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Re-activation characteristics of preserved aerobic granular sludge

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Abstract: In some industrial plants, wastewater was intermittently or seasonally generated. There may be periods during which wastewater treatment facilities have to be set into an idle phase over several weeks. When wastewater was generated again, the activated sludge flocs may have disintegrated. In this experiment, re-activation characteristics of aerobic granular sludge starved for 2 months were investigated. Specific oxygen utilization rate(SOUR) was used as an indicator to evaluate the metabolic activity of the sludge. The results revealed that aerobic granular sludge could be stored up to two months without running the risk of losing the integrity of the granules and metabolic potentials. The apparent color of aerobic granules stored at room temperature gradually turned from brownish-yellowish to gray brown. They appeared brownish-yellowish again 2 weeks after re-activation. The velocity and strength of granules after 2-month idle period could be fully restored about 3 weeks after re-activation. Metabolic activity, however, dropped to 15.8 mg O_2/(g MLVSS·h), i.e. 74 % reduction after 2 months of storage. After restarting the reactor, it took 2 weeks that SOUR of up to 48.5 mg O_2/(g MLVSS·h) was achieved. A stable effluent COD concentration of less than 150 mg/L was achieved during the re-activation process.

Keywords: aerobic granular sludge; re-activation characteristics; SBR; specific oxygen consumption rate

Introduction

The capacity of a wastewater treatment plant ultimately depends upon two features: the metabolic capabilities of the microorganisms in the system and the effectiveness of solid/liquid separation at the last stage of the treatment process (Shwarzenbeck, 2004). Granular sludge demonstrates high settling velocities leading to good solid-liquid separation, high biomass retention, high activity, and an ability to withstand high loading rates. In the field of anaerobic wastewater treatment, granular sludge in the up-flow anaerobic sludge blanket reactor(UASB) has been extensively applied in industrial and domestic wastewater treatment practice since 1980(Seghezzo, 1998). Recently, research attention has turned to develope aerobic granular sludge in sequencing batch reactors(SBRs)(Morgenroth, 1997; Tay, 2001; Beun, 1999). Most of research on aerobic granulation had been focused on fundamental aspects of aerobic granulation, while there is little information currently available on potential application of aerobic granular SBR in specific field of wastewater treatment.

In some industrial plants, high variation of flow and concentration of wastewater was common. Wastewater was intermittently or seasonally generated. There may be periods during which wastewater treatment plant has to be temporarily shut down. The SBR technology has been applied in coping with fluctuating wastewater flows (Irvine, 1997). In addition, the SBR system could handle long out-of-service periods (Morgenroth, 2000). Evidence shows that aerobic granules have advantages over conventional bioflocs, e.g. dense and strong microbial structure, good settling ability, high biomass retention and ability to withstand a high organic loading rate. Therefore, aerobic granular sludge in SBR has a specific potential in polishing the intermittent or seasonal wastewater from industrial plants.

In this experiment, aerobic granular sludge was formed in a laboratory-scale SBR fed with synthetic wastewater, and preserved over a period of 2 months. Then the aerobic granules were re-activated in the SBR. The re-activation characteristics and performance of the preserved aerobic granules were investigated. It is expected that this study could provide a good insight into potential application of aerobic granular sludge SBR in the intermittent or seasonal wastewater treatment practice.

1 Materials and methods

1.1 Reactor set-up and operation

Aerobic granular sludge was cultivated in a column reactor. The reactor with a working volume of 2.4 L was operated in a sequencing mode (Fig. 1). Effluent was discharged from the middle port of the column reactor, i.e. exchange ratio was fixed at 50%. Air was introduced from the bottom of the column through a fine bubble aerator. The airflow rate was maintained at 4.5 L/min, equivalent to a superficial air velocity of 0.0375 m/s. The reactor was operated at a cycle time of 4 h, 5 min of feeding and 5 min for effluent withdrawal. The settling time was initially set as 25 min and reduced gradually to 1 min based on the improving of the sludge settling property. The remainder was the reaction time. Municipal activated sludge obtained from a local municipal wastewater treatment plant was used as inoculum.

