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THE IMPACT OF REACTOR HEIGHT/DIAMETER (H/D) RATIO ON AEROBIC GRANULAR SLUDGE (AGS) FORMATION IN SEWAGE

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Abstract

Until now, the development of aerobic granules sludge (AGS) has been extensively reported using sequencing batch reactor (SBR) with reactor height/diameter (H/D) ratio of over 10. This is because the formation process of aerobic granules itself is depending upon the flowing trajectory inside reactor indulge by reactor height and superficial air velocity (SUAV). Thus, this study aims to determine effect of reactor H/D ratio on performance of AGS develop in two SBR_S with equal working volume and organic loading rate (OLR). The two SBRs namely as SBR1 and SBR2 had a difference in reactor H/D ratio of 11.3 and 4.4, respectively. At an aeration rate of 4 L/min, SUAV for SBR1 was two time higher than in SBR2, which were 1.33 cm/s and 0.7 cm/s, respectively. Thus, the SBR2 configuration condition seems unfavorable for development of compact aerobic granules. However, it was found that aerobic granules can be developed in both SBRs at an OLR as low as 0.12 kg CODs/m^3 d and up to 0.49 kg CODs/m^3 d. Mature aerobic granules were successfully developed after 49 and 89 days of formation, for Batch1 AGS and Batch2 AGS, respectively. At stable conditions, the highest CODs removal and SS effluent for Batch1 AGS and Batch2 AGS were more than 80% and below 26 mg/L, respectively. While effluent performance in both reactors was high, analysis on SVI_{30} indicated that SBR1 produced more sludge than SBR2. Compare to SBR1, at similar settling time of 15 min, SBR2 provide a short settling distance for biomass which was preferable in case of system breakdown due to shock OLR.

Keywords: AGS; height to diameter ratio; sewage

Abstrak

Sehingga kini, perkembangan enapcemar granul aerobic (AGS) telah dilaporkan dengan meluas menggunakan reaktor penjujukan berkumpulan (SBR) dengan nisbah tinggi/garis pusat (H/D) reaktor lebih daripada 10. Ini kerana proses pembentukan granul aerobik sendiri bergantung kepada pengaliran trajektori dalam reaktor disebabkan oleh ketinggian reaktor dan halaju udara dangkal (SUAV). Oleh itu, kajian ini bertujuan untuk menentukan kesan nisbah reaktor H/D kepada prestasi AGS dalam dua SBRS yang mempuyai isipadu kerja dan kadar beban organik (OLR) yang sama. Dua SBRs dinamakan sebagai SBR1 dan SBR2 mempunyai perbezaan dalam nisbah reaktor H/D iaitu masing-masing 11.3 dan 4.4. Pada kadar pengudaraan 4 L/min, SUAV untuk SBR1 adalah dua kali lebih tinggi daripada SBR2, iaitu masing-masing 1.33 cm/s dan 0.7 cm/s. Oleh itu, keadaan konfigurasi SBR2 nampaknya tidak menguntungkan untuk pembangunan granul aerobik padat. Walau bagaimanapun, didapati bahawa butiran aerobik berjata dihasilkan di dalam kedua-dua SBRs pada OLR serendah 0.12 kg CODs/m^3 d dan sehingga 0.49 kg CODs/m^3 d. Granul aerobik matang berjaya diperolehi selepas 49 dan 89 hari proses pembentukan, masing-masing untuk Batch1 AGS dan Batch2 AGS. Pada keadaan stabil, penyingkiran CODs tertinggi dan SS efluen untuk Batch1 AGS dan Batch2 AGS adalah masing-masing lebih dari 80% dan di bawah 26 mg / L. Walaupun prestasi efluen dalam kedua-dua reaktor adalah tinggi, analisis pada SVI_{30} menunjukkan bahawa SBR1 menghasilkan enapcemar lebih daripada SBR2. Berbanding dengan SBR1, pada masa pegenapan yang sama iaitu 15 min, SBR2 menyediakan jarak pengenapan yang dekat untuk biojisim, dimana sangat berguna dalam kes kerosakan sistem akibat kejutan OLR

Kata kunci: AGS; nisbah tinggi kepada garis pusat; air kumbahan

1.0 INTRODUCTION

The existing conventional sewage treatment plants (STPs) needs to be upgraded in conjunction with the expansion of socio economics and life style especially in highly populated area. This is because the pollutions load and composition of pollutants in raw sewage will be much higher and variable. Land acquisition will become a major issue in selecting or upgrading the new STPs since conventional treatment system like activated sludge required a large area to accommodate the different conversion and sludge stabilization process [1].

Aerobic granular sludge (AGS) treatment system is based on self-immobilization of bacteria to aggregates with suspended biomass to form a discrete well define granules without any carrier material. Unlike activated sludge, the stratification of microbial population inside aerobic granules at different zones (aerobic, anoxic and anaerobic) will excite the simultaneous carbon, nitrogen and phosphorus removal in a single reactor [1]–[3].

