Original Article

Biological Excess Sludge Reduction in Adsorption/Bio-Oxidation Process by Enhancing Predators' Growth

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Abstract

Aims: This study was carried out to investigate the effect of predators' growth on biological excess sludge reduction of adsorption/bio-oxidation process (A/B process) as a modification of activated sludge system. **Materials and Methods:** The real municipal wastewater after screening and gritting was pumped into A/B pilot plant which consists of two aeration and sedimentation tanks in series. The hydraulic residence time for A and B stages was set at 1 and 4 h, respectively, at an average flow rate of 32 L/h. During operation, the mixed liquor suspended solids (MLSS) in A and B stages was gradually increased. In this period, the operational parameters including dissolved oxygen, pH, volatile suspended solids (VSS), MLSS, alkalinity, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), phosphorus, nitrogen, and sludge volume index were monitored. **Results:** The results showed that with increasing solid retention time (SRT) from 0.6 to 56.8 days in Stage A, the biomass yield (*Y*) decreased from 1.29 to 0.23 g VSS/g COD. Similar results were observed in Stage B and correspondence to 67% reduction of *Y* as SRT increased from 1.6 to 123.8 days. During the A/B operation, overall $tBOD_5$ and tCOD removal was 70% ± 20% and 57% ± 24%, respectively. **Conclusion:** Based on the results, A/B process operation with high SRT led to predator growth enhancement and lower biological excess sludge production.

Keywords: Aquatic worm, predators, sludge reduction, solid retention time, two-stage activated sludge

Introduction

Activated sludge (AS) process is a frequent wastewater treatment plant (WWTP) for both industrial and municipal wastewater treatments.[1] In an AS process, the *Y* coefficient is about 0.4–0.6 volatile suspended solids (kg VSS)/chemical oxygen demand (kg COD),[2] thus a large amount of sludge is produced during organic matter oxidizing. On the other hand, legislations for sludge discharge to environment have been strengthened. The sludge mainly consists of water, and its conventional treatment process includes thickening, stabilization, and dewatering, which impose 50%–60% of the total costs on the WWTP operation costs.[3] A feasible and environmental-friendly method is highly desired to reduce excess sludge. In previous studies, different approaches to reduce excess sludge were investigated. Mainly, sludge reduction processes have been divided into two categories: (a) *in-situ* sludge reduction processes and (b) sludge post treatment. Comparing to posttreatment process, *in-situ* sludge reduction process has some advantages. In case of *in-situ* sludge reduction process, the minimization occurs by decreasing the yield of the sludge production.[4] The *in-situ* reduction treatment includes chemical and biological uncoupling metabolism (such as oxic-settling-anaerobic), maintenance metabolism, and predation.[5,6]

Predation is one of the *in-situ*, biological approaches to reduce biological excess sludge. The primary consumers in wastewater

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treatment systems are bacteria, which themselves are consumed by higher organisms in food chain such as metazoa and protozoa. The worm predation is described as using microfauna to feed on microorganisms. Hence, to reduce biological excess sludge, inducing such organisms' growth can help.[7]

The present study was aimed to evaluate the presence and growth of predators on sludge reduction of adsorption/bio-oxidation (A/B process) fed by real wastewater from the North Isfahan WWTP.

Materials and Methods

In this study, a two-stage AS (A/B process) with similar pattern as the North Isfahan WWTP (Isfahan, Iran) was implemented. The schematic of the studied A/B process is shown in Figure 1, which was made by stainless steel.

The influent was collected from real municipal wastewater after passing screening and gritting and then was pumped into the A/S process pilot at a flow rate of 30 L/h. The characteristics of the influent wastewater are summarized in Table 1. Before A/B process operation, in order to providing microbial consortium, the AS was extracted from Stages A and B of North Isfahan WWTP with mixed liquid suspended solid (MLSS) of 5264 and 4142 mg/L, respectively. After that, aeration was started, and the dissolved oxygen (DO) concentration was kept in the range of 0.5–1 mg/L in Tank A and 1–2 mg/L in Tank B.

The pilot was operated for 183 days. After 22 days of A/B process operation, the MLSS concentration reached to 3132 and 3500 mg/L in Tanks A and B, respectively. In order to enhance predator's growth and also to reduce the excess biological sludge, the solid retention time (SRT) was increased to higher than the North Isfahan WWTP. To SRT increment, the sludge withdrawal was avoided unless it was necessary.

