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Development of aerobic granular sludge for sewage treatment in a hot climate

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ABSTRACT

This study is conducted to develop the aerobic granules for domestic wastewater treatment application in a hot climate (specifically at a temperature of 30°C). A 3 L laboratory scale, slightly modified sequencing batch reactor (SBR) was built and used for the experimental study. The observation shows that after 90 d of the SBR operation, stable aerobic granules with an average size of 1.1 mm were formed at 30°C (fed with acetate). The formation of the aerobic granules is also achievable with a complex influent (pre-treated sewage) after operating the SBR system for 125 days and the average size of the granules from this operation was found to be 0.8 mm. In addition, the results also proved that high temperature (30°C) did not affect the development of stable, dense and good settle able granules; thus making the granular sludge SBR system an effective technology for wastewater treatment in hot climates.

INTRODUCTION

Over the last decades, different compact treatment systems have been developed and such systems like the biofilm system, membrane bioreactors, and aerobic granular sludge technology [1-5] have been put to task. Aerobic granules technology offers a possibility for compact wastewater treatment plant based on simultaneous organic (chemical oxygen demand, cod) and nutrient (nitrogen and phosphorus) removal in one sequencing batch reactor. Because of the high settling ability of the granules, the use of a traditional settler is not necessary and therefore, the installation can be very compact with a lower cost. Many laboratory studies [1,6,3,4,7] and a pilot study [8-10] show the potential of aerobic granules in wastewater treatment applications.

Since this technology was first introduced in the european continent, therefore most aerobic granule studies carried out so far were at low temperatures from 8 to 15°C and room temperatures from 20 to 25°C. In Malaysia, the temperature of domestic sewage is usually around 30°C and may increase up to 40oc during the hot and dry spells. It has still not yet clearly been determined in the understanding of the mechanism and operational related issues of the physical characteristics of aerobic granules developed in high temperatures. Therefore, this study aims at exploring the granule formation process under aerobic conditions in temperatures of 30°C thus making it possible in determining the physical characteristics of the developed granules. For this study, granule formation using synthetic (acetate-fed) and actual wastewater (pre-treated sewage) were studied and it is expected that the outcomes derived would be useful for the development of aerobic granule sludge technology and for further application of it for domestic wastewater treatment in countries with hot climate such as malaysia.

MATERIALS AND METHODOLOGY

Reactor system and operation

A 3 L laboratory scale sequencing batch column reactor (SBR) was used for this study (Figure 1). An SBR operates in a true batch mode with both the aeration and sludge settlement processes occurring in the same tank. The parameter set-up followed previous studies [11]: where the pH was maintained at 7.0 ±0.2 by dosing 1 M NaOH or 1 M HCl. The dissolved oxygen concentration however was not controlled but during aeration a constant airflow rate 4 $L.min^{-1}$ was applied. The reactor was operated in successive cycles of 3 h (60 minutes feeding from the bottom of the reactor (plug-flow through the settled bed), 110 minutes aeration, 5 minutes settling (to keep only particles settling faster than 12 $m.h^{-1}$ in the reactor) and 5 minutes of effluent withdrawal); hydraulic retention time was 5.6 h and the substrate load was 1.6 kg $COD.m^{-3}.d^{-1}$ The composition of the synthetic influent media referred to was according to de Kreuk *et al.* [11]. The main difference was the temperature applied in this study, was 30°C controlled via water heat circulation system. Fresh activated sludge from local municipal wastewater treatment plant (Bandar Uda Utama - JBT 220, Johor, Malaysia) was used as the inoculum to start-up the reactor. For experiments with actual wastewater, the influent was also collected from the same plant. Table 1 shows the characteristics of actual and synthetic wastewater used in the study.

