PAPER • **OPEN ACCESS**

To Optimize Sequencing Batch Reactor (SBR) and Monitor Aerobic Granular Sludge (AGS) Development for Domestic Wastewater Treatment

To Optimize Sequencing Batch Reactor (SBR) and Monitor Aerobic Granular Sludge (AGS) Development for Domestic Wastewater Treatment

Norazah Mohd Kassim[1*], Aznah Nor Anuar [1*], Hakim Halim[1*], Noor Atiqah Sharani[2], Alijah Md Aris[2], Khor Bee Chin[2]

[1] Department of Chemical and Environmental Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[2] Indah Water Research Centre, Kuala Lumpur, Malaysia

*Corresponding Author: norazahmohdkassim@gmail.com, aznah@utm.my, mohdhakim@utm.my

Abstract. The aim of this study is to determine design and process parameters of the aerobic granular sludge system to treat actual domestic wastewater. The aerobic granular sludge was developed in a 2.5 L lab-scale bioreactor which uses the operational system based on the sequencing batch reactor (SBR). The bioreactor was fed with influent from local sewerage treatment plant and seeding with fresh inoculums (seed sludge) from activated sludge tank. The operation of the reactor was based on the SBR system with a complete cycle time of 4 hours and specifically designed to be operated for 24 hours continuously. Two sets of experiments were carried out in a single-walled cylindrical glass column bioreactor. These two sets of experiments are referred to as SBR_A and SBR_B with different time setting. SBR systems have four stages which is feeding, aeration, settling and decant. It was carried out in sequence: (1) 'feeding with aeration' for SBR_A (feed and aerate pumps operated simultaneously); 'feeding without aeration' for SBR_B (feed and aerate pumps operated separately), (2) 'aeration only', (3) 'settling', and (4) 'discharge'. Removal performance of the SBR such as BOD, COD, AMN, $NO3^-$, TSS, VSS and TP along with the other several parameters of the SBR such as DO, SOUR, ORP and settling profile are monitored daily. Starting from day 1 until day 26 the average DO values were around 1 - 2 mg/l but after 1.5 hours the DO values increased drastically. It shows that the microbe did not consumed air during the process. Day 13 onwards SOUR profiles show that the microbe consumed oxygen slowly. These results suggest that low amount of readily oxidized organic available in the bioreactor. The SVI reading shows good settling performance which is less than 100 mL/g. The settling profile shows the sludge has been further compact day by day. From the finding, it is suggested that it would be better for feed and aerate pumps to be operated separately.

1. Introduction

The dramatic increase of human population and industrialization has resulted in excess scale of wastewater to be handled before it becomes reusable and enters into ecosystems, which means new development of sewage technique are needed [1]. Aerobic granulation is described as a self-aggregation process that transform loose biomass into dense and compact granules under control conditions [2]. AGS is well known for its physical characteristics including regular in shape and compact structure [3]. As a dense microbial aggregate, AGS has great settling ability which can enhance the effectiveness of sludge separation from treated effluent. It also has high biomass levels that would ensure faster and efficient removal of pollutants [4]. The high surface area and porosity of AGS also provide excellent resistance towards toxic substances. Besides, other notable features of AGS are the ability to tolerate high organic loads and carry out the simultaneous removal of organic substances and nutrients [5]. AGS technology demonstrates a 20-25% reduction in operation costs, 23-40% less electricity requirement and a 50-75% reduction in space requirements compared to the conventional activated sludge treatment system [6].

In an existing activated sludge system, a mixed culture of suspended biomass is growing and removing organic carbon and nutrients from the influent. In such a process the biomass (the activated sludge), which are usually present as flocs, are mixed with the wastewater in a large aerated basin. Supply of fresh wastewater to the bioreactor and discharged of treated wastewater from the bioreactor occur continuously. The discharged wastewater is led to a settling tank. In the settler, separation of activated sludge from the treated wastewater is carried out by means of gravitational forces. The treated wastewater can then be discharged into surface waters, or is used for further treatment. Existing activated sludge plants produce surplus sludge. Part of the settled activated sludge is recycled to the bioreactor. The remainder of the sludge is usually treated anaerobically and later disposed in landfills, or is used as fertilizer in agriculture.

