THE INFLUENCE OF TEMPERATURE AND TYPES OF FILTER MEDIA ON THE PALM OIL MILL EFFLUENT (POME) TREATMENT USING THE HYBRID UP-FLOW ANAEROBIC SLUDGE BLANKET (HUASB) REACTOR

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قُلْ إِنَّنِي هَدَانِي رَبِّي إِلَىٰ صِرَاطٍ مُسْتَقِيمٍ دِينًا قِيَمًا مِلَّةَ إِبْرَاهِيمَ حَنِيفًا ۚ وَمَا كَانَ مِنَ الْمُشْرِكِينَ (161) قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ (162) لَا شَرِيكَ لَهُ ۖ وَبِذَٰلِكَ أُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ (163) قُلْ أَغَيْرَ اللَّهِ أَبْغِي رَبًّا وَهُوَ رَبُّ كُلِّ شَيْءٍ ۚ وَلَا تَكْسِبُ كُلُّ نَفْسٍ إِلَّا عَلَيْهَا ۚ وَلَا تَزِرُ وَازِرَةٌ وِزْرَ أُخْرَىٰ ۚ ثُمَّ إِلَىٰ رَبِّكُمْ مَرْجِعُكُمْ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ فِيهِ تَخْتَلِفُونَ (164).

الانعام, اية 161–164

Say: "Verily, my Lord hath guided me to a way that is straight,- a religion of right,- the path (trod) by Abraham the true in Faith, and he (certainly) joined not gods with Allah." **((161)).** Say: "Truly, my prayer and my service of sacrifice, my life and my death, are (all) for Allah, the Cherisher of the Worlds: **((162)).** No partner hath He: this am I commanded, and I am the first of those who bow to His will **((163)).** Say: "Shall I seek for (my) Cherisher other than Allah, when He is the Cherisher of all things (that exist)? Every soul draws the meed of its acts on none but itself: no bearer of burdens can bear the burden of another. Your goal in the end is towards Allah. He will tell you the truth of the things wherein ye disputed." **((164)).**

***The Holy Quran,* chapter 6, verse 161-164.**

To my Beloved Parents ***Samaa*** *and* ***Abood***
in recognition and love
their sacrifices, patience and affection
are beyond description

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ABSTRACT

Anaerobic wastewater treatment has been introduced as a clean technology due to its efficient feasibility for the treatment of high strength wastewater. It is now implemented in many tropical countries especially in Malaysia. However, some operational parameters are still under research and required additional knowledge. This research was thus conducted using the hybrid up-flow anaerobic sludge blanket (HUASB) reactor packed with oil palm shell (OPS) as filter material, for the biological treatment of palm oil mill effluent (POME). This research aimed at investigating the effects of temperature, type of filter media and sludge bed development on the system treatment efficiency. Long term operation (233 days) was conducted using three reactors operated at several temperatures (26-61°C) and organic loading rates (from 1.87 to 14.06 kg COD. $m^{-3}.day^{-1}$), in order to assess the optimal treatment conditions. The feasibility of OPS was deeply investigated, where results showed favourable characteristics of OPS such as lightweight material (Specific gravity of 1.18), relatively high porous material (porosity of 26%), high specific surface area (0.205 $m^2.g^{-1}$), rough surface (according to the SEM examination) and very high organisms' adherence of 26 to 34%. The average removals of the parameters tested were: 80% COD, 65% total solids, 80% total suspended solids, 85% volatile suspended solids, 53% total nitrogen, 45% total phosphorus, 48% colour and 56% turbidity at specific conditions (temperature ranges 37-58°C packed with OPS material). The sludge bed development was also studied. According to the overall results obtained in this study, the operated system could reflect a feasible alternative system that can be successfully adapted by the palm oil plantations for cleaner environment and process.

ABSTRAK

Rawatan anaerobik air sisa telah diperkenalkan sebagai teknologi bersih disebabkan oleh feasibiliti kecekapan nya untuk merawat air sisa kekuatan tinggi. Buat masa sekarang ia dilaksanakan di negeri-negeri tropika terutamanya di Malaysia. Walau bagaimanapun, beberapa parameter operasi masih dalam penyelidikan dan perlu pengetahun tambahan. Dalam kajian ini dijalankan dengan menggunakan reactor hibrid tujah aliran blanket slug (HUASB) yang dimasukkan bersama dengan temporung kepala sawit (OPS) sebagai material penapis, untuk rawatan biologi efluen kilang minyak kelapa sawit (POME). Kajian ini bertujuan menyiasat kesan suhu, jenis media penapis dan membangunkan lapisan slug pada kekecapan rawatan sistem. Operasi jangka panjang (233 hari) telah dijalankan dengan menggunakan tiga reaktor yang beropersi pada beberapa suhu (26 – 61^{o}C) dan kadar beban organic (dari 1.87 hingga 14.06 kg COD.m^{-3}.hari), supaya dikaitkan dengan keadaan rawatan optima. Potensi OPS dikaji secara mendalam dimana keputusan menunjukan ciri-ciri yang menggalakkan terutama OPS sebagai bahan ringan (Graviti tentu 1.18), keliangan tinggi (keliangan 26%), keluasan permukaan tentu yang tinggi (301 m^{2}.m^{-3}), permukaan kasar (mengikut pemeriksaan SEM) dan kelekatan organisma yang tinggi 26 hingga 34%. Nilai purata penyingkiran parameter yang diuji iaitu COD: 80%, jumlah pepejal: 65%, jumlah pepejal terampai: 80%, pepejal terampai teruap: 85%, jumlah nitrogen: 53%, jumlah fosforus: 45%, warna: 48% dan kekeruhan pada keadaan tertentu (suhu antara 37-58°C dipenuhkan dengan bahan OPS): 56%. Pembentukan lapisan enapcemar juga dikaji. Keputusan keseluruhan yang diperolehi dalam kajian ini, mendapati sistem yang diguna mudah dikendalikan serta efektif dari segi kos operasi dan boleh diaplikasikan diladang-ladang kelapa sawit kerana kobolehan kerja yang tinggi dan sesuai untuk persekitaran dan proses yang lebih bersih.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	-	Degree Celsius
ΔG°	-	Gibbs free energy
ABR	-	Anaerobic baffled reactor
ADF	-	Anaerobic digestion foaming
AF	-	Anaerobic filter
ASF	-	Activated sludge foaming
ASTM	-	American association for testing materials
BOD	-	Biochemical oxygen demand
C	-	Carbon
CH_3COOH	-	Acetic acid or Ethanoic acid
CH_4	-	Methane
CO_2	-	Carbon dioxide
COD	-	Chemical oxygen demand
CPO	-	Crude palm oil
DO	-	Dissolved oxygen
ECP	-	Extracellular polymeric
FBR	-	Fluidized bed reactor

