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Validation of accumulation models for inorganic suspended solids of different particle size in an activated sludge system

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HIGHLIGHTS

- The influence of influent ISS with different particle sizes was studied.
- 4 Fates of ISS in an activated sludge system were proposed.
- ISS accumulation model based on the proportion of ISS in the 4 fates was proposed.

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ABSTRACT

In this study the effect of different particle sizes of inorganic suspended solids (ISS) on the ISS accumulation in an activated sludge system was investigated. The volume mean particle diameters (Dv) of ISS were 26, 73, 106, 165, and 210 μm. There are four fates of ISS in an activated sludge system: (1) suspending in the activated sludge, (2) depositing at the bottom of the reactors, (3) discharged from the reactors via excess sludge, and lastly (4) discharged from the reactors via effluent. The accumulated ISS in the bioreactor was unevenly distributed. Based on the accumulation proportion of ISS in bioreactor, an ISS accumulation model was established, from which the ISS accumulation concentration and the MLVSS/MLSS could be predicted. The proportion of ISS suspending in activated sludge was 0.22, 0.21, 0.042 and 0.031. The proportion of ISS depositing at the bottom of bioreactors was 0.31, 0.47, 0.75, 0.76 and 0.92.

1. Introduction

The suspended solids (TSS) of activated sludge include both organic (volatile) suspended solids (VSS), and inorganic suspended solids (ISS). Much of the previous research has focused on VSS only. In fact, current design procedures (WRC, 1984) and simulation models (Dold et al., 1980; Henze et al., 1987) only include the influent wastewater characteristics that affect the organic components (e.g. VSS) of mixed liquor. Reliable predictive models for VSS concentration in activated sludge system reactors have been developed (Wentzel et al., 1990; Henze et al., 1995; Henze et al., 1987, 1999). In contrast to the above organic models, predictive models for reactor ISS concentration have not received similar levels of attention, or have been widely accepted.

Based on: (1) the entrapment in the activated sludge of the influent ISS; and (2) the uptake of inorganic dissolved solids by the active organisms in the reactor, Ekama and Wentzel (2004) and Ekama et al. (2006) described predictive models for ISS in an activated sludge reactor. As most of the total inorganic solids (TIS) were dissolved, only a small fraction (2.8–7.5%) of the influent total inorganic solids (TIS) was incorporated into the mixed liquor. This had little impact on the ratio of mixed liquor volatile suspended solid to the mixed liquor suspended solid (MLVSS/MLSS) (Wentzel et al., 2002). In addition, the distribution of the ISS of different particle sizes was not considered in these previous reports.

In wastewater treatment plants, particle size distribution (PSD) is an important parameter for evaluation of physical, chemical, and biological treatment processes (Dulekgurgen et al., 2006; Karaham et al., 2008). The importance of PSD in primary treatment (Sophonsiri and Morgenroth, 2004), secondary treatment (Garcia-Mesa et al., 2010a,b), and in membrane bioreactors (Zhang et al., 2011; Garcia-Mesa et al., 2010b) has previously been studied. However,

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these studies mainly focused on PSD of the activated sludge and influent SS, rather than the PSD of ISS in an activated sludge system.

SBR and Oxidation Ditch are the two of the most widely used wastewater treatment processes worldwide. In order to ensure adequate carbon source for biological nitrogen and phosphorus removal, and save land occupation, many WWTPs using SBR and Oxidation Ditch cancelled use of primary settling tanks (Xie et al., 2013). However, most of the urban drainage systems are combined drainage systems in China, resulting in relatively high concentrations of influent inorganic suspended solids (ISS). The cancellation of the primary settling tank has led to increases of ISS in the activated sludge, negatively affecting WWTP performance. In fact in recent years, ISS deposition has been demonstrated to occur in a large number of WWTPs with biological nutrient removal functions (He et al., 2013). At the same time, the MLVSS/MLSS of activated sludge declined significantly, with the MLVSS/MLSS of some WWTPs being approximately 0.3–0.5 in China (Yan et al., 2013), much lower than the normal value of 0.7 (Metcalf and Eddy, 2002; Gianico et al., 2013). With the cancellation of the primary settling tank, ISSs with particle sizes of less than 200 μm (which cannot be removed by grit chambers) directly flow into the biological treatment systems. As the influent ISS was ignored, and the influence of ISS on the activated sludge system was regarded as negligible, the PSD of ISS is not taken into account in existing models (Ekama and Wentzel, 2004; Chen et al., 2009, 2012). The primary objective of this study was to examine the fate of ISS with particle sizes of less than 200 μm in the absence of settling tanks. An accumulation model based on the PSD characteristic of ISS was also established.