Performance of activated sludge system deteriorates due to sludge separation problem caused by sludge bulking. Bulking activated sludge which settles slowly and compacts poorly is still one of the most common operational problems plaguing the wastewater treatment plant. Moreover However, existing activated sludge plants take up a substantial footprint. In order to treat large amounts of wastewater completely, large aeration tanks are needed. The settling tanks cover a large area, because the settling velocity of the activated sludge flocs is very low, normally <1 mh^{-1}.

AGS cultivation has been preferentially carried out in sequencing batch reactors (SBRs). In this system, all phases (filling, reaction, settling, decanting, idling) take place in the same tank. Therefore, a secondary clarifier is not needed as in activated sludge system. AGS has a small footprint and a low energy demand compared to conventional municipal wastewater treatment technologies [7]. Since the available ground area to build the treatment plant is usually limited, especially in Malaysia, there is a need for a more compact and high-performance reactor. This need for more compact reactors and short hydraulic retention time (HRT) directed the study towards the development of systems with high biomass concentrations. Furthermore, it demonstrated unique features including granules without carrier material, excellent settling properties, great biomass enrichment, simple single-tank concept with simultaneously biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate ($NO3^-$), ammoniacal nitrogen (AMN) and total phosphate (TP) removal and low costs compared with conventional activated sludge processes.

The objectives of this study are (i) to optimize sequencing batch reactor (SBR) and (ii) to monitor aerobic granular sludge (AGS) development for domestic wastewater treatment whereby this study will utilize fully hundred percent actual domestic wastewater to comply with the existing wastewater treatment operation. This could be a benchmark for local sewerage services to start-up their full-scale aerobic granulated sludge system.

2. Materials and Methods

2.1. Designed and Setting Up Bioreactor

Cyclic Aerobic Granular Sludge Bioreactor (CAgABio); a 2500 mL laboratory-scale reactor have been used to develop the granules as shown in Figure 1. The basis of this reactor set-up was developed according to the reactor configuration built in the Kluyver Laboratory for Biotechnology, Delft University of Technology, the Netherlands [8]-[10]. The schematic diagram of the reactor set-up is shown in Figure 2. The operation of the reactor was based on the normal SBR system with a complete cycle of 4 hours and specially designed to be operated for 24 hours continuously. Two sets of experiments were carried out in a single-walled cylindrical glass column bioreactor with a working volume of 2.5 L. The two sets of experiments are referred to as SBR_A and SBR_B. The process flow diagram of the CAgABio system is shown in Figure 3.

