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Development and Testing of a Pilot Scale Anaerobic Sequencing Batch Reactor (ASBR) For Palm Oil Mill Waste Water Treatment and Biogas Generation

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Abstract: A anaerobic sequencing batch reactor system was developed as a new anaerobicprocess with an emphasis on methane production from palm oil mill wastewater at the Leventis Farm, Weppa Agenebode, Nigeria. The three-stage anaerobicsequencing batchreactor system consisted of three bioreactors connected in series. It was operated at37 ^{0}C with a fixed recycle ratio of 1:1 (final effluent flow rate to feed flow rate). The washout sludgefrom the fourth bioreactor of the Palm Oil Mill Effluent (POME) present in the final effluent was recycled to the first bioreactor.The pH of the first bioreactor was controlled at 5.5, while the pH values of the other three bioreactorswere not controlled. Under the optimum chemical oxygen demand loading rate of 18 kg/m^{3}d(based on the three bioreactors' feed chemical oxygen demand load and total volume). With abioreactor volumetric ratio of 1:1:1, the system provided the highest gas production performancein yields of methane and other gases that were not characterised and the highest overall chemical oxygen demandremoval.

Interestingly, the three-stage anaerobic sequencing batch reactor system gave a much higherenergy production rate and a higher optimum chemical oxygen demand loading rate than previouslyreported anaerobic systems since it was able to maintain very high microbial concentrations in allbioreactors with very high values of both alkalinity and solution pH, especially in the fourth bioreactor,resulting in insufficient levels of micronutrients for anaerobic digestion.Otherhighlights of the batch reactor were the quality of wastewater generated. The tests carried out showed improvements in the quality of the wastewater during the ASBR stages.

Keywords: Three-stage anaerobic sequencing batch reactor (ASBR); hydrogen and methaneproduction; thermophilic temperature; volumetric reactor ratio; POME

1. Introduction

Biogas production through anaerobic digestion processes is gaining popularity worldwide due to its environmental friendliness and high energy yield [1–10]. When compared to single-stage anaerobic systems, implementing a two-stage process can boost biogas generation efficiency [11–15]. The anaerobic digestion process consists of four sequentialsteps: (i) hydrolysis (organic polymers are hydrolysed to water-soluble organic monomers such assugars and amino acids); (ii) acidogenesis (water-soluble organic monomers are converted to short-chain fatty acids, carbon dioxide (CO_2), hydrogen (H_2), and alcohols by acidogens); (iii) acetogenesis(acetogens further consume sizeable molecular weight organic acids to produce acetic acid (HAc),CO_2 and H_2) and (iv) methanogenesis (acetic acid is finally converted to methane (CH_4) and CO_2,and H_2 is also consumed with CO_2 to produce CH_4) [2,16,17]. The groups of bacteria involved in eachstep have different growth rates and require different environmental conditions [14].

As a result, it was projected that a three-stage anaerobic process would perform better than a single-stage or two-stage anaerobic process because it could offer sufficient conditions in each bioreactor to meet the environmental criteria for each step anaerobic decomposition. Indeed, prior research has shown that a three-stage up-flow anaerobic sludge blanket (UASB) system can produce high values for both overall COD removal and total energy yield [18].A three-stage anaerobic sequencing batch reactor (ASBR) system processing POME wastewater at a thermophilic temperature was used in this work to create both H_2 and CH_4 at varying COD loading rates, with a focus on maximum CH_4 generation. The pH of the first bioreactor was kept constant at 5.5, while the pH of the other two bioreactors was not. The final effluent from the third bioreactor was recycled to the first bioreactor with a predetermined recycling ratio of 1:1 to reduce the amount of NaOH solution necessary for pH adjustment (final effluent flow rate to feed flow rate).To maximise the CH_4 production efficiency, the washout sludge present in the finaleffluent was recycled to the first bioreactor. Based on the different growth rates of the three groups ofbacteria, the volumetric ratio of the three bioreactors was varied to maximise the productionrate of CH_4.

2. Materials and Methods

2.1 Design Concepts

The methodology adopted included:

a. Design and fabrication of the ASBR system with the potential of solar P.V. installation for instrumentation was conceptualised. The ASBR system's theoretical design method was considered; POME circulation system, temperature, mechanism of storage/transportation for both POME and gases collected, pH and temperature control system.
b. The theoretical design was translated into the simple design used for the construction of the pilot-scale ASBR system.

