CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106200

Cultivation of Aerobic Granular Sludge in a Column Bioreactor with 3 h SBR Cycle Time for Low Strength Domestic Wastewater

Noor A. Sharani[a,*], Aznah N. Anuar[a], Alijah M. Aris[b], Bee C. Khor[b]

[a]Department of Chemical and Environmental Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[b]Indah Water Research Centre, Planning and Engineering Department, Titiwangsa 1RSTP, Jalan Chan Chin Mooi, Lot 3938, Kuala Lumpur, 53200, Setapak, Kuala Lumpur, Malaysia
atiqahsharani@gmail.com

Aerobic Granular Sludge (AGS) technology received special attention among wastewater researchers due to the compact system and simultaneous organics and nutrient removal in one single unit reactor, especially for domestic wastewater treatment. However, it is reported in the studies that the stability of AGS formation depending on organic loading rate (OLR). A low organic loading rate led to the problem of occurrence of the filamentous bacteria in the system, which disturbed the stability of compact granules formation. Therefore, researchers intended to further investigate this bottleneck of the AGS technology. This study aims to cultivate aerobic granular sludge in actual domestic wastewater at organic loading rate of 1.6 kg COD per day and COD/N/P ratio was 200/25/10. The experiment was carried out in a 2.5 L working volume of column reactor that operated with 3 h of sequencing batch reactor (SBR) cycle time for 29 days. This AGS system achieved reliability results in the treatment of domestic wastewater with a good average removal rate for COD, around 80 %. For Ammoniacal Nitrogen (AMN) and Total Phosphorus (TP), AGS system successfully treat up to the maximum of 88.6 and 71.7 %. Meanwhile, AGS size >1.0 mm was successfully cultivated with an average settling velocity of 40 m/h and 30 min Sludge Volume Index (SVI) of 60 mL/g.

1. Introduction

Aerobic Granular Sludge (AGS) is an advanced technology in biological wastewater treatment. The AGS was firstly observed in an aerobic upflow sludge blanket reactor, and the report about it was published in 1991 (Mishima and Nakamura, 1991). Morgenroth et al. (1997) reported that AGS was successfully tested in a sequence batch reactor (SBR) in 1997. The AGS was first patented by Heijnen (2003) in 1998. Since then, AGS technology received special attention among wastewater researchers due to its compact design and simultaneous organics and nutrient removal in a single unit reactor, particularly for domestic wastewater. Organic loading rate (OLR) measuring the amount of organic matter fed into a reactor in a given volume per unit time (Oliver and Yang, 2021). The organic loading rate significantly impacted the structure formation of AGS in SBR (Su et al., 2012). Tay et al. (2004) found that a low organic loading rate (OLR) of 4.0 kg/(m3d) did not promote AGS formation. AGS cultivation in low OLR wastewater is disturbed by the filamentous bacteria, making the granules fluffy, and even disaggregating the granules. However, based on Oliver and Yang (2022), an AGS system that faces low OLR will have the highest species diversity, be more stable and show good pollutant removal in the wastewater. In this study, researchers are deemed to further investigate the stability of AGS formation and its performance in treating real domestic wastewater at low OLR in a tropical hot climate country without any addition of any carrier in this study. Most of the previous research explored the application of AGS system by using synthetic wastewater at lab scale and adding carriers to expedite the AGS formulation (Hamiruddin et. al, 2021).

Paper Received: 19 March 2023; Revised: 18 July 2023; Accepted: 30 September 2023
Please cite this article as: Sharani N.A., Anuar A.N., Aris A.M., Khor B.C., 2023, Cultivation of Aerobic Granular Sludge in a Column Bioreactor with 3 h SBR Cycle Time for Low Strength Domestic Wastewater, Chemical Engineering Transactions, 106, 1195-1200 DOI:10.3303/CET23106200

2. Methodology

2.1 Designed and setting up bioreactor

Figure 1 shows a 2500 mL Aerobic Granular Sludge (AGS) lab scale bioreactor used for granule development. The reactor used a sequencing batch reactor (SBR) system and ran continuously for 24 hours. A process flow diagram can be referred to in Figure 2.

