DEVELOPMENT AND CHARACTERISTICS OF AEROBIC GRANULAR SLUDGE AT 40°C

Siti Izaidah Azmi[1], Mohd Hakim Ab Halim[1], Nur Syahida Abdul Jamal [1], Aznah Nor-Anuar[2], Mustafa M. Bob[3], Zaini Ujang[2]

[1]*Department of Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[2]*Institute of Environment and Water Resource Management, WATER Research Alliance, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[3]*Department of Civil Engineering, College of Engineering, University of Taibah, 30001 Universities Road, Al Madinah Al Munawarah, Kingdom of Saudi Arabia*

Abstract: This study is conducted to develop aerobic granular sludge (AGS) for domestic wastewater treatment application in a hot climate and low humidity condition such as for Middle East countries e.g. Saudi Arabia and to investigate the performance of the granular sludge in organic matter and nutrient removal by using sequencing batch reactor (SBR). The operation of the reactor was based on the SBR system with a complete cycle time of 3 hours (5 min of feeding, 140 min of aeration, 15 to 30 min of settling, 5 min of discharging and 3 min idling) and operated at 1.6 g COD / L.d organic loading rate. Granular sludge was developed at temperature 40ºC in 30 days operation by using synthetic wastewater as the influent. Result showed that developed granular sludge had good settling ability with average size of the granules was found to be 1.03 to 2.42 mm. Meanwhile, the removal efficiencies of chemical oxygen demand (COD), ammonia nitrogen (NH_3-N) and total phosphorus (TP) are 87.31%, 91.93% and 61.25%. The study shows AGS can be developed at high temperature and capable to treat organics and nutrients present in domestic wastewater at hot climates and low humidity condition.

Keywords: *aerobic granular sludge; hot climate; 40^{o}C; sequencing batch reactor; domestic wastewater treatment.*

1.0 Introduction

Biological treatment is an important and integral part of any wastewater treatment plant that treats wastewater from either municipality or industry having soluble organic impurities or a mix of the two types of wastewater sources. Activated sludge is one of the method of biological treatment had been practiced for well over a century. In hot climate and low humidity condition such as in the Middle East countries e.g. Saudi Arabia had faced water availability challenges as the location within arid and semi-arid areas, which fresh water resources are limited (Aljassim, 2013; Mizyed, 2013). Moreover, wastewater treatment system in Saudi Arabia is still at early stages (Aljassim, 2013; Rabah, 2013), which conventional activated sludge system, that also had been used by other countries. Therefore, improvement and effective technology in treated wastewater in Saudi Arabia is needed as the water resources are limited.

Aerobic granulation sludge technology is a new and promising environmental biotechnological process that increasingly interest of researchers engaging in work in the area of biological wastewater treatment (de Kreuk *et al*., 2005; Kong *et al*., 2013). Aerobic granulation is a process of microbial self-immobilization without the support of a carrier to form a multicellular association and compact structure (Cui *et al*., 2014). There are millions of microorganisms per gram of biomass, which play different roles in removing biodegradable organic matter from municipal and industrial wastewater (Song *et al*., 2009). As reported by previous researchers, compared to conventional aerobic wastewater treatment systems, the aerobic granulation sludge system has several advantages, such as compact physical structure, dense, high settling ability of the granules (Abdullah *et al*., 2011; Othman *et al*., 2013; Rosman *et al*., 2013), high biomass retention for solid-effluent separation, greater ability to withstand shock loadings as well as able to reduce space demand (Khan *et al*., 2013; Zhu *et al*., 2013). Aerobic granulation would be applicable for improving treatment efficiency, renovating existing processes and thus reducing construction and running cost (Song *et al*., 2009), which will be more applicable in the future of wastewater treatment.

Currently, many researchers have been performed widely in order to investigate the important factors of aerobic granular sludge formation. In term of temperature influence, most of the researches were done at low e.g. 8 - 20ºC (de Kreuk *et al*., 2005) and ambient temperature e.g.