2.1.1 Fabrication and Installation of the ASBR System for POME

This included: (a) allocating a fabricator to construct the ASBR chambers and accessories; and (b) appropriate selection of materials of construction to fabricate the ASBR chambers and accessories. (c) observing the fabrication process to ensure that it adheres to acceptable working standards.

c:**Testing the System**

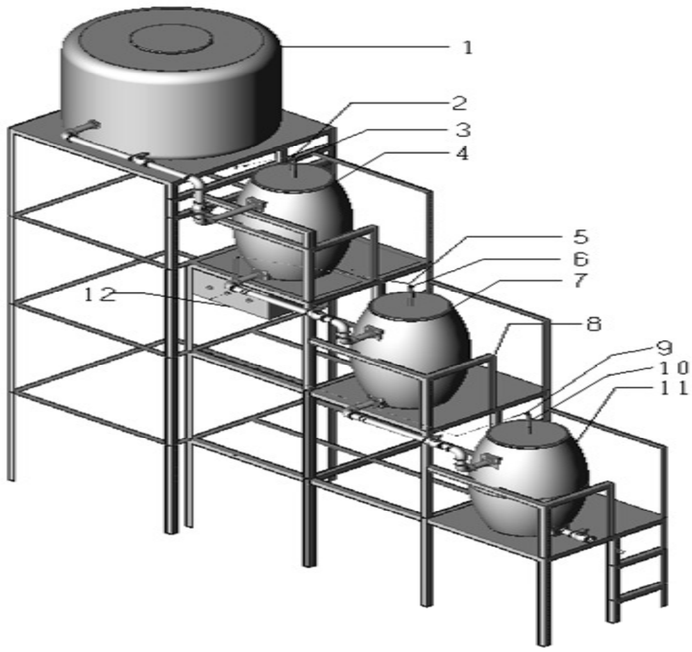
1. Evaluation of thetemperature, pH and gas production efficiency of the ASBR system was monitored and evaluated throughout the preservation and detention periods.
2. Assessment of POME quality and their characterisationwere obtained from the Oyo State Water Corporation and compared to other POME samples controlled by conventional means.
3. The fabricated ASBR system was installed behind the Chemical Engineering Technology laboratory at Auchi Polytechnic for performance evaluation.

2.1.2 Design process

A theoretical design of the ASBRsystem considering (i) POME circulation system (ii) controlling the thermophilic system (iii) detention/transportation with the aid of the technology (iv) relative pHlevels and temperature control system across the three reactors and the storage tank.

2.1.3 **Reactor Configuration and Process Flow**

POME was used to feed into a 1,000-litre IBC tank and then into the ASBRs in this system. The schematic diagram of the ASBR system is shown in Figure 1. The ASBR was created to work in an automated system with threeHDPE reactors with a working volume of 200 litres each.A peristaltic pump (Master flex L/S drives, 6–600 rpm, Cole-Parmer North America, Vernon Hills, IL, USA) was used to add palm oil wastewater to the reactor. The level inside the reactor was controlled by a level sensor that was submerged in the reactor. The external membrane tank was used for membrane filtration. During continuous operation, the reactor temperature was kept between 37 and 55 degrees Celsius. Approximately 60% of the reactor volume was filled with seed sludge at start-up.Initially, the reactor was started in the mesophilic condition of around 35 ◦C and increased to the thermophilic condition. Throughout that period, pH, volatile organic acids to alkaline buffer capacity (FOS/TAC ratio), and biogas production rates were measured daily.



S/N	DESCRIPTION
1	INTERNATIONAL BULK CONVERTER
2	TEMPERATURE PROBE CABLE 1
3	TEMPERATURE SENSOR 1
4	DRUM 1
5	TEMPERATURE PROBE CABLE 2
6	TEMPERATURE SENSOR 2
7	DRUM 2
8	SUPPORT AND FRAME
9	TEMPERATURE PROBE CABLE 3
10	TEMPERATURE SENSOR 3
11	DRUM 3
12	MICROCONTOLLER UNIT
13	PIPLE CONNECTIONS AND VALVE

Figure 1. Schematic diagram of the Pilot-Scale -Thermophilic ASBR

2.2. Seed Sludge Preparation

For the start-up in this investigation, the reactors mixed liquor volatile suspended solids (MLVSS) were maintained between 11000 mg/L to 20000 mg/L for each bioreactor. Seed sludge was collected from the bottom of a POME wastewater reservoir at the Leventis Farm in Weppa Agenebode, Nigeria, and filtered through a 1 mm sieve in an International Bulk Container (IBC) to remove any large solid particles.The seed sludge from the IBC storage wasagitated. The temperature was raised at 45°C for 300 minutes to remove any H_2-consuming bacteria and enhance primarily H_2-producing bacteria [19–22] before releasing them into the bioreactors. Tap water was utilised to fill all three bioreactors once the seed sludge was added.