The development of AGS has been extensively reported using sequencing batch reactor (SBR) system. A review by Liu and Tay [4] had highlighted that column-type upflow reactor with higher H/D ratio can provide a longer circular flowing trajectory, which in turn creates an effective hydraulic attrition for microbial aggregation. Existing studies [1]-[4] concerning aerobic granules formation were mainly established on well-controlled laboratory scale SBR with reactor height/diameter (H/D) ratio of over 10. This kind of practice will limit the practical application of aerobic granule since the existing SBR mostly has low H/D ratio. In practice, factors like maintenance problems and impact of natural disaster will be critical and has to be considers in designing a long slender reactor.

Currently, only Kong et al. [5] had published a research work regarding formation of aerobic granules at different H/D ratios (diameters were fixed to 5 cm). Kong et al. [5] had concluded that H/D ratio or minimal settling velocity of reactor did not have influence on granulation or granule properties. However, since the different in aspect of working volume and organic loading rate (kg COD/m^3 day) were neglected, this research aim to address this issues.

Two lab-scale sequencing batch reactors (SBRs) with equal working volume of 4.5 L were used for aerobic granules cultivation. SBR1 and SBR2 had a different in H/D ratio which were 11.3 and 4.4, respectively. These two H/D ratio were selected in order to understand the behaviours of aerobic granules development when the flowing trajectory inside reactor from longer circular (BSR1) was cut down to half (SBR2) circular. The operating strategies for both SBRs comprised of two phases. During Phase 1, cycle time was 4 hour, filling and discharge time were fixed to 6 min, with reaction (195-220 min) and settling (30-5 min) time were changed accordingly to the performance of AGS. In order to retain sufficient biomass that had poor settling ability during start-up, longer settling time of 30 min was applied. After certain period, settling time was reduced to 15 min and 5 min in line with formation of aerobic granules. During Phase 2, the cycle time was changed to 3 hour. As showed in Figure 1, effluent standpipe was fixed for a volumetric exchange rate of 50%. Aeration was supplied from the bottom of SBRs at an air flow rate of 4 L/min resulting in a superficial air velocity (SUAV) of 1.33 cm/s for SBR1 and 0.7 cm/s for SBR2. The SBRs were operated at room temperature without pH control.

2.0 EXPERIMENTAL

2.1 SBR Setup And Procedure

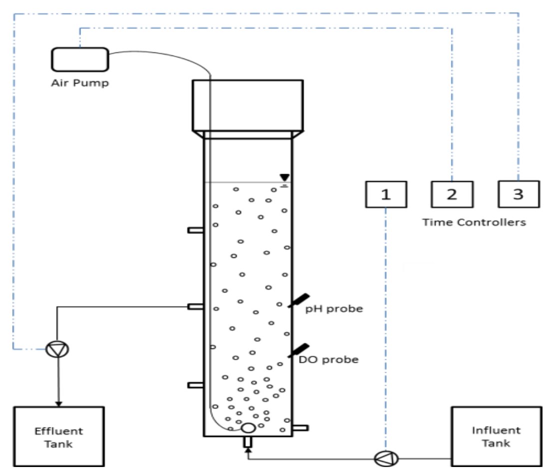

Figure 1 The schematic diagrams of basic SBR operations for SBR1 and SBR2.

2.2 Sewage And Activated Sludge Characteristics

Sewage and activated sludge were collected from Pantai 1 sewage treatment plant (Pantai 1 STP), located at Pantai Dalam at south central end of Kuala Lumpur city, Malaysia. Pantai 1 STP was designed based on activated sludge system to treat sewage from a contributing PE of 377, 000. The raw sewage and activated sludge were taken directly from primary clarifier and anoxic tank, respectively. During the start-up, 2.3 L of activated sludge after aeration for 1 day were used as seed, resulting in an initial concentrated mixed liquor suspended solids (MLSS) of 7.6 g/L. sewage was stored at 5 °C for a maximum of 18 days. During this time, the settled suspended solids from sewage tanks were removed. Influents for the SBRs were replaced for every 2 or 3 days.

2.3 Analytical Methods

Parameters such as MLSS, soluble COD (CODs), suspended solids (SS) and sludge volume index (SVI), Oxygen Uptake Rate (OUR) and Specific Oxygen Uptake Rate (SOUR) were analyzed according to Standard Methods for the Examination of Water and Wastewater [6]. pH was measured just before the reaction time ended. Measurements of the parameters were carried out for two to three times per week.

2.4 FESEM Sample Preparation

The microstructure and microbial distribution within the granules were observed with Field emission scanning electron microscope (FESEM). Sample preparation of aerobic granules for FESEM was carried out at Electron microscope unit Laboratory, Faculty of Medicine, University of Malaya. Aerobic granules were fixed with 4% glutaraldehyde in 0.1 M phosphate buffer for minimum of 4 h at 4 ºC and post-fixed in 1% osmium (O_SO_4) at room temperature for 1 h. Later, fixed aerobic granules were washed in distilled water for 20 min and dehydrated in ascending series of ethanol (30% - 50% - 70% - 80% - 90% - 95% -100%, 15 min per step). Dehydration processed was continued in ethanol-acetone mixture (3:1 - 1:1 - 1:3, 15 per step), and finished up with pure acetone for 3 x 20 min. Subsequently, aerobic granules were dry by means of critical point drying (CPD) with CO_2 for 1 h before being mounted on tubes with carbon adhesive for gold coating.

