The Potentials of an Integrated Ultrasonic Membrane Anaerobic System (IUMAS) in Treating Sugar Cane Wastewater

Abdurahman Hamid Nour*, Yasmeen Hafiz Zaki, Hybat Salih Mohamed, and Hesham Hussein Rassem

Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak 26300, Gambang, Pahang, Malaysia

* ***Corresponding author:***

email: nour2000_99@yahoo.com

Received: August 3, 2018
Accepted: December 4, 2018

DOI: 10.22146/ijc.40866

Abstract: *Excess levels of organic and inorganic matters in the discharge from sugarcane mill effluent (SCME) wastewater causes the earnest environmental issue. In this study, a single unit integrated ultrasonic membrane anaerobic system (IUMAS) has been investigated for industrial sugarcane wastewater treatment. The "Membrane-fouling" is one of the main constraints of IUMAS which eventually reduce the processing ability. In the present study, most researchers resort to cost reduction. IUMAS was alternatively applied as an economical approach to SCME wastewater treatment. The application of "Multiple-analysis" methods (COD, BOD, TSS) and three kinetic models during the treatment, suggested the specific range of organic loading rate to produce biogas. The result showed an increase in methane gas production up to 80% in the biogas, with 94–96% of COD removal efficiency from the SCME wastewater. Results concluded the effectiveness and efficiency of IUMAS to reduce the membrane fouling and to treat the SCME wastewater as well as enhance the production of methane gas.*

Keywords: *chemical oxygen demand; integrated ultrasonic membrane anaerobic system; kinetics*

INTRODUCTION

Nowadays, the production of wastewater is a big issue throughout the world; therefore, researchers and organizations are focusing on treating the wastewater produced from industrial processes to prevent the environmental problems caused by these wastewaters. Currently, many methods are in use for the treatment of wastewater, including aerobic, membrane bioreactors, disinfection technologies, electrochemical systems, and denitrifying biofilters [1]. The environment contains many compounds with different physical and biological conditions. Nowadays, environmental issues exposed humans to different kinds of health problem [2]. Researchers found that the wastewater discharged from industrial processes is the main problem for the environment, which contains highly toxic organic pollutants [3]. Where it has been tested a few of these chemicals, only around 20% of the many chemicals which consider enough to affect the health and the environment [4]. There are different kinds of testing apparatus for the level of water pollution like COD and BOD that can be determined and compared with the uniform effluent standard. Wastewater treatment is a costly process which requires high investments, large areas, and advanced processing [5]. Almost, 168 million tons of biomass produced in the world yearly in Malaysia, involve oil palm waste, municipal, slaughterhouses, sugarcane wastes, and coconut trunk fibers [6]. In Malaysia, sugarcane is produced widely at Chuping, Perlis (MSM Malaysia Holdings Berhad), Gula Padang Terap Kedah, and Central Sugars Refinery (CSR) for the production of sugar. However, in 2011, the sugarcane cultivation has been stopped and was replaced by a palm tree. Still, sugar production extends in Malaysia, but cane sugar has been imported from other countries like Thailand and Brazil [7].

Usually, sugarcane is cultivated in tropical and subtropical environments. The main product of the sugarcane is sucrose, while there are some by-products as well including bagasse, molasses, and filter cake. This process requires a high amount of water along with fertilizers and the large areas of land, which is the big challenge in the development of bioenergy process [8]. After cutting, the cane is loaded by hand and mechanical grab loaders. Usually, trucks, barges, and trailers were used for cane transportation to the processing plants and place of the cane field. Once the sugarcane is cut, an immediate deterioration starts [7]. The wastewater discharged from sugarcane industries is considered as a good feedstock for the production of methane gas and fuel as well [9-10]. Methane and fuel are considered as the largest source of energy (natural gas and Liquefied Natural Gas (LNG)) which were produced from the sugarcane wastewater [11]. The benefit of producing methane gas could decrease the cost of generating electricity and fuel [8].