2.2. Characterisation of POME

The POME wastewater was sampled from the first and final discharge point at the Leventis Farm in Weppa Agenebode, Nigeria and stored at 5 ◦C to prevent it from undergoing microbial degradation. POME was analysed at the Oyo Water Corporation in Nigeria for the parameters of COD, BOD_5, suspended solids, MLVSS oil and grease, total volatile solids, pH, temperature, Total Kjeldahl Nitrogen (TKN) and ammonia, following the standard methods [7].

Table 1. Characteristics of the POME wastewater used in this research

Parameter	Units	Value
pH	-	6.8
Total chemical oxygen demand (COD)	mg/L	80,000
Total volatile fatty acids (VFA)	mg/L	2,000
Total suspended solids (TSS)	mg/L	41,200
BOD_5	mg/L	16.0
Total nitrogen (N)	mg/L	20.0
COD: N:P	mg/L	24.0
TDS	mg/L	31,000
Grease	mg/L	3,000
Ammoniacal Nitrogen	mg/L	16.0
Temperature	◦C	37
Colour	-	75

The three reactors served as the complete stirred tank reactor (CSTR), and the setup and the stirring mechanism necessitated the production of Hydrogen sulphide(H_2S) and methane gas. The Specific methane production rate (SMPR) could not be determined due to a lack of proper instrumentation like the Bio-processor machine.Following the initial start-up and stabilisation of the reactor, the ASBR was operated in a continuous mode for 90 days, including the acclimatisation period of 30 days. The performance of the ASBR was evaluated with the same influent COD concentration of 80,000 mg/L in three stages in a continuous mode. The organic loading rates (OLR) were varied stepwise to characterise each stage. The reactor operation was partly automated with the Raspberry Pi and Arduino kits and timer control. Effluents from the POME anaerobic reactor were collected and taken for laboratory analysis. The settled down biomass was recirculated back to the IBC bioreactor.

3.0 **Results and Discussion**

3.1. ASBR Start-up Phase

The chemical and physical parameters of the POME wastewater utilised in the investigation are shown in Table 1. The BOD5/COD ratio was at 0.7, which is typical of POME wastewater. The ASBR's start-up period lasted 90 days, following which the reactor was stabilised. The pH in the reactor fluctuated from 6.96 to 7.63 during the start-up period, with a mean of 7.23 0.16, which is within the ideal working range for anaerobic systems.During this period, biogas generation fluctuated in the range of 2.68 ± 0.54 L/d. Figure 1 illustrates the setup of the ASBR and the reactor acclimatisation.To avoid a temperature shock, the temperature was increased from the mesophilic condition (35 ◦C) to the target temperature of 45-55 ◦C by gradual increments of 2 ◦C per time through agitation and natural solar irradiation due to demography (Edo-State, Nigeria). The operational pH in the Continuously Stirred Tank Reactor should be kept between 6.5 and 8.2 since this range is thought to be optimal for methanogenic microorganisms to create biogas and to buffer capability against acid shock owing to overload conditions [11]. During the start-up phase, the pH value in the reactor was found to be steady at 7.23 0.16 and within the optimal range. Previous studies with anaerobic membrane bioreactors treating industrial wastewater showed roughly three months of acclimation [12,13]. On the other hand, this study was able to achieve steady-state conditions after only 90 days of acclimatisation.