3.0 RESULTS AND DISCUSSION

3.1 Effect Of H/D Ratio On Period To Achieve Stable Conditions

Theoretically, configuration of SBR2 seems unfavourable for development of compact aerobic granules that required high shear force and H/D ratio. At an aeration rate of 4 L/min, superficial air velocity (SUAV) for SBR1 was two time higher than in SBR2, which were 1.33 and 0.7 cm/s, respectively.

Figure 2 showed MLSS profile for aerobic granule cultivated in SBR1 and SBR2 called as Batch1 and Batch2, respectively. As showed in Figure 2, the biomass concentration measured as MLSS for both Batch1 and Batch2 were altered according to the change in influent CODs for the first 63 days of formation process. Batch1 formation was stopped on day 63 after analysis on effluent quality since day 49 had showed a constant efficiency with average 84% CODs removal and effluent SS lower than 26 mg/L (Figure 3). As showed in Figure 3, Batch2 was mostly stable in period between day 89 to 103, with the highest CODs removal up to 90% was recorded on day 95, followed with low effluent SS of 10 mg/L.

At stable conditions, SBR system should be comprise of mature aerobic granules that easily to adapt and stabilize in variable substrate concentration and changes of operating conditions. As showed in Figure 2, MLSS concentration for both batches did not substantially increase with significant changes in influent CODs during and after stable period. This is in conjunction with analysis on food to microorganism ratio (F/M) as indicated in Figure 4. The F/M ratio varies distinctively at early stage of Batch 1 (first 30 day) and Batch2 (first 70 day). Batch1 stabilized at average MLSS of 440 mg/L, F/M ratio of 1.10 g CODs/g MLVSS d and sludge retention time (SRT) of 5 d. Whilst, Batch2 stabilized at average MLSS of 412 mg/L, F/M ratio of 0.96 g CODs/g MLVSS d and sludge retention time (SRT) of 6 d.

Longer period to achieve stable conditions for Batch2 compare to Batch1 is expected based on consideration for SUAV and F/M ratio factors. According to Tay et al. [7], higher shear force is preferable for development of regular, rounder, strength and compact granules. It was found that bioflocs and regular granule were observed in reactors with SUAV of 0.3 cm/s and 1.2 cm/s, respectively. Since then, the SUAV of 1.2 cm/s has become as a threshold value for a successful cultivation of AGS [8] in SBR. A study by Li et al. [9] also had indicated that F/M ratio as high as 1.1 g CODs/g SS d initiated rapid formation of large granules within 15 d. Whilst, a low F/M ratio of 0.3 g CODs/g SS d would result in a slow granulation process of more than 40 d.