The Renewable Fuels Association (2004) reported that more attention is required to develop alternative energy sources such as ethanol fuel after the 20th century. Besides, many organizations revealed that sugarcane wastewater is also a good source of green gas like methane. [9,11]. Sugarcane wastewater can be identified by its vicious brownish appearance, and its pH value ranging from 5.3 to 8.8. Some other notable features of this water are the 560 mg/L biochemical oxygen demand (BOD), coupled with 1984 mg/L and 375 mg/L chemical oxygen demand (COD) and suspended solids (SS) components respectively. Pollution problems resulting from sugarcane wastewater influence on the environment where the sugarcane wastewater treatment has been the present success to create methane gas. The conventional methods of wastewater treatment such as a physicochemical process in wastewater treatment (coagulation and flocculation) are not considered as a proper technique due to high processing cost and low yield.

Therefore, biological treatment is an extended field that it showed great success in the remediation of hazardous waste problems. One of these treatments is anaerobic [12-14]. Anaerobic digestion is the most appropriate way to treat sugar cane. It can be described as the decay of organic matter through an orchestrated decay route involving methanogenic anaerobic processed [15]. As such, degradation of organic matter is achieved through the help of anaerobic microorganisms of different species. One major requirement of the anaerobic digestion is that molecular oxygen is not present in the substrate decomposition procedures [16-17]. As the known, methanogens will convert hydrogen, acetic acid, and ammonia, to methane (CH_4) and carbon dioxide (CO_2) [18-19]. The features of anaerobic digestion can hence be seen from the perspective of renewable energy source with good energy conservation and decreased the emission of landfill gas into the weather. The advancement in the efficiency of anaerobic digestion was conducted by modulating the existing digester design by incorporating suitable improved methods. The conventional methods special used membrane faces some problems effected on the treated wastewater and produce biogas such as damaged pumps, clogging, extremely high maintenance costs and the capture of methane gas are few.

This study aims to assess the performance of IUMAS with respect to OLR, as well as the efficiency of IUMAS for treating wastewater emanating from sugarcane mill effluent. In addition, estimation of the dynamic process parameters shall be carried out using

Table 1. Mathematical Substrate utilization rates for kinetic models

Kinetic Model	Equation 1	Equation 2
Monod (1949) [26]	$U = \frac{kS}{k_s + S}$	$\frac{1}{U} = \frac{K_s}{K}\left(\frac{1}{S}\right) + \frac{1}{k}$
Contois (1959) [27]	$U = \frac{U_{max} \times S}{Y(B \times X + S)}$	$\frac{1}{U} = \frac{a \times X}{\mu_{max} \times S} + \frac{Y(1+a)}{\mu_{max}}$
Chen and Hashimoto (1980) [28]	$U = \frac{\mu_{max} \times S}{YKS_0 + (1-K)SY}$	$\frac{1}{U} = \frac{YKS_0}{\mu_{max}S} + \frac{Y(1-K)}{\mu_{max}}$

three kinetic models. Table 1 presents the rates for applications of the specific substrate as calculated from the kinetic models such as Monod, Contois, as well as Chen and Hashimoto.

METHODOLOGY

Wastewater of crude sugarcane was treated by IUMAS method with an effective volume of 200 L in a laboratory digester. The schematic representation of IUMAS is shown in Fig. 1. This process is including of feeder tank, centrifugal pump, pressure gauge and an ultrasonic membrane combined with a cross-flow ultrafiltration membrane (CUF) anaerobic reactor consisting of ultrasonic transducers which have 25 KHz multi-frequency capacity. The transducer produces high mechanical energy in the surrounding of the membrane surface for particle suspending. The ultrasonic frequency of 25 KHz comprises 6 permanent transducers units which are connected to the tank chamber from both sides and also bonded to a single unit Crest's Genesis Generator with 250 Watts and 25 KHz capacity. The molecular weight cut-off (MWCO) in UF membrane module is 200,000 μm, 0.1μm average pore size, and a 1.25 cm tube diameter. Each tube had a length of 30 cm, whereas the four-membrane total effective area was 0.048 m^2. In this process, the membrane has an operating pressure of about 55 bars in maximum, pH range between 2 to 12 and temperature at 70 °C. The process consists of a heavy reactor whose total height is about 250 cm whereas the internal diameter is about 25 cm. To maintain the pressure in the ranges of 2 to 4 bars, the operating system is equipped by manipulating valves in the retentate line following the CUF unit.

