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Influence of salinity on microorganisms in activated sludge processes: A review

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A B S T R A C T

The use of seawater and production of some chemicals produce a lot of saline wastewater. There are many treatment technologies for treating saline wastewater, such as physical, chemical and biological treatment. Biological treatment processes, especially the activated sludge processes, show advantages over other processes due to its cost-effectiveness and avoiding of secondary pollution, and many researches have been performed in this field. In this paper, the progresses of researches about the effect of salinity on activated sludge and its microorganisms were reviewed which included the effect of salinity on sludge structure and properties, microbial species and biomass, microbial physiological changes, and microbial molecules and cells. The mechanisms of the effect of salinity on sludge and the microbes were also summarized. Additionally, the feasibility of treatment of saline wastewater by using the acclimated salt tolerant activated sludge was evaluated. Future research needs were also proposed which include the study on the mechanisms of salt stress on activated sludge microorganisms at cellular and molecular levels and enzyme activity, screening and acclimation of salt-tolerant bacteria including halophiles, and optimizing of process parameters for saline wastewater treatment.

1. Introduction

In order to alleviate the shortage of freshwater resource, seawater has been directly used over the years in many countries. The heavy use of seawater causes the discharge of high salinity wastewater, which results in the salt concentration of wastewater up to 15–45 g/L, while the salt concentration of seawater is 25–35 g/L usually (Sun et al., 2010b). In addition, some industries including petroleum, printing and dyeing, paper, chemical, and pesticide industries discharge a large amount of wastewater which contains highly inorganic saline, recalcitrant or toxic organic pollutants, and the these wastewaters can have salinities ranging from 3.5 wt% to 20 wt% (Woolard and Irvine, 1995; Lefebvre et al., 2005). In wastewater treatment, saline wastewaters are defined as salinity at least 1 wt% and hypersaline wastewaters generally contain more than 3.5 wt% salinity (Shi et al., 2012). In recent decades, the inflow of saline and hypersaline wastewater to treatment plants has increased considerably, represents as much as 5% of the worldwide wastewater treatment streams (Lefebvre et al., 2007).

At present, the treatment methods of chemical and physical technology used in the disposal of salinity wastewater are adsorption method, membrane separation, ion exchange or electrodialysis, etc (Fan et al., 2011; Neilly et al., 2009; Dincer and Kargi, 2000). However, these treatment methods always lead to some problems such as high cost, secondary pollution, and as a consequence, these technologies are only applied in certain conditions. By contrast, biological treatments especially activated sludge process are preferred, because of their better economic performance, moreover they can avoid secondary pollution (Boopathy et al., 2007; Shi et al., 2014). Some researches focus on the effect of salt-tolerant sludge on saline wastewater treatment process and removal efficiency, such as two stage biological contact oxidation process, sequencing batch reactor (SBR), biofilm sequencing batch reactor (BSBR), upflow anaerobic sludge blanket (UASB), anaerobic

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filter, anaerobic aerobic process, etc (Gao et al., 2013; Ferrer-Polonio et al., 2016b; Jiang et al., 2016; Wang et al., 2005; Lu et al., 2011). Predecessors researched the nitrogen removal efficiency and improved methods in the condition of salinity from different aspects, such as saline concentration, operational conditions, removal rate of organic pollutant and nitrogen removal efficiency (Belkin et al., 2007). Due to the differences of process and wastewater quality, there are various opinions on the treatment process of saline wastewater by using activated sludge especially the treatment effect, some researchers found that the removal efficiency of wastewater was decreased in saline wastewater but other researchers studied that the removal efficiency of saline wastewater was not affected (Aslan and Simsek, 2012; Zhao et al., 2013). Besides, the microorganisms of activated sludge were acclimated into salt tolerant microorganisms by increasing influent salinity gradually and then the microorganisms had good capacity of nutrition removal at high saline conditions (Rene et al., 2008). Researches showed that activated sludge regains the ability of nitrogen removal by adding the cultivated microbes into traditional activated sludge process (Kulkarni, 2013; Figueroa et al., 2008). Base on so many researches about the treatment process and removal efficiency of saline wastewater, there are many related articles which have summarized activated sludge treatment, organic removal and biological nitrogen removal performance (Chowdhury et al., 2010; Lofrano et al., 2013).

Until now, there are many researches about the influences of salinity on the activated sludge microorganisms. For instance, a certain concentration of inorganic salt (such as Cl^-, SO_4^{2-}, PO_4^{3-}, Mg^{2+}, Ca^{2+}) plays an important role in the growth of microbes, such as maintaining membrane equilibrium, adjusting osmotic pressure, promoting enzyme activity, etc (Gatti et al., 2010). However, when the concentration of inorganic salt is excessively high (>2 wt% salinity), the removal of nitrogen in wastewater will be influenced. Because high salinity can raise osmotic pressure, separate microbial cell plasma, at the same time it can reduce the metabolic enzyme activity, destroy the structure of microbial enzymes and inhibit the growth of microorganisms (Hong et al., 2013). Meanwhile, high salinity can cause activated sludge bulking and loss, and the performances of biological treatment process were badly affected (Wilson et al., 2013). Quick salinity increasing of influent wastewater can lead to the release of intra-cellular constitutes and also the increase of soluble COD (Lefebvre and Moletta, 2006). However, there is only a little literature review in this aspect (Wang et al., 2011).