FFB	-	Fresh fruit bunches
FG	-	Fine gravel
GLS	-	Gas-liquid-solid
H^+	-	Hydrogen ion
H_2	-	Hydrogen
H_2O	-	Water molecule
H_2S	-	Hydrogen sulphide
hr	-	Hour
HRT	-	Hydraulic retention time
HUASB	-	Hybrid up-flow anaerobic sludge blanket
ICR	-	Immobilised cell reactor
K_1	-	First order kinetic constant
kg	-	Kilogram
kj	-	kilojoule
L	-	Litre
µm	-	Micrometre
m	-	Metre
MAS	-	Membrane anaerobic system
MCRT	-	Mean cell retention time
mg	-	Milligram
mm	-	Millimetre

MPOB	-	Malaysia Palm Oil Board
MLSS	-	Mixed liquor suspended solid
MLVSS	-	Mixed liquor volatile suspended solid
NH_3	-	Ammonia
O_2	-	Oxygen
OLR	-	Organic loading rate
OPS	-	Oil palm shell
POME	-	Palm oil mill effluent
PORIM	-	Palm Oil Research Institute of Malaysia
PORLA	-	Palm Oil Registration and Licensing Authority
PVC	-	Polyvinyl chloride
RPF	-	Reticulated polyurethane foam
SD	-	Standard deviation
SEM	-	Scanning electron microscope
SG	-	Specific gravity
SMA	-	Specific methanogenic activity
SRT	-	Solid retention times
SSA	-	Specific surface area
SSD	-	Saturated surface dry
TN	-	Total nitrogen
TP	-	Total phosphorus

TS	-	Total solids
TSS	-	Total suspended solids
UASB	-	Up-flow anaerobic sludge blanket
UV	-	Up-flow velocity
VFA	-	volatile fatty acid
VSS	-	Volatile suspended solids

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CHAPTER 1

INTRODUCTION

1.1 Background on palm oil

The oil palm, *Elaeis guineensis*, is indigenous to West Africa, with the first countries that started to plant the oil palm being Sierra Leone, Liberia, the Ivory Coast, Ghana, and Cameroon (Yusoff, 2006). Palm oil cultivation has gained prominence due to the versatility of the crop. Therefore, the cultivation of the crop has expanded beyond Africa to South East Asia, since the seeds were carried over to Indonesia in 1848. The seeds reached Malaysia in 1871 (Basiron & Chan, 2004).

The tropical ambiance and the rich soil contributed to the success of oil palm plantation in Malaysia. In 1911 and 1912, Malaysia witnessed the first commercial oil palm plantation, the crop began to be regarded as an important economic asset (Tate, 1996). The development of palm oil industry can be divided into three phases; the experimental phase (1895 to 1916), the plantation development phase (1917 to 1960) and the expansion phase that is currently in place. Palm oil cultivation has been significantly advantageous to Malaysia. It has contributed to the economy by being a successful export as well as means of livelihood for about 0.3 million families employed in various land schemes and palm oil lands (Abdeghameed, 2005).

An important development in palm oil cultivation was the increase in planted areas. In 1960, the total planted area was 54,638 hectares. This has rapidly expanded in

REFERENCES

Abbasi, T., Tauseef, S.M. & Abbasi, S.A. (2012). Biogas Capture from wastewaters: the high-rate anaerobic digesters. *Biogas Energy*, 2, pp.63-104.

Abdeghameed, A.A. (2005). *An econometric study of palm oil import demand in the Middle East and North African countries*. Universiti Putra Malaysia: Ph.D. Thesis.

Agamuthu, P. (1999). Specific biogas production and role of packing medium in the treatment of rubber thread manufacturing industry wastewater. *Bioprocess and Biosystems Engineering*, 21(2), pp.151-155.

Ahmad, A., Ghufran, R. & Wahid, Z.A. (2011). Role of calcium oxide in sludge granulation and methanogenesis for the treatment of palm oil mill effluent using UASB reactor. *Journal of Hazardous Materials*, 198, pp.40-48.

Ahmad, A.L., Ismail, S. & Bhatia, S., (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, 157, pp.87-95.

