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Rapid method of aerobic granular sludge bioreactor start-up for domestic wastewater treatment

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Abstract. This study presents a rapid method on how to speed up aerobic granular sludge (AGS) cultivation and ensure excellent and stable removal performance during bioreactor operation for domestic wastewater treatment. This new strategy consists of start-up the bioreactor using only anaerobic granular sludge (AnGS) as a seed and feeding with crude sewage extracted from a full-scale Extended Aeration Plant. This experiment used a 2.5 L lab-scale sequencing batch reactor (SBR). The bioreactor operated at low dissolved oxygen (DO) concentration controlled at the value of 2.0 mg/L and below. After 60 days of operation, it clearly showed that almost 90% of AnGS seeds turned from black color to brown. The physical characterization analysis showed that the average sizes were unchanged, and the granules remained compact. Also, the SBR operation monitored with brown granules showed stable removal performance. Average removal efficiencies during steady-state cycles at room temperature of COD, ammoniacal nitrogen, and phosphate reached 84%, 92%, and 100%, respectively.

1. Introduction

Aerobic granular sludge (AGS) technologies are one of the biological wastewater treatment technologies [1, 2] that have lower requirements of land used and operation cost since the whole treatment process can be done within a single sequence batch reactor [3-7]. AGS technology has developed in both treating performance and variety of domestic [8, 9] and industrial [3, 10-14] wastewater in the recent decade. However, one of the main bottlenecks of this technology is the long granulation period during start-up. The cause of AGS long start-up time due to AGS usually cultivated from activated sludge which required several months to develop into granules [15]. Several methods had proposed to overcome the long granulation time during the start-up of AGS technology, such as adding additive [16-18], storing AGS in different forms [2, 19-23], and transforming AnGS to AGS [24, 25].

Transforming AnGS to AGS method was conducted in this research since AnGS is easy to find and purchase compared to AGS. Furthermore, AnGS did not require a complicated condition to store, and transforming AnGS into AGS consumes less time than granulating the AGS from activated sludge. The cultivating of AnGS in a reactor feeding with wastewater for a while was how to obtain the AGS. The AnGS transforming methods that have been proposed by converting AnGS to AGS cultivating in a continuous up-flow reactor can be done within 45 days [25], while cultivating in an SBR can be done in 60 days [24] by both methods used the synthetic wastewater to develop.

Based on the research of Chen *et al.* [26], the AGS that develop with actual wastewater can adapt faster and better to the change of the wastewater during the operation compared to AGS cultivated from synthetic wastewater. Resulting in more sustainable on treating the actual domestic wastewater where there was always a fluctuation in the composition.

The success of transforming AnGS into AGS to lower the start-up time of AGS technology had indicated in previous research. However, during cultivation, the influent used was synthetic wastewater. The use of synthetic wastewater led to high costs and a low possibility to adopt it into full scale. This research investigated the possibility of granulating the AGS in the SBR by using only the AnGS as the seed sludge with the actual domestic wastewater influents to shorten the long start-up period of AGS technology. As a result, the research can enhance the development of AGS with less time consuming, lower cost, the possibility to be used in full scale, and the obtained AGS be able to sustain and adapt to the fluctuation of wastewater.

2. Materials and Methods

2.1. Reactor setup and operation

An automated 2.5 L lab-scale SBR operated in the laboratory room at Indah water research center, Kuala Lumpur, Malaysia; the reactor had a diameter of 6 cm and 100 cm in height. The working volume of the reactor was 2350 mL with an exchange volume of 850 mL. The influent port and the bubble diffuser were at the bottom of the reactor. The effluent port was at the middle of the reactor, and the whole reactor was operated automatically with the time relay switches. The reactor operated at lab room temperature. The aeration was controlled with an airflow meter and made sure not to be too harsh to lower the break of granules. The DO in the reactor was maintained to be around 1.5-2.0 mg/L. The schematic diagram of the SBR used in this research was as shown in Figure 1.