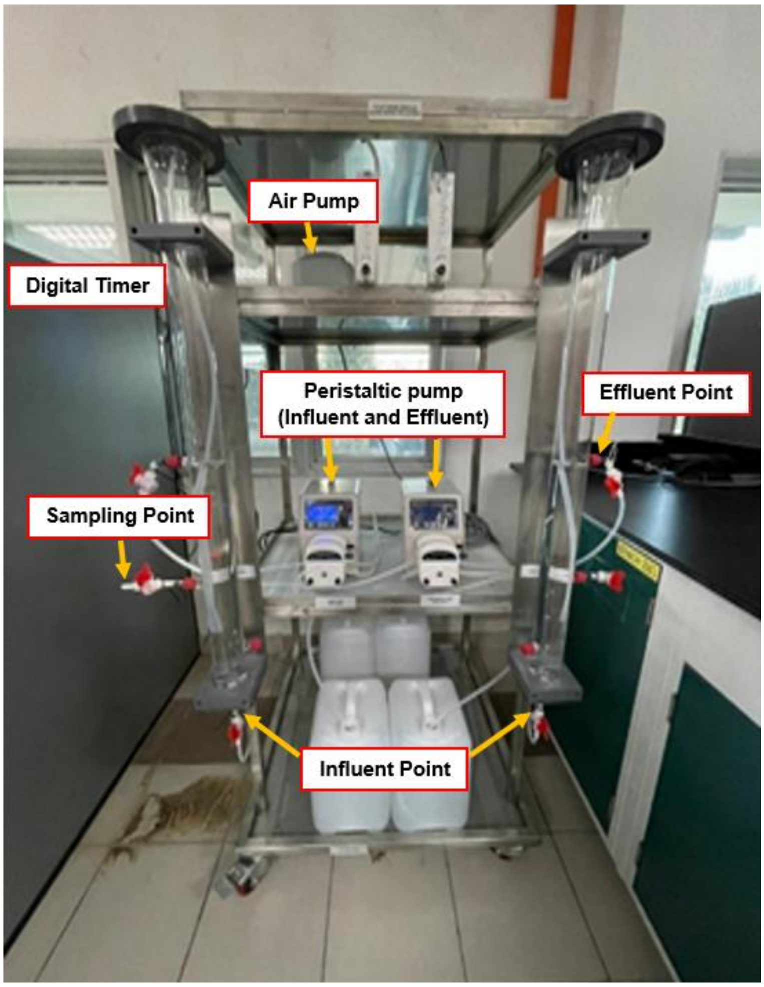

Figure 1. 2500 mL laboratory-scale SBR.

2.2. Seeding Sludge
A fresh activated sludge taken from a Sequencing Batch Reactor Treatment Plant (Bunus STP – KLR 403, Kuala Lumpur) was used as seed sludge in the reactor. The seed sludge characteristics used in this experiment is given in Table 1. The characterisation study is essential to provide physical and morphological information for the initialisation of the granulation process where at the end of the study, the final characteristics of granulated seed sludge could be figured out. The physical characteristics were determined in terms of sludge volume index (SVI), size and settling velocity (v).

2.3. Influent Feeding
The influent for the experiments with actual domestic wastewater were collected from wastewater treatment plant (BUNUS STP – KLR 403 Kuala Lumpur). For every cycle, 1000 mL of actual domestic wastewater was dosed to the reactor. The composition of the influent dosed to the laboratory-scale is given in Table 2.

2.4. Analytical Procedures
All analytical measurements performed in this study were conducted according to Standard Methods for the examination of water and wastewater [11].

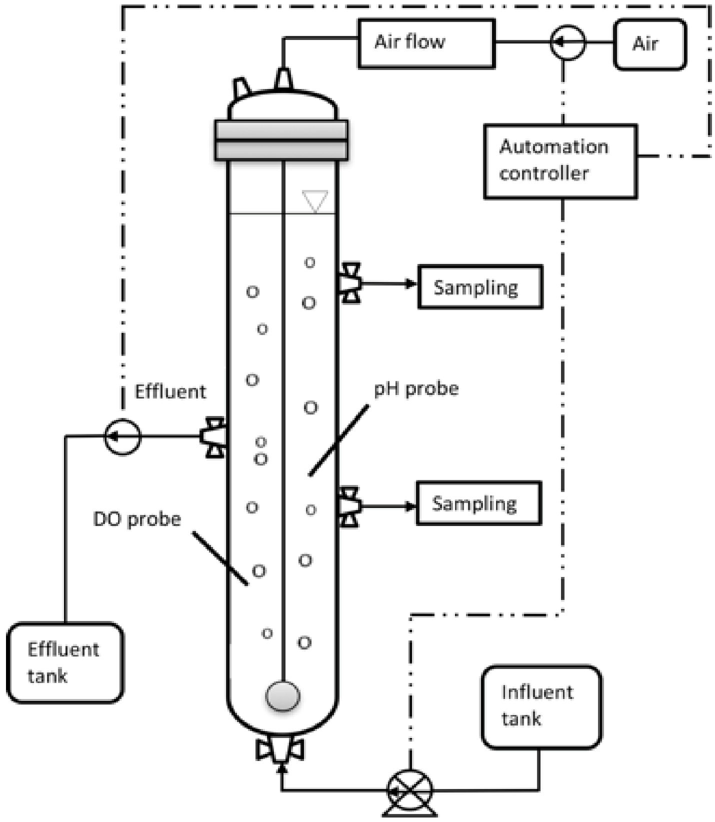

Figure 2. Schematic diagram of reactor.