2. Methods

2.1. Experiment methods

Quartz sand (the primary component is SiO_2; relative density of 2.65) was used as the inorganic solid. Five different particle sizes (Table 1) were obtained using a sieve. The quartz volume mean diameter (Dv) distribution following a 5d H_2O soak did not change from initial values indicating stability of the sand.

The influent feed was raw (settled) municipal wastewater from Chongqing University (China). Starch and glucose were used to adjust the COD concentration. The concentrations of ISS and COD following these adjustments are shown in Table 1.

2.2. Laboratory-scale system

Six sequencing batch reactors (SBRs) (H × R = 0.7 m × 0.19 m) were used to in this study, each with a working volume of 18 L, and an influent volume of 9 L. The reactors were operated for 40 d under anaerobic–aerobic conditions. Cycle duration averaged 6 h (feeding = 0.5 h, anaerobic treatment = 0.5 h, aeration (aeration power is 5 w) = 3.5 h, settling = 1 h, and effluent withdrawal = 0.5 h). The sludge retention time (SRT) in the SBR was approximately 20 d. Activated sludge mixed liquor of 900 mL was discharged from the bottom of SBR reactors at following aeration (prior to settling).

2.3. Test methods

Activated sludge samples were collected at following aeration (prior to settling). The MLSS and MLVSS, excess sludge, and effluent were sampled each day.

Particle size was determined using a laser particle size analyzer (BT-9300HT, Bettersize Instruments Ltd., China). The COD was determined using a DR1010 COD Analyzer (HACH, USA). All samples were passed through a 0.45 μm filter and dried to a constant weight at 105 °C to obtain MLSS. Inorganic solids (MLISS) were also determined by weighing following incineration at 600 °C for 2 h. Organic solids (MLVSS) were calculated as the difference between MLSS and MLISS.

3. Results and discussion

3.1. Concentration of ISS in the activated sludge system

The changes in the inorganic solids concentration of differing particle sizes are presented in Table 2. The ratio of MLVSS/MLSS is presented in Fig. 1.

The ISSs of both 26 μm and 73 μm noticeably accumulated in both mixtures and the excess sludge, whereas those of 106 μm accumulated mostly in the excess sludge. All ISSs were discharged with the effluent at a low concentration. The MLVSS/MLSS ratio input ISS of Dv 26 μm decreased from 0.84 to 0.35 after 20 d (Fig. 1). However, in the reactor input of Dv 210 μm, this ratio remained at 0.73 even after 40 d. During this extended operation time, the MLVSS/MLSS input ISS of Dv 73 μm exhibited a similar trend as the ISS of 26 μm.

Compared with the dissolved inorganic solid (Wentzel et al. 2002), the ISS that incorporated into the mixed liquor was more

Table 1
Experimental conditions.

NO. of reactors	1	2	3	4	5	Control group
Particle size range/μm	1.03–74.42	3.94–204.98	5.84–217.84	64.44–294.43	90.11–357.23	
Dv/μm	26	73	106	165	210	Without quartz sand
Raw wastewater (settled)	The concentration of ISS and COD was about 10 and 100 mg L^{-1}, respectively.					
Wastewater after adjustment	The concentration of ISS and COD was about 300 and 350 mg L^{-1}, respectively.					

Table 2
Concentration of ISSs with different Dvs (mg L^{-1}).

Dv (μm)	Activated sludge			Excess sludge			Effluent		
	Range	Mean	Standard deviation	Range	Mean	Standard deviation	Range	Mean	Standard deviation
26 μm	464–5759	3724.36	1497.43	493–9982	5185.85	2475.13	7.0–16.5	12.6	2.3
73 μm	337–5648	1976.50	1521.30	388–12534	3404.47	3054.98	2.5–11.0	6.1	1.6
106 μm	515–1447	886.47	255.54	591–6589	2351.03	1952.17	3.5–9.0	6.1	1.6
165 μm	352–1140	620.73	203.94	468–8454	2237.77	2486.13	2.5–12.0	7.1	2.1
210 μm	360–870	542.67	102.64	500–3394	1367.10	644.85	3.0–12.0	6.7	1.9
Control group	376–601	506.62	55.23	474–739	587.38	60.25	1.5–11.5	5.5	2.2