From the macroscopic and microcosmic angle, this paper summarizes the influence of salinity on the sludge structure and properties, microbial community, physiological effects and internal mechanism of activated sludge, and reviews recent research progresses about microorganisms of activated sludge in the saline wastewater treatment. And this paper can provide some ideas for further studies about impact of salinity on activated sludge treatment.

2. Influences of salt on sludge property and community

2.1. Influences of salt on sludge structure and settlement

Nowdays, the research conclusions about the influence of inorganic salt on the sludge structure and settling property are inconsistent. Some studies suggest that increasing salinity is beneficial to sludge settlement (Moon et al., 2003; Pronk et al., 2014). Because high salt inhibits the rapid growth of the filamentous bacteria, and the size of sludge flocs becomes small and the flocs close together, so that the sludge settling property is increased. For instance, Moussa at al. (2006) studied that the sludge volume index (SVI) gradually reduced and the sludge settling velocity increased when the salinity was increased from 0 to 40 g/L Cl^-. Besides, they found that big activated sludge granules, closed zoogloea structures, loose microbial flocs and a large number of filamentous bacteria existed in the activated sludge when the Cl^- concentration was 0 g/L. However when the Cl^- concentration was 40 g/L, the size of sludge folcs was very small and became extremely close, and filamentous bacteria were hardly seen by microscopy. In their studies, only the nitrifiers lived in the bioreactor as the Cl^- concentration was 40 g/L. In these researches, the use of optical microscopy and scanning electron microscopy (SEM) provides an easy and intuitive way to indicate the sludge morphological changes in salinity wastewater (Ng et al., 2005).

Tokuz and Eckenfelder (1979) studied the effect of sodium chloride and sodium sulfate on the performance of the activated sludge process, when NaCl concentration was less than 35 g/L, effluent suspended solid was less than 10 mg/L, the sludge settling property was not affected, and they found that the effect of sodium sulfate on the system was even less profound. Dahl et al. (1997) studied the biological treatment of high-salinity wastewater as the Cl^- concentration was 20 g/L, they found that the sludge settling property was not affected and the SVI value was 32 mL/g in the activated sludge process. Campos et al. (2002) used the activated sludge to treat high ammonia saline wastewater, they clarified that high salt concentrations (20 g Cl^-/L) did not have long-term effects on the physical properties of sludge, the SVI value was decreased from 42.4 to 11.4 mL/g at the treatment process. Bassin et al. (2012) researched the effects of different salt adaptation on the microbial activity and settling property of sludge in two sequencing batch reactors. And they observed that the SVI decreased with the increase of salinity in both reactors. In the SBR1 as NaCl concentration increased gradually from 5 to 20 g/L, the SVI decreased gradually from 110 to 70 mL/g. In the SBR2 as the NaCl concentrations increased from 10 to 20 g/L, the SVI dropped from 110 to 60 mL/g, a slightly higher as compared to that observed in the SBR1. And also their results showed that a gradual increase in NaCl concentration had a positive effect on the settling properties and the nitrification performance of sludge was not affected. These researches showed that the sludge structure and settling property were not affected in high salinity environment.

However, some researchers suggested that the sludge structure and settling property would become bad in high salinity environment (>1 wt% salinity) (Amin et al., 2014; Zhao et al., 2016). As salinity was above 1 wt%, the settlement of sludge was unbeneficial because of the increase of wastewater density. For instance, Uygur and Kargi (2004) studied the biological nutrient removal from saline wastewater using SBR, and they found that the SVI value increased with the increase of NaCl concentration. When NaCl concentration was increased from 5 to 60 mg/L, the SVI value increased from 50 to 97 mL/g almost linearly. The sludge settling performance was damaged because the microbial biomass of activated sludge reduced under high salt condition. Amin et al. (2014) studied the saline wastewater treatment by sequencing batch reactor with adapted and non-adapted consortiums. Their results illustrated that the SVI values increased with the increase of salinity in both SBRs. And the increased rate of SVI in adapted SBR was below the increased rate in non-adapted SBR. Zhao et al. (2016) researched the SBR treating at different salt concentration (0–3 wt%) wastewater and the treatment performance and microbial community profiles of SBR were discussed. The results showed that as no salt existed, the SVI value was 84 mL/g, however with the addition of salt to 3 wt%, the SVI increased to 116 mL/g steeply. And also they illustrated that the SVI increased due to the high sensitivity of activated sludge microorganisms to salinity variations.

In addition, when activated sludge system is shocked by salinity, sludge flocs are broken and the settling property of activated sludge