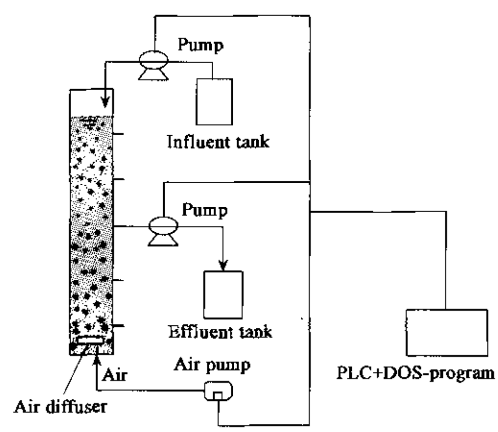

Fig.1 Schematic representation of the SBR

After 3 months operation, aerobic granules were approximately 4 mm in diameter, had a smooth surface and

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the biomass concentration remained around 7.3 g/L. The settling velocity of 72—90 m/h was achieved. Thereafter no significant change of the granules occurred. The steady-state conditions were established. Then, to simulate an intermittent period during which no wastewater was generated in the catchment area of the treatment plant, the feeding, aeration and decanting of the SBR were discontinued. The aerobic granules in the SBR were preserved at room temperature for 2 months. After 2-month idle period, the aerobic granules were re-activated. The settling time was set for 1 min, and the influent loading and other operational conditions were applied as previously.

1.2 Media

During the whole experiment, the synthetic wastewater with the following composition was used: $C_6H_{12}O_6$, 0.9375 g/L; NaAc, 1.28 g/L; NH_4Cl, 0.2 g/L; $K_2HPO_3 \cdot 3H_2O$, 0.08 g/L; peptone, 0.005 g/L; $CaCl_2$, 0.02 g/L; $MgSO_4 \cdot 7H_2O$, 0.03 g/L; $FeSO_4 \cdot 7H_2O$, 0.02 g/L; trace element solution, 2 ml/L. The composition of the trace solution was prepared according to Tay *et al*. (Tay, 1996). The influent COD was in the range of 1000—4200 mg/L. The influent pH value was adjusted to about 7.0 by adding NaOH and HCl.

1.3 Analytical procedures

Effluent COD, sludge mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and sludge volume index (SVI) were measured according to the standard methods (APHA, 1998). The settling velocity of single granule harvested from the reactors was measured by applying free-settling tests according to Lee *et al*. (Lee, 1996). The physical strength of the granules was determined as described previously (Ghangrekar, 1996). The physical strength is expressed in terms of integrity coefficient (%), which is defined as the ratio of residual volatile suspended solid (VSS) to total suspended solids (TSS) after 5 min shaking. The specific test procedure was conducted as follows: The sample sludge from the SBR was diluted 10 times with tap water and 25 ml of the diluted sample was allowed to settle in a column of 7.5 cm diameter and 75 cm height. The fraction of the diluted sludge that settled in the first one minute was collected to determine its strength. The collected granules were diluted to 150 ml with tap water. Then the sample was kept on a platform shaker at 200 r/min for 5 min. After five minutes the sample was poured into a 150 ml measuring cylinder and allowed to settle for one minute followed by decanting of the supernatant and weighing of the residual VSS. The ratio of the residual VSS to the TSS of the granular sludge was expressed as integrity coefficient.

SOUR (specific oxygen utilization rate) was measured by using USA standard methods (APHA, 1998). 330 ml glass bottle having a ground-glass stopper and a flared mouth was used as test cell. Clean bottles with a detergent, rinse thoroughly, drain before use, and maintained a constant temperature of 20 ± 0.5℃ during analysis. For mixing, a magnetic bar was used, which rotated at a moderate speed of 150 r/min. 400 ml mixed liquor was taken from the reactor at the same initial period of aeration during operation, and placed in a plastic cylinder. DO concentration of the sample was increased over 7 mg/L by bubbling air through it. Then the sample was transferred to the test cell, and the decrease of the DO was recorded at time intervals of less than 1 min, depending on rate of consumption. Record data over a 15 min period or until DO becomes limiting, whichever occurs first. The oxygen probe may not be accurate below 1 mgDO/L. SOUR in milligram per gram per hours was calculated as follows:

$$R_{SOUR} = \frac{\gamma_{O_2}}{V} \times 60.$$

Where, R_{SOUR} is specific oxygen consumption rate, mg/(g·h); γ_{O_2} is oxygen consumption rate, (mg/L)/min; V is volatile suspended solids, g/L.

