American Journal of Quantum Chemistry and Molecular Spectroscopy
2021; 5(1): 10-15
http://www.sciencepublishinggroup.com/j/ajqcms
doi: 10.11648/j.ajqcms.20210501.12

Influence of Unlike Proportions of Preliminary and Activated Sludge on Methane Generation During Anaerobic Co-digestion

Md. Nurul Islam Siddique[1, *], Mohd Zamri Bin Ibrahim[1], Mohd Mokhlesur Rahman[2]

[1]Faculty of Ocean Engineering Technology and Informatics, University Malaysia Terengganu (UMT), Terengganu, Malaysia
[2]East Coast Environmental Research Institute, Universiti Sultan Zainal Abidin, Terengganu, Malaysia

Email address:
m.nurul@umt.edu.my (Md. N. I. Siddique)
[*]Corresponding author

To cite this article:
Md. Nurul Islam Siddique, Mohd Zamri Bin Ibrahim, Mohd Mokhlesur Rahman. Influence of Unlike Proportions of Preliminary and Activated Sludge on Methane Generation During Anaerobic Co-Digestion. *American Journal of Quantum Chemistry and Molecular Spectroscopy*. Vol. 5, No. 1, 2021, pp. 10-15. doi: 10.11648/j.ajqcms.20210501.12

Received: April 20, 2021; **Accepted**: May 7, 2021; **Published**: May 27, 2021

Abstract: The aim of this study was to look into methane generation using different amounts of initial sludge (IS) and activated sludge (AS) for anaerobic transformation. To compare the best combination in analysis with a benchmark combination, C0, three experimental ratios (IS: AS) (v/v) were used: C1 (60: 40), C2 (80: 20), and C3 (100: 00). (40: 60). Anaerobic digestion was carried out at 37°C in mesophilic conditions with a 12 day HRT and a loading rate of 1.63 0.06 kg TVS/m3 day. In comparison to C0, biogas generation for ratios C1 and C2 increased from 25% to 38%. The maximum amount generated by combination C3, which was 52.44 percent more than that of C0, showed a clear improvement in specific methane generation. C1, which involves using less initial sludge and increasing activated sludge condensing, is the most realistic combination to use on a large scale. IS has a C/N proportion that is 2 times more than AS because of the higher organic compounds in IS. The obtained proportion of IS that ought to be added to AS to achieve the greatest methane production were 60 and 80% (combination C1 and C2), separately than the reference conditions, C0. Nevertheless, the influent ought to be deliberately arranged with a gradual increment to the ideal influent proportion to acclimatization of the microorganisms and avoid over-loading. 3.72 years are found to be the time needed to recover expenses.

Keywords: Methane, Anaerobic Co-digestion, IS: AS Ratio, Sludge

1. Introduction

The increasing population and industrialization have caused exceptional changes in water resources and reliable treatment techniques have turned into the significant focal point of research throughout the globe [15]. Scarcity of power sources turned into the primary objective in trend-setting innovations to beat vitality costs related to water and wastewater purification [16].

The abundance and deficient utilization of non-renewable energy sources have quickened the consumption of worldwide nonrenewable assets and environmental change [17]. Around the world, the activated sludge process is the most widely recognized organic treatment applied on wastewater treatment plants (WWTP) and is a compelling and effective treatment innovation just as large consumer of bio-energy, utilizing 40% of the electricity [18].

The expanding applications of treatment plants in ongoing decades caused a continuous increment in the quantity of sludge generation and in energy utilization [8, 9]. Creating feasible technologies has become significantly important because of the rising energy requirements, to limit worldwide energy utilization regardless of the nature of treated wastewater [10, 11]. This methodology might be applied by redesigning the various units of treatment plants, to improve the anaerobic treatment of sewage sludge [6]. Sludge treatment and minimization have turned into a first issue, as sludge generation will be increasing because of stringent ecological guidelines [18].

Anaerobic digestion is broadly utilized for the adjustment of blended sludge, a combination of initial sludge (IS) and activated sludge (AS) [2, 13]. IS is produced during physical treatment of preliminary sedimentation, while AS is created in the organic treatment system of treatment plants [19].

Besides, sludge handling expenses are around sixty percent of the total operating expenses of treatment plants. This implies that the challenge is to propose new arrangements which may be adjusted to traditional commercial-scale treatment plants, utilizing anaerobic digestion of blended sludge as a bio-process innovation, improving the energy stability [7].