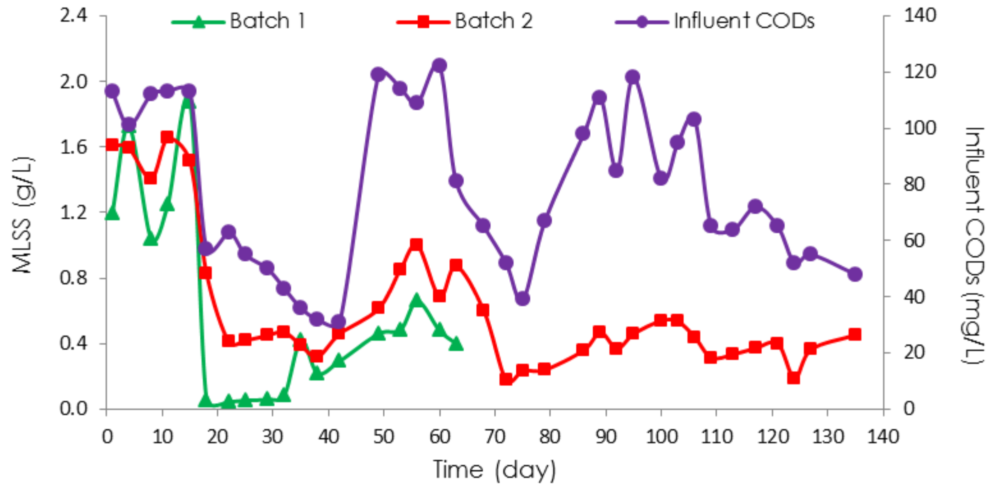

Figure 2 Profile of MLSS and influent CODs

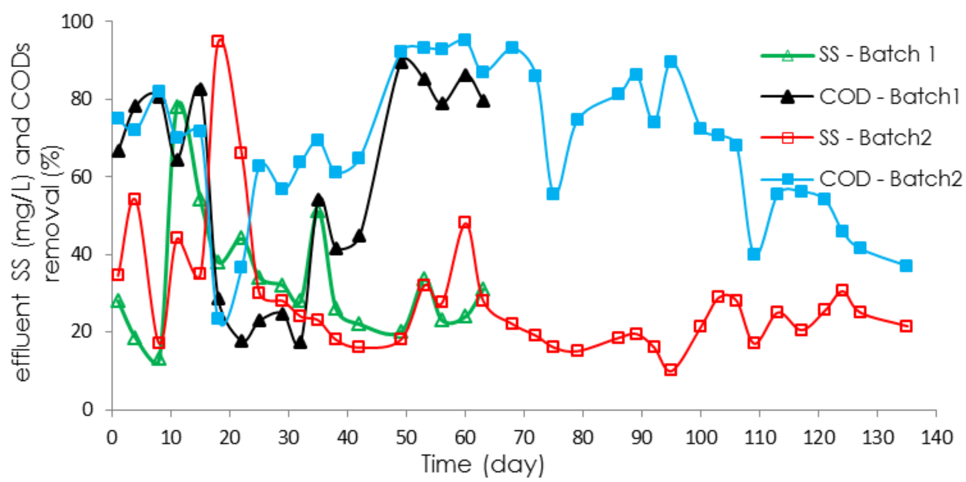

Figure 3 Profile of effluent SS and CODs removal percentage..

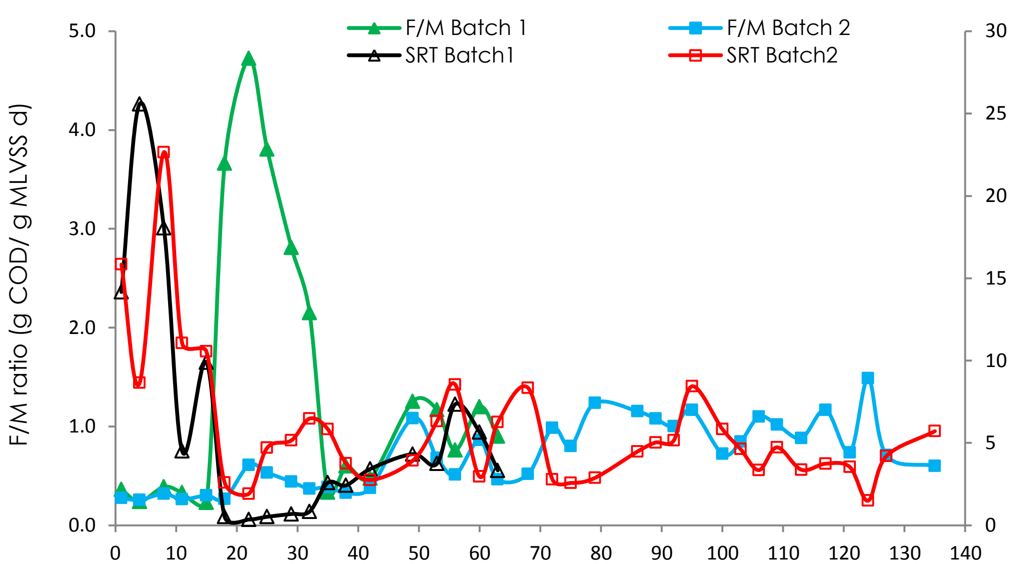

Figure 4 Profile of F/M ratio and SRT.

3.2 Effect of H/D Ratio On Settling Time And SVI

3.2.1 Batch1 AGS Develop In SBR1

Figure 5 and 6 exhibited profiles of SVI for Batch 1 and 2 at 5 min intervals of settling time. The arrow above graphs area indicated the settling time applied during formation process. From observation, the proliferation of filamentous bacteria on the wall of SBR1 started on day 5 had decreased MLLS concentration on day 8. Hence, in order to discharge off filamentous bacteria that floating freely or extending from small flocs, settling time was reduced from 30 to 15 min on day 9. As a result, effluent SS increased relatively higher on day 11 which was 78 mg/L compared to 13 mg/L on day 8. SRT of 5 d on day 11 (Figure 4) was in conjunction with decreased in SVI_5 and SVI_{30} (Figure 5) on day 15. Where, as off day 15, more than 50% of SVI_5 and SVI_{30} of day 11 were discharged off. Nevertheless, MLSS concentration continued to increase in line with improvement of effluent performance until day 15.