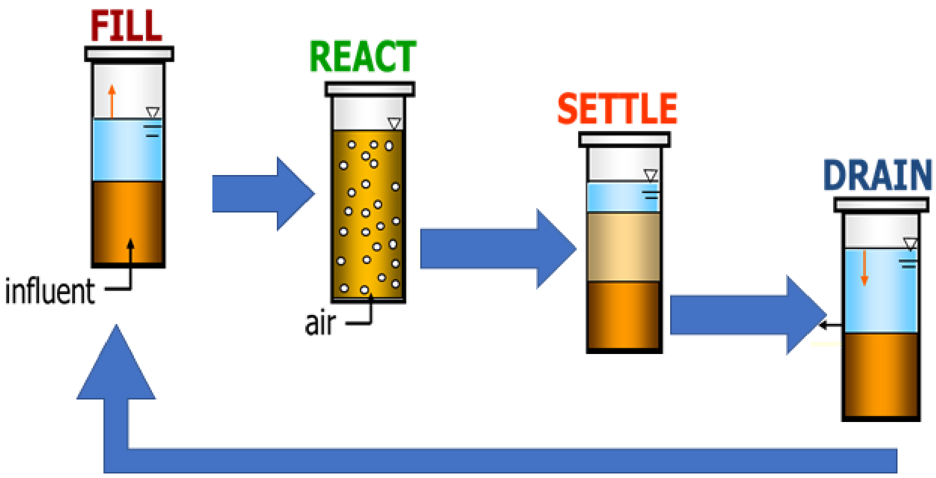

Figure 3. Process flow diagram.

Table 1. Physical characteristic of activated sludge (seed sludge).
(BUNUS STP – KLR 403 Kuala Lumpur).

No	Set Value	Descriptions
1.	pH	7.0
2.	DO (mg/L)	2.0
3.	SV_{30} (mL/g)	150
4.	Size (mm)	<0.2
5.	Settling velocity (m/h)	0.6

Table 2. Composition of influent from BUNUS STP – KLR 403 Kuala Lumpur.

No	Set Value	Descriptions
1.	pH	6.7
2.	COD (mg/L)	304
3.	BOD_5 (mg/L)	123
4.	Ammoniacal Nitrogen (AMN), NH_3-N (mg/L)	20
5.	Nitrate, $NO3^-$ (mg/L)	0.5
6.	Total Phosphate (TP), PO_4^{3-} (mg/L)	5

3. Results and Discussion

3.1. Bioreactor time setting

SBR systems have four processes and it was carried out in sequence feeding, aeration, settling and decant: (1) 'feeding with aeration' (feed and aerate pumps operated simultaneously), (2) 'aeration only and without feeding', (3) 'settling', and (4) 'discharge'. Starting from day 1 until day 26 the average Dissolved Oxygen (DO) values were around 1 - 2 mg/l but after 1.5 hours the DO values increased drastically. It shows that the microbe did not consumed air during the process. Day 13 onwards SOUR profiles show that the microbe consumed oxygen slowly. These results suggest that low amount of readily oxidized organic available in the bioreactor. Oxygen Reduction Potential (ORP) reading shows that no denitrification happened along the cycle. The lowest value of ORP monitored was 111 mV whereby the normal (ORP) value for denitrification should be ranges between -50 mV to +50 mV. Oxidation-reduction potential or ORP has been used for many years in facilities that process wastewater generated by metal finishing plants, but only recently has it become prominent in municipal wastewater treatment plants [12]. To meet the ORP corresponding values, setting time for aeration has changed by separated operating of the aeration pump during feeding (feeding without aerate).

3.2. Formation and settling velocity of Granules

Day 32 first batch of AGS was harvested using 0.3mm, 0.6mm and 1.0mm sieve. The diameter of the granules was obtained under microscope observation with an average diameter of 1.64mm (irregular shapes of granules were developed). The developed granules at 32 days are shown in Figure 4. Morphology characteristic are shown in Figure 5 (micro colonies Cocci-shaped bacteria acted as a supporting consortia during the formation of granular), Figure 6 (extracellular polymeric substances EPS acts as a sticky glue between the microbial cells and strengthen the structure of the granules) and

Figure 7 (cavities act as a passage for the transportation of substrate, oxygen, and nutrients into the inner cores of the granules and ensure the stability within the granules composition). Different methods to measure the granule density include the pycnometer method, the Percoll density gradient method, the dextran blue method, and the settling velocity method [13]. Settling velocity method was used in this study. The granule's settling velocity is approximately thirty times faster than the actual activated sludge (actual activated sludge 0.6 m/h and AGS 18.04 m/h). The granules minimum settling velocity is 30 m/h and can reach up to 70 m/h depending on the compactness and density of the granules [14]. The SVI_{30} of granules (average 60 mL/g is lower than actual activated sludge with SVI_{30} value of 150 mL/g). The SVI of AGS is lower than 100 mL/g while activated sludge flocs, 150 mL/g and above [15]. Figure 8 and Figure 9 shows SVI_{30} for 1st and 2nd aeration setting time.