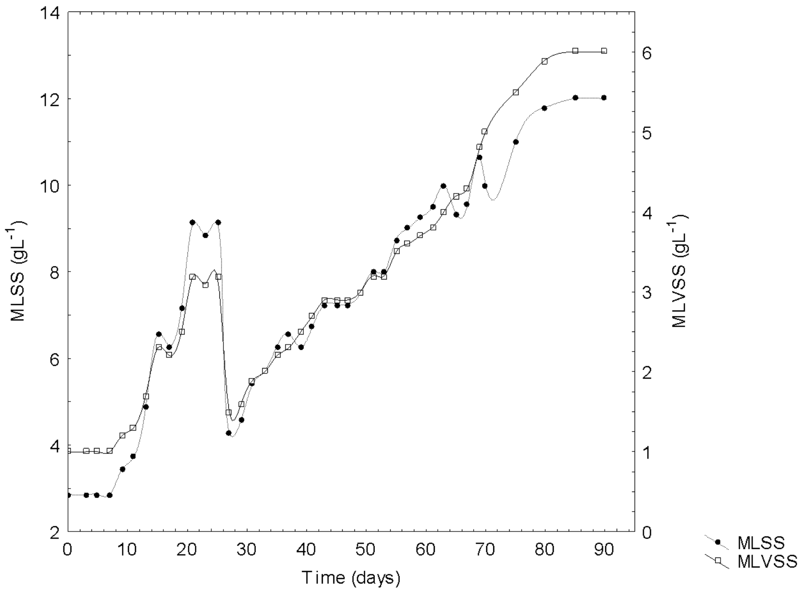


Figure 1: MLSS and MLVSS concentrations of the bioreactorin a 90 d operation

Analysis

The granules developed in the SBR column were analyzed for their physical characteristics, include settling velocity, sludge volume index (SVI) and granular strength (density of granules). The settling velocity was determined by averaging the time taken for an individual granule to settle at a certain height in a glass column filled with tap water. The SVI assessment was carried out according to the procedure described by Beun *et al.* [1] and density of granule was determined using Dextran blue test. The morphological and structural observations of the granules were carried out by using a stereo microscope equipped with digital image processing and analyzer. Measurement and determination of the granular strength was based on procedure developed in a previous study [12]. Other parameters such as mixed liquor suspended solid (MLSS), and mixed liquor volatile suspended solid (MLVSS) were analyzed according to the Standard Methods [13].

Table 1: Composition of synthetic and actual wastewater used in the study

Component (mg.L^{-1})	Pre-treated sewage[1]	Synthetic[2]
Suspended solids	150	0
Soluble COD	250	396
Total COD	300	396
VFA	85	396
PO_4^{3-}-P	8	20
NH_4^+-N	55	50
Total-N filtered	85	50
Total-Nunfiltered	73	50

[1] This study: influent values after storage at 4°C (average values)
[2] [11].

RESULTS AND DISCUSSION

Granule formation of aerobic granular sludge: acetate-fed

Physical characteristics. The experiments were conducted for 3 months to develop aerobic granules at 30°C. The first two columns of Table 2 present the results of the physical characteristics of acetate- fed granules obtained after 90 d of the granule formation process at a temperature of 30°C in the SBR compared with seed sludge. Their physical characteristics are determined in terms of mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge volume index (SVI), settling velocity (ν), size – average diameter (ϕ) and density (ρ) and strength characteristics.

Biomass Concentration. The aerobic granule formation increased the biomass concentration in the SBR system with time. Figure 1 illustrates that after seeding, the biomass concentration in the reactor increased. The initial MLSS concentration of seed sludge was 3.0 g.L^{-1}. However, on day 27, the MLSS and MLVSS values of the sludge decreased sharply and this was attributed by the disorder of the time controller due to the electricity breakdown in the system. This caused the instability of the pH which decreased the biomass concentration and instantly increased the SVI value. After recovering from this failure, the MLSS and MLVSS of the biomass rose slightly again, and reached a relatively stable level of about 12.0 and 6.0 $g.L^{-1}$ on day 90.

