



Laporan Akhir Projek Penyelidikan Jangka Pendek

**An Innovative Technology Based On
Granular Biomass For Palm Oil Mill
Effluent (POME) Treatment Using
Sequencing Batch Reactor**

by

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Prof. Azlina Harun @ Kamaruddin

Prof. K. Sudesh Kumar

2012



A.	PARTICULARS OF RESEARCH / MAKLUMAT PENYELIDIKAN:
(i)	Title of Research: <i>Tajuk Penyelidikan:</i> An Innovative Technology Based On Granular Biomass For Palm Oil Mill Effluent (POME) Treatment Using Sequencing Batch Reactor
(ii)	Account Number: <i>Nombor Akaun:</i> 1001/PJKIMIA/814043
B.	PERSONAL PARTICULARS OF RESEARCHER / MAKLUMAT PENYELIDIK:
(i)	Name of Research Leader: <i>Nama Ketua Penyelidik:</i> Dr Vel Murugan Vadivelu
	Name of Co-Researcher <i>Nama Penyelidik Bersama:</i> Prof. Abdul Latif Ahmad Prof. Azlina Harun @ Kamaruddin Prof. K. Sudesh Kumar
(ii)	School/Institute/Centre/Unit : <i>Pusat Pengajian /Institut/Pusat/Unit :</i> School of Chemical Engineering
C.	Research Platform (Please tick (/) the appropriate box): <i>Pelantar Penyelidikan (Sila tanda (/) kotak berkenaan):</i> <input type="checkbox"/> A. Life Sciences <i>Sains Hayat</i> <input type="checkbox"/> B. Fundamental <i>Fundamental</i> <input checked="" type="checkbox"/> C. Engineering & Technology <i>Kejuruteraan & Teknologi</i> <input type="checkbox"/> D. Social Transformation <i>Transformasi Sosial</i> <input type="checkbox"/> E. Information & Communications Technology (ICT) <i>Teknologi Maklumat & Komunikasi</i> <input type="checkbox"/> F. Clinical Sciences <i>Sains Klinikal</i> <input type="checkbox"/> G. Biomedical & Health Sciences <i>Bioperubatan Sains Kesihatan</i>

G. COMPREHENSIVE TECHNICAL REPORT

Laporan Teknikal Lengkap

Applicants are required to prepare a comprehensive technical report explaining the project.

(This report must be attached separately)

Sila sediakan laporan teknikal lengkap yang menerangkan keseluruhan projek ini.

[Laporan ini mesti dikepilkan]

List the key words that reflectour research:

Senaraikan kata kunci yang mencerminkan penyelidikan anda:

English	Bahasa Malaysia
Aerobic granular biomass	Biojisim butiran aerobik
Sequencing batch reactor (SBR)	Reaktor berkelompok penjujukan
Palm oil mill effluent (POME)	Kumbahan kilang kelapa sawit

H.

a) Results/Benefits of this research

Hasil Penyelidikan

No. Bil:	Category/Number: Kategori/ Bilangan:	Promised	Achieved
1.	Research Publications (Specify target journals) <i>Penerbitan Penyelidikan</i> (Nyatakan sasaran jurnal)	3	4
2.	Human Capital Development		
	a. Ph. D Students	1	—
	b. Masters Students	7 1	2
	c. Undergraduates (Final Year Project)	—	2
	d. Research Officers	—	—
	e. Research Assisstants	—	1
	f. Other: Please specify	—	—
3.	Patents <i>Paten</i>	—	—
4.	Specific / Potential Applications <i>Spesifik/Potensi aplikasin</i>	—	—
5.	Networking & Linkages <i>Jaringan & Jalinan</i>	—	—
6.	Possible External Research Grants to be Acquired <i>Jangkaan Geran Penyelidikan Luar</i> <i>Diperoleh</i>	—	—

- Kindly provide copies/evidence for Category 1 to 6.

Research Publications

- Gobi K, Mashitah M D, Vadivelu V M. 2011. Adsorptive removal of Methylene Blue using novel adsorbent from palm oil mill effluent waste activated sludge: Equilibrium, thermodynamics and kinetic studies, Chem. Eng. J. 171(3), 1246-1252.
- Gobi K, Mashitah M D, Vadivelu V M. 2011. Development and utilization of aerobic granules for the palm oil mill (POM) wastewater treatment. Chem. Eng. J. 174(1), 213-220.
- Gobi K, Mashitah M D, Vadivelu V M. 2011. Utilizing waste activated sludge from a palm oil mill effluent treatment plant to remove methylene blue in continuous column studies. International Journal of Environmental Engineering (Accepted).
- Muttalib N.A.A., Kamaruddin A.H. and Vadivelu V. M. 2012. Adsorption of ammonium using waste activated sludge from palm oil mill effluent treatment plant. Int. J. Global Environmental Issues, Vol. 12, Nos. 2/3/, 256-268.

Masters Students

- Gobi Kanadasan, 2011, Development and utilization of aerobic granular biomass in palm oil mill effluent (POME) treatment. Universiti Sains Malaysia, 21st September 2011.
- Nor Azyati Abdul Muttalib, 2011, Adsorption of ammonium using waste activated sludge from palm oil mill effluent wastewater treatment plant. Universiti Sains Malaysia, viva 6th December 2011.

b) Equipment used for this research.

Peralatan yang telah digunakan dalam penyelidikan ini.