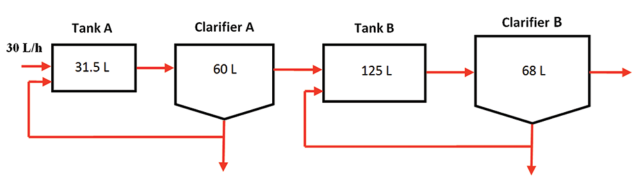

Figure 1: Schematic diagram of the two-stage activated sludge pilot[8]

Table 1: Characteristics of the de-gritted influent wastewater

Parameter (unit)	Value
pH	7.4±0.2
tCOD (mg/L)	547±16
sCOD (mg/L)	260±11
BOD_5 (mg/L)	281±9
TSS (mg/L)	325±10

Analysis

For A/B process performance monitoring, the influent and effluent wastewater were analyzed with respect to the operation period of DO, pH, temperature, VSS, MLSS, mixed liquor volatile suspended solids (MLVSS), alkalinity, biochemical oxygen demand (BOD_5), COD, phosphorus, nitrogen, and sludge volume index (SVI). The analyses were accomplished according to the standard methods for water and wastewater examination.[9]

Calculation

The Y coefficient in A/B process was calculated by using equations (1) and (2):

$$Y_{obs} = \frac{Y}{1 + (k_d \times SRT)} + \frac{f_d \times k_d \times Y \times SRT}{1 + (k_d \times SRT)} \quad (1)$$

where Y_{obs} is observed biomass yield coefficient (gVSS/gCOD), Y is absolute biomass yield coefficient (g VSS/g COD), k_d is death rate constant (d_{-1}), and f_d is residue mass (d^{-1}).

$$SRT = \frac{MLVSS \times V_{aeration}}{(X_w \times Q_w) + (X_e \times Q_e)} \quad (2)$$

where SRT is sludge retention time (days), MLVSS is mixed liquor volatile suspended solids of the reactor (mg/L), $V_{aeration}$ is aeration tank volume (L), X_w is VSS of waste sludge (mg/L), X_e is VSS of effluent (mg/L), Q_w is the flow of waste sludge (m^3/day), and Q_e is the flow rate of effluent (m^3/day).

$$Y_{obs} = \frac{\sum VSS_{produced}}{\sum COD_{removed}} = \frac{\sum\left(F_W \times VSS_W \times F_{ef} \times VSS_{ef} \times \Delta VSS_{system}\right)}{\sum\left(F_{in} \times (COD_{in} - COD_{ef})\right)} \quad (3)$$

where F_w is waste sludge flow rate (m^3/day), VSS_w is VSS in waste sludge, F_{ef} is the flow rate of effluent, VSS_{ef} is VSS in effluent, F_{in} is influent flow rate, and COD_{in} and COD_{out} are COD of influent and effluent wastewater, respectively.

Equations 1 and 3 were used to calculate sludge reduction.[6]

Results

Variation of *Y* coefficient during adsorption/bio-oxidation process operation

Variation of Y_{obs}, as a function of SRT, is shown in Figure 2. As depicted in Figure 2, the operation A/B process with high SRT led to lower Y_{obs}. With SRT increasing from 0.6 to 56.8 days in Tank A, the Y coefficient decreased from 1.29 to 0.23 g VSS/g COD and also reduced from 0.57 to 0.19 g VSS/g COD; in Stage B, as the SRT increased from 1.64 to 123.78 days, the biomass yield coefficient decreased. Figure 3 illustrates the effect of SRT on excess sludge reduction during A/B process operation.

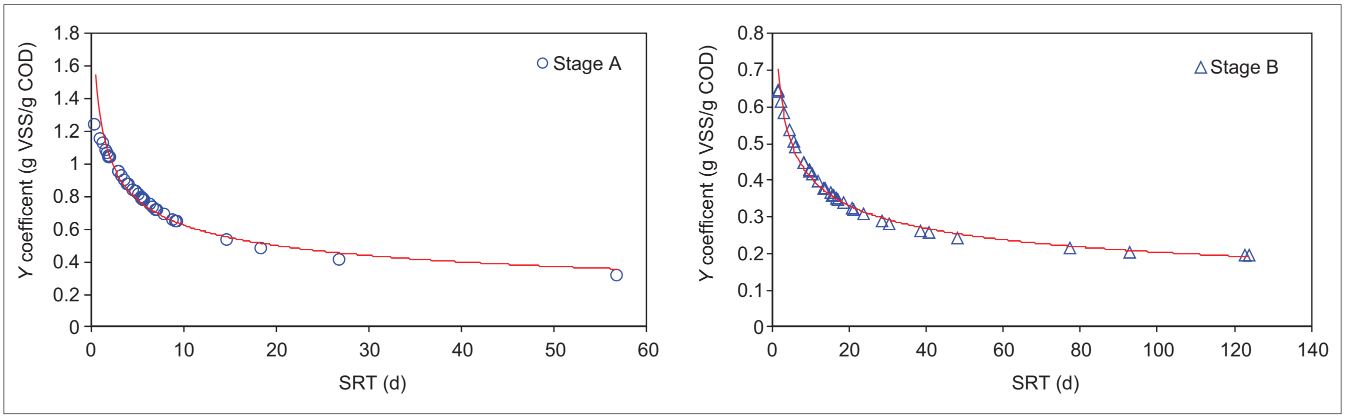

Figure 2: Variation of observed biomass yield in Tanks A and B during the pilot operation