The reactor runs 3 h per cycle, including influent feeding for 1 h, followed by aerating for 1 h 50 min, then 5 min of settling, and 5 min of discharge. The reactor runs continuously for 60 days.

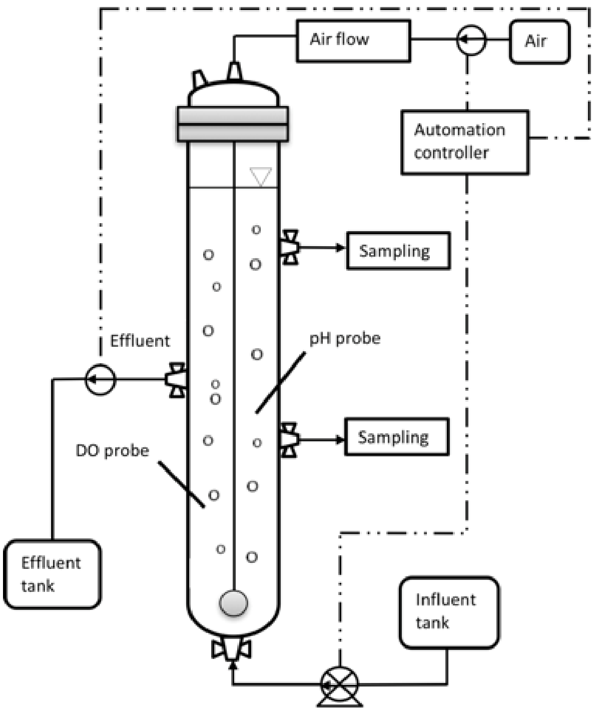

Figure 1. Schematic diagram of 2.5L lab-scale SBR.

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2.2. Influent and seeding sludge
The AnGS was purchased from Thailand and used as seed sludge with an average diameter of 2.0-3.0 mm. The granules have a round shape and black color.

The influent used in this research was an actual domestic wastewater pass-through screening and grit removal from a full-scale extended aeration type plant. The influent tank was empty and refilled manually every two days.

2.3. Analytical
The granules characteristic was done both before and after transforming to AGS. The analysis of MLSS, MLVSS, SVI_5, and settling velocity using the standard method [27]. A Leica EZ4W stereomicroscope with a 5-megapixel camera was used to determine the granules' size. The granule's pictures took using Huawei P30 Pro in super macro mode with a 20-megapixel camera and regular mode with a 40-megapixel camera.

The DO in the reactor was monitored during the transformation process using YSI Pro ODO optical dissolved oxygen instrument. The influent and effluent samples for performance analysis after 60 days of operation. COD, BOD_5, ammoniacal nitrogen ($NH_3 - N$), nitrate (NO_3^-), phosphate ($PO_4^{3-} - P$), and total suspended solids (TSS) were analyzed using the standard method [27]. The COD and $PO_4^{3-} - P$ were digested by HACH COD 45600 reactor, then measured with HACH DR 3900 spectrophotometer. Moreover, $NH_3 - N$ and NO_3^- were also measured using HACH DR 3900 spectrophotometer. BOD_5 was measured using HACH BODTRAK II at 20°C.

3. Result
3.1. General observation
The SBR was started up by seeding with the AnGS purchased from Thailand. After 30 days of cultivation, the granule's color becomes brown except the bottom part where the granules were clogged and not exposed to enough aeration, as shown in Figure 2. According to the visual inspection, the granules remain round and compact. The DO in the reactor was maintained to be around 1.5-2.0 mg/L.