Ahn, Y.H. (2000). Physicochemical and microbial aspects of anaerobic granular biopellets. *Journal of Environmental Science and Health*, 35(9), pp.1617–1635.

Alimahmoodi, M. (2004). *CO2 capture and bioconversion to biogas in an anaerobic system using an UASB reactor.* Concordia University: Master's Thesis.

Alkalay, D., Guerrero, L., Chamy, R. & Schiappacasse, M. (1997). Microbial adherence studies for anaerobic filters. *Bioprocess Engineering*, 16(6), pp.311-314.

Alphenaar, P.A., Visser, A. & Lettinga, G. (1993). The effect of liquid upward velocity and hydraulic retention time on granulation in UASB reactors treating

wastewater with a high sulphate content. *Bioresource Technology*, 43(3), pp.249-258.

Al-Shayah, M. & Mahmoud, N. (2008). Start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage. *Bioresource Technology*, 99(16), pp.7758–7766.

Alvarez, J.A., Armstrong, E., Gomez, M. & Sotoa, M. (2008). Anaerobic treatment of low-strength municipal wastewater by a two-stage pilot plant under psychrophilic conditions. *Bioresource Technology*, 99(15), pp.7051–7062.

Anushuya, R. & Sudhir, K.G. (2008). Effect of hydraulic retention time on the biodegradation of complex phenolic mixture from simulated coal wastewater in hybrid UASB reactors. *Journal of Hazardous Materials*, 153(1-2), pp.843–851.

APHA. (1998). *Standard methods for the examination of water and wastewater*. 20th ed. Washington, USA: DC.

Arthur, R. & Glover, K. (2012). Biomethane potential of the POME generated in the palm oil industry in Ghana from 2002 to 2009. *Bioresource Technology*, 111, pp.155–160.

ASTM (1988). *Standard test method for specific gravity and absorption of coarse aggregate*. West Conshohocken, United States: C 127.

ASTM (1997a). *Standard test method for bulk density ("unit weight") and voids in aggregate*. West Conshohocken, United States: C 29/C 29M.

ASTM (1997b). *Standard test method for density, absorption, and voids in hardened concrete*. West Conshohocken, United States: C 642.

Awuah, E. & Abrokwa, K.A. (2008). Performance evaluation of the UASB sewage treatment plant at James town (Mudor) Accra. *Proc. of the 33rd int. conf. on Water, Engineering and Development Centre*. Accra, Ghana: Loughborough University. pp.322-328.

Ayati, B. & Ganjidoust, H. (2006). Comparing the efficiency of UAFF and UASB with hybrid reactor in treating wood fiber wastewater. *Iranian Journal of Environmental Health Science Engineering*, 3(1), pp.39-44.

Banu, R.J., Kaliappan, S. & Yeom, T.I. (2007). Treatment of domestic wastewater using upflow anaerobic sludge blanket reactor. *International Journal of Environmental Science and Technology*, 4(3), pp.363-370.

Barjenbruch, M., Hoffmann, H., Kopplow, O. & Tränckner, J. (2000). Minimizing of foaming in digesters by pre-treatment of the surplus-sludge. *Water Science and Technology*, pp.235–241.

Basiron, Y. & Chan, K.W. (2004). The Oil Palm and its Sustainability. *Jurnal of Oil Palm Research*, 16(1), pp.1-10.

Bellouti, M., Alves, M.M., Novais, J.M. & Mota, M. (1997). Flocs vs. granules: differentiation by fractal dimension. *Water Research*, 31(5), pp.1227-1231.

Bhunia, P. & Ghangrekar, M.M. (2007). Required minimum granule size in UASB reactor and characteristics variation with size. *Bioresource Technology*, 98, pp.994–999.

Bodík, I., Herdová, B. & Drtil, M. (2000). Anaerobic treatment of the municipal wastewater under psychrophilic conditions. *Bioprocess Engineering*, 22, pp.385-390.

Borja, R. & Banks, C.J. (1994a). Anaerobic digestion of palm oil mill effluent using up-flow anaerobic sludge blanket reactor. *Biomass Bioenergy*, 6, pp.381-389.

Borja, R. & Banks, C.J. (1994b). Treatment of palm oil mill effluent by upflow anaerobic filtration. *Journal of Chemical Technology and Biotechnology*, 61, pp.103–109.

Borja, R. & Banks, C.J. (1995). Response of an anaerobic fluidized bed reactor treating ice-cream wastewater to organic, hydraulic, temperature and pH shocks. *Journal of Biotechnology*, 39(3), pp.251-259.

Chen, J. & Lun, S.Y. (1993). Study on mechanism of anaerobic sludge granulation in UASB reactors. *Water Science and Technology*, 28(7), pp.171-178.

Choorit, W. & Wisarnwan, P. (2007). Effect of temperature on the anaerobic digestion of palm oil mill effluent. *Research Article*, 10, pp.376-385.

Chow, M.C. & Ho, C.C. (2000). Surface active properties of palm oil with respect to the processing of palm oil. *Jurnal of Oil Palm Research*, 12(1), pp.107-116.

CILAS (2004). *Frequently asked questions on particle size Analyse by laser diffraction*.. France: CILAS PSA 920, 1064, 1180.

Costerton, J.W., Irving, R.T. & Cheng, K.J. (1981). The bacterial glycocalyx in nature and diseas. *Annual Review of Microbiology*, 35, pp.299-324.

de Sousa, J.T., Vazoller, R.F. & Foresti, E. (1997). Phosphate removal in an UASB reactor treating synthetic substrate simulating domestic Sewage. *Brazilian Journal of Chemical Engineering*, 14(4), pp.214-219.