Items Perkara	Approved Equipment	Approved Requested Equipment	Location
Specialized Equipment Peralatan khusus	Peristaltic Pump pH Meter DO Meter	Respirometer	Enviromental Laboratory, School of Chemical Engineering, USM
	Overhead stirrer COD Analysis Unit		
Facility Kemudahan	© Division of Research & Innovation – Universiti Sains Malaysia – 2011331		
Infrastructure Infrastruktur			

I. BUDGET / BAJET

Total Approved Budget : RM 285,462.48
Total Additional Budget : -
Grand Total of Approved Budget : RM 285,462.48

Yearly Budget Distributed

Year 1 : RM 135,154.16
Year 2 : RM 79,654.16
Year 3 : RM 70,654.16

Additional Budget Approved

Year 1 : RM
Year 2 : RM
Year 3 : RM

Total Expenditure : RM 285,455.27
Balance : RM 7.21

- Please attach final account statement from Treasury

Vel Murugan Vadivelu

Signature of Researcher
Tandatangan Penyelidik

DR. VEL MURUGAN VADIVELU

Lecturer

School of Chemical Engineering

Engineering Campus

Universiti Sains Malaysia, 14300 Nibong Tebal,
Pulau Pinang.

16/10/2012

Date
Tarikh

H.

COMMENTS OF PTJ'S RESEARCH COMMITTEE
KOMEN JAWATANKUASA PENYELIDIKAN PERINGKAT PTJ

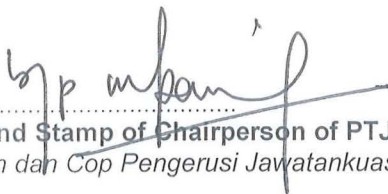
General Comments:

Ulasan Umum:

Projek telah berjaya ditamatkan.

Signature and Stamp of Chairperson of PTJ's Evaluation Committee

Tandatangan dan Cop Pengerusi Jawatankuasa Penilaian PTJ



Date :

Tarikh :

Signature and Stamp of Dean/ Director of PTJ

Tandatangan dan Cop Dekan/ Pengarah PTJ

Date :

Tarikh :

PROFESOR AZLINA HARUN @KAMARUDDIN

Dekan
Pusat Pengajian Kejuruteraan Kimia
Kampus Kejuruteraan
Universiti Sains Malaysia, Seri Ampangan
14300 Nibong Tebal, Seberang Perai Selatan
Pulau Pinang.

Purchase Requisition ▶ Purchase Order ▶ Suppliers ▶ Maintenance ▶ Financials ▶ Coda Info ▶ Reports ▶ Admin ▶

UserCode: SHARIDA / USMKTLIVE / PJKIMIA

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Switch Language : English / Malay

Wildcard : eg. Like 100%, Like 10%1, Like %1

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Element 2: %

Element 4: PJKIMIA

Element 5: 814043

Year: 2012

Detail	Excel	Budget Rule	Budget Control	Account Description	Budget Account Code	Roll over	Budget	Cash Received	Advanced	Commit	Actual	Available	Percentage
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Technical Report

Title : An Innovative Technology Based on Granular Biomass for Oil Palm Mill Effluent (POME) Treatment Using Sequencing Batch Reactor

Objektif (*Objectives*)

The primary aim of this research is to develop a biological wastewater treatment process for palm oil mill effluent (POME) using granular sludge in sequencing batch reactor. The specific aims are:

- To design and fabricate lab scale sequencing batch reactor for the treatment of POME using granulation technology.
- To develop granular sludge (microbial granules) in lab scale sequencing batch reactor to treat POME.
- To study the influence of POME composition (such as fats, grease, suspended solids) on the morphology of microbial granules.
- To study the impact of the operational parameters (loading rate, settling time, hydraulic retention time, dissolved oxygen concentration, pH) on the feasibility of using granular sludge in treatment of POME.
- To develop and evaluate process designs and operations to achieve higher treatment capacity using granular sludge.

Latar Belakang (*Background*)

(i) Tinjauan Literature/ *Literature Review*

Palm oil producing countries such as Malaysia, Nigeria and Indonesia are facing environmental problems caused by the palm oil mill (POM) wastewater. The principal problems associated with the POME are the high content of Chemical Oxygen Demand (COD) and high turbidity level [1]. The high level of COD and turbidity have equally endangered the aquatic livings and limited the source of clean water [1, 2]. Hence, the need for efficient treatment of POME is critically warranted.

Currently, it has been reported that, 85% of the POME treatment plant is using biological treatment [3]. Though the operating cost of the biological treatment system is cheaper compared

to the other available methods, the treatment efficiency of it is highly open to discussion. Large occupational of land area and varying treatment efficiency of biological treatment system has paved way for other treatment methods to be utilized in POME treatment. In the past decade, upgraded biological treatment system or alternative technologies such as the upflow anaerobic sludge blanket (UASB), upflow anaerobic filtration (UAF) and membrane technology have been successfully used to treat the POME at lab scale [4-6]. However, UASB still facing problems in terms of non-operational at the high organic loading rate due to the presence of suspended solids in the POME [7]. Meanwhile, the up scaling of UAF and membrane technology to industrial level is not feasible due to the high operational and maintenance cost.

Another major drawback of the conventional biological treatment system is the poor separation between biomass and the treated effluent [8]. In order to solve the presence of sludge in the effluent, a better separation between effluent and the sludge is needed. One of the possible ways to overcome this problem is by transforming activated sludge into aerobic granule. Aerobic granule is the aggregation of microorganism into compact and spherical shape with clear boundaries under the influence of air [9]. Earlier, aerobic granule has been successfully developed and used in wastewater treated in SBR [9-11]). The aerobic granule possesses excellent settling ability, subsequently achieving better separation between effluent and biomass [12]. In addition, the aerobic granule is able to withstand shock loadings, survive in toxic conditions and robust [13]. Till date, no investigation has been attempted on developing aerobic granule in POME.

Methodology

Sequencing Batch Reactor (SBR)

A highly enriched mixed culture will be established in sequencing batch reactor (SBR) (Figure 1). Commonly, SBR system has five steps, which are carried out in sequence as follows (i) fill, (ii) react, (iii) settle (sedimentation/clarification), (iv) draw (decant) and (v) idle. Biological reactions are initiated as the raw wastewater fills the tank. During the fill and react phase, the waste is aerated and mixed. After the react phase, the mixed liquor suspended solids are allowed to settle. The treated supernatant is discharged during the draw phase. The idle stage, the time between the draw and fill depends on wastewater flow demand (may be zero or a few days).