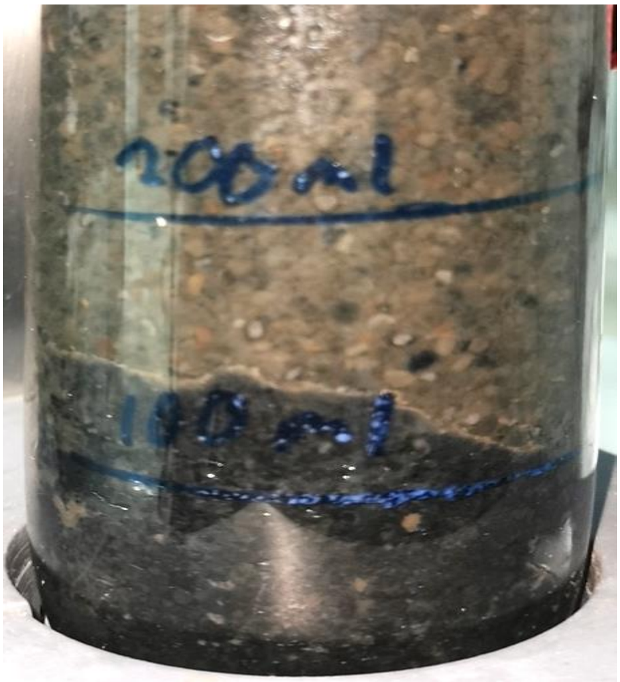

Figure 2. Black granules at the bottom of the reactor.

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3.2. AnGS and AGS characteristics

The randomly sampling AnGS had an overall diameter of 2.0-3.0 mm with a dense, round, and compact size. The granules had black color with the MLSS and MLVSS of 3600 mg/L and 2500 mg/L. While the SVI_5 and settling velocity of the AnGS were 59 mL/g and 98.77 m/h. Figure 3 shows the picture of AnGS color and size, and Table 1 indicates the characteristics of AnGS.

After 60 days of operation, the granules were sampled randomly for characteristic analysis. The result showed that granules had an average diameter around 2.0-3.0 mm, still round, compact, and dense as before transformed into AGS. The granule's color became brown. MLSS and MLVSS were 3450 mg/L and 2760 mg/L. The AGS SVI_5 and settling velocity are 62 mL/g and 62.18 m/h, respectively. Figure 3 shows the color and size of the AGS, and Table 1 shows the characteristics of AnGS and AGS.

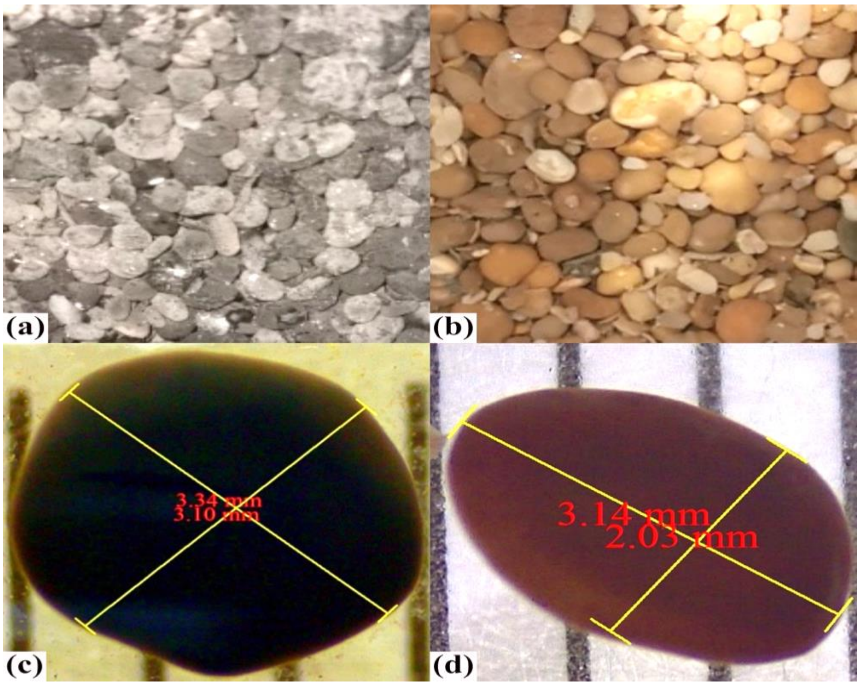

Figure 3. Color of (a) AnGS and (b) AGS. Size of (c) AnGS and (d) AGS.