Diamantis, V. & Aivasidis, A. (2010). Kinetic analysis and simulation of UASB anaerobic treatment of a synthetic fruit wastewater. *Global Nest*, 12(2), pp.175-180.

Dolfing, J. (1987). *Microbiologic al aspects of granular methanogenic sludge*. Agricultural University Wageningen: Ph. D. Thesis.

Dolfing, J., Griffioen, A., Van Neerven, A.R.W. & Zevenhuizen, L.P.T.M. (1985). Chemical and bacteriological composition of granular methanogenic sludge. *Canadian Jornal of Microbiol*, 31, pp.744-750.

Downing, L.S. & Nerenberg, R. (2007). Performance and microbial ecology of the hybrid membrane biofilm process for concurrent nitrification and denitrification of wastewater. *Water Science and Technology*, 55(8–9), p.355–362.

Dubourgier, H.C., Prensier, G. & Albagnac, G. (1987). Structure and microbial activities of granular anaerobic sludge. *microbiology and Technology*, 12, pp.18–33.

El-Mamouni, R., Leduc, R. & Guiot, S.R. (1997). Influence of the starting microbial nucleus type on the anaerobic granulation dynamics. *Applied Microbiology and Biotechnology*, 47, pp.189–194.

Elmitwalli, T.A., van Dun, M., Bruning, H., Zeeman, G & Lettinga, G. (2000). The role of filter media in removing suspended and colloidal particles in an anaerobic reactor treating domestic sewage. *Bioresource Technology*, 72, pp.235-242.

Fang, H.H.P., Chui, H.K. & Li, Y.Y. (1994a). Microbial structure and activity of UASB granules treating different wastewaters. *Water Science and Technol*, 30, pp.87-96.

Fang, H.H.P. & Chui, H.K. (1994b). Comparison of start-up performance of four anaerobic reactors for the treatment of high-strength wastewater. *Resources Conservation and Recycling*, 11, pp.123-138.

Fang, H.H.P., Chen, T., Li, Y.Y. & Chui, H.K. (1996). Degradation of phenol in wastewater in an up-flow anaerobic sludge blanket reactor. *Water Research*, 30(6), p.1353–1360.

Fátima, R.L.F., Borges, A.C., de Matos, A.T., Duarte, I.C.S., Fia, R & de Campos, L.C. (2010). Development of biofilm in anaerobic reactors treating wastewater from coffee grain processing. *Revista Brasileira de*, 14(2), pp.210–217.

Flemming, H.C. & Wingender, J. (2001). Relevance of microbial extracellular polymeric substances (EPS)-part I: structural and ecological aspects. *Water Science and Technology*, 43(6), pp.1-8.

Frostell, B. (1978). *Influence of media properties on the loading capacity of anaerobic filters*. Sweden: Swedish Water and Air Pollution Research Institute. Report, pp.22.

Ganesh, P.S., Ramasamy, E.V., Gajalakshmi, S. & Abbasi, R.S. (2007). Studies on treatment of low-strength effluents by UASB reactor and its application to dairy industry wash waters. *Indian Journal of Biotechnology* , 6, pp.234-238.

Gangagni Rao, A. Venkata Naidu, G., Krishna Prasad, K., Chandrasekhar Rao, N., Venkata Mohan, S., Jetty, A & Sharma, P.N. (2005). Anaerobic treatment of wastewater with high suspended solids from a bulk drug industry using fixed film reactor (AFFR). *Bioresource. Technology.*, 96(1), pp.87-93.

Ganidi, N. & Tyrrel, S. (2009). Anaerobic digestion foaming causes – A review. *Bioresource Technology*, 18, pp.5546–5554.

Graaff, M.S.D., Temmink, H., Zeeman, G. & Buisman, C.J.N. (2010). Anaerobic treatment of concentrated black water in a UASB reactor at a short HRT. *Water*, 2, pp.101-119.

Habeeb, G.A. & Fayyadh, M.M. (2009). Rice husk ash concrete: the effect of rha average particle size on mechanical properties and drying shrinkage. *Australian Journal of Basic and Applied Sciences*, 3, pp.1616-1622.

HACH (2000). *DR/2010 Spectrophotometer procedures manual*. United State: Hach Company, Manual.

HACH (2005). *DR/5000 spectrophotometer procedures manual*. United State: Hach company, Manual.

Hang, S.S. & Byeong, C.P. (1990). Improved performance of upflow anaerobic sludge blanket (UASB) reactors by operating alternatives. *Biotechnology Letters*, 12(6), pp.469-474.

Hassan, M.A., Yacob, S & Shirai, Y. (2004). Treatment of Palm Oil Wastewaters. In Wang, L. K., Hung, Y., Lo, H. H., Yapijakis, C. *Handbook of Industrial and Hazardous Wastes Treatment*. New York: Marcel Dekker, Inc., pp.719-35.

Heard, J., Harvey, E., Johnsona, B.B., Wellsa, J.D & Angove, M.J. (2008). The effect of filamentous bacteria on foam production and stability. *Biointerfaces* , 63(1), pp.21-26.

Herumurti, W., Mohamed, I.H. & M, S.R. (2008). Treatment of pharmaceutical wastewater using mesophilic UASB and hybrid UASB reactors. *Proc. of the 4th Int. Conf. on Sustainable Water Environment Innovative Technologies and Energy Efficient Solutions*. Singapore: pp.214-219.