4. Conclusion

Because of their excellent treatability and biogas generation, anaerobic treatment techniques have gained popularity in treating palm oil mill wastewater. The use of externally submerged membranes in anaerobic reactors helps to keep the biomass contained within the reactor. The ASBRs in this investigation were operated at 37-45 degrees Celsius under thermophilic settings.This study showed that the three-stage ASBR is an effective method fortreating POME. The removal efficiency of COD, BOD, and TSS was over 60% in theorganic loading rates of 100kg, 50kg and 20 kg COD/m^3·d. Biogas generation rate and methanecomposition increased linearly with the organic loading rates, but the gas was expelled. Therefore, it can be concluded that ASBR can be an alternative way for effective POME treatment. The study suggests that the system could perform at stable conditions at higher organic loading rates. Again, there is the need for further treatment of the POME wastewater for decolourisation possible by using an adsorbent. Further testing of the POME through the ASBR will capture the decolourisation of the POME.

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Writing-Original Draft Preparation, Suleiman A. I

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Nomenclature

ASBR Anaerobic sequencing batch reactor

COD Chemical oxygen demand

CSTR Complete stirred tank reactor

H_2S Hydrogen sulfide

MLVSS mixed liquor volatile suspended solids

N Nitrogen

P Phosphorous

SMPR Specific methane production rate

TSS Total suspended solids

VFA Volatile fatty acids

VSS Volatile suspended solids

REFERENCES

1. Wang, J.; Mahmood, Q.; Qiu, J.P.; Li, Y.S.; Chang, Y.S.; Li, X.D. Anaerobic treatment of palm oil mill effluentin pilot-scale anaerobic EGSB reactor. Biomed. Res. Int. 2015, 2015, 398028. [CrossRef]
2. Lam, M.K.; Lee, K.T. Renewable and sustainable bioenergies production from palm oil mill effluent (POME): Win-win strategies toward better environmental protection. Biotechnol. Adv. 2011, 29, 124–141. [CrossRef][PubMed]
3. Ma, A.N. Environmental management for the palm oil industry. Palm Oil Dev. 2000, 30, 1–10.
4. Choi, W.; Shin, C.; Son, S.; Ghorpade, P.A.; Kim, J.; Park, J. Anaerobic treatment of palm oil mill effluent using combined high-rate anaerobic reactors. Bioresour. Technol. 2013, 141, 138–144. [CrossRef] [PubMed]
5. Khanal, S.K. Anaerobic Biotechnology for Bioenergy Production: Principles and Applications; Wiley & Sons, Inc.: New York, NY, USA, 2008.
6. Jeong, J.Y.; Son, S.M.; Pyon, J.H.; Park, J.Y. Performance comparison between mesophilic and thermophilic anaerobic reactors for palm oil mill effluent treatment. Bioresour. Technol. 2014, 165, 122–128. [CrossRef]
7. APHA. Standard Methods for the Examination of Water and Wastewater; American Public Health Association: Washington, DC, USA, 2017.
8. Ahmad, A.; Ghufran, R.; Wahid, Z.A. Bioenergy from anaerobic degradation of lipids in palm oil mill effluent. Rev. Environ. Sci. Biotechnol. 2011, 10, 353–376. [CrossRef]
9. Comte, I.; Colin, F.; Whalen, J.K.; Grünberger, O.; Caliman, J.P. Agricultural Practices in Oil Palm Plantations and Their Impact on Hydrological Changes, Nutrient Fluxes, etc Water Quality in Indonesia. A Review; Elsevier Ltd.: New York, NY, USA, 2012; Volume 116, ISBN 9780123942777.
10. Chan, Y.J.; Chong, M.F.; Law, C.L. An integrated anaerobic-aerobic bioreactor (IAAB) for treating palm oil mill effluent (POME): Start-up and steady-state performance. Process. Biochem. 2012, 47, 485–495. [CrossRef]
11. Usack, J.G.; Spirito, C.M.; Angenent, L.T. Continuously-stirred anaerobic digester to convert organic wastes into biogas: System setup and basic operation. J. Vis. Exp. 2012, 65, e3978. [CrossRef] [PubMed]
12. Achilli, A.; Marchand, E.A.; Childress, A.E. A performance evaluation of three membrane bioreactor systems: Aerobic, anaerobic, and attached-growth. Water Sci. Technol. 2011, 63, 2999–3005. [CrossRef]
13. Xia, T.; Gao, X.; Wang, C.; Xu, X.; Zhu, L. An enhanced anaerobic membrane bioreactor treating bamboo industry wastewater by bamboo charcoal addition: Performance and microbial community analysis. Bioresour. Technol. 2016, 220, 26–33. [CrossRef]
14. Iorhemen, O.; Hamza, R.; Tay, J. Membrane bioreactor (MBR) technology for wastewater treatment and reclamation: Membrane fouling. Membranes 2016, 6, 33. [CrossRef] [PubMed]
15. Stuckey, D.C. Recent developments in anaerobic membrane reactors. Bioresour. Technol. 2012, 122, 137–148. [CrossRef] [PubMed]