20 - 25ºC (de Kreuk and van Loosdrecht, 2004). However, there is still lacking of information about the formation of granules at high temperature. As reported by previous researches, the highest temperature had been done to develop granular sludge is at temperature as high as 55ºC,(Zitomer *et al*., 2007). While others researches are at 27-30ºC (Song *et al*., 2009; Ebrahimi *et al*., 2010; Muda *et al*., 2010; Abdullah *et al*., 2011; Bassin *et al*., 2012; Nor-Anuar *et al*., 2012; Rosman *et al*., 2013; Othman *et al*., 2013) and 35ºC (Song *et al*., 2009; Ebrahimi *et al*., 2010; Cui *et al*., 2014). As reported by Song et al. (2009), the optimum temperature for mature aerobic granules cultivation is 30ºC, where the granules had excellent settleability, more compact structure and higher bioactivity as compared to others temperatures, which 25ºC and 35ºC. While the percentage removal of COD and TP respectively 97% and 75%.

The aims of this study was to investigate the possibility of developing aerobic granular sludge at temperature 40ºC by using synthetic wastewater and activated sludge taken from Madinah municipal wastewater in SBR system and removal efficiency of organic matter and nutrients as the reactor performance in treating wastewater. Moreover, characteristics of aerobic granular sludge were also investigated in this study. This study expected to contribute further understanding of the mechanism of aerobic granulation at high temperature.

2.0 Materials and Methods

2.1 Bioreactor set-up

The schematic diagram of bioreactor set-up is shown in Figure 1. A bioreactor column was designed for a working volume of 1800 mL in SBR mode with internal diameter of 5 cm and total height of 35 cm. The bioreactor was operated continuously 3 hours per cycle, including 5 min of influent filling, 140 min of aeration, 15 to 30 min of settling, 5 min of effluent discharge and 2 min of idle. A programmable logic controller (PLC) had been used to control influent, effluent and aeration pumps by setting time at each phase. The influent filling was entered through ports located at the bottom and air was introduced through the bottom by a fine bubble aerator. The effluent discharge through an outlet port located at the middle of the bioreactor height which had a volumetric exchange ratio of 50%. The bioreactor was operated at temperature of (40 ± 1) ºC and at dissolve oxygen level 2 to 5 mg/L while the pH was observed to vary in the range of 6 to 8.

Figure 1: Schematic Layout of the SBR system

2.2 Synthetic wastewater compositions

According to previous study by Nor-Anuar et al. (2008), the aerobic granular sludge was successful developed in synthetic wastewater instead of using real wastewater. The composition of synthetic wastewater had been prepared as referred to Nor-Anuar et al. (2008) and de Kreuk et al. (2005) which consists of two medias, namely medium A and medium B. The compositions medium A are 65.1 mM NaAc, 3.7 mM $MgSO_4.7H_2O$ and 4.8 mM KCl, while medium B are 35.2 mM NH_4Cl, 2.2 mM K_2HPO_4, 4.4 mM KH_2PO_4 and 10 mL of trace elements solution according to Vishniac and Santer (1975).

2.3 Seed sludge

An activated sludge taken from an aeration tank of Madinah Municipal Wastewater Treatment Plant was used as seed sludge. Before adding into bioreactor, the sludge was sieved to remove large debris and inert impurities. The amount of seed sludge had been used was about 900 mL, with a mixed liquor suspended solid (MLSS) concentration 3.7 g/L and mixed liquor volatile suspended solid (MLVSS) concentration 7.1 g/L.

2.4 Analytical methods

Measurements of the parameters such as chemical oxygen demand (COD), total phosphate (TP), ammonia nitrogen (NH_3-N), MLSS, MLVSS and settling velocity were tested according to the method stated in Standard Methods for the Examination of Water and Wastewater. The pH and DO were continuously monitored by using pH/DO meter (Orion 4-Star Benchtop pH/DO Meter).

The morphological and structural observations of the granules were carried out by using a stereo microscope equipped with digital image processing and analyzer (PAX-ITv6, ARC PAX-CAM).