Hug, T. (2006). *Characterization and Controlling of Foam and Scum in Activated Sludge Systems*. Swiss Federal Institute of Technology Zurich: Ph.D. Thesis.

Hulshoff Pol, L.W. (1989). *The phenomenon of granulation of anaerobic sludge*. Agricultural University of Wageningen: Ph.D. Thesis.

Hulshoff Pol, L.W., Lopes, S.I.D., Lettinga, G. & Lens, P.N.L. (2004). Anaerobic sludge granulation. *Water Research*, 38(6), pp.1376–1389.

Hwang, P.C. & Cheng, S.S. (1991). Treatment of p-cresol with a recirculating UASB reactor using the concept of kinetic control. *Water Science and Technology*, 24, pp.133–140.

Idris, M.A., Jami, M.S. & Muyibi, S.A. (2010). Tertiary treatment of biologically treated palm oil mill effluent (POME) using UF membrane system: effect of MWCO and transmembrane pressure. *International Journal of Chemical and Environmental Engineering*, 1(2), pp.108-112.

Irvan, Trisakti, B., Wongistani, V. & Tomiuchi, Y. (2012). Methane emission from digestion of palm oil mill effluent (POME) in a thermophilic anaerobic reactor. *International Journal of Science and Engineering*, 3(1), pp.32-35.

Ji, G.D., Sun, T.H., Ni, J.R. & Tong, J.J. (2009). Anaerobic baffled reactor (ABR) for treating heavy oil produced water with high concentrations of salt and poor nutrient. *Bioresource Technology*, 100, pp.1108-1114.

Jose, B.C., Karina, B. & Pedro, L. (2010). Treatment of phenol in an anaerobic fluidized bed reactor (AFBR): continuous and batch regime. *Biodegradation*, 21, pp.603-613.

Kalyuzhnyi, S., Estrada de los Santos, L. & Rodriguez Martinez, J. (1998). Anaerobic treatment of raw and preclarified potato-maize wastewaters in a UASB reactor. *Bioresource Technology* , 66(3), pp.195–199.

Karim, K., Klasson, K.T., Hoffmann, R., Drescher, S.R., de Paoli, D.W & Al-Dahhan, M.H. (2005). Anaerobic digestion of animal waste: effect of mixing. *Bioresource Technology*, 96, pp.1607–1612.

Kim, J.K., Oh, B.R., Chun, Y.N. & Sim, S.W. (2006). Effects of temperature and hydraulic retention time on anaerobic digestion of food waste. *Journal of Bioscience and Bioengineering*, 102(4), pp.328-332.

Krishnan, K., (2009). *Feasibility study of upflow anaerobic filter for pretreatment of municipal wastewater*. National University of Singapore: Master's Thesis.

Latif, M.A., Ahmad, A., Ghufran, R. & Wahid, Z.A. (2012). Effect of temperature and organic loading rate on upflow anaerobic sludge blanket reactor and CH4 production by treating liquidized food waste. *Environmental Progress and Sustainable Energy*, 31(1), pp.114–121.

Leal, M., Freire, D., Cammarota, M. & Sant'Anna Jr, G. (2006). Effect of Enzymatic Hydrolysis on Anaerobic Treatment of Dairy Wastewater. *Process Biochemistry*, 41(5), pp.1173-1178.

Leita˜o, R.C. (2004). *Robustness of UASB reactors treating sewage under tropical conditions*. Wageningen University: Ph.D. Thesis.

Leita˜o, R.C., van Haandel A, C., Zeeman, G. & Lettinga, G. (2006). The effects of operational and environmental variations on anaerobic wastewater treatment systems. *Bioresource Technology*, 97, pp.1105-1118.

Lettinga, G., Hulshoff Pol L, W.H. & Zeeman, G. (2000). Anaerobic Wastewater Treatment. In Henze, M. *Biological Wastewater Treatment*. The Netherlands: Wageningen University. pp.200-215.

Lew, B., Tarre, S., Belavski, M. & Green, M. (2004). UASB reactor for domestic wastewater treatment at low temperatures: a comparison between a classical UASB and hybrid UASB-filter reactor. *Water Science and Technology*, 49(11–12), pp.295-301.

Liu, C.F., Yuan, X.Z., Zeng, G.M., Li, W.W & Li, J. (2008). Prediction of methane yield at optimum pH for anaerobic digestion of organic fraction of municipal solid waste. *Bioresource Technology*, 99(4), pp.882–888.

Loftus, T. (2003, June 17). Nitrogen in wastewater. *Lagon Systems in Maine*. Retrieved February 12, 2011, from http://www.lagoonsonline.com/laboratory-articles/nitrogen-part2.htm.

MacLeod, F.A., Guiot, S.R. & Costerton, J.W. (1990). Layered structure of bacterial aggregates produced in an upflow anaerobic sludge bed and filter reactor. *Applied Environmental and Microbiology*, 56(6), p.1598-1607.

Madhubabu, S., Mathava, K., Ligy, p. & Venkobachar, C. (2007). Treatment of carbofuran-bearing synthetic wastewater using UASB process. *Environmental Science and Health*, 42(2), pp.189–199.

Maier, R.M., Pepper, I.L. & Gerba, C.P. (2000). *Environmental Microbiology*. San Diego, CA: Academic Press.