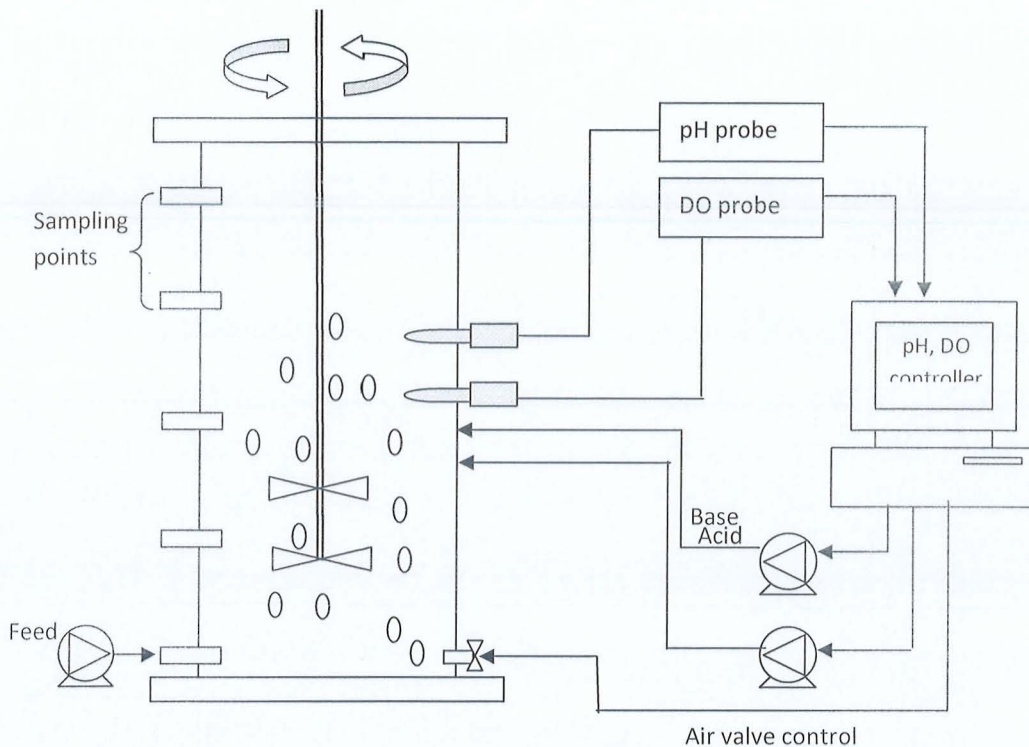


Figure 1 Schematic of sequencing batch reactor (SBR) unit for establishment of biomass.

Development of aerobic granular biomass in SBR

The biological treatment of POME was carried out in a SBR with 8 L working volume and 25% exchange ratio at room temperature ($30 \pm 3^\circ\text{C}$). The aeration diffuser and the feeding port are located at the bottom of the SBR. The compressed air flows at 5 l/min to provide the aeration in the SBR. The SBR was connected to the computer system, in which software is used to control the operation of this reactor.

POME was the sole feed for the SBR. SBR was operated in a 6 hours cycle with 4 phases, namely, filling, aeration, settling and decanting periods which are set at 10 minutes, 340 minutes, 0.5 minute and 9.5 minutes, respectively. The pH and temperature of the SBR are monitored throughout the experiment. The activated sludge collected from the facultative pond of the biological treatment plant at Tali Ayer Palm Oil Mill, Bagan Serai, Perak was used as the seed sludge.

COD and mixed liquor suspended solid (MLSS) were analysed according to the standard methods (APHA, 1998). The granule morphology was qualitatively observed using trinocular

stereozoom microscope (Olympus SZX9). Meanwhile, the turbidity of POME was analyzed using the turbidity meter.

Results and Discussion

Development of aerobic granules

Figure 2 depicts the morphological transformation of the seed sludge from the first day to 140th day of SBR operation. These images are captured using trinocular stereozoom microscope (Olympus SZX9). After 70 days of operation, the activated sludge started to aggregate (floccular biomass) but granules were not observed yet (Figure 2b). After 110 days, the transformation from floccular biomass into aerobic granules was visible, with granules size in the range of 0.3-0.5 mm dominating the reactor. The morphology of these initial granules was round but fluffy with filament growth observed on the edges (Figure 2c). By 140th day, regular, non-fluffy and round shape granules dominated in the SBR (Figure 2d). In earlier research, alteration to the exchange ratio and pH of wastewater has been done in order to achieve round and non-fluffy aerobic granules [14]. These alterations were done to increase the selectiveness towards denser aerobic granules instead of fungi dominating aerobic granules (filamentous growth). However, in this work, no alternation in any parameters was done to achieve regular and non-fluffy granules. The average diameter of these granules on 140th day was 0.9 mm and the largest diameter of the aerobic granules were 3.1 mm. Comparing the size of the granules with the earlier works on real wastewater [9, 11], the diameter of aerobic granules developed in this work using POME are much larger for the similar time frame. This could be due to the usage of pilot plant scale reactor in the previous works, where it took longer period for the steady state operation to be established in the reactor before the aerobic granules' diameter started to increase.

The transformation of floccular sludge into aerobic granules is believed to be related to the aeration rate applied [15, 16]. High aeration rate controls the oxygen transfer which enhances the aerobic granulation [16]. As suggested by Liu et al., [17], the hydrodynamic shear force provided by the aeration is believed to stimulate the secretion of EPS. The role of EPS in the formation of aerobic granules has been widely discussed in the previous works [18-20]. EPS has been reported to possess the ability to increase the hydrophobicity and alter the surface charges on the microorganisms [18]. It is generally accepted that the hydrophobicity and surface charges

are imperative in microbial cell adhesion and granulation. Hence, in this work also, the EPS is believed to have played its role in the formation of aerobic granules.