Blended sludge as a solitary substrate is described by a lower C/N proportion (below ten) and generally lower anaerobic bio-digestibility, as the refractory materials present in sludge require longer retention time [20, 21]. Although anaerobic technology is considered an economic and naturally benevolent innovation, carries certain constraints which might be overcome by novel techniques [22-24].

As indicated by the previous studies in the field of the anaerobic digestion of sewage, two main concerns had been mentioned: improvement in biodegradability and methane generation in the anaerobic system [25-27].

Yet, little data can be found in the previous studies on the adjustments of sludge to improve methane generation to confront the imperatives in a traditional medium [28-30]. For this reason, the research work was started to overcome the few limitations of anaerobic digesters. The objective of this manuscript is to fill this gap by considering a few different ways of obtaining higher energy productions from IS and AS by their chemical structure and energy contents. In Europe, the most widely recognized sustaining blend of IS and AS utilized in treatment plants is 40: 60 (v/v), complying with different investigations. Subsequently, the objective of this work is to study the usefulness of a variation on this proportion to improve methane generation and waste minimization.

This study offers the advancement of sustainable power source generation, considering various properties of substrate blends and by the assessment of the IS and AS bioconversion into bio-methane. This methodology gives the likelihood of applying basic adjustments in feed substrates without disturbing the normal functions of the water treatment plants.

2. Materials and Methods

2.1. Substrates and Inoculum

The sludge utilized in this investigation was initial sludge (IS) and activated sludge (AS) and was collected from a full-scale wastewater treatment plant named Quantum Hydromech Sdn. Bhd., Kuantan, Pahang, Malaysia. Analysis was performed on IS and AS samples two times every month and transferred to Laboratory where they were kept at 4°C for further examinations. The fundamental properties of IS and AS utilized in this examination are listed in Table 1.

Table 1. *Properties of Feed wastewater (Average±SD).*

Parameters	Primary sludge	Waste activated sludge
TCOD (g/ L)	65±4	24±4
SCOD (g/ L)	5±0.05	0.3±0.15
SCOD/TCOD (%)	7	2
pH	5.7±0.3	6.5±0.2
EC (mS/ cm)	17±1	5±0.04
TS (g/ L)	55±3	24±1.5
TVS (g/ L)	37±4	19±3
TVS/TS (%)	67	79
TVSS (g/ L)	33±12	18±3
TVSS/TVS (%)	88	95
TKN (g/ L)	1.25±0.3	1.5±0.5
NH_4^+-N (g/ L)	0.3±0.03	0.4±0.05
TOC (g/ L)	22±5	11±1
TP (g/ L)	0.3±0.08	0.4±0.1
C/N	19	8

2.2. Batch Tests

To achieve the commercial-scale anaerobic degradation, a benchmark combination was prepared with a similar proportion of IS and AS (40: 60, v/v) and characterized as preliminary combination 0 (C0), after the acclimatization was established. To examine various combinations to improve the sustaining blend usually utilized in a treatment plant and to enhance the methane yield, three combinations of IS: AS (v/v) were utilized: combination 1 (C1), 60: 40; combination 2 (C2), 80: 20; and combination 3 (C3), 100: 0. Besides, to keep up the loading rate of 1.63±0.06 kg TVS/m^3 day related to the commercial scale, sustaining blends were diluted (Table 1) as per [3, 4] methods.

2.3. Fermentation

Anaerobic digestion was performed in a continuous stirred tank reactor comprised of stirrer, pumps, and temperature control panels. Biogas was collected in a gas collection bag by water displacement method. The parts of the anaerobic reactor were shown in Figure 1.

Figure 1. *Photograph of experimental set up.*

Initially, 65% nitrogen gas was used for 2 minutes to ensure anaerobic condition in the CSTR. The CSTR was seeded with 3 L of sludge from Quantum Hydromech Sdn.

Bhd., Kuantan, Pahang, Malaysia wastewater treatment plant. To keep away from the retention of the activated biomass in the reactor the stirrer works two additional times each day. The start-up was achieved after 2 months until acclimatization was established. Substrate blends were prepared as per the reference combination (C0).

Mesophilic (37°C) state with an HRT of 12 days were chosen for the experiments according to [31], and were continued for 4 months, separated into four combinations (C0, C1, C2, and C3).