Malakahmad, A., Zain, S.M., Ahmad Basri, N.E., Mohamed Kutty, S.R & Isa, M. H. (2009). Identification of anaerobic microorganisms for converting kitchen waste to biogas. *Proc. of the Int. Conf. on Ecological and Engineering and Technology*. Thailand: World Academy of Science. pp.1336-1341.

Mara, D. & Horan, N., (2003). *The Handbook of Water and Wastewater Microbiology*. San Diego, California: Elsevier.

Metcalf & Eddy. (2003). *Wastewater Engineering, Treatment, Disposal and Reuse*. 4th ed. New York, USA: McGraw-Hill.

Mohd Noor, M.J.M., Ahmad, J. & Abdul Halim, G. (1989). POME treatment utilizing high-rate hybrid anaerobic reactor. *Journal of Islamic Academy of Sciences*, 2(1), pp.13-16.

Morgan, J.W., Evison, L.M. & Forster C, F., (1991). Internal architecture of anaerobic sludge granules. *Journal of Chemical Technology and Biotechnology*, 50, pp.211-226.

Najafpour, G.D., Zinatizadeh, A.A.L., Mohamed, A.R., Isa, M.H & Nasrollahzadeh, H. (2006). High rate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge-fixed film bioreactor. *Process Biochemistry*, 41, pp.370-379.

Najafpour, G.D., Tajallipour, M., Komeili, M. & Mohammadi, M. (2009). Kinetic model for an up-flow anaerobic packed bed bioreactor: Dairy wastewater treatment. *African Journal of Biotechnology*, 8(15), pp.3590-96.

Öktem, Y. & Tüfekçi, N. (2006). Treatment of brewery wastewater by pilot scale upflow anaerobic sludge blanket reactor in mesophilic temperature. *Journal of Scientific & Industrial Research*, 65(March), pp.248-251.

Padilla, G.E. & López, L.A. (2010). Kinetics of organic matter degradation in an upflow anaerobic filter using slaughterhouse wastewater. *Journal of Bioremediation and Biodegradation*, 1(2), pp.1-6.

Park, N.B., So, K.H., Lee, D.B., Jun, H.B., Yoon., A.H & Park, S.M. (2007). Effect of methane production the single - and two phased reactors in the anaerobic treatment of piggery wastewater. *Proc. of the 9th Int. Conf. on the East and*

Southeast Asia Federation of Soil Science Societies. Koria: Korean Society of Soil Science and Fertilizer. pp.151-152.

Passeggi, M., López, I. & Borzacconi, L. (2012). Modified UASB reactor for dairy industry wastewater: performance indicators and comparison with the traditional approach. *Journal of Cleaner Production*, 26, pp.90-94.

Pereboom, J.H.F. (1994). Size distribution model for methanogenic granules from full scale UASB and IC reactors. *Water Science and Technology*, 30(12), pp.211-221.

Poh, P.E. & Chong, M.F. (2009). Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. *Bioresource Technology*, 100, pp.1-9.

Pratiwi, W. (2007). *Industrial and Hazardous Waste Treatment and Management*. Bandung, Indonesia: Center for Pulp and Paper. Review Report.

Punal, A., Trevisan, M., Rozzi, A. & Lema, J.M. (2000). Influence of C:N ratio on the start-up of up-flow anaerobic filter reactors. *Water Science and Technology*, 34(9), pp.2614-2619.

Rajakumar, R. & Meenambal, T. (2008). Comparative study on start-up performance of HUASB and AF reactors treating poultry slaughterhouse wastewater. *International Journal of Environmental Research*, 2(4), pp.401-10.

Rajakumar, R., Meenambal, T., Banu, R.J. & Yeom, I. (2011). Treatment of poultry slaughterhouse wastewater in upflow anaerobic filter under low upflow velocity. *International journal of Environmental Science and Technology*. 8(1), pp.149-158.

Ramakrishnan, A. & Gupta, S.K. (2006). Anaerobic biogranulation in a hybrid reactor treating phenolic waste. *Journal of Hazardous Materials*, 137, pp.1488-95.

Ronnachai, C., Piyarat, B., Poonsuk, P. & Sumate, C. (2007). Effect of organic loading rate on methane and volatile fatty acids productions from anaerobic treatment of palm oil mill effluent in UASB and UFAF reactors. *Journal of Science and Tecknology*, 2, pp.311-323.

Ruiz, I., Veiga, M.C., De Santiago, P. & Blázquez, R. (1997). Treatment of slaughterhouse wastewater in a UASB reactor and an anaerobic filter. *Bioresource Technology*, 60, pp.251-258.

Russo, C., Anna, S., G.L & de Carvalho Pereira, S.E. (1985). An anaerobic filter applied to the treatment of distillery wastewaters. *Agricultural Wastes*, 14, pp.301-313.

Safiuddin, M. & Hearn, N. (2005). Comparison of ASTM saturation techniques for measuring the permeable porosity of concrete. *Cement and Concrete Research*, 35, pp.1008- 1013.

Saleh, M.M.A. & Usama, F.M. (2003). UASB/EGSB Application for Industrial Wastewater Treatment. *Proc. of the 7th Int. Conf. on Water Technology*. Egypt: Al-Azhar University, pp.335-344.

Salmiah, A. (2000). *Non-Food Uses of Palm Oil and Palm Kernel Oil*. Kuala Lumpur, Malaysia: MPOPC Palm Oil Information Series. Report.

Sam-Soon, P., Loewenthal, R., Dold, P.L. & Marais, G. (1987). Hypothesis for pelletisation in the upflow anaerobic sludge bed reactor. *Water SA*, 13(2), pp.69–80.