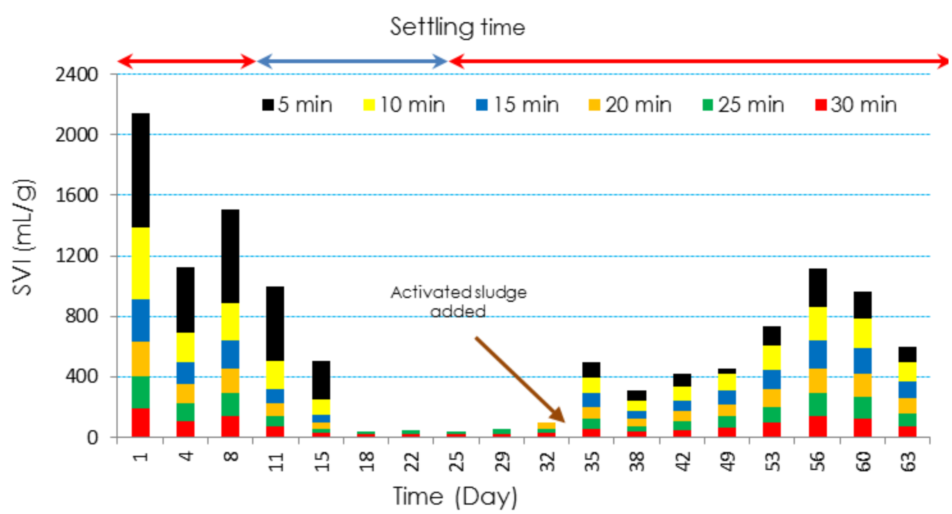

Figure 5 Profile of SVI at 5 min intervals of settling time for Batch1

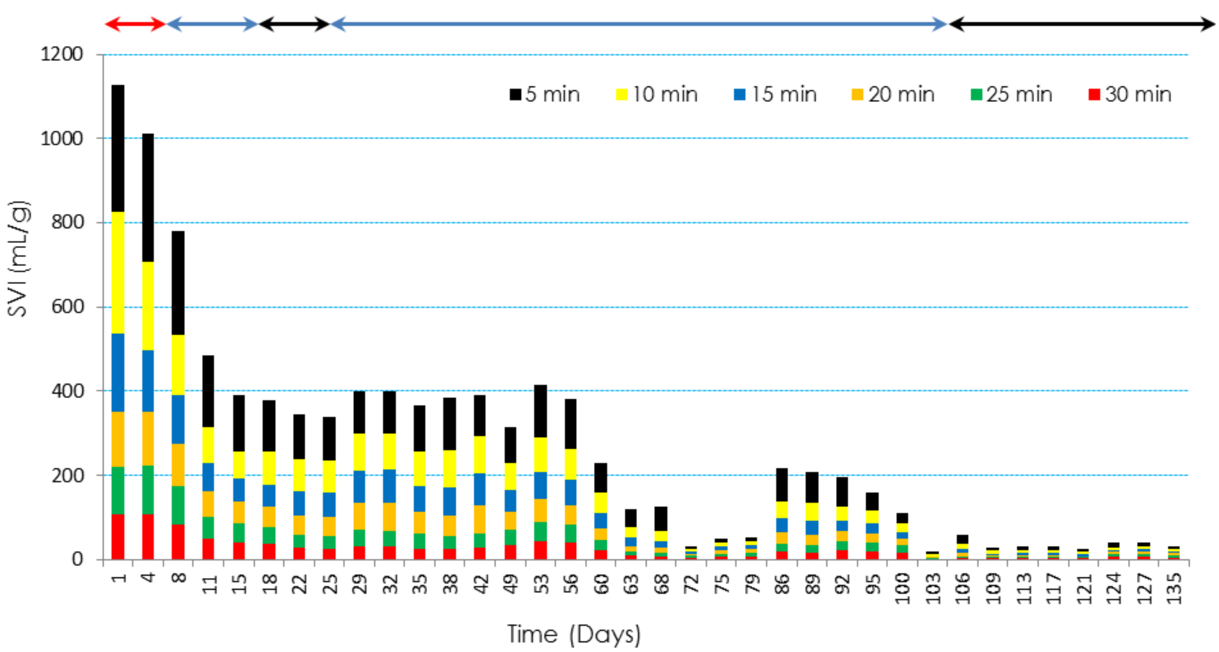

Figure 6 Profile of SVI at 5 min intervals of settling time for Batch 2

A sharp decreased in organic loading rate (OLR) from 0.34 to 0.17 kg COD/m^3 d on day 16 had almost completely washed out MLSS in SBR1. Even after settling time was reset to 30 min on day 23, MLSS concentration remained low until day 32, in which around 0.06 g/L. Although SOUR had greatly increased up to 394 mg O_2/g MLVSS h (Figure 7), CODs removal receded to less than 30%, with high concentration of effluent SS due to insufficient amount of microbial (MLVSS) in reactor to degrade the increasing influent COD concentration. Hence, by looking at MLSS and OUR result that remained linearly low but with slightly increased, SOUR value at this point was not a decent indicator to reflect microbial activity in SBR1. Result on SVI_5 indicated that small aerobic granules on day 15 were completely removed from reactor.

As presented in Figure 4, F/M ratio for Batch 1 was exceptionally high between days 18 to 32 due to MLSS losses. Thus, in order to recover the losses of biomass in SBR1, 0.6 L of activated sludge was added on day 33 and followed by changed in cycle time from 4 to 3 h on day 38. On day 38 onwards, MLSS concentration in SBR1 had gradually improved in line with effluent performance. Despite off high OLR increment on day 49, SVI_{30} and MLSS concentration showed a slight increased since system was already in stable condition.