Analytical

The parameters analyzed were total suspended solids (TSS), pH, BOD, COD, and volatile suspended solids (VSS). Measurement the COD was achieved through the help of a HACH colorimetric digestion method (Method 8000, HACH Company, and Loveland, CO, USA). On the other hand, determination of the mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) was carried out by drying the sample at 105 and 550 ± 50 °C. Gas chromatography was used to determine the methane gas with a specification of 200 cm × 0.3 cm stainless steel column which is packed with 30–60 mesh active carbon, and thermal conductivity detector. Other parameters such as VSS, volatile fatty acids, alkalinity and TSS were evaluated using established procedures [20].

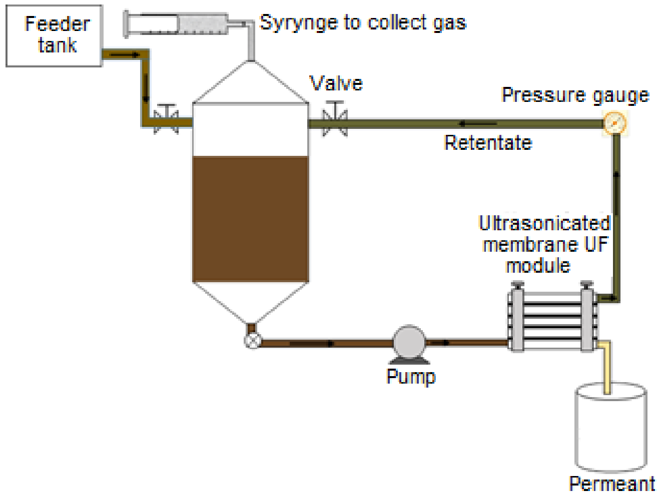

Fig 1. Experimental design

Sugarcane (SC) Wastewater

Raw samples of the wastewater were obtained from the effluent of a sugarcane mill which is situated in Perak-Malaysia. The samples were chilled at 4 °C before use to retain the microorganism's properties. This raw wastewater contains a large number of suspended solids, organic matter, and also mud [21]. Hence the samples were subjected to analysis for assessing the COD, TSS, pH, SUR, SSUR, and VSS. Raw sugarcane wastewater sample includes higher organic loading rate (OLR). SO, the raw samples undergo a screening process or sieving before entering the bioreactor to avoid pump blockage during the treatment process (it is a major reason to stop the experiment). Let the sample in bioreactor five days before the experiment was run to ensure microbial become acclimatized to a new environment on the first day of the reactor[16].

Operation of the Bioreactor

The IUMAS design was estimated under six fixed conditions and each need around 9-14 days. Next, the experiment was run for 5 and 3 h interval of ultrasonic waves onto the system. Table 2 shows the effect of OLR

Table 2. Characteristics of sugarcane wastewater

Steady State (SS)	1	2	3	4	5	6
COD feed, mg/L	9200	11500	17300	19900	22400	26100
COD permeate, mg/L	340	560	780	970	1020	1570
Total gas yield, L/g COD/d	0.41	0.47	0.58	0.65	0.70	0.75
Gas production (L/d)	190.5	220	260	320	360	373
% Methane	76	72.4	70.3	68.8	66.8	64.7
CH_4 yield, l/g COD/d	0.31	0.34	0.57	0.59	0.58	0.61
MLVSS, mg/L	5874	8339	10129	11606	12425	13068
MLSS, mg/L	8500	9650	11400	12800	13850	14700
% VSS	69.40	86.41	88.85	90.67	89.71	88.90
HRT, d	280.5	66.40	18.70	15.80	12.60	9.8
SRT, d	580	298	127	26.8	13.44	11.8
SSUR, kg COD/kg VSS/d	0.164	0.195	0.252	0.263	0.294	0.314
SUR, kg COD/m^3/d	0.023	0.724	2.225	4.576	5.685	7.347
OLR, kg COD/m^3/d	5.0	7.0	9.0	11	13	15
Percent COD removal (UMAS)	96.3	95.1	95.5	95.1	95.4	94.0