In conjunction with the hydrodynamic shear force, the settling time also played a major role in the formation of the aerobic granules [21]. Hence, in order to promote granulation, the settling time was set at 5 minutes during the initial days of the SBR operation and gradually reduced to 0.5 minutes within a period of 70 days to select the fast settling biomass. After 70th day, the settling time was kept constant throughout the rest of the SBR operation period. The short settling time adapted in this work has favored the denser particle to remain in the reactor. It has been extensively reported that the short settling time makes the fluffy particles removed from the reactor [22, 23]. The denser particles remained in the reactor eventually transformed into aerobic granules.

Although the granulation time (110 days) in this study was much longer than previous studies performed with synthetic wastewater [10, 24], it is comparable with the studies conducted with real industrial and even domestic wastewaters. Schwarzenbeck et al., [25] needed 147 days to obtain a fully granular system when treating malting wastewater and Ni et al., [11] required almost 300 days to develop an aerobic granular system with domestic wastewater. One of the principal reasons of earlier appearance of aerobic granules in this study could be the height to diameter (H/D) ratio of the SBR. Significant contribution of the higher H/D ratio towards the formation of aerobic granules has been reported and emphasized on many literature works [17, 26]. The H/D ratio affects the hydrodynamic, mass transfer behavior of the reactor and subsequently it influences the metabolic behavior of the microorganisms [26]. In this work, the H/D ratio used is 6.67, whereas, Schwarzenbeck et al., [25] used H/D ratio of 5.35 only, which may explain the shorter duration needed for the aerobic granules appearance in this work.

Another highlight of this study is the pH of the influent was not adjusted to the neutral range as the previous works [10, 25]. The raw POME has pH around 4.5. Generally, if real industrial wastewater has been used to develop the granules, the initial pH is adjusted with chemicals if the raw wastewater is in the acidic or alkaline region. Addition of chemicals to alter the pH will lead to operational cost increase as well as making the waste sludge harmful to be disposed. However, till date, no or limited works (if any) have been reported on the development of aerobic granules in the acidic wastewater without any alteration of the pH. Nevertheless, the mechanism behind the faster appearance of the aerobic granules in this work compared to those

with altered pH remains unidentified. Further works could be dedicated towards finding the reason for the faster appearance of the aerobic granules in this work.

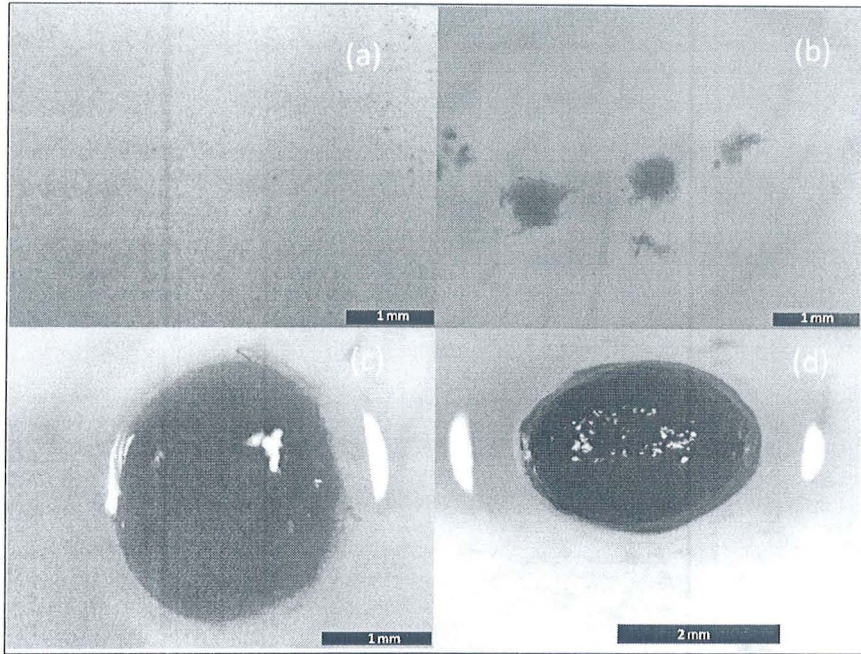


Figure 2 External morphology of the sludge present in the SBR: (a) 1st day, (b) 70th day, (c) 110th day and (d) 140th day.

Performance of aerobic granules for POME treatment

Figure 3 shows the percentage of COD removal, influent COD and effluent COD concentrations. During initial stages of SBR operation, fluctuation on the COD removal percentage was observed. However, the COD removal percentage remained above 88%. It can be inferred that the biomass in the SBR was able to oxidize the carbon source provided by the POME. The COD removal is closely related to the amount of biomass in the SBR. Referring to Figure 4, the MLSS (biomass) concentration in the SBR was reduced substantially from 3600 mg/l to 2500 mg/l before granulation. Albeit the decrease in the biomass concentration, it did not affect the removal of COD. The reduction in MLSS could be attributed by the changes in the settling time applied on SBR. As the settling time gradually reduced over 70 days, the slow settling biomass was removed from the reactor and as a result, only the fast settling and denser biomass remained in the reactor.