3.0 Result and Discussion

3.1 Formation of granules

Aerobic granules development was observed by using stereomicroscope and the initial seed sludge was seen in the form of fluffy flocs, loose and irregular structure. Microscopic observation shows the shape of the mature granules was close to spherical which was obviously different from the seed sludge and activated sludge floc as well. After 2 weeks, the sludge floc gradually disappeared and was replaced by granules with average diameter of 1.03 mm. In contrast, the granules were larger and irregular formed by self aggregation of bacteria with settling velocity 25.02 m/h. subsequently, the small granules change to more regular shape and slowly increased in size in the next following days. After 30 days of operation, a large amount of granules that close to spherical shape structure was appeared in the bioreactor. The mature granular sludge had a compact structure with good settling ability, which settling velocity about 31.27 m/h. The developed granules at 15 and 30 days are shown in Figure 2.

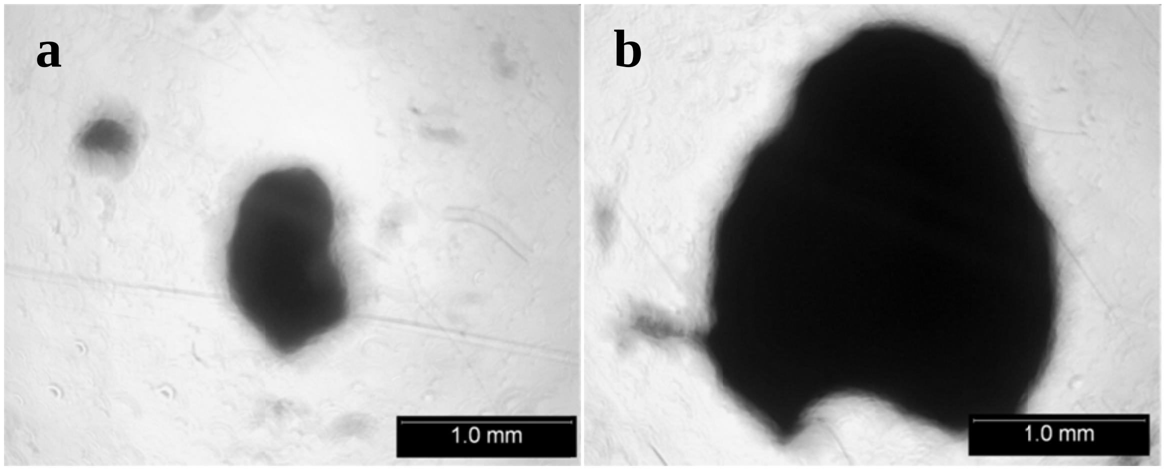


Figure 2: SEM images of granules (a) after 15 days and (b) after 30 days.

3.2 Biomass profile and settling characteristics of granules

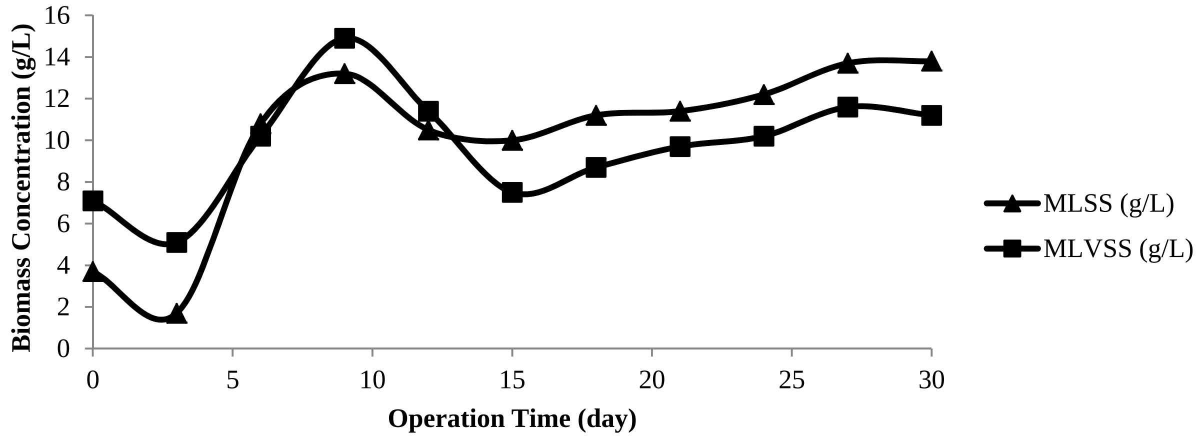
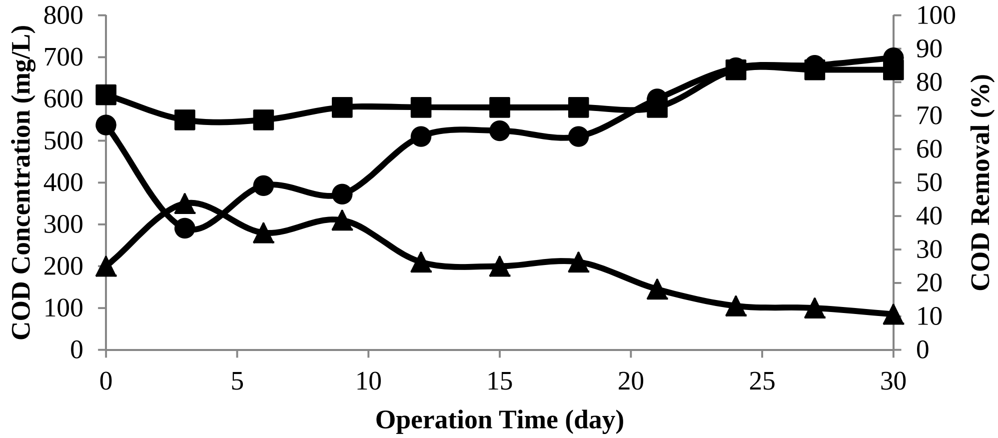