Table 2: Physical characteristics of aerobic granular sludge developed at 30°C using synthetic and actual wastewater

Physical characteristics	seed sludge	granules (acetate-fed)	granules (sewage-fed)
MLSS ($g.L^{-1}$)	3	12	6
MLVSS ($g.L^{-1}$)	1	6	3.5
ϕ (mm)	< 0.2 mm	0.5 – 1.2	0.2 – 1.0
Average ϕ (mm)	< 0.2 mm	1.1	0.8
ρ ($gTSS.L^{-1}$)	N.D	135	75
ν (mh^{-1})	<10	10 -30	10 - 30
SVI_{10} ($mL.g^{-1}$)	190	20	40

Sludge volume index and settling velocity. The aerobic granules formed in the SBR system have a good settling ability. With the granule formation, the value of SVI gradually decreased from 190 to 20 $mL.g^{-1}$ and the average settling velocities of the aerobic granules are in the range of 10-30 $m.h^{-1}$. Figure 2 shows the SVI profile of the SBR system during the 90 day operation. The initial SVI of seed sludge was 190 $mL.g^{-1}$. After about 20 d, as shown in Figure 2, filamentous bacteria in the reactor disappeared and the SVI decreased from 70 to 50 $mL.g^{-1}$. However after 27 d of operation, the SVI increased to 100 $mL.g^{-1}$due to the electrical breakdown in the system as shown in Figure 2. As mentioned before, this problem caused the instability of the pH which decreased the biomass concentration and instantly increased the SVI value. After the recovery of the reactor, the SVI dropped to 50 $mL.g^{-1}$ in 25 days. Along with the formation of aerobic granules, the SVI decreased gradually. At the termination of the experiment, the SVI of the sludge decreased to only 20 $mL.g^{-1}$ thus indicating that the mature aerobic granules had an excellent settling characteristic. The average settling velocities of the granules was in the range of 10 - 30 $m.h^{-1}$. These values are comparable to those of the aerobic granules in other SBR systems [11, 14] and are at least two times greater than those of the activated sludge flocs (lower than 9 $m.h^{-1}$) [15]. It was observed that after 5 minutes of settling; the mature aerobic granules were well settled, leaving a clear supernatant in the reactor.

Experiment with Pre-treated Sewage

As reported in the literature [1,11] and described earlier, the aerobic granular sludge can be optimally developed using synthetic wastewater (acetate-fed). However, studies on aerobic granules using synthetic influent did not consider the complex substrates and suspended solids. Therefore, the ability of aerobic granules to develop and grow with this kind of influent has to be investigated. Only preliminary investigations with domestic and industrial influent are reported in previous studies [9,11,16, 17]. A lower COD content of domestic wastewater compared to industrial wastewater is expected to influence the process performance. [17] produced granules using pharmaceutical effluent, but however, the biomass density was more than 50% lower (45 $mg.L^{-1}$) than when a synthetic influent was used and the granule stability was also reported to be low. Arrojo *et al.* [18] used dairy wastewater as an influent containing particulate organics. One reactor was reported to be started-up with synthetic wastewater, which was gradually replaced by industrial wastewater after the granules had developed, while the other was directly started-up with dairy wastewater. Both reactors resulted in stable operations, with granule diameter between 2.4 and 4.0 mm and a settling velocity larger than 20 $m.h^{-1}$. These three experiments show that aerobic granules can be formed on complex industrial influent and that a stable operation is possible. Contrary to experiments with industrial wastewater, only one experiment has been reported so far on aerobic granule formation using domestic wastewater. In the study conducted [11], granules were developed using pre-treated sewage from local municipal wastewater treatment plant, Berkel in the Netherlands. The granules were reported to be stable with a SVI of 38 $mL.g^{-1}$ with an average diameter of 1.1 mm, but however the temperature at which it was developed was at 20°C. Using this information as a basis, this experiment was therefore conducted to explore the aerobic granule formation with actual wastewater at 30°C.