Schmidt, J.E. & Ahring, B.K. (1996). Granular sludge formation in up-flow anaerobic sludge blanket (UASB) reactors. *Biotechnology and Bioengineering*, 49(3), pp.229-246.

Shafigh, P., Zamin, M.J. & Mahmud, H. (2010). Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: A review. *International Journal of the Physical Sciences*, 5(14), pp.2127-2134.

Shin, S.G., Yoo, S., Hwang, K., Song, M., Kim, W., Han, G & Hwang, S. (2011). Dynamics of transitional acidogenic community along with methanogenic population during anaerobic digestion of swine wastewater. *Process Biochemistry*, 46(8), pp.1607-1613.

Shivayogimath, C.B. & Ramanujam, T.K. (1999). Treatment of distillery spentwash by hybrid UASB reactor. *Bioprocess Engineering*, 21, pp.255-259.

Show, K.Y., Wang, Y., Foong, S.F & Tay, J.H. (2004). Accelerated start-up and enhanced granulation in up-flow anaerobic sludge blanket reactors. *Water Research*, 38(9), pp.2293-2304.

Singh, K.S., (1999). *Municipal wastewater treatment by upflow anaerobic sludge blanket (UASB) reactors*. University of Regina: Ph.D. Thesis.

Singh, R.P., Kumar, S. & Ojha, C.S.P. (1999). Nutrient requirement for UASB process: a review. *Biochemical Engineering*, 3, pp.35–54.

Sivawan, P., Naraporn, H. & Khanitta, H. (2002). *Performance of upflow anaerobic sludge blanket (UASB) reactor treating rubber latex wastewater under acidogenic conditions*. Thailand: University of Technology Thonburi. Report.

Soto, M., Ligero, P., Vega, A., Ruiz, I., Veiga, M.C & Blazquez, R. (1997). Sludge granulation in UASB digesters treating low strength wastewaters at mesophilic and psychrophilic temperatures. *Environmental Technology*, 18(11), pp.1133-45.

Sunil, K.G. & Gupta, S.K. (2005). Morphological study of the granules in UASB and hybrid reactors. *Clean Techn Environ Policy*, 7, pp.203-212.

Syutsubo, K., Harada, H., Ohashi, A. & Suzuki, H. (1997). Effective start-up of thermophelic UASB reactor by seeding mesophilically-grown granular sludge. *Water science and Technology*, 36(6-7), pp.391-408.

Takuma. (2005, June 1). Takuma anaerobic digestion process for livestock manure. *Global Environment Centre Foundation*. retrieved January 22, 2011, from http://www.gec.jp/water/data/water_16-6.html.

Tate, D.J.M. (1996). *The RGA History of the Plantation Industry in the Malay Peninsula*. Oxford University: Ph.D. Thesis.

Tay, J.H., Xu, H.L. & Teo, K.C. (2000). Molecular mechanism of granulation. I: H+ translocation–dehydration theory. *Journal of Environmental Engineering*, 126, pp.403-410.

Teo, D.C.L., Mannan, M.A., Kurian, V.J. & Ganapathy, C. (2007). Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties. *Building and Environment*, 42, pp.2614-2621.

Tessele, F., Monteggia, L.O. & Rubio, J. (2005). Treatment of municipal wastewater UASB reactor effluent by unconventional flotation and UV disinfection. *Water Science and Technology*, 52(1-2), pp.315-322.

Thaveesri J., Daffonchio, D., Liessens, B., Vandermeren, P & Verstraete, W. (1995). Granulatio n and sludge bed stability in upflow anaerobic sludge bed reactors in relation to surface thermodynamics. *Applied and Environmental Microbiology*, 61(10), pp.3681-366.

Tiwari, M.K., Guha, S., Harendranath, C.S. & Tripathi, S. (2005). Enhanced granulation by natural ionic polymer additives in UASB reactor treating low-strength wastewater. *Water Research*, 39(16), pp.3801-3810.

Uemuraa, S. & Haradab, H. (2000). Treatment of sewage by a UASB reactor under moderate to low temperature conditions. *Bioresource Technology*, 72, pp.275-282.

van der Merwe, M & Britz, T.J. (1993). Anaerobic digestion of baker's yeast factory effluent using an anaerobic filter and hybrid digester. *Bioresource Technology*, 43, pp.169-174.

van Haandel, A., Kato, M.T., Cavalcanti, P & Florencio, L. (2006). Anaerobic reactor design concepts for the treatment of domestic wastewater. *Reviews in Environmental Science and Biotechnology*, 4, pp.5-21.

van Lier, J.B. (2008). High-rate anaerobic wastewater treatment: diversifying from end-of-the-pipe treatment to resource-oriented conversion techniques. *Water Science and Technology*, 57(8), pp.1137-1148.

Vanderhaegen, B., Ysebaert, K., Favere, K., van Wambeke, W., Peeters, T., Panic, V., Vandenlangenbergh, V & Verstraete, W. (1992). Acidogenesis in relation to in-reactor granule yield. *Water Science and Technology*, 25(7), pp.21-30.

Varley, J., Brown, A.K., Boyd, J.W.R., Dodd, P.W & Gallagher, S. (2004). Dynamic multipoint measurement of foam behavior for a continuous fermentation over a range of key process variables. *Biochemical Engineering Journal*, pp. 61–72.

Veeresh, G.S., Kumar, P & Mehrotra, I. (2005). Treatment of phenol and cresols in up-flow anaerobic sludge blanket (UASB) process: a review. *Water Research*, 39, pp.154-170.