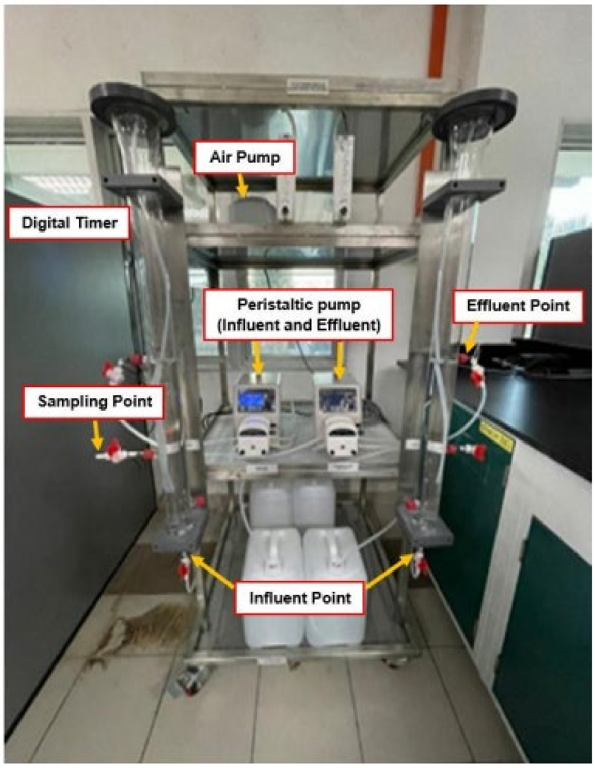

Figure 1: 2500mL AGS lab scale reactor

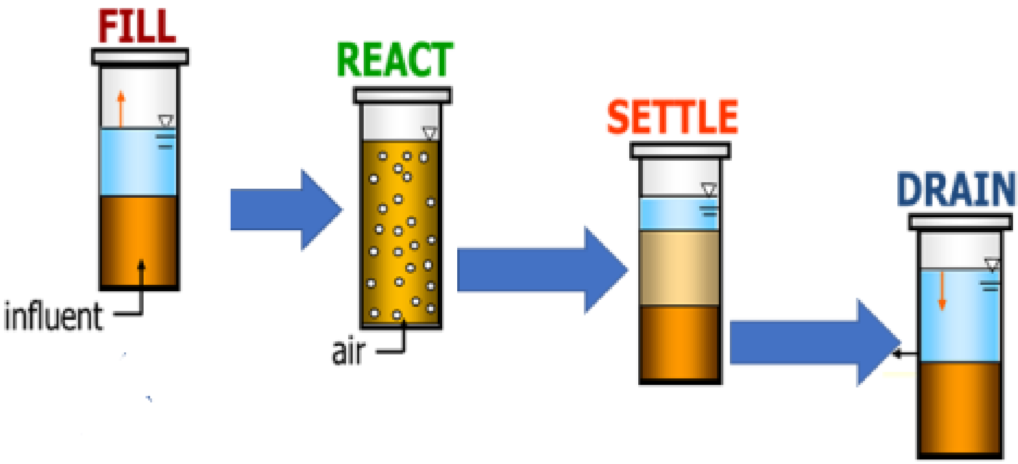

Figure 2: Process flow diagram of AGS lab scale

2.2 Seeding and influent

Influent for the AGS lab scale bioreactor was obtained from Titiwangsa 2 Regional Sewage Treatment Plant located in Kuala Lumpur. The sample has been taken in the preliminary treatment tank, which is before the biological treatment system. The raw sewage has been collected fresh every day since the AGS lab scale bioreactor was installed at Indah Water Research Centre, Titiwangsa 1 Sewage Treatment Plant. The seeding for the bioreactor is activated sludge collected from Sequential Batch Reactor treatment tank in Titiwangsa 2 RSTP with an amount of 1.4 L.