in the range of 3.0 to 15 kg COD/m^3/d and range of COD concentrations between 9,200 and 26,100 mg/L. The organic loading rates (OLR) used in this study was from (3.0 to 15 kg COD/m^3/d) and the concentration of COD was ranging between (9,200 to 26,100 mg/L), as explained in Table 2. Herein, the IUMAS was assumed to have reached a steady state. Hence in this system, ± 10% allowance was given for the control and operating of the average value of all parameters. The biogas yield includes both CO_2 as well as CH_4, so to separate these components, a solution of NaOH was added to absorb the CO_2 effectively, by using a syringe. The resulting gas components were CO_2 and CH_4, then to absorb the CO_2 without any effect to CH_4, NaOH solution was added. Table 3 illustrates the results obtained from the implementation of the substrate utilization models.

RESULTS AND DISCUSSION

Performance of the Integrated Ultrasonic-Membrane Anaerobic System (IUMAS) Performance

The data generated from the estimation of the IUMAS performance is presented in Table 2. The implementation and recording of the IUMAS procedures were made under varying COD influent concentrations, as well as HRTs. From Eq. 2, the coefficients models were obtained using a linear relationship as shown in Table 1, and the value of the coefficients models are summarized in Table 3. When the influent COD concentrations of 9,200–26,100 mg/L, the experimental reached the steady-state conditions, IUMAS showed a good performance due to the ability of ultrasonic membrane that cleans the surface of the collected particles from

Table 3. Results of the application of three known substrate utilization models

Model		Equation	R^2 (%)
Monod	U^{-1}	$= 2025^{-1}\ S^{-1} + 3.61$	
	K_S	= 498	
	K	= 0.350	96.0
	μ_{max}	= 0.284	
Contois	U^{-1}	$= 0.306\ X\ S^{-1} + 2.78$	
	B	= 0.111	
	μ_{max}	= 0.344	
	a	= 0.115	93.0
	μ_{max}	= 0.377	
	K	= 0.519	
Chen and Hashimoto	U^{-1}	$= 0.0190\ S_0\ S^{-1} + 3.77$	
	K	= 0.006	
	a	= 0.006	58.5
	μ_{max}	= 0.291	
	K	= 0.374	

U: Specific substrate utilisation rate (SSUR) (g COD/G VSS/d); K_S: Half velocity coefficient (mg COD/L); K: Maximum substrate utilization rate; S: Effluent substrate concentration (mg/L); S_0: Influent substrate concentration; X: Micro-organism concentration wastewater. In addition, the pH within the reactor was found to be stable to the optimal points ranging from (6.7–7.8) for anaerobic digesters.

At the initial state, the MLSS concentration was 8,500 mg/L, while MLVSS was 5,874 mg/L. This value represents 69.40% of the MLSS. The presence of high suspended solids in the sugarcane wastewater might have led to the decreased value of this result. However, at the 6th state, there has been an increase of about 88.90% amount of VSS in the reactor with respect to the MLSS. This suggests that the IUMAS SRT which is long could help to facilitate the hydrolysis of the suspended solids such that their transformation to CH_4 becomes easier, that is in agreement with the results found by Abdurahman et al., and Martinez-Jimenez et al. [15-16]. When the OLR is 15 kg COD/m^3/d, the highest COD influent was obtained at the 6th steady-state with a value of about 26100 mg/L. At this stage, the IUMAS offered 94% COD removal with a COD effluent equal to 1570 mg/L. Table 2 depicted an increasing OLRs which indicated an increase in the substrate utilization rates (SUR), as well as specific substrate utilization rates (SSUR). This suggests that there is a multiplication in the population of bacteria within the IUMAS [26]. Hence, the increase in the concentration of the substrate might have led to the significant increment in the specific substrate utilization rates, and SSURs. This is an indication that the increasing amount of COD influent supplied to the reactor was accounted for by the amount of COD consumed by the bacteria populations.