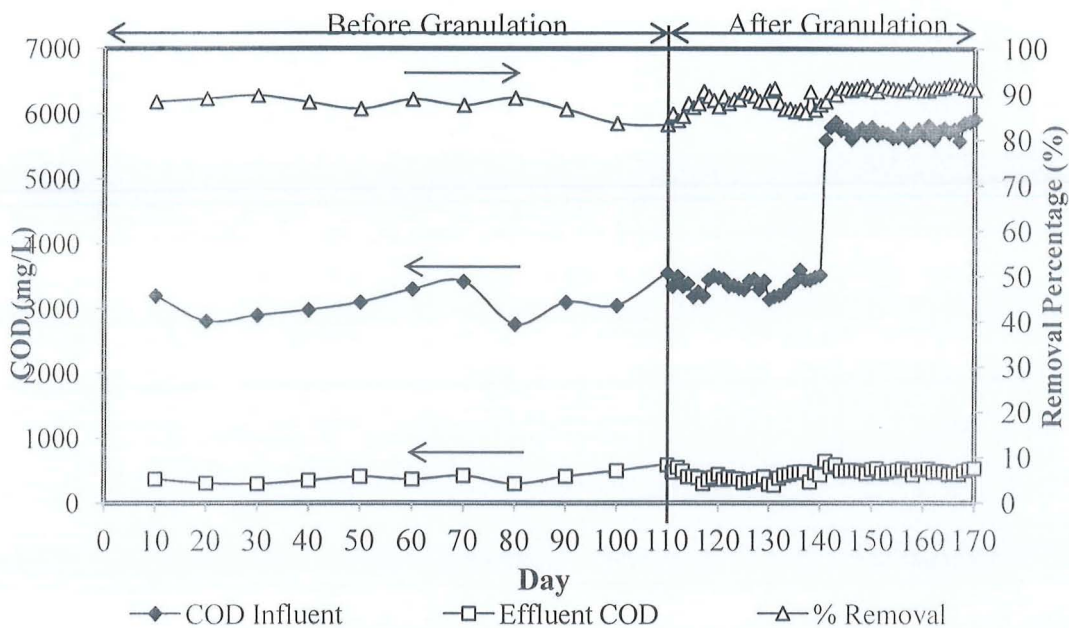


Figure 3 COD in influent and effluent, and percentage of COD removal

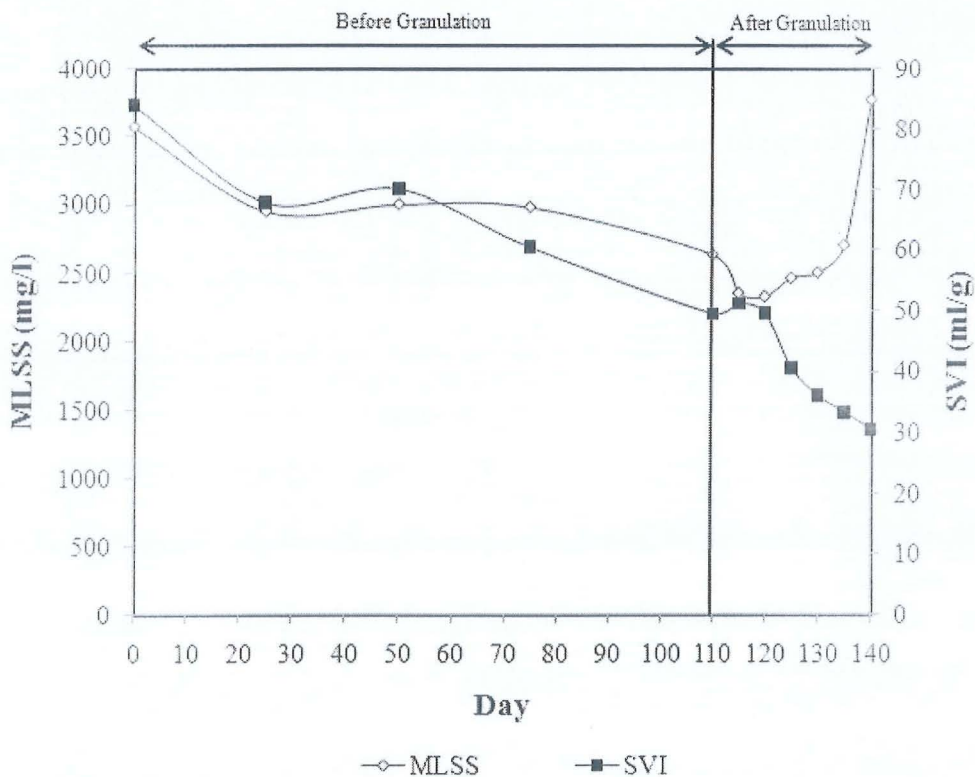


Figure 4 MLSS and SVI of the reactor

After aerobic granules were formed, the morphology of the biomass and performance of the SBR was monitored for a period of 1 month. The COD, MLSS and SVI measurements were carried out regularly to analyze the feasibility of using aerobic granules in treating POME. OLR of about 3.0 kg COD/day.m³ (same as in the before granulation period) was maintained throughout this period.

The percentage of COD removal after granulation in the SBR and COD content of the effluent are shown in Figure 3. It can be deduced that the highest percentage of COD removal recorded after aerobic granules formed was 93%. It should be noted that the MLSS concentration decreased after the formation of aerobic granules. However, the ability of aerobic granules to oxidize COD was not affected. The average COD removal remained stable at about 88% even after the decrease in MLSS concentration.

The MLSS concentration in the reactor after granulation is shown in Figure 4. It can be observed that the average MLSS value decreased slightly, after the formation of aerobic granules. This phenomenon could be due to the filamentous growth around the aerobic granules during the initial period of aerobic granules development. These filamentous aerobic granules affected the settling ability of the granules and subsequently some of them were removed from the SBR. After 120th day, the MLSS started to increase gradually. This is due to the newly developing aerobic granules in the SBR while the earlier formed aerobic granules were getting bigger. At the same time, the filamentous growth around the aerobic granules disappeared gradually after 120th day. It can be inferred that the aerobic granules started to become compact and denser without being fluffy after 120th day.