2 Results and discussion

2.1 Structure and appearance

The structure appearance of aerobic granular sludge in SBR is shown in Fig.2. As shown in Fig.2b, most of the aerobic granules were visually in good granular shape after storage for two months, and no significant changes are observed, although some debris were seen on the surface of granular sludge. The aerobic granules still had spherical structure. Fig. 2c indicates that the re-activated granules seemed more compact and smoother compared with the 2-month idle ones. At this point, they could be comparable with the fresh granules shown in Fig.2a. The apparent color of aerobic granules stored at room temperature turned from brownish-yellowish (fresh granules) to gray brown at the end of storage. Interestingly, they appeared brownish-yellowish again 2 weeks after re-activation. It seemed to be reasonable that the changes of apparent color during the storage resulted from anaerobic metabolism of the granules.

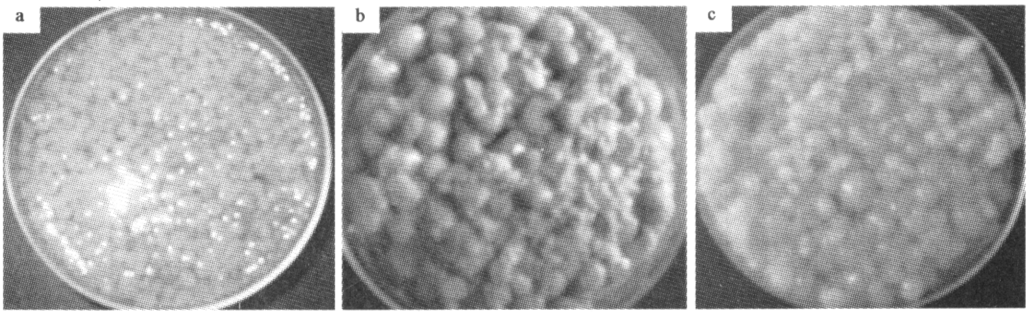

Fig.2 Structure appearance of aerobic granular sludge in SBR
a. fresh granules; b. granules before re-activation; c. granules 2 weeks after re-activation

2.2 COD removal and ability of withstanding high loading rate

In order to find the operational problems in the re-startup of aerobic granular SBR reactor rested for a long period, as well as to know the time required for granular sludge to recover its activity and the ability of withstanding high loading rate, a reactor re-feeding test was conducted in SBR mode. In this investigation, emphasis was given to the removal of COD at different organic loading rates during the whole re-activation process. The removal of COD during the re-activation process is presented in Fig. 3. With the re-activation of the stored aerobic granules, the influent concentration was gradually increased. A stable effluent COD concentration of less than 150 mg/L was observed in the SBR reactor during the re-activation process. However, when an influent COD concentration of 4200 mg/L equivalent to a loading rate of 12.5 gCOD/(L · d) was applied, aerobic granules began to disintegrate, leading to the unstable operation. The effluent COD concentration was greatly increased. Moy *et al*. reported that aerobic granules could withstand high organic loading rate(OLR) of 15 gCOD/(L·d) without compromising granule integrity(Moy, 2002). In fact, OLR was an important operational parameter in the design of wastewater treatment plants. Although the maximum OLR investigated in this study here was 12.5 gCOD/(L·d), it was worth noting that aerobic granules were likely able to handle higher OLRs. This could be accomplished by adjusting parameters such as superficial gas velocity. In addition, high biomass concentration in reactor systems would be in favor of the stable effluent and have the advantage to buffer the high shocking loading.