Microscopic observation

The A/B operation with higher SRT led to more predators' growth in sludge. In Stage A, as SRT increased up to 4 days, the *Paramecium* spp. was observed and maintained during the A/B process operation. By increasing SRT from 10 to 123 days in Stage B, the rotifers and *Lumbriculus variegatus* worms with 1 cm of length were seen. *Paramecium* and worm observed in Stage B of the A/B process are depicted in Figure 4.

Food-to-microorganism ratio variation

Variation of food to microorganism (F/M) ratio in A and B stages during the A/B process operation is depicted in Figure 5. The mean F/M in Tanks A and B was 0.62 ± 0.36 and 0.16 ± 0.2/day, respectively. As illustrated in Figure 5, the steepness trend of F/M ratio as a function of SRT was observed in A and B stages.

Adsorption/bio-oxidation process performance

In biological wastewater treatment, the organic compounds were qualified with BOD_5 and COD as indicators. In this study, the performance of A/B process with respect to BOD_5 was monitored, and BOD_5 variation during the A/B process operation is presented in Figure 6. As shown in Figure 6, during 180 days of operation, the $tBOD_5$ concentration ranged from 221 ± 118 to 114 ± 42 mg/L and also from 114 ± 42 to 61 ± 35 mg/L in Stages A and B, respectively. The removal efficiency of $tBOD_5$ in Stages A and B was 45% ± 15% and 46% ± 23%, respectively. In addition, the overall $tBOD_5$ removal efficiency A/B process was 70% ± 20%. Similarly, the same trend was observed in case of $sBOD_5$. The average of effluents $sBOD_5$ in A and B stages were 103 ± 53, 45 ± 26, and 22 ± 13 mg/L, respectively. The average of $sBOD_5$ removal efficiency in Tanks A and B and the overall A/B process was 53% ± 19%, 47% ± 20%, and 76% ± 13%, respectively.

For the prediction of sludge-settling behavior, SVI was monitored. The SVI during the A/B process did not drastically change. The mean SVI in A and B stages was 62 ± 17 and 85 ± 30 mL/g, respectively. In order to calculate waste excess sludge during the A/B process, the quantification of suspended solids (SS) and volatile

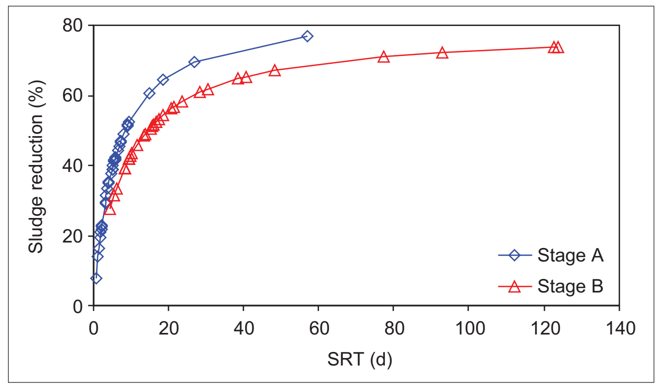

Figure 3: Effect of solid retention time enhancement on excess sludge reduction

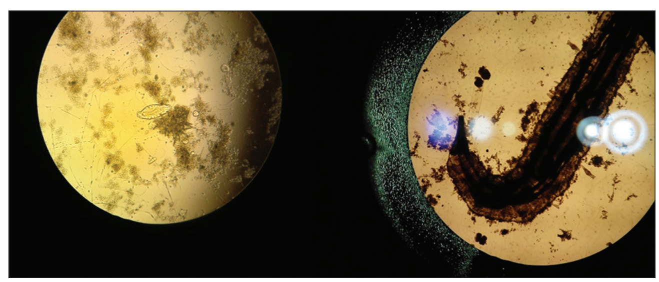

Figure 4: The paramecium and worm observed in the two-stage activated sludge pilot

suspended solid (VSS) in returned AS is critical. During A/B process operation, the average of SS and VS in returned AS in Stage A was 16,000 ± 8900 and 10,635 ± 6200 mg/L and also in Stage B was 10,500 ± 7000 and 6700 ± 5200 mg/L, respectively. The VS/SS ratio is a vital parameter to evaluate AS quality. As monitored in the present study, the VS/SS ratio was 0.68 ± 0.12 and 0.66 ± 0.16 in A and B stages, respectively. Previous studies demonstrated that the VS/SS ratio for high-quality AS was higher than 0.75.[9] To assess the nutrient removal of A/B process during long-term operation, the total Kjeldahl nitrogen (TKN) and ammonia were selected. Overall, the average of TKN and ammonia removal was 92% and 88%, respectively.