2.3 Analytical methods

The wastewater sample of influent and effluent has been analysed to determine the performance of the AGS system. The parameters that will be analysed are chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solid (TSS), ammoniacal nitrogen (AMN), nitrate nitrogen (NO_3N), total phosphorus (TP). All analytical measurements in this study were carried out in accordance with Standard Methods for Water and Wastewater Examination (2012). Eq(1) shows is the formula for removal efficiency.

$$Removal\ Efficiency = \frac{C_{influent} - C_{effluent}}{C_{influent}} \times 100\% \qquad (1)$$

Where, $C_{influent}$ = influent concentration (mg/L) and $C_{effluent}$ = effluent concentration (mg/L)

3. Result and discussion

3.1 Bioreactor setting

The SBR system has been applied for this experiment using 3 h per cycle which consist of anaerobic filling, aeration, settling and decant phase. The most critical part is during anaerobic filling and settling time. Settling time is greatly indicator to monitor the aerobic granulation process. From Figure 3 below, it shows that the Sludge Volume Index (SVI) has decreased from 109 to 60 mL/g. During this time, the biomass that has been agglomerated becomes granules and improves settling properties, which also shortens the settling process. However, SVI suddenly increased to 81 mL/g which might be due to the granules being covered by filaments. When the filamentous begins to cover the granules, it causes irregular shape and low shear resistance (Bassin et. al, 2019). According to Mora et. al (2018), the growth of filamentous bacteria can be controled by controlling the Sludge Retention Time (SRT), so that all the slow settling microbe, including filamentous bacteria, can be efficiently removed.

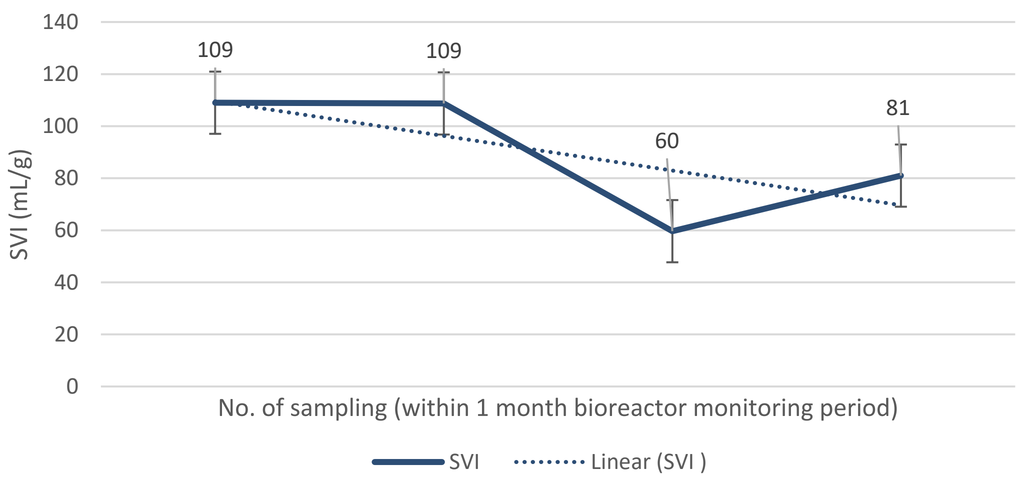

Figure 3: SVI profile of biomass in the AGS system

3.2 Performance of AGS system

This experiment was conducted using real domestic wastewater at one of the sewage treatment plants in Kuala Lumpur, which can be categorized as low strength of wastewater. COD removal efficiency averages around 80 %, with an average of effluent discharge of 28 mg/L (Refer Figure 4).. This is already compliant with modified

Standard A (50 mg/L) effluent discharge compliance under Environment Regulation (Sewage) Regulation 2009. During the monitoring of the AGS system, the highest COD removal was 97% and the lowest COD removal was 70.4%. The fluctuation incoming crude sewage concentration may be caused by the rainy season or a sudden increase in sewage flow in the sewage network pipes, which can sometimes increase and decrease the COD concentration (Laila et. al, 2019).