Figure 4 shows the plot of SVI against time. In the initial days after the formation of the aerobic granules, the SVI slightly increased due to the poor settling characteristics of the granules. However, after 120th day till 140th day, the SVI value decreased notably from 50 to 30 ml/g. This SVI value of aerobic granules is much smaller compared to the conventional activated sludge used in the work done by Chan et al., [27], where they treated the POME using the SBR. As the aerobic granules have good settling characteristic compared to conventional activated sludge, it results in shorter settling time. Thus, good separation of biomass from the treated effluent was observed.

Effect of organic loading rate

In order to study the effect of organic loading rate (OLR) on the aerobic granules and its performance, the OLR of the reactor was increased from 3.0 to 6.0 kg COD/m³.day. The SBR was operated for 30 days (from 140th to 170th day) with the new OLR. As a result of this increase, the mean diameter of the aerobic granules increased substantially. The largest diameter of the aerobic granules was increased from 3.1 mm (OLR 3.0 kg COD/m³.day) to around 4 mm (OLR 6.0 kg COD/m³.day). This phenomenon is closely related to the increase of hydrophobicity of the microorganism. As the OLR of the SBR increased, the hydrophobicity of the microorganism increased simultaneously. Similar observation was made by Thanh et al., [28]. As a result of hydrophobicity increase at higher OLR, the aerobic granules became larger due to the attachment of cells on the existing aerobic granules in the reactor [29]. Besides cell hydrophobicity, the larger amount of EPS with increased OLR also could be the contributing factor for the growth of aerobic granules [28]. Despite the increase in size, the microscopic observations demonstrated that the granules could still maintain their regular, non fluffy and round shape in the higher OLR. The biomass settling quality was improved and the average SVI value recorded was 21 ml/g with the new OLR. The recorded SVI value is in tandem with the morphology of the aerobic granules.

Meanwhile, the performance of the aerobic granules was not affected by the increase of OLR. The COD removal was about 90% even after OLR has been increased. Increase in OLR, could enhance the growth rate of the microorganism and thereby increase the concentration of aerobic granules in the SBR [27]. This phenomenon is believed to be the reason for the increase in removal efficiency. Further, Figure 3 clearly indicates that there is no lag phase required for the granules to acclimate to the new OLR. The biomass immediately responded to the OLR increment.

As a function of time, the diameter of the aerobic granules increased and upon reaching the maximum diameter, they disintegrated. The disintegration happens in a continuous cycle throughout the SBR operation. Disintegration of them is presumably caused by the endogenous respiration at the core of the aerobic granules [19]. The endogenous respiration at the core of the aerobic granules due to the limitation of the oxygen and substrate transfer has caused the microorganism to utilize the EPS and subsequently weakens the whole aerobic granules [19, 30].

References

- [1] A.L. Ahmad, S. Ismail, S. Bhatia, Water recycling from palm oil mill effluent (POME) using membrane technology, *Desalination*, 157 (2003) 87-95.
- [2] S. Bhatia, Z. Othman, A.L. Ahmad, Coagulation-flocculation process for POME treatment using *Moringa oleifera* seeds extract: Optimization studies, *Chemical Engineering Journal*, 133 (2007) 205-212.
- [3] K. Vijayaraghavan, D. Ahmad, M. Aziz, Aerobic treatment of palm oil mill effluent, *Journal of Environmental Management*, 82 (2007) 24-31.
- [4] A.L. Ahmad, M.F. Chong, S. Bhatia, S. Ismail, Drinking water reclamation from palm oil mill effluent (POME) using membrane technology, *Desalination*, 191 (2006) 35-44.
- [5] A.A.L. Zinatizadeh, A.R. Mohamed, A.Z. Abdullah, M.D. Mashitah, M.H. Isa, G.D. Najafpour, Process modeling and analysis of palm oil mill effluent treatment in an up-flow anaerobic sludge fixed film bioreactor using response surface methodology (RSM), *Water Research*, 40 (2006) 3193-3208.
- [6] R. Borja, C.J. Banks, Treatment of palm oil mill effluent by upflow anaerobic filtration, *Journal of Chemical Technology and Biotechnology*, 61 (1994) 103-109.
- [7] G.D. Najafpour, A.A.L. Zinatizadeh, A.R. Mohamed, M. Hasnain Isa, H. Nasrollahzadeh, High-rate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge-fixed film bioreactor, *Process Biochemistry*, 41 (2006) 370-379.
- [8] Q.S. Liu, J.H. Tay, Y. Liu, Substrate concentration-independent aerobic granulation in sequential aerobic sludge blanket reactor, *Environmental Technology*, 24 (2003) 1235-1242.
- [9] Y.Q. Liu, B. Moy, Y.H. Kong, J.H. Tay, Formation, physical characteristics and microbial community structure of aerobic granules in a pilot-scale sequencing batch reactor for real wastewater treatment, *Enzyme and Microbial Technology*, 46 (2010) 520-525.
- [10] K. Muda, A. Aris, M.R. Salim, Z. Ibrahim, A. Yahya, M.C.M. van Loosdrecht, A. Ahmad, Z. Nawahwi, Development of granular sludge for textile wastewater treatment, *Water Research*, 44 (2010) 4341-4350.
- [11] B.J. Ni, W.M. Xie, S.G. Liu, H.Q. Yu, Y.Z. Wang, G. Wang, X.L. Dai, Granulation of activated sludge in a pilot-scale sequencing batch reactor for the treatment of low-strength municipal wastewater, *Water Research*, 43 (2009) 751-761.
- [12] B. Arrojo, A. Mosquera-Corral, J.M. Garrido, R. Mendez, Aerobic granulation with industrial wastewater in sequencing batch reactors, *Water Research*, 38 (2004) 3389-3399.
- [13] M. Pijuan, U. Werner, Z. Yuan, Effect of long term anaerobic and intermittent anaerobic/aerobic starvation on aerobic granules, *Water Research*, 43 (2009) 3622-3632.
- [14] N. Schwarzenbeck, J.M. Borges, P.A. Wilderer, Treatment of dairy effluents in an aerobic granular sludge sequencing batch reactor, *Applied Microbiology and Biotechnology*, 66 (2005) 711-718.
- [15] J.H. Tay, Q.S. Liu, Y. Liu, The effects of shear force on the formation, structure and metabolism of aerobic granules, *Applied Microbiology and Biotechnology*, 57 (2001) 227-233.