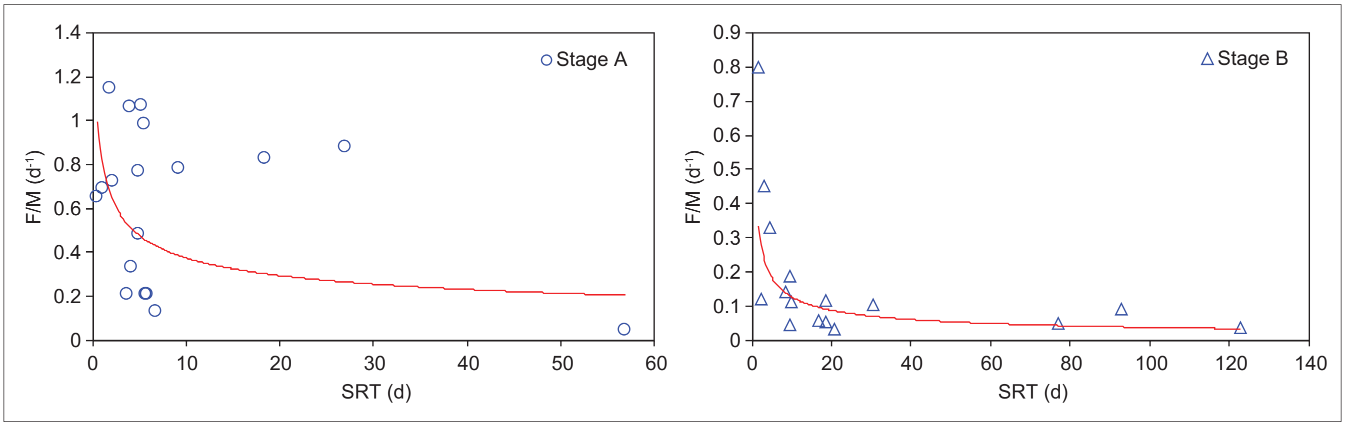

Figure 5: Effect of solid retention time enhancement on food-to–microorganism ratio