3.3. Removal Efficiency of Granules

During the 32 days development parameter such as BOD, COD, Ammoniacal Nitrogen (AMN), $NO3^-$, TSS, TP, MLSS and MLVSS were monitored daily and weekly. The performance of the reactor from 1st to 2nd aeration setting time improved satisfactory. Average percentage BOD removal was about 33% to 76.7%. COD removal 42% to 89.7%. These results indicate the removal performance of BOD and COD improved at different operation setting time, due to the transformation of the flocculent sludge into granular sludge took place in the bioreactor system. These results are comparable to the previous study by Ab Halim et al. (2018) [16] who also conducted experiment by using actual domestic wastewater for the biological activity of granules. AMN removal 95.5% to 74.2% slightly decreased (it may due to the influent which has high AMN content) but still complied with Malaysia Environmental Quality Act (design effluent values discharge to river/stream for Standard A < 5 mg/L). The removal of NO3 was decreased 22.6% to -95.9%. However, the value of 6.5 mg/L of $NO3^-$ still complied with Malaysia Environmental Quality Act (design value required was 10 mg/L). TSS and TP the removal performance percentage were 40% to 91.9% and -74% to 96.3%, respectively (refer Figure 10, Figure 11 and Table 3).

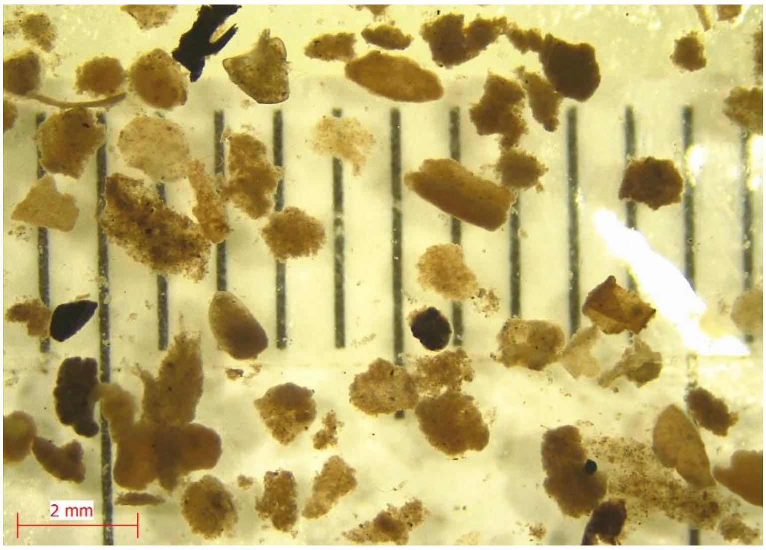

Figure 4. Microscope images of granules at 32 days.

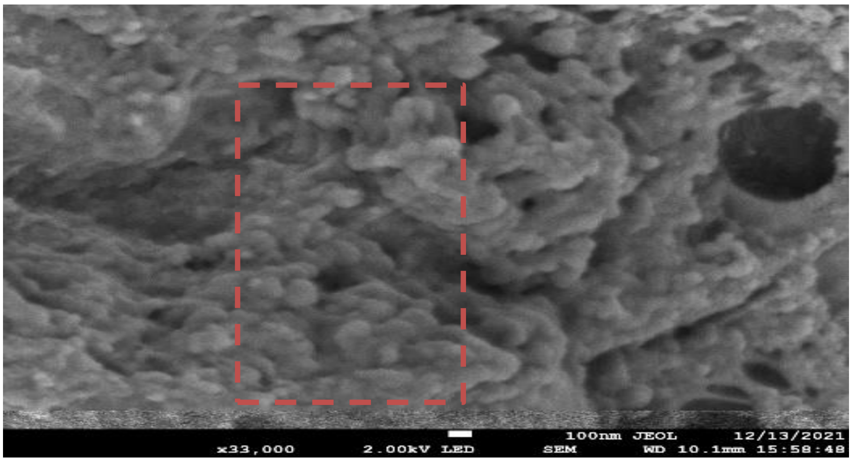

Figure 5. Photo of microbes captured within the granules (Cocci-shaped) using scanning electron microscope.