At the end of the formation process, aerobic granules in SBR1 continued to re-cover from the high and low shock OLR and achieved stable conditions between days 49 to 60. This was in conjunction with result on SRT that showed an increment from 40 min on day 22, to 7 d on day 56 onwards. According to Malaysian Standard [10], the optimal SRT for conventional activated sludge system is 5 to 10 days. Outside this range (too short or long SRT), reactor performance will deteriorate [11]. Beside, Muda et al. [12] had conclude that sludge biomass will lose bioactivity characteristic based on overall specific biomass growth rate (ı\`$_{overall}$) endogenous decay rate (k_d) and biomass yield (Yobs, Y) when SRT is increased. System with long SRT will favors filamentous growth because of a low specific growth rate of filamentous bacteria [13].

3.2.2 Batch2 AGS Develop in SBR2

In contrast to SBR1, after 1 day of formation process at identical operating conditions, SBR2 managed to retain higher MLSS due to the short settling distance for suspended SS. Hence, even after settling time was reduced to 15 min on day 5, MLSS concentration had only slightly vary until day 15. In SBR1, the proliferation of filamentous bacteria started after 5 day of formation process. However in SBR2, filamentous bacteria start to proliferate on day 11 attribute to changes in settling time from 30 to 15 min on day 5. The highest effluent SS concentration from SBR2 was recorded on day 18 due to change in settling time from 15 to 5 min on day 16, and followed by a relatively lower OLR of 0.17 kg/m^3 d compared to 0.34 kg/m^3 d on day 15. In order to avoid washed out of small flocs that started to disintegrate due to low OLR, settling time was changed back to 15 min on day 23, and cycle time was adjusted from 4 to 3 h on day 38.

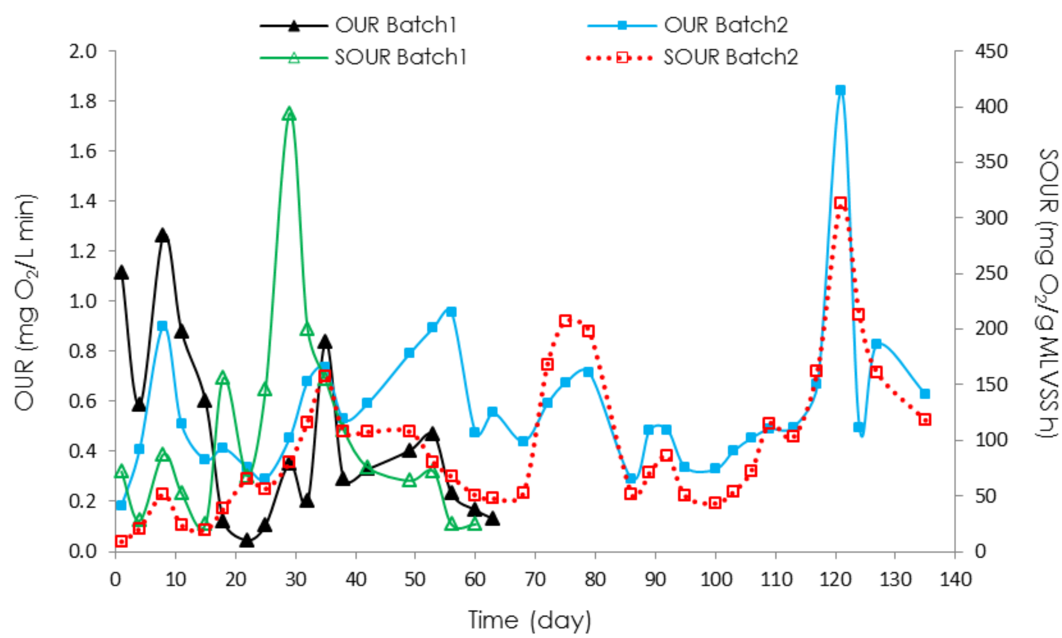

Figure 7 Profile of OUR for Batch1 and Batch 2

From observation, the proliferation of filamentous bacteria on SBR1 wall was severe as compare to SBR2. Thus unlike Batch1, an excessive low OLR up to 0.10 kg/m^3 d that continued until day 42 did not significantly affected the performance of Batch2. Instead, result on MLSS and SVI (Figure 6) between days 18 to 42 were rather constant. This was cause by changes in settling time at the beginning of formation process. A study conducted by Adav et al. [14] had noted that selection of settling time was only crucial at the beginning of cultivation process, since most of the cyclic period was during aeration phase. Applying a short settling time at the beginning of cultivation process will ensure a washout of non-flocculating strains from sludge seed that correspond to the shift of microbial community in granular sludge.

After 60 days of formation, Batch2 AGS had become more resistance to the fluctuation of influent CODs. Effluent performance remained high even after a sharp decreased of OLR on day 63 which had resulted with low SVI_{30} of 9 mL/g. In order to avoid being washed out from reactor due to low F/M ratio of 0.46 g CODs/g MLVSS d, microbial activity during this period was high. This indeed was in conjunction with OUR and SOUR (Figure 7) result on day 68 to 89. In contradiction, OUR exhibited a decreasing trend between days 16 to 42 with average F/M ratio of 0.4 g CODs/g MLVSS d. The identical decreasing OUR trend between days 16 to 42 for Batch2 can also be observed in Batch1. This was presumably attributed by the maturity of aerobic granules or microbial species that did not well develop in early stage of formation process. The highest CODs removal up to 90% was recorded on day 95, followed with low effluent SS of 10 mg/L for Batch2.