Figure 3: Profiles of biomass concentrations for 30 days of experiment.

Figure 3 represents the profile of biomass concentration in the SBR system from the start-up until the end of the study. At the beginning of experiment, the reactor experienced a large amount of seed sludge wash out from the bioreactor due to poor settling properties, which causing a rapid decrease in the biomass concentration. During the start-up, the MLSS reduced from 3.7 g/L to 1.7 g/L mainly due to short settling time applied in the system. On the 9^{th} day, the MLSS reduced from 13.2 g/L to 10.5 g/L apparently due to transition from flocculating sludge to granular form. When aerobic granular sludge had appeared in the bioreactor on day 15, the concentration of MLSS had improved which about 13.8 g/L on the day 30. It is similarity on the trend of MLVSS concentration which about 7.1 g/L on the beginning stage and 11.2 g/L on the day 30. The MLVSS and MLSS ratio is about 0.81 and a stable condition of biomass concentration shows a good accumulation of biomass in the bioreactor.

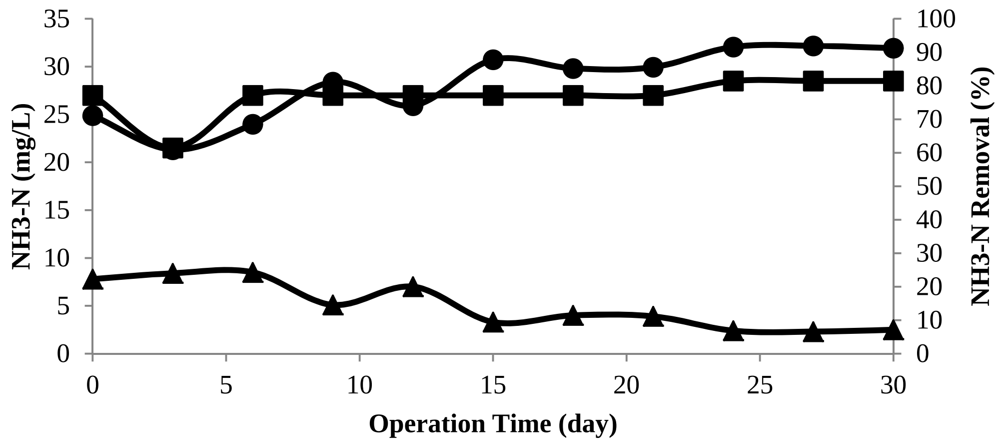
3.3 Removal efficiencies of granules

(a)