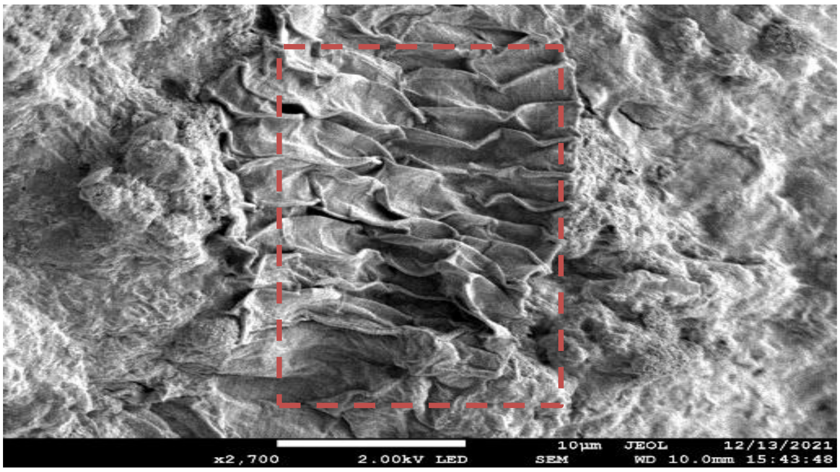

Figure 6. Photo of EPS captured within the granules using scanning electron microscope.

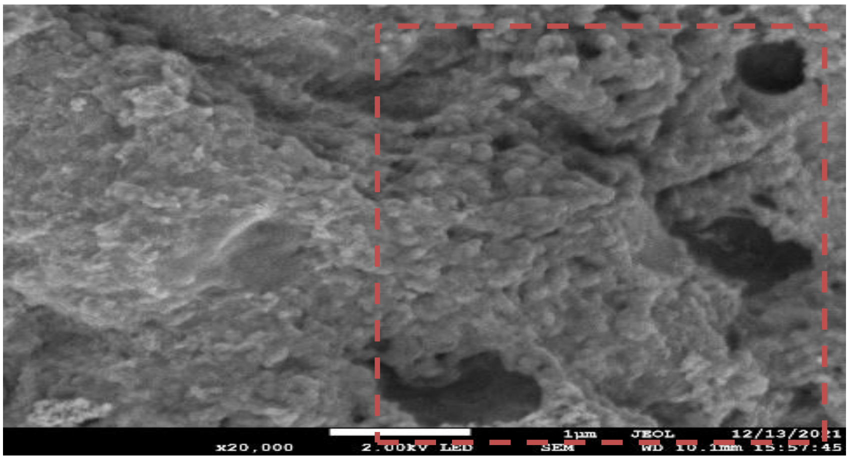

Figure 7. Photo of cavities captured within the granules using scanning electron microscope.

SVI Profile for SBR_A, Feed and Aerate Pumps Operated Simultaneously

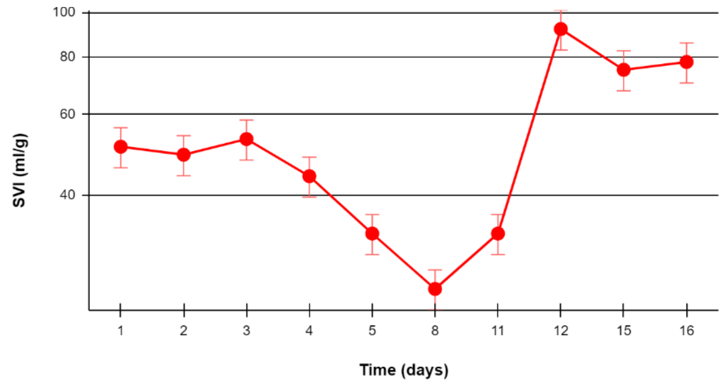

Figure 8. SVI_{30} value until day 16 with 1st aeration setting time.