2.4. Analysis

All the water quality parameters were analyzed by standard methods of [1]. The biogas produced by the CSTR 0was assessed by OMEGA® building gas meters. Biogas synthesis and VFAs were estimated by (Siddique et al., 2014). Standard techniques [1] were applied for pH, electrical conductivity (EC), TS, TVS, TSS, TVSS, TCOD, SCOD, TOC, TKN, NH_4 - N, and TP. The characteristics of the blends and effluents generated in each trial are listed in Table 2.

Table 2. *Digester output for after operation (Average±SD).*

Parameters	C0 (40: 60), V/V		C1 (60: 40), V/V		C2 (80: 20), V/V		C3 (100: 0), V/V	
	Feed	**Effluent**	**Feed**	**Effluent**	**Feed**	**Effluent**	**Feed**	**Effluent**
TCOD (g/ L)	41±0.4	23±0.2	39±1.5	21±8	40±2	22±5	38±4	18±0.4
SCOD (g/ L)	4.5±0.05	3.6±0.1	3±0.09	3.7±0.1	3.2±1.5	5.4±1.2	2.8±0.2	3.5±1
pH	5.9±0.3	7.2±0.3	5.7±0.2	7.5±0.2	5.6±0.2	7.4±0.2	5.4±0.2	7.3±0.4
EC (mS/ cm)	14.4±0.3	13±0.3	15.2±2	13.6±0.4	17±1.5	14±0.4	17.3±3	14.6±0.2
TS (g/ L)	32.6±0.7	26.4±0.7	33.7±1.7	25.3±2.5	34.6±0.5	25.8±2	33±4	20.6±7
TVS (g/ L)	24.9±0.9	15±0.5	22.7±1.3	13±3	25.9±0.9	11.5±8.5	22.6±2.3	9.7±1.9
TVS/TS (%)	76.5	57	67.5±0.2	51.4±0.2	73.4±0.1	69±0.4	68.5±0.2	46.8±0.3
TVSS (g/ L)	23±0.9	13±0.07	19±0.3	10.5±2	21.4±0.5	8.4±0.7	19±6	7.9±0.2
TKN (g/ L)	1.8±0.2	1.6±0.08	1±0.2	1±0.2	1.2±0.3	1.2±0.3	0.9±0.1	0.7±0.3
NH_4^+-N (g/ L)	0.4±0.2	0.7±0.05	0.3±0.02	0.6±0.02	0.3±0.02	0.6±0.02	0.3±0.04	0.3±0.03
TOC (g/ L)	14.4±1.5	8.7±0.04	13.2±1.2	7.5±1.3	14±0.06	10.3±2	13.3±2.6	5.6±0.3
TP (g/ L)	0.6±0.05	0.6±0.03	0.4±0.02	0.4±0.02	0.4±0.08	0.3±0.02	0.3±0.04	0.2±0.03
C/N	10	7	15	9	16	8	18	10

3. Results and Discussion

3.1. Characterization

The principle qualities of IS and AS utilized amid the test measures are demonstrated in Table 1.

Evaluating the properties of IS and AS, their contribution to the improvement of the anaerobic digestion system can be observed. Concerning C/N proportion of the IS and AS, we can observe that the increase of IS ratio in the mixture can improve the methane yield due to its C/N proportion approximately 2 times higher than that of AS. This complies with the study of [5, 6]. Another significant parameter to show the dependability of an anaerobic system is pH [11, 12]. Moreover, the pH of influents demonstrated a declining trend: 5.9 (C0), 5.7 (C1), 5.6 (C2), 5.4 (C3), showing that utilizing the C3 might make it progressively hard to accomplish stable states [13, 14]. In any case, investigating the effluent properties the pH was observed to be 7.2 (C0), 7.5 (C1), 7.4 (C2), 7.3 (C3) demonstrated that the response of the CSTR showed a sensible buffering capacity.

The various combinations of IS and AS in every experiment clarified the distinctions seen in the physicochemical properties examined, as listed in Table 2. The response of the sustaining blend properties demonstrated the synergetic impact of enhanced IS ratios in the CSTR influents to improve methane productions [32, 33].