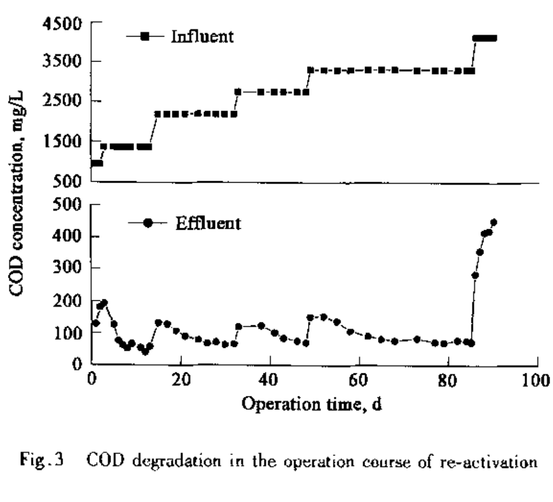

Fig.3 COD degradation in the operation course of re-activation

2.3 Settling velocity and physical strength

During sedimentation, the granules did not coagulate and form larger aggregates from activated sludge flocs. Instead, the granules settled as individual particles. As presented in Table 1, the settling velocity of the fresh aerobic granules before the idle period(after 3 months of operation) and after 2-month idle period was in the range of 70—90, 55—80 m/h, respectively, while the settling velocity of the re-activated particles(3 weeks after re-activation) was in the same range as the fresh granules. It was implied that there was no significant difference in settling velocity for aerobic granules during the storage and re-activation. In fact, the settling velocity of conventional activated sludge was generally less than 10 m/h(Compos, 1999).

A thin layer of flocculent sludge was noted on the top of the blanket of the settling granular sludge in the first week of the re-activation. Thereafter the flocs disappeared as a result of wash out. As mentioned above, the settling time was set for 1 min in the process of re-activation. Thus, the flocs and some small particles had no chance to reside in the reactor.

Table 1 The measurement of settling velocity and physical strength for granular sludge

Granular sludge	Settling velocity, m/h	Physical strength, %
Before the idle period	70—90	98
After 2-month idle period	55—80	89
3 weeks after re-activation	70—90	97

The integrity coefficient is related to the strength of the granules, which can thus be interpreted as indirect index for strength of granules. The higher the integrity coefficient is, the more the strength of granules is. Although, the integrity coefficient does not give exact shear strength, it represents the strength of granules against abrasion and shear, which granules often undergo during normal operation of the reactor. Compared to fresh granules, it was found that the strength of the stored granules decreased from 98 % to 89 % after 2 months storage at room temperature. After 3 weeks after re-activation, the strength of the re-activated granules restored to about 97% again. The data in table 1 show that even after such a long storage period, aerobic granules could still maintain good physical strength. At this point, the aerobic granules cultivated in this study were completely comparable with those anaerobic granules, which were well known for their excellent storage stability(Bae, 1995).

2.4 Sludge volume index and retainable biomass in reactor

The fresh aerobic granules(after 3 months of operation) had an average SVI value of 45 ml/g. After aerobic granules were re-activated, the SVI value at the beginning of re-activation increased to 95 ml/g (Fig. 4). That might be because some of granular sludge had a tendency to disintegrate when they were re-activated. The partly broken granules led to a poor settling ability at the beginning. As expected, with the re-activation operation, the SVI value gradually decreased to about 52 ml/g at day 32. When the maximum OLR(organic loading rate) of 12.5 gCOD/(L·d) was applied at the day 85, the aerobic granules began to disintegrate, resulting in the high SVI value(158 ml/g) as shown in Fig.4. The settling properties of aerobic granules determined the efficiency of solid-liquid separation that was essential for the proper functioning of wastewater treatment systems. As illustrated in Fig.4, during the re-activation MLSS gradually increased with the operation. After the stable operation was reached, MLSS fluctuated at around 7.0 g/L. Obviously, high retainable biomass in a reactor would ensure a faster and more efficient removal of the organic pollutants. Better settling ability of aerobic granules was consistent with higher biomass density, which would be the result of denser microbial structure. When the aerobic granules began to disintegrate, a great quantity of floc sludge was discharged with the effluent, leading to the decreased MLSS as shown in Fig.4.