Reducing settling time from 15 to 5 min on day 103 onwards, and followed by low OLR (f 0.41 to 0.26 kg CODs/m^3 d) on day 109 had extremely altered the performance of Batch2 AGS. It was estimated that consecutive changes in operating parameters within a short time had not allowed spaces for microbial or aerobic sludge to fit in the current conditions. System performance continued to decline after sewage was exchanged with sewage mixture that consists of leachate and industrial wastewater on day 118 onwards. Analysis on BOD concentration indicated that sewage mixture (BOD_5 of 24 mg/L) was less biodegradable than sewage (BOD_5 of 53 mg/L). SRT had decreased from 6 d (at stable conditions) to 1 day on day 124.

Based on analysis for effluent SS, CODs removal and SVI, the optimum settling time for SBR1 and SBR2 under variable OLR is 30 and 15 min, respectively. Following on founding by Beun et al. [15] and Qin et al. [16] that regard a short settling time was preferentially for the growth of rapidly-settling bioparticles, a settling time within the range of 2 to 15 min had often being used by other researchers in order to enhance the granulation process

3.3 Morphology of AGS

The morphology of aerobic granules is affected by a number of operational parameters such as seed, substrate composition, OLR, reactor configuration and hydrodynamic shear force [17]. Figured 8 exhibited morphology of Batch1 AGS collected on day 38 and 61. Despite of a noteworthy differences in size at 300 µm image scale (a, c), both aerobic granules had displayed a straggler shaped and loose structure. A closed up image on day 60 (d) revealed that aerobic granules consisted of filamentous and cocci shaped bacteria which had extending from aerobic granules.

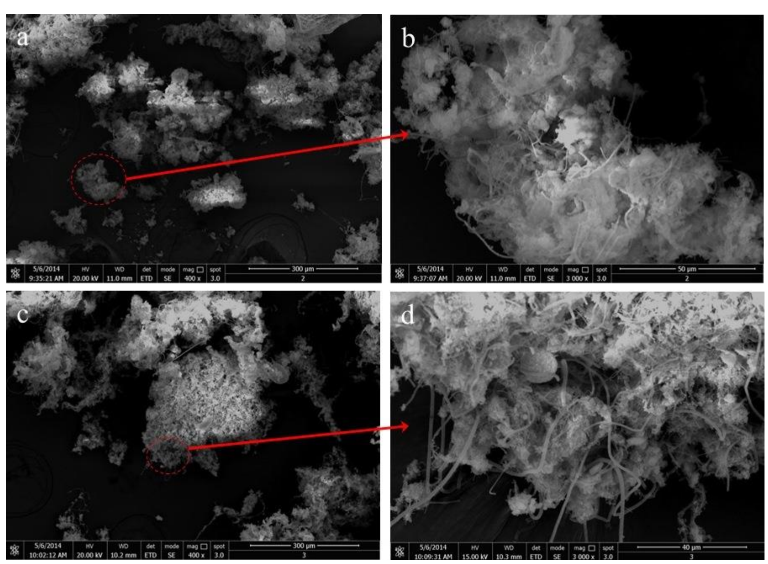

Figure 8 FESEM images of Batch1 AGS at day 38 (a, b) and 60 (c, d)