3.2. Co-digestion Operation

In Table 3, the most extreme Ground-penetrating radar, GPR attained by combination C3 with an enhancement of around 37% compared to that of C0. An obvious enhancement was seen in specific methane production (SGP) produced by the combination, C3, which was 52.44% greater than that of C0. While examining specific methane generation utilizing an alternate parameter (SGP Methane, mL g/ TVS), we can see an identical trend ranged between 59.24% and 87%. The best outcome produced from the combination, C3 in terms of C/N proportion [12, 13]. The impact of this ratio among IS and AS, as mentioned between combinations C1 and C3, resulted in an improvement of the C/N proportion. This is suggested for the anaerobic system by [4]. Another fascinating viewpoint is the impact on CSTR performance while enhancing the ratio among IS and AS, as observed from the combination, C0 to C3, which appeared by an increment in TVS removal productivity of 42.85%.

The specific methanogenic capacity was steadily below 0.38 per day. Therefore, the activity of the methanogens was never surpassed indicating the likelihood of enhancing the OLR without the danger of digester instability that is as per past investigations of [34- 36]. Table 4 shows the day-by-day biogas generation during various experiments, with a mean of 8, 9, 10, and 11 NL /day for combinations C0, C1, C2, and C3 respectively. In comparison with C0 and the accompanying combinations achieved increments of 13, 25, and 38% individually, demonstrating an enhancement in the day-by-day biogas generation with the higher ratios of IS applied in blends. The properties of IS and AS could explain this enhancement as IS contains the more effectively biodegradable compound. Likewise, Figure 2 shows the specific methane generation that is as per the biogas generation profile, affirming the outcomes that appeared in Table 3. The specific methane generation enhanced from 59.24% to 87%. This synergistic impact was determined by the difference between the methane production from C0 and the methane production from combination C1, C2and C3 enhancing the ratio of IS in the substrate combination, which is as per the study of [37-39].

Table 3. *Operating parameters during experimental runs (Average±SD).*

Runs	C0	C1	C2	C3
Temperature °C	37±0.6	37±0.6	36±0.6	37±0.6
Substrate ratio (v/ v)	40: 60	60: 40	80: 20	100: 0
HRT (days)	17	17	17	17
GPR (NmL/L. day)	581	689	760	796
Methane (%)	64	71	69	72
SGPMethane (NmL g/TVS)	246 220	355 318	389 304	418 374
SGPMethane (NmL g/TCOD)	164 136	210 189	215 198	250 224
SGPMethane (NmL g/TVSS)	265 237	422 378	462 308	496 443
TVS removal,%	42	45	56	60
TCOD removal,%	46	47	50	54
TVSS removal,%	46	49	61	62
Specific methanogenic capacity (per day)	0.22	0.27	0.34	0.36

Table 4. *Daily Biogas production in different substrate ratios (C0-C3) (Average±SD).*

	C0	C1	C2	C3
Daily Biogas production (NL/day)	7±0.5	9±0.6	10±0.6	11±0.6

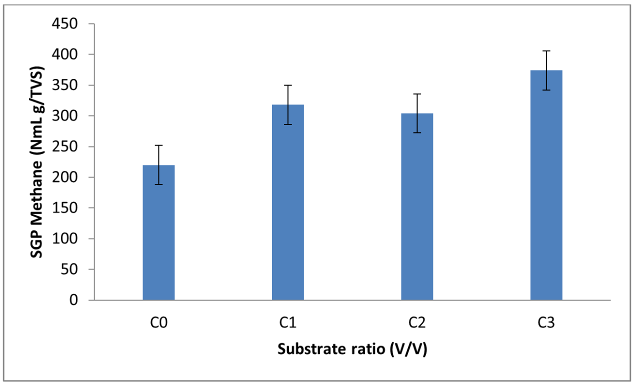

Figure 2. *Methane productions for different substrate (v/v) proportion.*

These increments might be clarified once the organic compounds (in TVS) are two times higher for IS than that of AS [40, 41, 42]. This conduct is likewise valid for the SCOD/TCOD proportion that was five times higher when comparing IS and AS [43-45]. It indicates an improvement in methane generation; these outcomes are as per the study of [46-48].

