage of simplicity and relatively accurate representativeness [25]. Growth kinetics or substrate consumption rates are independent of substrate concentration as a zero-order growth kinetics when the substrate concentration is much more than K_s, the half-saturation constant in Monod equation referring to substrate concentration at which the growth rate corresponds to half the maximum specific growth rate (μ_{max}). In this case the maximum substrate consumption rate of saline wastewater treatment with/without pressure can be estimated through the linearization of substrate concentration versus reaction time. Fig. 1 shows the changes of TOC concentrations over time of the two reactors batch fed with saline synthetic wastewater of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% salinity (NaCl), respectively.

The plot of these data shows a series of straight lines whose slopes are equivalent to the values of maximum TOC removal rates. In all cases, the regression coefficients (analyzed by OriginPro 8.0 software) are higher than 0.92, indicating that these kinetic coefficients are reliable. The effects were accordant with zero-order growth kinetics in Monod equation under conditions of high sub-