- [16] J.F. Wana, Y. Bessiere, M. Sperandio, Alternating anoxic feast/aerobic famine condition for improving granular sludge formation in sequencing batch airlift reactor at reduced aeration rate, *Water Research*, 43 (2009) 5097-5108.
- [17] Y. Liu, J.H. Tay, State of the art of biogranulation technology for wastewater treatment, *Biotechnology Advances*, 22 (2004) 533-563.
- [18] Z. Wang, L. Liu, J. Yao, W. Cai, Effects of extracellular polymeric substances on aerobic granulation in sequencing batch reactors, *Chemosphere*, 63 (2006) 1728-1735.
- [19] Z.W. Wang, Y. Liu, J.H. Tay, Biodegradability of extracellular polymeric substances produced by aerobic granules, *Applied Microbiology and Biotechnology*, 74 (2007) 462-466.
- [20] T. Seviour, M. Pijuan, T. Nicholson, J. Keller, Z.G. Yuan, Gel-forming exopolysaccharides explain basic differences between structures of aerobic sludge granules and floccular sludges, *Water Research*, 43 (2009) 4469-4478.
- [21] L. Qin, Y. Liu, J.H. Tay, Effect of settling time on aerobic granulation in sequencing batch reactor, *Biochemical Engineering Journal*, 21 (2004) 47-52.
- [22] S.S. Adav, D.J. Lee, J.Y. Lai, Aerobic granulation in sequencing batch reactors at different settling times, *Bioresource Technology*, 100 (2009) 5359-5361.
- [23] J.H. Tay, Q.S. Liu, Y. Liu, Aerobic granulation in sequential sludge blanket reactor, *Water Science and Technology*, 46 (2002) 13-18.
- [24] G.P. Sheng, A.J. Li, X.Y. Li, H.Q. Yu, Effects of seed sludge properties and selective biomass discharge on aerobic sludge granulation, *Chemical Engineering Journal*, 160 (2010) 108-114.
- [25] N. Schwarzenbeck, R. Erley, B.S. Mc Swain, P.A. Wilderer, R.L. Irvine, Treatment of malting wastewater in a granular sludge sequencing batch reactor (SBR), *Acta Hydrochimica Et Hydrobiologica*, 32 (2004) 16-24.
- [26] Y.H. Kong, Y.Q. Liu, J.H. Tay, F.S. Wong, J.R. Zhu, Aerobic granulation in sequencing batch reactors with different reactor height/diameter ratios, *Enzyme and Microbial Technology*, 45 (2009) 379-383.
- [27] Y.J. Chan, M.F. Chong, C.L. Law, Biological treatment of anaerobically digested palm oil mill effluent (POME) using a Lab-Scale Sequencing Batch Reactor (SBR), *Journal of Environmental Management*, 91 (2010) 1738-1746.
- [28] B.X. Thanh, C. Visvanathan, R. Ben Aim, Characterization of aerobic granular sludge at various organic loading rates, *Process Biochemistry*, 44 (2009) 242-245.
- [29] J.H. Tay, S. Pan, Y.X. He, S.T.L. Tay, Effect of organic loading rate on aerobic granulation. II: Characteristics of aerobic granules, *Journal of Environmental Engineering-Asce*, 130 (2004) 1102-1109.
- [30] X. Zhang, P.L. Bishop, Biodegradability of biofilm extracellular polymeric substances, *Chemosphere*, 50 (2003) 63-69.



Adsorptive removal of Methylene Blue using novel adsorbent from palm oil mill effluent waste activated sludge: Equilibrium, thermodynamics and kinetic studies

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ABSTRACT

Waste activated sludge (WAS) from palm oil mill effluent (POME) treatment plant was used to adsorb Methylene Blue (MB) in a batch system. The WAS was prepared at lower temperature compared to the previous studies. Parameters such as initial MB concentration, pH, and temperature were studied for their effects on the adsorption process. Results showed that the uptake of MB increased with an increase in both the initial MB concentration and the pH, and decreased with an increase in temperature. Both the Langmuir and the Freundlich Isotherms are fit to explain the MB adsorption on WAS. The maximum monolayer adsorption capacity of WAS was found to be 66.23 mg/g at 30 °C. The kinetic data for this study fit well the pseudo-second-order kinetic with a R^2 more than 0.95. Thermodynamic analysis was performed by evaluating the Gibbs Free Energy (ΔG°), enthalpy (ΔH°), and entropy (ΔS°) of the process. The evaluation showed that the MB adsorption process onto WAS is an exothermic process and is spontaneous in nature. Hence, this work reveals that the use of POME WAS is an innovative application of a local waste product as an adsorbent for MB removal.

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1. Introduction

Biological treatment is the preferred choice in the palm oil mill effluent (POME) treatment. Even though other methods are available to treat POME, such as membrane technology [1], coagulation–flocculation [2], and the evaporation method [3], biological treatments continue to provide the cheapest options with acceptable effectiveness. At present, 85% of all POME treatments are based on biological anaerobic digestion, followed by aerobic oxidation in ponds [4].

Despite its many advantages, however, the major drawback of a biological treatment system is the continuous generation of waste activated sludge (WAS). The excess production of WAS from biological wastewater treatment (BWT) plants poses a serious problem because the handling and disposal of such wastes often represent the largest operational cost to a business [5]. Usually, removed WAS is disposed in landfills or occasionally used as fertilizer [6].