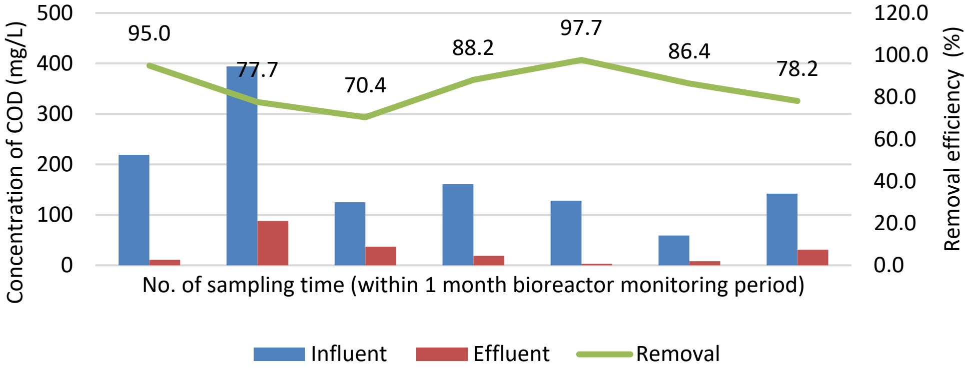

Figure 4: COD removal performance in the AGS system

Figure 5 and 6 show the removal performance of AMN and Total Phosphorus (TP), known as nutrient removal. The results show that the AGS system successfully treated up to 88.6 and 71.7 %. AMN and TP effluent discharge range from 2.3 to 13.0 mg/L and 3.6 to 11.5mg/L. However, there are some results that can comply with Standard A EQSR 2009, which is 5mg/l for both nutrients.

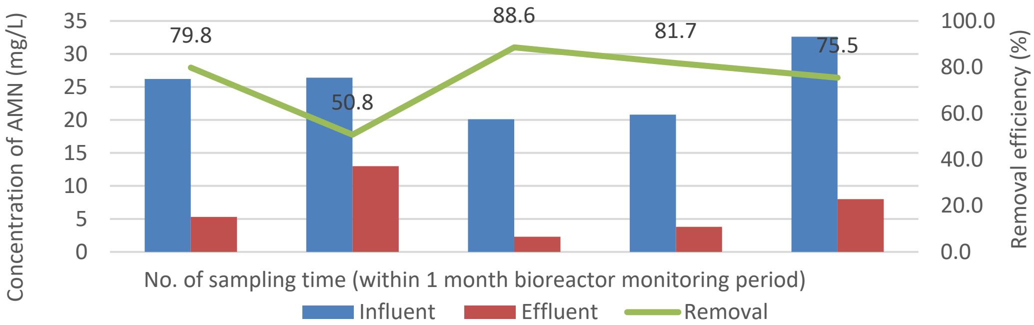

Figure 5: AMN removal performance in the AGS system

According to Fenny (2021), the AGS system can fully treat the nutrients, which consist of nitrogen and phosphorus. This is due to the multi-layer of microbes in the granules themselves, of which the deepest layer is an anaerobic microbe, followed by a denitrifier microbe, and the outer layer is an aerobic microbe, which consists of microbes that can treat organic compounds and the nitrifier microbe to treat ammonia.Based on the Figure 7 below, it shows the removal trend of COD, AMN and TP in one cycle of the AGS system. It is clear that COD and AMN decrease dramatically during the anaerobic filling phase, which is 44 and 42 %. While for TP, it is slightly increase 11 % during anaerobic filling phase. This is due to the fact that polyphosphate accumulating organisms (PAOs) in sludge release phosphorus to the sewage during anaerobic conditions, then uptake phosphorus from the sewage during the aeration phase, storing it as intracellular polyphosphates inside their cells and using it for energy generation (Oliver et. al, 2022). As overall, all parameters slowly reduce from aeration phase until decant phase.