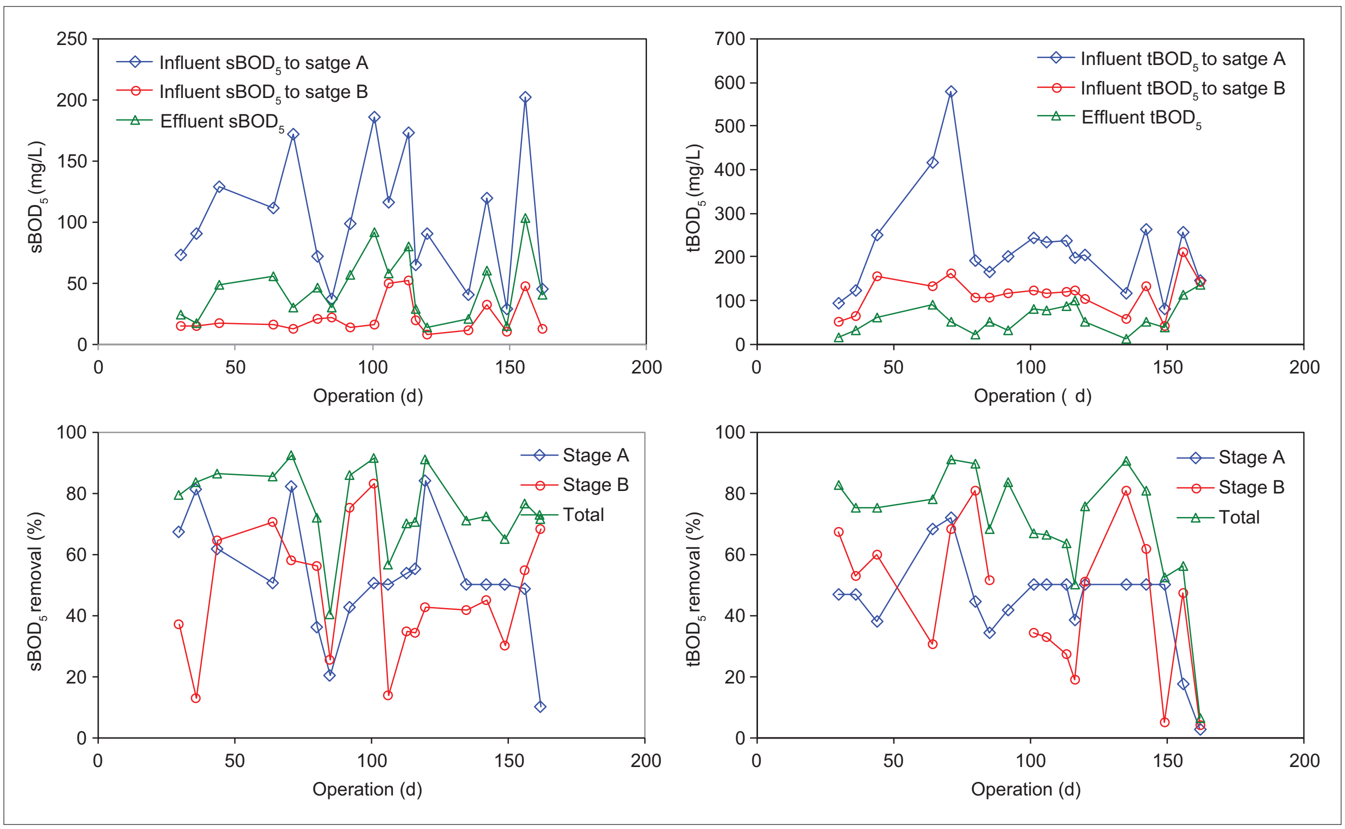

Figure 6: Pilot efficiency for $tBOD_5$ and $sBOD_5$ removal. BOD: Biochemical oxygen demand

Discussion

For predators' growth enhancement and proliferation and also to reduce excess achieved sludge, the SRT was increased to much more than A/B process design criteria. As a result, the predators developed and Y_{obs} decreased. The maximum excess sludge reduction in A and B stages of A/B process was 76% and 65%, respectively.

The operation of A/B process with higher SRT leads to lower Y_{obs}, which means that sludge production is decreased.[10,11] The obtained results showed that with increasing SRT, the predators' growth was intensified. Predators consume sludge flocs as food source and as a result, the dry mass of sludge is reduced and also a clarified effluent and a biomass full of protein are produced.[12]

Elissen reported that the operation of a reactor with fixed media led to *Lytechinus variegatus* growth promotion and found 75% of the total suspended solid (TSS) removal efficiency for influent wastewater with 4000 mg/L of TSS.[13]

As depicted in Figure 5, diminishing of the F/M was related to SRT increment. This behavior may be attributed to the accumulation of activated biomass in aeration tank and also the constant concentration of inlet substrate. When F/M ratio is <0.2, the bacteria's growth shifts to endogenous phase and leads to better settlement of sludge.[13]

The average of SVI in A and B stages was 62 ± 17 and 85 ± 30 mL/g, respectively. The result of SVI monitoring reflected improvement of sludge sedimentation properties with increasing SRT and growth promotion of predators. The direct relationship between SVI and sludge dewaterability was demonstrated in a previous study, which indicates that better settlement rate leads to a better dewatering rate.[11,15]

The lower SVI in A stage presumably related to a small population of filamentous bacteria. In comparison to a conventional AS, the higher F/M ratios and lower DO concentration in A stage led to the act of aeration tank as a selector. As a result, the conditions are more suitable for floc forming organism growth than filamentous organisms.[12]

Conclusion

In present study, the effect of predators' growth on biological excess sludge reduction of A/B process was studied. A/B process was consisted of two aeration and sedimentation tanks in series and feed with real municipal wastewater after screening and gritting. During A/B process operation, MLSS in aeration tanks was gradually increased and effluent wastewater subjected to DO, pH, VSS, MLSS, alkalinity, BOD5, COD, nutrient analysis. Based on the results, the following conclusion could be drowned.

- By increasing SRT from 0.6 to 56.8 d in stage A, the Y coefficient was decreased from 1.29 to 0.23 g VSS/g COD.
- In stage B, the SRT increasing from 1.6 to 123.8 d lead to 67% reduction of Y coefficient.
- During the A/B operation, overall tBOD5 and tCOD removal was 70% ± 20% and 57% ± 24%, respectively.

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Conflicts of interest

There are no conflicts of interest.

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