Granule formation of aerobic granular sludge: sewage-fed

The main goal of this experiment was to demonstrate aerobic granule formation on sewage in an SBR system at 30°C. In order to do so, the reactor was started-up with influent from the wastewater treatment plant of Bandar Uda Utama, Johor and inoculated with activated sludge and suspended solids (< 0.2 mm) from the effluent of a laboratory-scale granular sludge reactor fed with synthetic influent. A 3 h cycle was selected according to positive results as described in the earlier experiments. However, the COD concentration of the earlier used synthetic influent resulted in a lower availability of readily biodegradable COD (0.8 kg $COD.m^{-3}.d^{-1}$, instead of 1.6 kg $COD.m^{-3}.d^{-1}$). This lower load resulted in an insufficient biomass increase in time as shown in Figure 3.

Figure 3 shows the profile of suspended solid concentrations in the reactor operation. All particles and biomass with a settling velocity lower than 4 $m.h^{-1}$ were washed out of the rector. The cycle time was shortened to a 1.5 h cycle (15 min filling ; 55 – 65 min for aeration; 15 – 5 min variable settling ; 5 min discharging), as suggested in the literature [11] to feed more wastewater. Seventy-five (75) days after changing the cycle time or 105 d after start-up, aerobic granules were obtained with an average diameter of 0.8 mm. It is believed that the high (uncontrolled) oxygen concentration contributed to obtaining the granules in this experiment [19]. The SVI_{10} decreased to 40 $mL.g^{-1}$, comparable to SVI found with granules-sewage fed developed at 20°C and also granules fed with synthetic.It was also observed that the development of the aerobic granules using actual wastewater was slower than in the reactor that was operated with synthetic influent. A 125 d operation was enough for the complete granule formation process compared to the 90 d operation for experiments with synthetic influent. Table 2 shows the physical characteristics of aerobic granules acetate-fed, compared to granule and seed sludge of the sewage-fed that developed at 30°C. Table 3 shows a comparison of granule development between aerobic granules developed using synthetic and actual wastewater. In contrast to granules fed with acetate, the granules fed with sewage are irregular. This can be explained by the presence of COD during the aerobic period and also by a lack of shear stress. This is probably due to the readily degradable substrates (e.g. acetate) been absorbed during the anaerobic period, while the complex substrates were still available during the aerobic period.