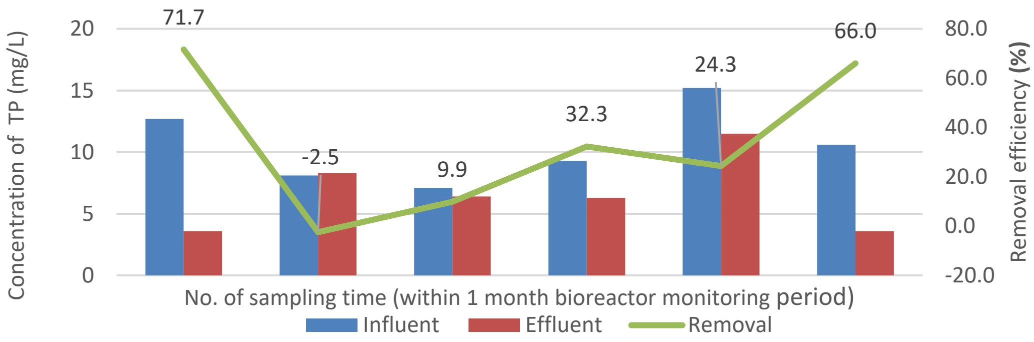

Figure 6: TP removal performance in the AGS system

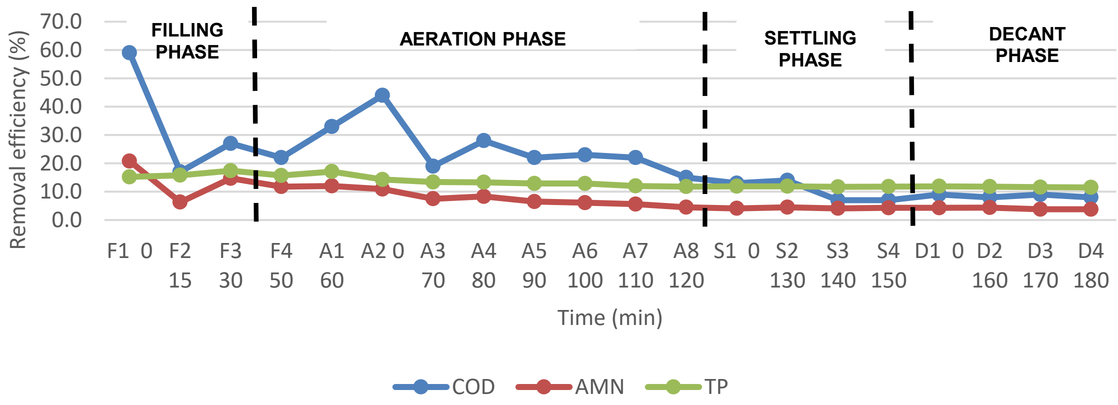

Figure 7: Cycle assessment for COD, AMN and TP removal

3.3 Physical characteristic of AGS

AGS with a size > 1.0 mm with settling velocity of 40 m/h and 30 min SVI of 60 mL/g was successfully cultivated in this study. Figure 8 depicts the photo of AGS forms. Mohamed et. al (2023) found that typical AGS sizes are greater than 1.0 mm and have a SVI of less than 80 mL/g. By having a larger particle size of granules, the settling and separation process between treated water and granules will be faster and more efficient (Bengtsson et. al, 2019)

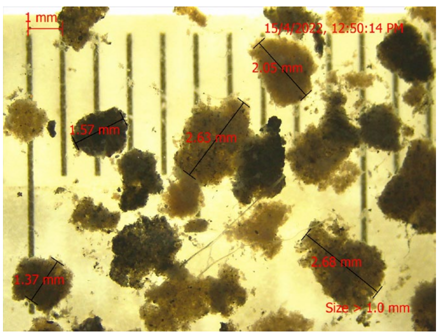

Figure 8: Photo of aerobic granules cultivated in the AGS system

4. Conclusions

A SBR system has been applied for this experiment using 3 h per cycle, which consist of anaerobic filling, aeration, settling and decant phase to treat low organic loading rate of real domestic wastewater treatment.