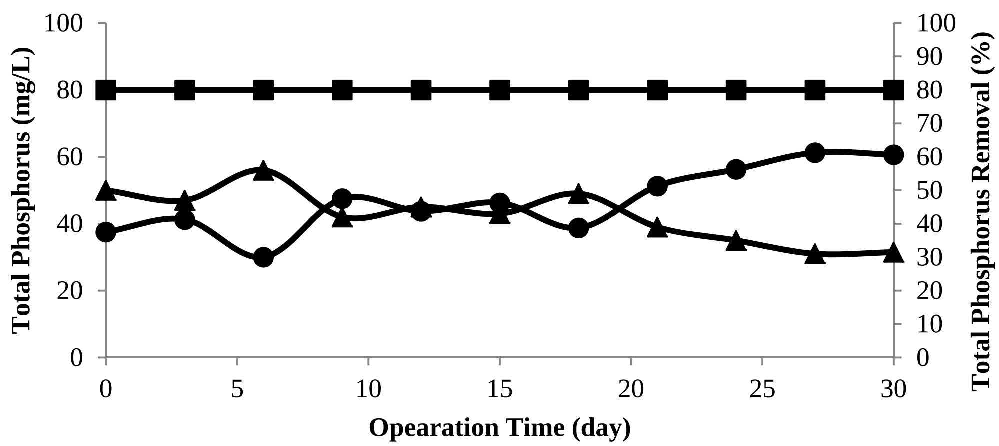
COD Concentration (mg/L)
COD Removal (%)
Operation Time (day)

(b)



NH3-N (mg/L)
NH3-N Removal (%)
Operation Time (day)

(c)



Total Phosphorus (mg/L)
Total Phosphorus Removal (%)
Opearation Time (day)

Figure 4: Profiles of removal performances in the SBR system within 30 days for (a) COD, (b) NH_3-N and (c) TP. (■) Influent concentration; (▲) Effluent concentration; (●) Percentage removal.

The COD, NH3-N and TP contents of effluent were regularly monitored during the 30 day of development. The performance of the reactor system from beginning until day 30 is given in Figure 4. At the initial stage of operation, the percentage removal for COD was 67.21% and decreased to 36.36% mainly due to the adapting process of the sludge with synthetic wastewater. The removal efficiency of COD was fluctuating and unsatisfactory as the percentage removal of COD was about 60% to 65%. After day 15, the percentage removal of COD was increased since the aerobic granules appeared in the bioreactor with average diameter size of 1.03 mm. the degradation ability for removal efficiency of COD had improved up to 87.31%.

At the beginning of bioreactor start-up, the percentage removal of ammonia nitrogen was 71.11% and decreased to 60.93%. The percentage removal of ammonia nitrogen was fluctuated until day 15 and remained stable after day 15 as well as the percentage increased when the formation of granules appeared. The contents of ammonia nitrogen in the effluent shows a significant better quality as the concentration maintained below 10 mg/L that indicated a good ammonia nitrogen removal efficiency, which above 90%.

During the initial stage, the percentage removal of TP was 37.50% and then became fluctuated until the formation of aerobic granules was appeared. The percentage removal is increased steadily up to 61.25%. However, in order to reach steady state and become stable with removal efficiency above 80%, aerobic granular sludge needed a longer period of time as many researchers required more than 30 days (Song Z. et al, 2009; Nor-Anuar A., 2008).

4.0 Conclusion

The development of aerobic granular sludge fed with synthetic wastewater at 40°C was successfully developed after 30 days operation in an SBR system. The mature granules were observed in the bioreactor with a good settling ability and an average diameter size of 2.42 mm. The removal efficiencies results showed that aerobic granules capable to remove organic matter and nutrients, which COD, ammonia nitrogen and TP with percentage removal of 87.31%, 91.93% and 61.25%. Thus, aerobic granular sludge can be developed at high temperature, which 40°C and capable to treat domestic wastewater at hot climate and low humidity condition such as in Middle East countries (e.g. Saudi Arabia).

References

Journal:

Abdullah, N., Ujang, Z. and Yahya, A. (2011). Aerobic granular sludge formation for high strength agro-based wastewater treatment. *Bioresource Technology*. 102, 6778-6781.

Bassin, J.P., Kleerebezem, R., Dezotti, M. and van Loosdrecht, M.C.M. (2012). Simultaneous nitrogen and phosphate removal in aerobic granular sludge reactors operated at different temperatures. *Water Research*. 46, 3805-3816.