4. Conclusions

The findings that can be concluded from this study are listed below:

(1) IS has a C/N proportion that is 2 times more than AS because of the higher organic compounds in IS;

(2) An obvious enhancement was seen in specific methane generation with the maximum amount produced by combination C3, which was 52.44% more than that of C0;

(3) Assuming C0 as a kind of benchmark combination, with the higher ratio of IS, methane generation (SGP Methane, mL g/ TVS) enhanced from 59.24% and 87%;

(4) The obtained proportion of IS that ought to be added to AS to achieve the greatest methane production were 60 and 80% (combination C1 and C2), separately than the reference conditions, C0. Nevertheless, the influent ought to be deliberately arranged with a gradual increment to the ideal influent proportion to acclimatization of the microorganisms and avoid over-loading;

(5) Thus, C1 is the best choice as it may be applied at a commercial-scale waste treatment plant with little adjustments.

Acknowledgements

The authors are thankful to the School of ocean Engineering, University Malaysia Terengganu (UMT) for allowing lab benefits. The present work AS made possible by FRGS-59439 University Malaysia Terengganu (UMT).

References

[1] APHA (2005). Standard methods for the examination of water and AStewater, 20th ed. Am Public Health Association, Maryland, USA.

[2] AR Syukor, A. Z., MIM Said, MNI Siddique, 2015. Bio-sorption of Chromium using aquatic plant, Lepironia articulata. Adv. Environ. Biol 1, 13.

[3] Cabbai, V., De Bortoli, N., Goi, D., 2016. Pilot plant experience on anaerobic codigestion of source selected OFMSW and sewage sludge. Waste Management 49, 47-54.

[4] Chen, C., Guo, W. S., Ngo, H. H., Chang, S. W., Nguyen, D. D., Zhang, J., Liang, S., Guo, J. B., Zhang, X. B., 2018. Effects of C/N ratio on the performance of a hybrid sponge-assisted aerobic moving bed-anaerobic granular membrane bioreactor for municipal wastewater treatment. Bioresource Technology 247, 340-346.

[5] Dai, X., Li, X., Zhang, D., Chen, Y., Dai, L., 2016. Simultaneous enhancement of methane production and methane content in biogas from waste activated sludge and perennial ryegrass anaerobic co-digestion: The effects of pH and C/N ratio. Bioresource Technology 216, 323-330.

[6] Harb, M., Lou, E., Smith, A. L., Stadler, L. B., 2019. Perspectives on the fate of micropollutants in mainstream anaerobic wastewater treatment. Current Opinion in Biotechnology 57, 94-100.

[7] Islam Siddique, M. N., Khalid, Z. B., Ibrahim, M. Z. B., 2020. Effect of additional nutrients on bio-methane production from anaerobic digestion of farming waste: Feasibility & Fertilizer recovery. Journal of Environmental Chemical Engineering 8 (1), 103569.

[8] Khalid, Z. B., Siddique, M. N. I., Nasrullah, M., Singh, L., Wahid, Z. B. A., Ahmad, M. F., 2019. Application of solar assisted bioreactor for biogas production from palm oil mill effluent co-digested with cattle manure. Environmental Technology & Innovation 16, 100446.

[9] Krishnan, S., Singh, L., Mishra, P., Nasrullah, M., Sakinah, M., Thakur, S., Siddique, N. I., Wahid, Z. A., 2017. Comparison of process stability in methane generation from palm oil mill effluent using dairy manure as inoculum. Environmental Technology & Innovation 8, 360-365.

[10] Leite, L. d. S., Hoffmann, M. T., Daniel, L. A., 2019. Microalgae cultivation for municipal and piggery wastewater treatment in Brazil. Journal of Water Process Engineering 31, 100821.

[11] Li, Y., Chen, Y., Wu, J., 2019. Enhancement of methane production in anaerobic digestion process: A review. Applied Energy 240, 120-137.

[12] Li, Y., Li, L., Sun, Y., Yuan, Z., 2018. Bioaugmentation strategy for enhancing anaerobic digestion of high C/N ratio feedstock with methanogenic enrichment culture. Bioresource Technology 261, 188-195.

[13] M Nasrullah, M. S., AW Zularisam, 2014. Effect of high current density in electrocoagulation process for sewage treatment. Asian Journal of Chemistry 26 (14), 4281.

[14] M. N. I. Siddique, M. F. I. a. A. W. Z., 2016. Enriched Renewable Methane from the Anaerobic Digestion of Petrochemical Wastewater: A Bio-Remediation Structure. INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGY AND SCIENCES 7, 1-8.