SVI Profile for SBR_B, Feed and Aerate Pumps Operated Separately

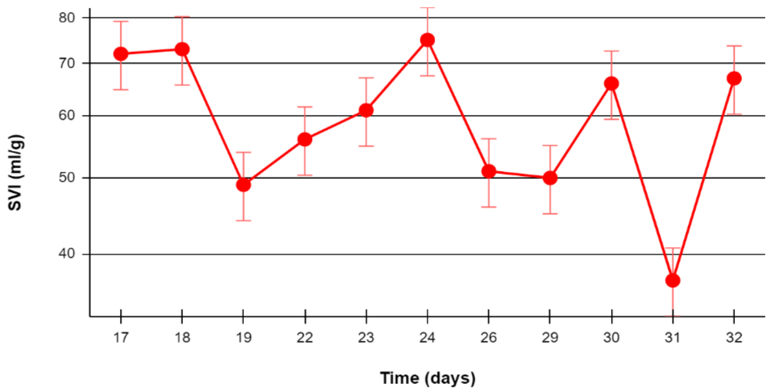

Figure 9. SVI_{30} value until day 32 with 2nd aeration setting time.

Removal Performance for SBR_A, Feed and Aerate Pumps Operated Simultaneously

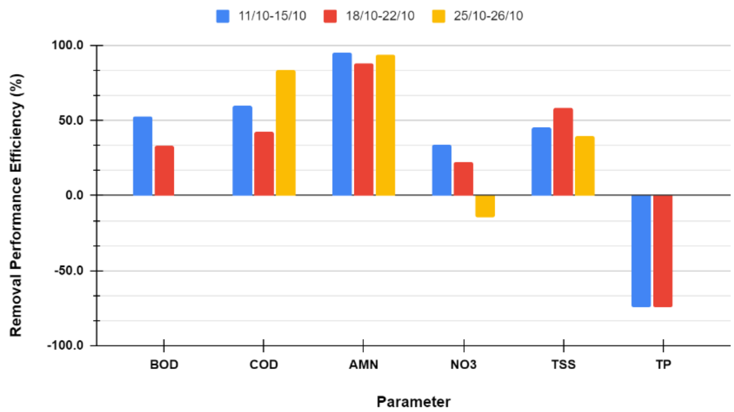

Figure 10. SBR removal performance for 1st aeration setting time.

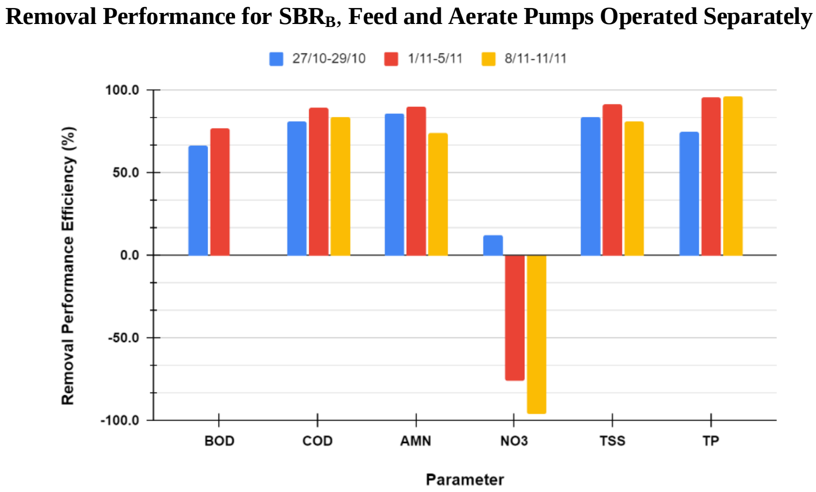

Figure 11. SBR removal performance for 2nd aeration setting time.

Table 3. Removal Performance for SBR_A and SBR_B

No	Parameters	SBR_A	SBR_B
1.	BOD	33%	76.7%
2.	COD	42%	89.7%
3.	AMN	95.5%	74.2%
4.	NO3	22.6%	-95.9%
5.	TSS	40%	91.9%
6.	TP	-74%	96.3%

4. Conclusion

The developed aerobic granular sludge (AGS) in SBR_A and SBR_B were harvested using 0.3mm, 0.6mm and 1.0mm sieve after 32 days and settling velocity for both reactors were analysed. From the finding, it is suggested that it would be better for feed and aerate pumps to be operated separately.