Veronez, R.G., Orra, A.A., Ribeiro, R., Zaiat, M & Ratusznei, S.M. (2005). A simplified analysis of granule behavior in ASBR and UASB reactors treating low-strength synthetic wastewater. *Brazilian Journal of Chemical Engineering*, 22(3), pp.361 - 369.

Vijayaraghavan, K., Ahmad, D. & Abdul Aziz, M.E. (2007). Aerobic treatment of palm oil mill effluent. *Journal of Environmental Management*, 82, pp.24-31.

Vlyssides, A., Barampouti, E.M. & Mai, S. (2008). Determination of granule size distribution in a UASB reactor. *Journal of Environmental Management*, 86, pp.660-664.

von Sperling, M., Freire, V.H. & Lemos Chernicharo, C.A. (2001). Performance evaluation of a UASB – activated sludge system treating municipal wastewater. *Water Science and Technology*, 43(11), pp.323-328.

Wang, K. (1994). *Integrated Anaerobic and Aerobic treatment of Sewage*. Wageningen Agricultural University: Ph.D. Thesis.

Wang, Z. & Banks, C.J. (2007). Treatment of a high-strength sulphate-rich alkaline leachate using an anaerobic filter. *Waste Management*, 27, pp.359-366.

Wang, J., Wang, X., Zhao, Z. & Li, J. (2008). Organics and nitrogen removal and sludge stability in aerobic granular sludge membrane bioreactor. *Applied Microbiology and Biotechnology*, 79, pp.679-685.

Westlund, A.D., Hagland, E. & Rothman, M. (1998). Operational aspects on foaming in digesters caused by Microthrix Parvicella. *Water Science and Technology*, pp.29-34.

Whitney, Elanor & Sharon, R. (2005). *Understanding Nutrition*. 10th ed. Florida, united States: Thomson-Wadsworth.

Wiegant, W.M. & Lettinga, G. (1985). Thermophilic anaerobic digestion of sugars in an up-flow anaerobic sludge blanket reactors. *Biotechnol and Bioengineering*, 27, pp.1603-1607.

Wu, W., Jain, M.K. & Zeikus, J.G. (1996). Formation of fatty acid-degrading, anaerobic granules by defined species. *Applied Microbiology and Biotechnology*, 62(6), pp.2037-2044.

Yacob, S.R., Shirai, Y., Hasan, M.A., Wakisaka, M & Subash, S. (2006). Start-up operation of semi-commercialcosed anaerobic digester for palm oil mill effluent. *Journal of Process and Biochemistry*, 41, pp.962-964.

Yan, B. Liu, K., Su, C., Zhao, W., Shi, J., Long, F & Wu, Y. (2011). Compared selection of pretreatment technology for cassava starch wastewater treated by anaerobic process. *Water Resource and Environmental Protection*, pp.1533-1536.

Yasar, A. Ahmad, N., Chaudhry, M.N., Rehman, M.S.U & Khan, A.A.A. (2007). Ozone for color and COD removal of raw and anaerobically biotreated combined industrial wastewater. *Polish Journal of Environmental Studies*, 16(2), pp.289-294.

Yetilmezsoy, K. (2008). *Treatability of poultry manure wastewater using anaerobic sludge bed reactor*. Yildiz Technical University: Ph.D. Thesis.

Yetilmezsoy, K. & Sakar, S. (2008). Improvement of COD and color removal from UASB treated poultry manure wastewater using Fenton's oxidation. *Journal of Hazardous Material*, 151, pp.547-558.

Yu, H.Q., Fang, H.H. & Tay, J.H. (2000). Effect of Fe2+ on sludge granulation in upflow anaerobic sludge blanket reactor. *Water Science and Technology*, pp.199-205.

Yu, L., Hai-Lou, X., Kuan-Yeow, S. & Joo-Hwa, T. (2002). Anaerobic granulation technology for wastewater treatment. *World Journal of Microbiology and Biotechnology*, 18, pp.99-113.

Yu, L., Hai-Lou, X., Shu-Fang, Y. & Joo-Hwa, T. (2003). Mechanisms and models for anaerobic granulation in upflow anaerobic sludge blanket reactor. *Water Research*, 37, pp.661-673.

Yusoff, S. (2006). Renewable energy from palm oil innovation on effective utilization of waste. *Journal of Cleaner Product*, 14, pp.87-93.

Yu, H.Q., Tay, M.J.H. & Fang, H.P. (2001). The roles of Calcium in sludge granulation during UASB reactor start-up. *Water Research*, 35(4), pp.1052-1060.

Zamanzadeh, M & Azimi, A.A (2004). Determination of design criteria for UASB reactors as a wastewater pretreatment system in tropical small communities. *International Journal of Environment Science and Technology*, 1(1), pp.51-57.

Zeikus, J.G. (1979). Microbial populations in digesters. In Stafford, D.A., Wheatley, B.I., & Hughes, D.E. *Anaerobic Digestion*. London: Applied Science Publications. pp.61-89.

Zhang, Z. Show, K., Tay, J., Liang, D & Lee, D. (2008). Enhanced continuous biohydrogen production by immobilized anaerobic microflora. *Energy and Fuels*, 22(1), pp.87-92.

Zhu, J., Hu, J. & Gu, X. (1997). The bacterial numeration and the observation of a new syntrophic association for granular sludge. *Water Science and Technology*, 36(6/7), pp.133-140.