16. 16. Abdurahman, N.H.; Rosli, Y.M.; Azhari, N.H. Development of a membrane anaerobic system (MAS) forpalm oil mill effluent (POME) treatment. Desalination 2011, 266, 208–212. [CrossRef]
17. Fakhru'l-Razi, A.; Noor, M. Treatment of palm oil mill effluent (POME) with the membrane anaerobic system(MAS). Water Sci. Technol. 1999, 39, 159–163. [CrossRef]
18. Damayanti, A.; Ujang, Z.; Salim, M.R. The influence of PAC, zeolite, and Moringa oleifera as biofoulingreducer (BFR) on hybrid membrane bioreactor of palm oil mill effluent (POME). Bioresour. Technol. 2011, 102,4341–4346. [CrossRef] [PubMed]
19. Ng, C.A.; Wong, L.Y.; Chai, H.Y.; Bashir, M.J.; Ho, C.D.; Nisar, H.; Lo, P.K. Investigation on the performanceof hybrid anaerobic membrane bioreactors for fouling control and biogas production in palm oil mill effluenttreatment. Water Sci. Technol. 2017, 76, 1389–1398. [CrossRef]
20. 20. Borja, R.; Banks, C.J.; Sánchez, E. Anaerobic treatment of palm oil mill effluent in a two-stage up-flowanaerobic sludge blanket (UASB) system. J. Biotechnol. 1996, 45, 125–135. [CrossRef]
21. Yacob, S.; Hassan, M.A.; Shirai, Y.; Wakisaka, M.; Subash, S. Baseline study of methane emission fromanaerobic ponds of palm oil mill effluent treatment. Sci. Total Environ. 2006, 366, 187–196. [CrossRef][PubMed]
22. Yacob, S.; Hassan, M.A.; Shirai, Y.; Wakisaka, M.; Subash, S. Baseline study of methane emission from opendigesting tanks of palm oil mill effluent treatment. Chemosphere 2005, 59, 1575–1581. [CrossRef]
23. Borja, R.; Banks, C.J. Treatment of palm oil mill effluent by upflow anaerobic filtration. J. Chem. Technol.Biotechnol. 1994, 61, 103–109. [CrossRef]
24. Tong, S.L.; Jaafar, A.B. POME Biogas capture, upgrading and utilisation. Palm Oil Eng. Bull. 2006, 78, 11–17.
25. Ibrahim, A.; Yeoh, B.G.; Cheah, S.C.; Ma, A.N.; Ahmad, S.; Chew, T.Y.; Raj, R.; Wahid, M.J.A. Thermophilicanaerobic contact digestion of palm oil mill effluent. Water Sci. Technol. 1984, 17, 155–165. [CrossRef]
26. Ariunbaatar, J.; Di Perta, E.S.; Panico, A.; Frunzo, L.; Esposito, G.; Lens, P.N.; Pirozzi, F. Effect of ammoniacalnitrogen on one-stage and two-stage anaerobic digestion of food waste. Waste Manag. 2015, 38, 388–398.[CrossRef] [PubMed]
27. Dvoˇrák, L.; Gómez, M.; Dolina, J.; Cern ˇ ín, A. Desalination and Water Treatment. Anaerobic membranebioreactors—A mini-review with emphasis on industrial wastewater treatment: Applications, limitationsand perspectives. Desalination Water Treat. 2016, 57, 19062–19076. [CrossRef]
28. Lin, H.; Peng, W.; Zhang, M.; Chen, J.; Hong, H.; Zhang, Y. A review on anaerobic membrane bioreactors:Applications, membrane fouling and future perspectives. Desalination 2013, 314, 169–188. [CrossRef]
29. Dereli, R.K.; Ersahin, M.E.; Ozgun, H.; Ozturk, I.; Jeison, D.; van der Zee, F.; van Lier, J.B. Potentials ofanaerobic membrane bioreactors to overcome treatment limitations induced by industrial wastewaters.Bioresour. Technol. 2012, 122, 160–170. [CrossRef]