Acknowledgements

This research was collaborated between MJIIT Universiti Teknologi Malaysia and Indah Water Research Centre. Indah Water Konsortium (IWK) is Malaysia's national sewerage company which has been entrusted with the task of developing and maintaining sewerage system. The authors are very grateful to IWK for facilitating samples collection and lab facilities.

References

[1] Liu, W., Wu, Y., Zhang, S., Gao, Y., Jiang, Y., Horn, H., & Li, J. (2020). Successful granulation and microbial differentiation of activated sludge in anaerobic/anoxic/aerobic (A2O) reactor with two-zone sedimentation tank treating municipal sewage. Water research, 178, 115825.

[2] Yin, Y., Sun, J., Liu, F., & Wang, L. (2019). Effect of nitrogen deficiency on the stability of aerobic granular sludge. *Bioresource technology*, *275*, 307-313.

[3] Awang, N. A., Shaaban, M. G., Lee, C. W., & Bong, C. W. (2017). Characterization of aerobic granular sludge developed under variable and low organic loading rate. *Sains Malays*, *46*(12), 2497-2506.

[4] Jalali, S., Shayegan, J., & Rezasoltani, S. (2015). Rapid start-up and improvement of granulation in SBR. *Journal of Environmental Health Science and Engineering*, *13*(1), 1-11.

[5] Khan, M. Z., Mondal, P. K., & Sabir, S. (2013). Aerobic granulation for wastewater bioremediation: a review. *The Canadian Journal of Chemical Engineering*, *91*(6), 1045-1058.

[6] Basri, H. F., Anuar, A. N., Yuzir, A., & Ab Halim, M. H. (2020, June). Diatomite carrier for rapid formation of Aerobic Granular Sludge. In *IOP Conference Series: Earth and Environmental Science* (Vol. 479, No. 1, p. 012028).

[7] Bengtsson, S., de Blois, M., Wilén, B. M., & Gustavsson, D. (2019). A comparison of aerobic granular sludge with conventional and compact biological treatment technologies. *Environmental technology*, *40*(21), 2769-2778.

[8] Beun, J. J., Hendriks, A., Van Loosdrecht, M. C. M., Morgenroth, E., Wilderer, P. A., & Heijnen, J. J. (1999). Aerobic granulation in a sequencing batch reactor. *Water research*, *33*(10), 2283-2290.

[9] De Kreuk, M. K. (2006). Aerobic granular sludge: scaling up a new technology.

[10] Nor Anuar, A., Ujang, Z., van Loosdrecht, M. C. M., & De Kreuk, M. (2006). Aerobic granular sludge technology for wastewater treatment—an overview. In *Paper on Asiawater Conference*.

[11] APHA/AWWA/WEF (2012). *Standard Methods for the Examination of Water and Wastewater Standard Methods 541*

[12] Environmental, Y. S. I. (2008). ORP Management in wastewater as an indicator of process efficiency. *YSI, Yellow Springs, OH http://www. ysi. com/media/pdfs/A567-ORP-Management-in-Wastewater-as-an-Indicator-of-Process-Efficiency. pdf (accessed on 15.08. 13)*.

[13] Van den Berg, L., Pronk, M., van Loosdrecht, M. C., & de Kreuk, M. K. (2021). Density measurements of aerobic granular sludge. *Environmental Technology*, (just-accepted), 1-27.

[14] Rosman, N. H. B. (2017). *Biogranular Sludge for Rubber Processing Wastewater In A Sequencing Batch Reactor* (Doctoral Dissertation, Universiti Teknologi Malaysia).

[15] Rosman, N. H. B. (2017). *Biogranular Sludge for Rubber Processing Wastewater In A Sequencing Batch Reactor* (Doctoral Dissertation, Universiti Teknologi Malaysia).

[16] Ab Halim, M.H. (2018). *Development of Aerobic Granules in Sequencing Batch Reactor System for Treating High Temperature Domestic Wastewater*. Doctor of Philosophy, Universiti Teknologi Malaysia, Skudai.