[15] Md Nurul Islam Siddique, Z. B. K., Muhammad Nomani Kabir, 2019. Progressive Two-Stage Efficient Co-Digestion of Food Waste and Petrochemical Wastewater for Higher Methane and Hydrogen Production. Asian Journal of Chemistry 31 (11), 2575-2578.

[16] Md Siddique, N. I., Zularisam Bin Abdul Wahid, 2018. Enhanced Methane Yield by Codigestion of Sewage Sludge with Microalgae and Catering Waste Leachate. Water Environment Research 90 (9), 835-839.

[17] Md. Nurul Islam Siddique, A., M. Sakinah, 2014a. Biomethane generation potential of petrochemical wastewater by anaerobic digestion using CSTR. 4th Johor Biotechnology Conference and Exhibition, malaysia.

[18] Md. Nurul Islam Siddique, A., M. Sakinah, 2014b. Intensified CSTR for bio-methane generation from petrochemical wastewater. International conference on chemical, environmental and biological sciences, IICBE-2014, Malaysia.

[19] Md. Nurul Islam Siddique, M. S., A. W. Zularisam, 2014. Sustainable bio-methane generation from petrochemical wastewater using CSTR. International Journal of Engineering Technology and Science. 1 (1), 1-4.

[20] Md. Nurul Islam Siddique, Z., 2012. Temperature and organic loading rate influence on biomethanation of Petrochemical wastewater using CSTR. International Journal of Civil Engineering and Geo-Environment. 2, 59-64.

[21] Md. Nurul Islam Siddique, Z. A., 2012. Continuous stirred tank reactor application for renewable methane from anaerobic biodegradation of Petrochemical wastewater. Engineering E-Transaction 7, 23-27.

[22] Mimi Sakinah Lakhveer Singh, M. N. I. S., Zularisam A. W., Mohd. Hasbi Ab. Rahim, 2012. Optimization of sustained hydrogen production from palm oil mill effluent using immobilized mixed culture. International Journal of Civil Engineering and Geo-Environment. 1 (1), 5-9.

[23] MNI Siddique, A. Z., 2013. Role of ammonium bicarbonates in methenogenesis while co-digesting petrochemical wastewater with activated manure sludge. Ener. Edu. Sci. Technol 31 (1), 80-90.

[24] MNI Siddique, A. Z., 2018. Application of natural seaweed modified mortar for sustainable concrete production. IOP Conference Series: Materials Science and Engineering 342, 012008.

[25] MNI Siddique, M. M., AW Zularisam, 2013a. Bioenergy production from codigestion of chemically-treated petrochemical wastewater and activated manure sludge. Ener. Edu. Sci. Technol 31, 59-70.

[26] MNI Siddique, M. M., AW Zularisam, 2013b. Cycle time minimization during renewable methane production from H2O2 enhanced anaerobic Co-digestion of Petrochemical wastewater in CSTR. Asian. J. Chem 25, 80-90.

[27] MNI Siddique, M. M., AW Zularisam, 2013. Role of hydrogen peroxide (H2O2) enhanced anaerobic co-digestion of petrochemical wastewater on cycle time minimization during biomethanation. Sci. Resear. and Essays: Acad. J 8 (22), 996-1009.

[28] MNI SIddique, M. M., AW Zularisam, 2014. Role of Bio-filtration in Petrochemical Wastewater treatment using CSTR. Int. J. Eng. Tech. Sci 2, 9-12.

[29] NI Siddique, A. Z., 2012. Renewable Methane from Ammonium Bicarbonate Supplemented Petrochemical Wastewater Treatment During Anaerobic Co-Digestion in CSTR. Procedia Engineering 50, 134-141.

[30] NI Siddique, Z. A. W., 2012. Application of chemical and biological coupled treatment technology in POME and petroleum waste water as biodegradation alternative. Journal of Environmental Science and Technology 5 (3), 155-167.

[31] Otieno, B., Apollo, S., Kabuba, J., Naidoo, B., Simate, G., Ochieng, A., 2019. Ozonolysis pre-treatment of waste activated sludge for solubilization and biodegradability enhancement. Journal of Environmental Chemical Engineering 7 (2), 102945.

[32] Roman, B., Brennan, R. A., 2019. A beneficial by-product of ecological wastewater treatment: An evaluation of wastewater-grown duckweed as a protein supplement for sustainable agriculture. Ecological Engineering: X 1, 100004.