Settling time is a great indicator to monitor the aerobic granulation process. The biomass profile in the AGS system shows that the SVI has decreased from 109 to 60 mL/g. During this time, the biomass that has been agglomerated becomes granules and improve settling properties, which also shortens the settling process. However, SVI suddenly increased to 81 mL/g, which might be due to the granules being covered by filaments. In terms of performance, this AGS system achieved high reliability in the treatment of domestic wastewater, with a good average COD removal rate of around 80 %. The AGS system successfully treats up to 88.6 and 71.7 % of AMN and TP. Meanwhile, AGS size >1.0 mm was successfully cultivated with an average settling velocity of 40 m/h and 30 min SVI of 60 mL/g. However, settling characteristic of AGS could be further improved by controlling the Sludge Retention Time (SRT), so that all the slow settling microbe, including filamentous bacteria, can be efficiently removed.

Acknowledgments

This study was conducted in collaboration with MJIIT Universiti Teknologi Malaysia and the Indah Water Research Centre. Indah Water Konsortium (IWK) is Malaysia's national sewerage company in charge of developing and maintaining the country's sewerage system.

References

APHA/AWWA/WEF, 2012, Standard methods for the examination of water and wastewater, American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Bassin J.P., Tavares D.C., Borges R.C., Dezotti M., 2019, Development of aerobic granular sludge under tropical climate conditions: The key role of inoculum adaptation under reduced sludge washout for stable granulation, Journal of Environmental Management, 230, 168–182.

Fenny C.A., 2021, Start-up of aerobic granular sludge (AGS) reactors inoculated with granular sludge from a full-scale plant, Master Thesis, Chalmers University of Technology, Sweeden

Heijnen J.J., 2003, Method for acquiring grain-shaped growth of a microorganism in a reactor, European Patent Office, EP0964831A1.

Laila D.A.P., Norhayati A., Mohd Hakim A.H., Ali Y., Arash Z., 2019, Performance of aerobic granular sludge for domestic wastewater treatment, International Journal of Innovative Technology and Exploring Engineering, 8(12), 3851–3854.

Mishima K., Nakamura M., 1991, Self-immobilization of aerobic activated-sludge - A pilot-study of the aerobic upflow sludge blanket process in municipal sewage-treatment, Water Science Technology, 23(1991), 981–990.

Mohamed S. Zaghloul, Asmaa M. Halbas, Rania A. Hamza, Elsayed Elbeshbishy, 2023, Digestibility of Aerobic Granular Sludge: A Mini Review, Processes, 11,326.

Morgenroth E., Sherden T., van Loosdrecht M.C.M., Heijnen J.J., Wilderer P.A., 1997, Aerobic granular sludge in a sequencing batch reactor, Water Research, 31, 3191–3194.

Moura L.L., Duarte K.L.S., Santiago E.P., Mahler C.F., Bassin J.P., 2018, Strategies to re-establish stable granulation after filamentous outgrowth: Insights from lab-scale experiments, Process Safety and Environmental Protection, 117, 606–615.

Hamiruddin N. A., Awang N. A., Mohd Shahpudin S. N., Zaidi N. S., Saida M. A. M., Chaplot B., Azamathulla H. M., 2021, Effects of wastewater type on stability and operating conditions control strategy in relation to the formation of aerobic granular sludge – a review, Water Science and Technology, 84, 2113.

Oliver T.I., Sandra U., Hongyu D., Yang L., 2022, Phosphorus removal from aerobic granular sludge: Proliferation of polyphosphate-accumulating organisms (PAOs) under different feeding strategies, Processes, 10(7), 1399.

Oliver T.I., Yang L. , 2021, Effect of feeding strategy and organic loading rate on the formation and stability of aerobic granular sludge, Journal of Water Process Engineering, 39, 101709

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

Su B., Cui X., Zhu J., 2012, Optimal cultivation and characteristics of aerobic granules with typical domestic sewage in an alternating anaerobic/aerobic sequencing batch reactor, Bioresource Technology, 110, 125–129.

Tay J., Jiang H., Tay S.T., 2004, High-rate biodegradation of phenol by aerobically grown microbial granules, Journal Environmental Engineering, 130, 1415–14