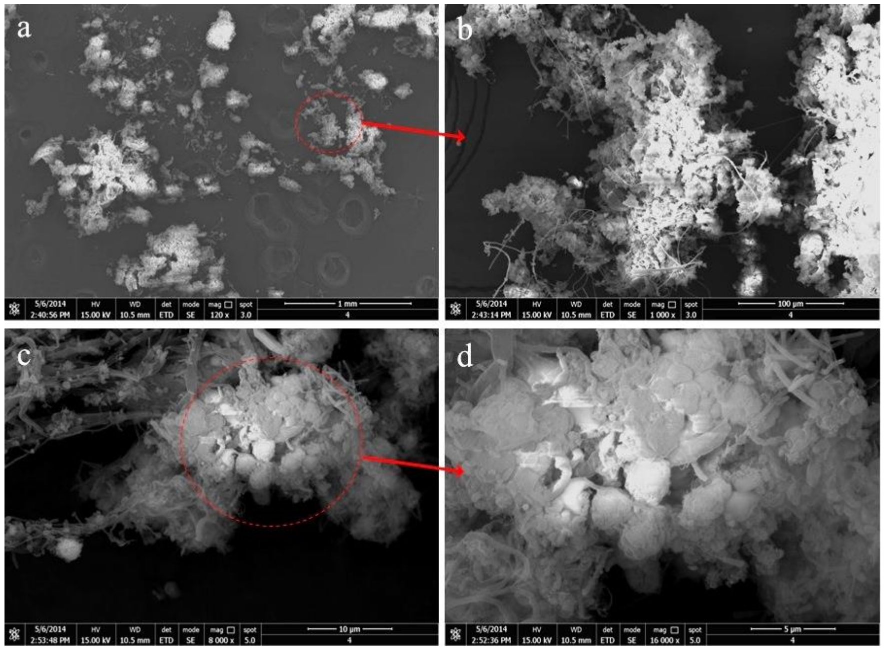

Figure 9 FESEM images of Batch2 AGS at day 38

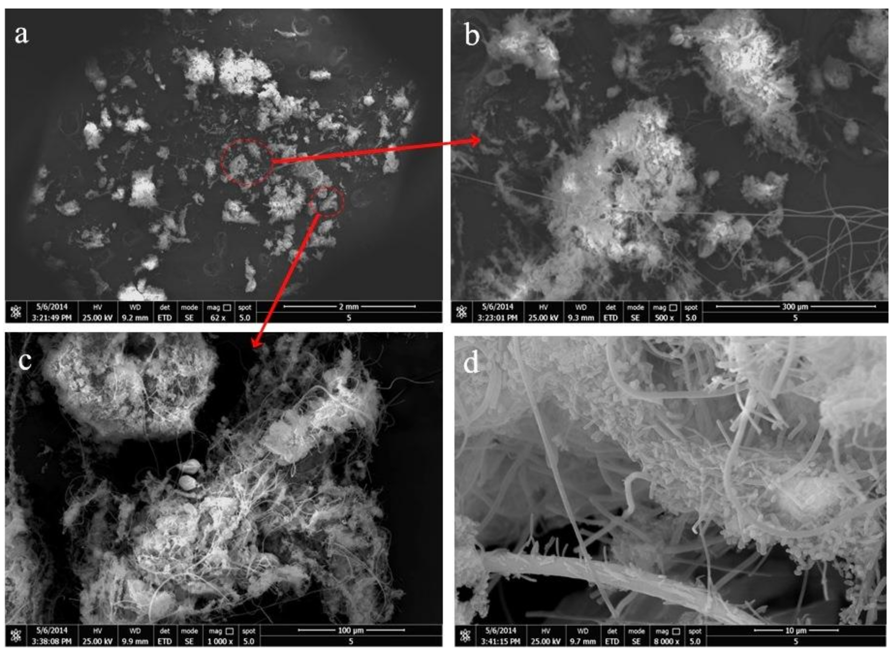

Figure 10 FESEM images of Batch2 AGS at day 93

A fluffy aerobic sludge was expected since Batch1 AGS was developed under low substrate concentration. Under low substrate conditions, diffusion of substrate will become a limiting factor in aerobic granular sludge formation [18], and thus tend to decrease the substrate removal rate. Peyong et al. [19] and Martins et al. [20] indicated that compact granules subjected to low substrate conditions will end up with loose structure and the existence of filamentous. This was attributed by the nature of filamentous to excellently fit in loose structure and lead to development of irregular shape.

FESEM observation of Batch2 AGS showed that aerobic granules on day 38 (Figure 9) were much bigger in size than aerobic granules on day 93 (Figure 10). Like Batch1, aerobic granules on day 38 and 93 displayed a straggler shape. Batch2 AGS was likely more sturdy than Batch1 AGS. A closed-up image (Figure 10c) indicated that aerobic granules on day 93 were not just a mixture of compact and loose structure consists of filamentous, cocci and bacilli shaped bacteria.

Microscopic observation of Batch1 and Batch1 AGS revealed that the granules were typically comprise off filamentous bacteria that linked with one another via bridging to serves as backbone for development of AGS. According to Wang et al. [21] filamentous bacteria also will associate with varying degrees of rod and cocci type bacterial morphtypes that occur in micro colonies as single cells or in flora forms that distributed randomly in granules.

4.0 CONCLUSION

In this study, aerobic granules were successfully developed in SBR2 with low H/D ratio and SUAV of 4.4 cm/cm and 0.7 cm/s, respectively. Advantage and disadvantages of reactor with low H/D ratio (SBR2) compare to reactor with high H/D ratio (SBR1) that can be point out from result and discussion are as follows:

- At similar working volume, the periods to achieve stable conditions or mature aerobic granules in SBR1 with high reactor H/D ratio was shorter than in SBR2 even after fresh activated sludge was added on day 33.
- Biological AGS reactor needs to retained sufficient amount of active biomass (MLSS and MLVSS) in order to recover the losses prior to excessive washed out. Compare to SBR1, at similar settling time which is 15 min, SBR2 provide a short settling distance for Batch2 AGS which was preferable in case of system breakdown (shock OLR).
- Both Batches exhibited a reduced in SVI_5 to SVI_{15} in which due to densify process in line with formation periods.
- SVI_{30} indicated that SBR1 produced more sludge than SBR2 while effluent performances in both reactors are high.
- Analysis on effluent quality showed that under variable OLR, 30 and 15 min is the optimum settling time for SBR1 and SBR2 respectively.

Acknowledgement

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