[33] Siddique, M. N. I., Abdul Munaim, M. S., Zularisam, A. W., 2015a. Feasibility analysis of anaerobic co-digestion of activated manure and petrochemical wastewater in Kuantan (Malaysia). Journal of Cleaner Production 106, 380-388.

[34] Siddique, M. N. I., Munaim, M. S. A., Ab. Wahid, Z., 2016a. Role of hydraulic retention time in enhancing bioenergy generation from petrochemical wastewater. Journal of Cleaner Production 133, 504-510.

[35] Siddique, M. N. I., Munaim, M. S. A., Wahid, Z. B. A., 2017. The combined effect of ultrasonic and microwave pre-treatment on bio-methane generation from co-digestion of petrochemical wastewater. Journal of Cleaner Production 145, 303-309.

[36] Siddique, M. N. I., Munaim, M. S. A., Zularisam, A. W., 2016b. Effect of food to microbe ratio variation on anaerobic co-digestion of petrochemical wastewater with manure. Journal of the Taiwan Institute of Chemical Engineers 58, 451-457.

[37] Siddique, M. N. I., Sakinah Abd Munaim, M., Zularisam, A. W., 2014. Mesophilic and thermophilic biomethane production by co-digesting pretreated petrochemical wastewater with beef and dairy cattle manure. Journal of Industrial and Engineering Chemistry 20 (1), 331-337.

[38] Siddique, M. N. I., Sakinah, M., Zularisam, A. W., 2015b. Influence of flow rate variation on bio-energy generation during anaerobic co-digestion. Journal of Industrial and Engineering Chemistry 27, 44-49.

[39] Siddique, M. N. I., Wahid, Z. A., 2018. Achievements and perspectives of anaerobic co-digestion: A review. Journal of Cleaner Production 194, 359-371.

[40] Siddique, N. I., Munaim, M. S. A., Wahid, Z. A., 2015. Role of biogas recirculation in enhancing petrochemical wastewater treatment efficiency of continuous stirred tank reactor. Journal of Cleaner Production 91, 229-234.

[41] Siddique, Z. N. I., 2019. Effect of Water-Cement Ratio On Performance of Seaweed-Modified Mortars. European Proceedings of Social & Behavioural Sciences EpSBS 12, 212-221.

[42] Solé-Bundó, M., Garfí, M., Matamoros, V., Ferrer, I., 2019. Co-digestion of microalgae and primary sludge: Effect on biogas production and microcontaminants removal. Science of The Total Environment 660, 974-981.

[43] Wang, S., Cui, Y., Li, A., Wang, D., Zhang, W., Chen, Z., 2019. Seasonal dynamics of bacterial communities associated with antibiotic removal and sludge stabilization in three different sludge treatment wetlands. Journal of Environmental Management 240, 231-237.

[44] Xu, R., Xu, S., Florentino, A. P., Zhang, L., Yang, Z., Liu, Y., 2019. Enhancing blackwater methane production by enriching hydrogenotrophic methanogens through hydrogen supplementation. Bioresource Technology 278, 481-485.

[45] Yu, L., Bian, C., Zhu, N., Shen, Y., Yuan, H., 2019. Enhancement of methane production from anaerobic digestion of waste activated sludge with choline supplement. Energy 173, 1021-1029.

[46] Zaied bin khalid, M. N. I. S., Zularisam Abd Wahid, Younis Mohammed Salih, 2019. Biomethane Production from Anaerobic Co-digestion of Palm Oil Mill Effluent with Cattle Manure: A Review. Asian Journal of Chemistry 31 (31), 2413-2424.

[47] Zaied, B. K., Nasrullah, M., Islam Siddique, M. N., Zularisam, A. W., Singh, L., Krishnan, S., 2019. Enhanced bioenergy production from palm oil mill effluent by co-digestion in solar assisted bioreactor: Effects of hydrogen peroxide pretreatment. Journal of Environmental Chemical Engineering, 103551.

[48] Zan, F., Zeng, Q., Hao, T., Ekama, G. A., Hao, X., Chen, G., 2019. Achieving methane production enhancement from waste activated sludge with sulfite pretreatment: Feasibility, kinetics and mechanism study. Water Research 158, 438-448.