2.5 Microbial activity

SOUR, as a simple indicator, is applied in the experiment to evaluate the activity of aerobic granular sludge.

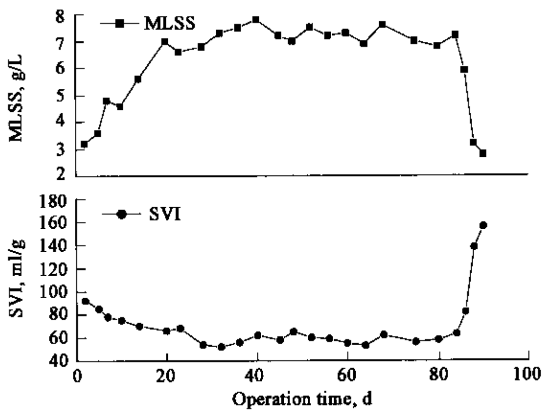

Fig.4 MLSS and SVI during the operation

The activity of aerobic granules during the storage is presented in Fig. 5a. It was observed that in the first seven days of storage, a reduction in microbial activity of aerobic granules was not significant. However, SOUR gradually decreased after 7 d, and it dropped to 15.8 mgO_2/(gMLVSS·h) at the day 60, i.e. 74% reduction after 2 months of storage. It might be reasonable considering that the loss in microbial activity would be associated with the length of storage.

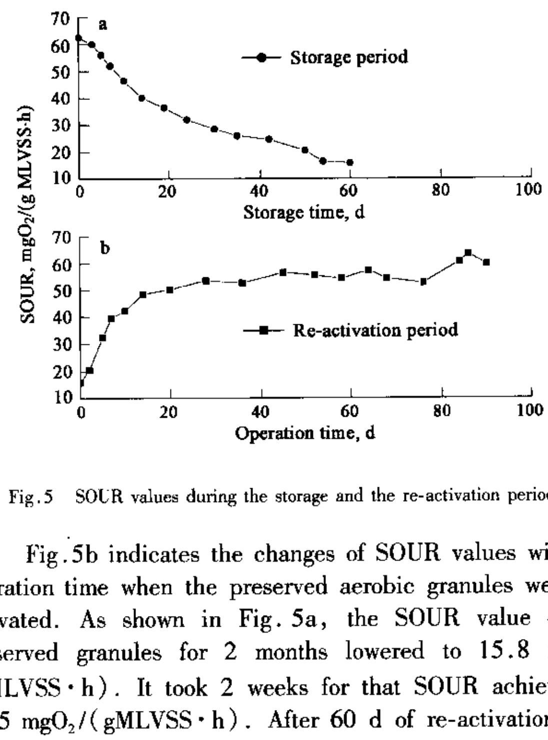

Fig.5 SOUR values during the storage and the re-activation periods

Fig.5b indicates the changes of SOUR values with the operation time when the preserved aerobic granules were re-activated. As shown in Fig. 5a, the SOUR value of the preserved granules for 2 months lowered to 15.8 mgO_2/(gMLVSS·h). It took 2 weeks for that SOUR achieved to 48.5 mgO_2/(gMLVSS·h). After 60 d of re-activation, the SOUR increased to 58.2 mgO_2/(gMLVSS·h). It was implied that aerobic granules could exhibit a comparable microbial activity to a conventional activated sludge after the re-activation.

3 Conclusions

Aerobic granular sludge could be stored up to two months without running the risk of losing the integrity of the granules and metabolic potentials. In 2-month storage of granular sludge, no remarkable changes were observed in their shape, strength and settling ability. The re-activated granules could withstand the maximum OLR of 12.5 g/(L·d), and a stable effluent COD concentration of less than 150 mg/L was achieved during the re-activation process. The preserved aerobic granular sludge could recover their activity very quickly. It took 2 weeks that the SOUR increased from 15.8 to 48.5 mgO_2/(gMLVSS·h).

Results from this study indicated that aerobic granular sludge could be stored and re-activated. Aerobic granular SBR system had a specific potential in polishing the seasonal or intermittent wastewater from the industrial plants.

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