Hence, researchers have explored the potential of WAS to be used as a color adsorbent in an attempt to increase its economical value [7–10]. The presence of various functional groups in sewage WAS aids the color adsorption process [11]. Some of the functional

groups that exist on WAS are –OH, –NH, –NH₂, –C=O, C=C, CH₃–, and CH₂– [12]. Previously, researchers only studied the WAS produced from municipal sewage treatment plants. To the best of our knowledge, no attempts have been made to convert WAS from POME treatment plants into color adsorbents.

Currently, activated carbon is used to remove the color components from wastewater via the adsorption process [13,14]. The high operating cost and high regeneration cost of such a process, as well as the high price of activated carbon, however, make it unsuitable in the large scale [15]. Alternatively, low-cost materials such as durian peel [16], rice husk [17], and fruit stones and nutshells [18] are used as color adsorbents, however, these materials were prepared via high thermal treatments (700–900 °C) to turn them into adsorbent. As a result, the treatment cost remains high though the raw material cost is reduced.

This work focuses primarily on converting POME WAS into an efficient color adsorbent via chemical activation. The chemical activation process lowers energy cost and shortens the time which indeed helpful in reducing the overall cost [19]. Methylene Blue (MB) (textile dye), one of several dyes that can cause harmful effects on living organisms, is used as an adsorbate in this study. The parameters affecting the adsorption process, such as the initial concentration of MB, pH, and temperature were investigated. In addition, the adsorption isotherm and kinetic models of the process were investigated, and a thermodynamic analysis was performed. This work could significantly contribute towards the body

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Development and utilization of aerobic granules for the palm oil mill (POM) wastewater treatment

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ABSTRACT

The high COD and turbidity level of palm oil mill (POM) wastewater has been the driving force to find an efficient treatment system. In this work, biological and adsorption methods are integrated and used to treat the POM wastewater. In biological treatment, aerobic granules are developed and used in the sequencing batch reactor (SBR), whereas in adsorption treatment, the waste aerobic granules (WAG) are utilized as adsorbent. Response Surface Methodology (RSM) has been used to model and optimize the adsorption of biologically treated POM wastewater. Aerobic granules took 110 days to appear and the average diameter was 0.9 mm (with a maximum value of 3.1 mm). The aerobic granules are able to remove 88% of the influent COD at organic loading rate (OLR) of 3.0 kg COD/m³ day. The increase of OLR to 6.0 kg COD/m³ day did not affect the COD removal efficiency and the aerobic granules immediately responded to the OLR increase. The adsorption system revealed that the 21% of the remaining COD (of the biologically treated POM wastewater) and almost 99% of the turbidity were removed. At optimum point (3.28 cm of bed height and 2.13 ml/min flow rate), the amount of COD and turbidity removed are 21% and 96%, respectively.

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1. Introduction

Palm oil producing countries such as Malaysia, Nigeria and Indonesia are facing environmental problems caused by the palm oil mill (POM) wastewater. The principal problems associated with the POM wastewater are the high content of Chemical Oxygen Demand (COD) and high turbidity level [1]. The high level of COD and turbidity have equally endangered the aquatic livings and limited the source of clean water [1,2]. Hence, the need for efficient treatment of POM wastewater is critically warranted.

Currently, it has been reported that, 85% of the POM wastewater treatment plant is using biological treatment [3]. Though the operating cost of the biological treatment system is cheaper compared to the other available methods, the treatment efficiency of it is highly open to discussion. Large occupational of land area and varying treatment efficiency of biological treatment system has paved way for other treatment methods to be utilized in POM wastewater treatment. In the past decade, upgraded biological treatment system or alternative technologies such as the upflow anaerobic sludge blanket (UASB), upflow anaerobic filtration (UAF) and membrane technology have been successfully used to treat the POM wastewater

at lab scale [4–6]. However, UASB still facing problems in terms of non-operational at the high organic loading rate due to the presence of high amount of suspended solids in the POM wastewater [7]. Meanwhile, the scaling up of UAF and membrane technology to industrial level is not feasible due to the high operational and maintenance cost.

Another major drawback of the conventional biological treatment system is the poor separation between biomass and the treated effluent [8]. In order to solve the presence of sludge in the effluent, a better separation between effluent and the sludge is needed. One of the possible ways to overcome this problem is by transforming activated sludge into aerobic granule. Aerobic granule is the aggregation of microorganism into compact and spherical shape with clear boundaries under the influence of air [9]. Earlier, aerobic granule has been successfully developed and used in wastewater treated in SBR [9–11]. The aerobic granule possesses excellent settling ability, subsequently achieving better separation between effluent and biomass [12]. In addition, the aerobic granule is able to withstand shock loadings, survive in toxic conditions and robust [13]. Till date, no investigation has been attempted on developing aerobic granule in POM wastewater.

Thus, an innovative way to overcome the shortcomings of the current treatment (biological treatment) or the alternative technologies is necessary. Integration of pre-treatment or post-treatment with individual treatment system could be a viable

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Adsorption of ammonium using waste activated sludge from palm oil mill effluent treatment plant

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Abstract: Low cost adsorbent was prepared using waste activated sludge (WAS) from a palm oil mill effluent (POME) treatment plant, and used to adsorb ammonium from aqueous solution. The effect of initial concentration, temperature, pH and adsorbent dose was studied in batch test to determine the kinetic and thermodynamic properties. The results showed that the uptake of ammonia increased with an increase in pH, initial concentration of ammonium and adsorbent dose but decrease with temperature. The adsorption of ammonium ion fitted both Langmuir and Freundlich isotherm. The highest monolayer saturation capacity of WAS was 37.07 mg/g at temperature 303oK. The $-\Delta H$ show the process is exothermic while the amount of free energy ($-\Delta G$) indicate the adsorption were spontaneous and thermodynamically favourable. For kinetic model, pseudo second-order more suitable and significant in rate-controlling step in adsorption kinetic.

Keywords: low cost adsorbent; waste activated sludge; WAS; ammonium; palm oil mill effluent; POME.

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