Interestingly, the value obtained herein surpasses what has been previously reported on digestion of wastewater through anaerobic processes [22]. As a result, the three models verified an excellent relationship (R^2 > 96%) for the treatment of sugarcane wastewater using an anaerobic membrane system as illustrated in Fig. 2–4. The first and second models detected a better performance, which is an indication that there is a need to consider the rates of organic loading in the digester implementation. Monod and Contois's models proposed that the permeate concentration of COD which was predicted (S) is a function of the concentration of COD influent (S_0). However, the third model suggests that S does not depend on S_0. Notwithstanding, the three models presents excellent suitability (R^2 > 97.8%). In essence, this study project proposed that the IUMAS approach can be explored process is eligible for managing organic loads in the range of 3 to 15 kg m$^{3/}$d.

The relationship between COD and HRT

There is a need for a certain degree of treatment of sugarcane wastewater before been discharged for agricultural or landscape irrigation or any use except drink water. This is often assessed in terms of COD. The

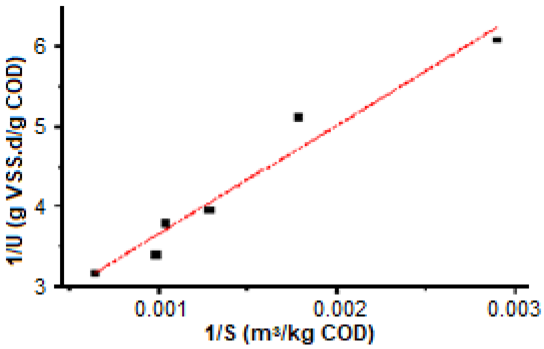

Fig 2. The Monod model

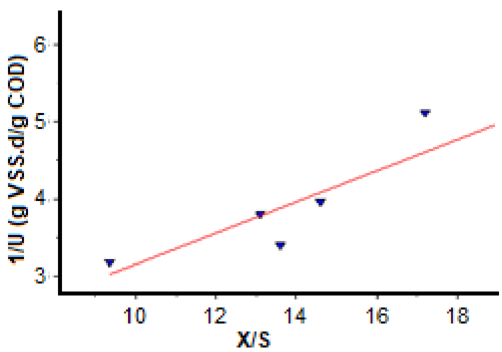

Fig 3. The Contois model

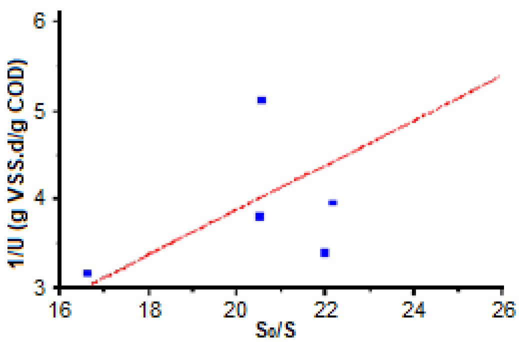

Fig 4. The Chen and Hashimoto model

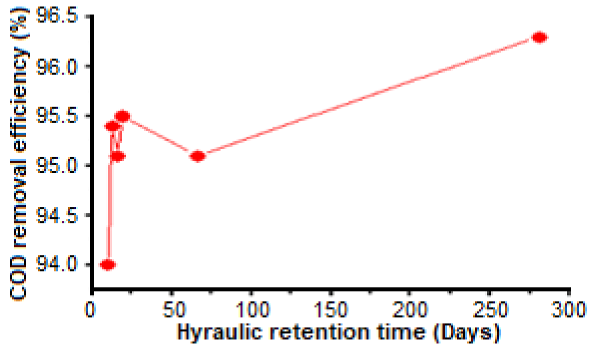

Fig 5. The COD removal efficiency of IUMAS HRT

amount of COD eliminated by IUMAS at different hydraulic retention time (HRT) is shown in Fig. 5. Notably, the efficiency and effectiveness of COD removal can be seen to increase when the HRT changes from 280.5 to 9.8 days with a removal efficiency in the range between 94 and 96.3%. Interestingly, this value is larger than 85% COD removal which was obtained when anaerobic fluidized bed reactors were used to treat wastewater from palm oil mill effluent (POME) [23]. Likewise, the value is larger than the 91.7–94.2% removal which was obtained for the treatment of POME wastewater through the use of MAS [24-25]. The efficiency of COD removal did not vary significantly as can be seen from the result of the efficiency of COD removal at HRTs of 280.5 days (96.3%) and 12.6 days (95.4%). However, at HRT of 9.8 days, the COD was reduced to 94%, wherein the efficiency of COD became lesser with shorter HRTs as explained in Table 2. This resulted in the washout phase for the reactor, and this is due to increasing biomass concentration in the system. This indicated that at high OLR with the low HRTs, degradation of the organic matter into volatile fatty acids (VFA) did occur. Fundamentally, there is a resultant effect on the HRTs by the influx-rates of the ultra-filtration, UF membrane which directly influences the amount of influent (SCME) which may be introduced into the reactor.