Cui, F., Park, S. and Kim, M. (2014). Characteristics of aerobic granulation at mesophilic temperatures in wastewater treatment. *Bioresource Technology*. 151, 78-74.

de Kreuk, M.K. and van Loosdrecht, M.C.M. (2004). Selection of slow growing organisms as a means for improving aerobic granular sludge stability. *Water Science and Technology*. 49 (11-12), 9-17.

de Kreuk, M.K., Heijnen, J.J. and van Loosdrecht, M.C.M. (2005) Simultaneous COD, Nitrogen and Phosphate Removal by Aerobic Granular Sludge. *Biotechnology and Bioengineering*. 90 (6), 761-769.

Ebrahimi, S., Gabus, S., Rohrbach-Brandt, E., Hosseini, M., Rossi, P., Maillard, J. and Holliger, C. (2010). Performance and microbial community composition dynamics of aerobic granular sludge from sequencing batch bubble column reactors operated at 20 °C, 30 °C, and 35 °C. *Environmental Biotechnology*. 87, 1555-1568.

Khan, M.Z., Mondal, P.K. and Sabir, S. (2013). Aerobic Granulation for Wastewater Bioremediation: A Review. *The Canadian Journal of Chemical Engineering*. 91, 1045-1058.

Kong, Q., Zhang, J., Ngo, H.H., Ni, S., Fu, R., Guo, W., Guo, N. and Tian, L. (2013). Nitrous oxide emission in an aerobic granulation sequencing batch airlift reactor at ambient temperatures. *International Biodeterioration & Biodegradation*. 85, 533-538.

Mizyed, N.R. (2013). Challenges to treated wastewater reuse in arid and semi-arid areas. *Environmental Science and Policy*. 25, 186-195.

Muda, K., Aris, A., Salim, M.R., Ibrahim, Z., Yahya, A., van Loosdrecht, M.C.M., Ahmad, A. and Nawahwi, M.Z. (2010). Development of granular sludge for textile wastewater treatment. *Water Research*. 44, 4341-4350.

Nor-Anuar, A., Ujang, Z., van Loosdrecht, M.C.M., de Kreuk, M.K. and Olsson, G.

(2012). Strength characteristics of aerobic granular sludge. *Water Science and Technology*. 309-316.

Othman, I., Nor-Anuar, A., Ujang, Z., Rosman, N.H., Harun, H. and Chelliapan, S. (2013). Livestock wastewater treatment using aerobic granular sludge. *Bioresource Technology*. 133, 630-634.

Rabah, F.K.J. (2013). Impact Assessment of Wastewater and Solid Waste Disposal in to Wadi Gaza on Groundwater, Soil, and Seawater. *International Journal of Emerging Technology and Advanced Engineering*. 3 (9), 71-81.

Rosman, N.H., Nor-Anuar, A., Othman, I., Harun, H., Sulong, M.Z., Elias, S.H., Hassan, M.A.H.M., Chelliapan, S. and Ujang, Z. (2013). Cultivation of aerobic granular sludge for rubber wastewater treatment. *Bioresource Technology*. 129, 620-623.

Song, Z., Ren, N., Zhang, K. and Tong, L. (2009). Influence of temperature on the characteristics of aerobic granulation in sequencing batch airlift reactors. *Journal of Environmental Sciences*. 21, 273-278.

Vishniac, W., and Santer, M. (1975). The Thiobacili. *Bacteriology Reision*. 21, 195-213.

Zhu, L., Yu, Y., Dai, X., Xu, X. and Qi, H. (2013). Optimization of selective sludge discharge mode for enhancing the stability of aerobic granular sludge process. *Chemical Engineering Journal*. 217, 442-446.

Zitomer, D. H., Duran, M., Albert, R. and Guven, E. (2007). Thermophilic Aerobic Granular Biomass for Enhanced Settleability. *Water Research*. 41, 819-825.

Thesis:

Aljassim, N.I. (2013). Antibiotic Resistant Bacteria and Their Associated Resistance

Genes in a Conventional Municipal Wastewater Treatment Plant. Master of Science, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.

Nor-Anuar, A. (2008). Development of Aerobic Granular Sludge Technology for Domestic Wastewater Treatment in Hot Climate. Doctor of Philosophy, Universiti Teknologi Malaysia, Skudai.