Table 1. Characteristics of AnGS compared with AGS.

Parameter	AnGS	AGS
pH	7.2	6.85
MLSS (mg/L)	3600	3450
MLVSS (mg/L)	2500	2760
SVI_5 (ml/g)	59	62
Size (mm)	2-3	2-3
Settling velocity (m/h)	98.77	62.18

3.3. Removal performance

After 60 days of operation, the removal performance of the transformed granules analyzes by sampling the influent and effluent from the reactor. The result indicated that the COD removal rate was over 80%, the BOD_5 removal rate was around 80%, the ammoniacal nitrogen removal rate was above 90%, and the phosphate removal rate could reach 100%. Table 2 shows the characteristics of influent and effluent after 60 days.

Table 2. The characteristics of influent and effluent after 60 days of operation.

Parameter	Influent	Effluent	Removal Percentage
pH	6.85	6.28	-
COD (mg/l)	317	52	83.56%
BOD_5 (mg/l)	123	24	80.49%
$NH_3 - N$ (mg/l)	30.1	2.3	92.36%
NO_3^- (mg/l)	6.7	9.2	No removal
$PO_4^{3-} - P$ (mg/l)	4.3	0	100%
TSS (mg/L)	210	80	61.90%

4. Discussion

4.1. Granules transforming observation

During the transformation process, after 30 days, most of the granules started to turn from black to brown color. In contrast, granules in the bottom of the reactors remain black. The granules at the bottom of the reactor were not transforming because they did not expose to enough aeration. The issue was solved by every 2-3 days manually stirring was performed during aeration to stir up the granules. With the solution, black granules were disappeared from the reactor. Figure 5 indicated the picture of black granules mixed with brown granules after stirring the bottom of the reactor.

According to the visual inspection, the granules remain round and compact. It indicated that maintaining the DO at around 1.5-2.0 mg/L where the aeration rate was not too harsh and hydrodynamic shear force is at optimum rate results in granules can maintain their morphology while transforming to AGS and lowering both the damage and the breaking off of the granules as expected. In contrast, granules still lost some of the volumes while operating due to the broken granules that could not be neglected but could reduce.

Figure 4. A mixture of black and brown granules after stirring.

4.2. AnGS and AGS comparison

According to the observation and analysis result, the AnGS successfully transform into AGS. The change in color from black to brown indicated that anaerobic microorganisms in the reactor started to phase out then aerobic microorganisms took place instead. The round shape and the same average size of granules showed that maintaining the DO to be around 1.5-2.0 mg/L to lower the damage on the granules was a success. The settling velocity decreased from 98.77 m/h to 62.18 m/h. The decrease in settling velocity occurred as supposed referred to Linlin *et al*. [24], decreasing in the settling velocity also indicated that the water content in the granules increased. The SVI_5 value remained the same, indicating no change in granules size.

4.3. Transformed AGS performance

According to the performance, analysis results indicated that AnGS was successfully transformed into AGS using actual domestic wastewater. In addition, the overall removal rate above 80% indicated that the transformed granules could treat wastewater. However, the evaluated removing performance seems not high compared to granules cultivated with synthetic wastewater, caused by fluctuation of composition within the influent water the granules must expose. In contrast, the removal performance of over 80% shows that the granules can sustain and adapt with the fluctuating composition of the actual domestic wastewater.

5. Conclusion

The research indicates that transforming AnGS into AGS with actual domestic wastewater is one of the possible ways to cultivate AGS that reduce the long cultivation time of AGS technology. The research also shows that the transformation of AnGS into AGS on a full scale was possible since the influent used was actual domestic wastewater. Using actual domestic wastewater also lowered the cost compared to using synthetic wastewater. The obtained AGS could maintain its shape and the removal performance is over 80%. The AGS obtained should be able to adapt and sustain to the change in influent composition. Maintaining the DO within the reactor to be around 1.5-2.0 mg/L lower the damage and break of the granules, led to no change in the average size after the AnGS successfully transformed into AGS.

Acknowledgments

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