CONCLUSION

The IUMAS was studied using three models (i.e., Monod, Contois, and Chen and Hashimoto models at R^2 > 97.8%). These three models were suitable over a large OLRs range (3–15, kg COD/m^3/d). This result concluded that the biological treatment of undiluted sugarcane waste water is suitable by IUMAS. IUMAS has kept 80% of CH_4 gas, with an overall substrate removal capacity which is considerably large (96.6%). Observation from the study revealed that the highest COD removal efficiency was observed in the range of 94 to 96.3% at HRT from 280.5 to 9.8 days. This was attributed to the increase in influent COD concentrations from 9,200 mg/L during the 1st steady state to a value of about 26,100 mg/L during the 6th steady state. These results indicated that during the IUMAS treatments, the solution and suspended organics in the sugarcane wastewater were adequately degraded.

ACKNOWLEDGMENTS

This study was kindly supported by the postgraduate student scholarship grant (PGRS 180332) by University Malaysia Pahang-UMP.

REFERENCES

[1] Angelakis, A.N., and Snyder, S.A., 2015, Wastewater treatment and reuse: Past, present, and future, *Water*, 7 (9), 4887–4895.

[2] Finkelman, R.B., Orem, W.H., Plumlee, G.S., and Selinus, O., 2018, "Applications of Geochemistry to Medical Geology" in *Environmental Geochemistry: Site Characterization, Data Analysis and Case Histories*, 2nd ed., Eds., De Vivo, B., Belkin, H.E., and Lima, A., Elsevier B.V., 435–465.

[3] Atalay, S., and Ersöz, G., 2016, *Novel Catalysts in Advanced Oxidation of Organic Pollutants*, Springer International Publishing.

[4] Aygun, A., Nas, B., and Berktay, A., 2008, Influence of high organic loading rates on COD removal and sludge production in moving bed biofilm reactor, *Environ. Eng. Sci.*, 25 (9), 1311–1316.

[5] Zhou, S., Patty, A., and Chen, S., 2017, Advances in Energy Science and Equipment Engineering II, *Proceedings of the 2nd International Conference on Energy Equipment Science and Engineering (ICEESE 2016)*, 12-14 November, 2016, Guangzhou, China.

[6] Ozturk, M., Saba, N., Altay, V., Iqbal, R., Hakeem, K.R., Jawaid, M., and Ibrahim, F.H., 2017, Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia, *Renewable Sustainable Energy Rev.*, 79, 1285–1302.

[7] Umo, A.M., and Alabi, S.B., 2016, Advances in super-saturation measurement and estimation methods for sugar crystallisation process, *Int. J. Food Eng.*, 2 (2), 108–112.

[8] Wang, S., Lu, G.Q., and Millar, G.J., 1996, Carbon dioxide reforming of methane to produce synthesis gas over metal-supported catalysts: State of the art, *Energy Fuels*, 10 (4) 896–904.

[9] Chen, T.T., Zheng, P., and Shen, L.D., 2013, Growth and metabolism characteristics of anaerobic ammonium-oxidizing bacteria aggregates, *Appl. Microbiol. Biotechnol.*, 97 (12), 5575–5583.