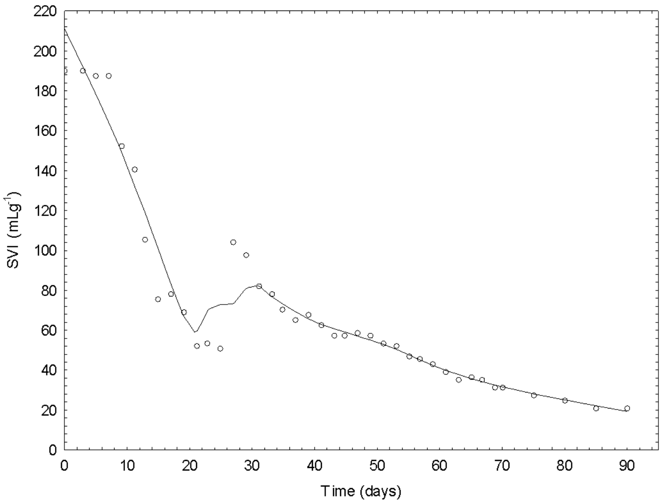


Figure 2: SVI profile of the SBR in 90 d operation

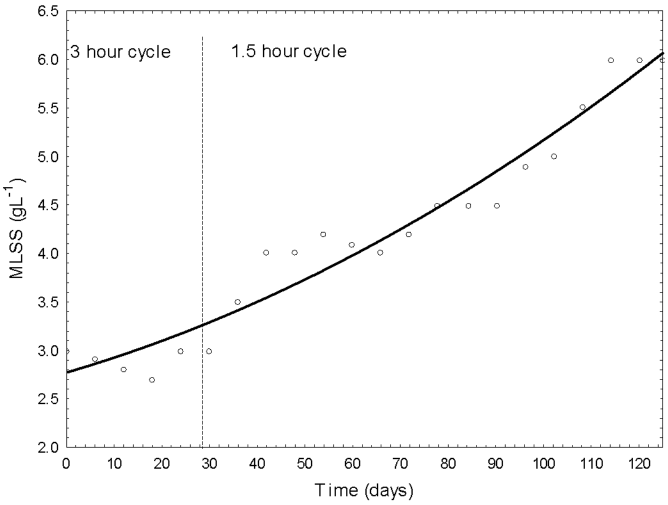
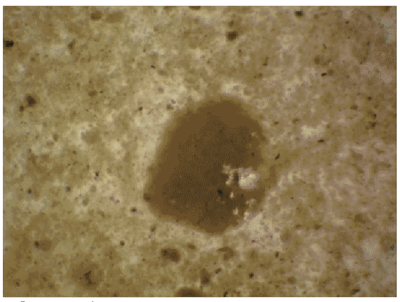
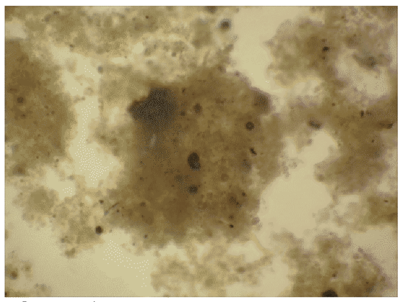
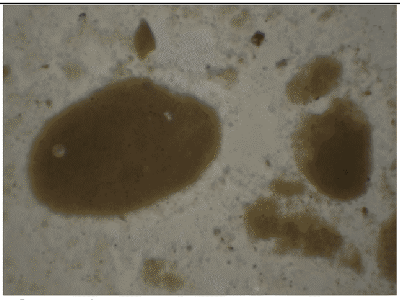
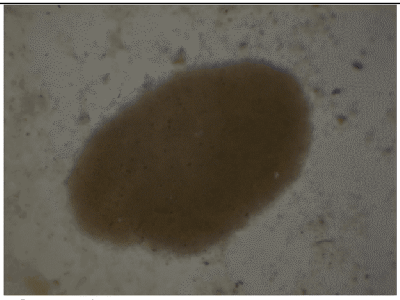
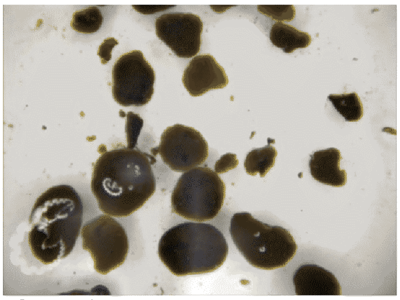
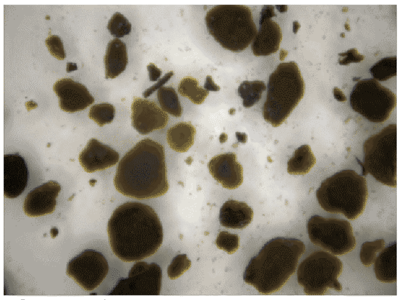


Figure 3: Suspended solid concentrations in the reactor during the operation

Table 3: The development of aerobic granule formation process at a temperature of 30°C using synthetic and actual wastewater

Observations	acetate-fed	sewage-fed
The first granules appeared. Normally, these first granules had many filaments the surface.	 After 31 d	 After 30 d

Smooth granules started to appear.	 After 64 d	 After 90 d
All granules were smooth and regular shape (stabilise) with average diameter >0.5 mm.	 After 90 d	 After 125 d

CONCLUSION

Aerobic granular sludge was developed in a 3 L laboratory-scale reactor fed with acetate as well as with sewage at a temperature of 30°C. The time taken to form aerobic granules with sewage was much longer than with the synthetic wastewater (125 d versus 90 d of operation respectively). The lower concentrations of readily degradable substrates and the presence of complex substrates during the aeration phase are the factors contributing to the outcome in the sewage experiment. This study also suggests that the COD-load will be an important process parameter for sufficient granule formation in applications at sewage treatment plants.

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