[10] Ullah, K., Ahmad, M., Sofia, Sharma, V.K., Lu, P., Harvey, A., Zafar, M., and Sultana, S., 2015, Assessing the potential of algal biomass opportunities for bioenergy industry: A review, *Fuel*, 143, 414–423.

[11] Stafford, W.H., Von Maltitz, G.P., and Watson, H.K., 2018, Reducing the costs of landscape restoration by using invasive alien plant biomass for bioenergy, *Wiley Interdiscip. Rev.: Energy Environ.*, 7 (1), 272.

[12] Cheremisinoff, N.P., 1997, *Biotechnology for Waste and Wastewater Treatment*, William Andrew Publishing, Norwich, United States.

[13] Kolarik L.O., and Priestley A.J., 1996, *Modern Techniques in Water and Wastewater Treatment*, CSIRO Publishing.

[14] Subramanian, B., and Pagilla, K.R., 2014, Anaerobic digester foaming in full-scale cylindrical digesters–Effects of organic loading rate, feed characteristics, and mixing, *Bioresour. Technol.*, 159, 182–192.

[15] Abdurahman, N.H., and Azhari, N.H., 2013, Performance of ultrasonic membrane anaerobic system (UMAS) in membrane fouling control, *IJESIT*, 2 (6), 480–491.

[16] Martinez-Jimenez, F.D., Pinto, M.P.M., Mudhoo, A., Neves, T.A., Rostagno, M.A., and Forster-Carneiro, T., 2017, Influence of ultrasound irradiation pre-treatment in biohythane generation from the thermophilic anaerobic co-digestion of sugar production residues, *J. Environ. Chem. Eng.*, 5 (4), 3749–3758.

[17] Poh, P.E., Tan, D.T., Chan, E. S., and Tey, B.T., 2015, "Current Advances of Biogas Production via Anaerobic Digestion of Industrial Wastewater" in *Advances in Bioprocess Technology*, Eds., Ranvindra, P., Springer International Publishing, 149–163.

[18] de Lemos Chernicharo, C.A., 2017, *Anaerobic Reactors*, IWA Publishing, London, UK.

[19] APHA, 2005, *Standard Methods for the Examination of Water and Wastewater*, 21st ed., American Public Health Association, Washington, DC, USA.

[20] Poddar, P.K., and Sahu, O., 2017, Quality and management of wastewater in sugar industry, *Appl. Water Sci.*, 7 (1), 461–468.

[21] Borja-Padilla, R., and Banks, C.J., 1993, Thermophilic semi-continuous anaerobic treatment of palm oil mill effluent, *Biotechnol. Lett.*, 15 (7), 761–766.

[22] Wu, T.Y., Mohammad, A.W., Jahim, J.M., and Anuar, N., 2010, Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes, *Environ. Manage.*, 91 (7), 1467–1490.

[23] Fakhru'l-Razi A., 1994, Ultrafiltration membrane separation for anaerobic wastewater treatment, *Water Sci. Technol.*, 30 (12), 321–327.

[24] Abdurahman, N.H., Rosli, Y.M., and Azhari, N.H., 2011, Development of a membrane anaerobic system (MAS) for palm oil mill effluent (POME) treatment, *Desalination*, 266 (1-3), 208–212.

[25] Abdullah, A.G.L., Idris, A., Ahmadun, F.R., Baharin, B.S., Emby, F., Noor, M.J.M.M., and Nour, A.H. 2005, A kinetic study of a membrane anaerobic reactor (MAR) for treatment of sewage sludge, *Desalination*, 183 (1-3), 439–445.

[26] Monod, J., 1949, The growth of bacterial cultures, *Annu. Rev. Microbiol.*, 3, 371-394.

[27] Contois, D.E., 1959, Kinetics of bacterial growth: Relationship between population density and space growth rate of continuous cultures, *J. Gen. Microbiol.*, 21 (1), 40–50.

[28] Chen, Y.R., and Hashimoto, A.G., 1980, Substrate utilization kinetic model for biological treatment processes, *Biotechnol. Bioeng.*, 22 (10), 2081–2095.