Asian Journal of Chemistry; Vol. 31, No. 10 (2019), 2403-2409

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2019.22195

Improving Methane Generation by Co-Digestion of Sewage Sludge and Petrochemical Wastewater: Influence of Heat and Alkali Pretreatment

M.N.I. Siddique[1,*], B.K. Zaied[2], S. Krishnan[3] and M.F. Ahmad[1]

[1]School of Ocean Engineering, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[2]Faculty of Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia
[3]Research Institute of Sustainable Environment, University Technology Malaysia, Johor Bahru 81310, Skudai, Malaysia

*Corresponding author: Fax: +609 5493006; Tel: +609 6683614; E-mail: m.nurul@umt.edu.my

Received: 13 May 2019; *Accepted*: 18 July 2019; *Published online*: 30 August 2019; AJC-19560

With the target of amplifying methane generation from sewage sludge (SS), co-digestion with petrochemical wastewater (PWW) was examined. In addition, the use of both 165 °C heat treatment and alkali pretreatment to mixed SS/PWW wastewater was assessed. Batch tests demonstrated that refractory materials were generated from pretreatment for petrochemical wastewater at the 165 °C heat and alkali pretreatments at the 75 or 115 °C and with pH value of 8, 9 or 10 producing enhanced preliminary methane generation percentage and a little effect for generation capacity of methane of the miscellaneous waste (+3–6 %). Anaerobic reactors which were operated more than four months semi-continuously with sewage sludge and petrochemical wastewater mix with the proportion of 85:15, 55:45 and 85:15 pretreated at alkaline environments maintaining the temperature of 75 °C and pH = 8. This pretreatment enhanced the production of methane at semi-continuous anaerobic reactors to + 59 %. Finally, this investigation demonstrated the viability of the co-digestion of sewage sludge with a higher ratio of petrochemical wastewater [45 % volume, 50 % volatile solid (VS) and 74 % COD, comparable with volatile fatty acids of 8 g L^{-1}]. The system produced an exact methane of 363 mL CH_4 g^{-1} VS while only sewage sludge generated 117 mL CH_4 g^{-1} VS.

Keywords: Methane, Anaerobic Co-digestion, Biochemical methane potential, Semi-continuous reactors.

INTRODUCTION

The transportation division is a critical source of producing greenhouse gases and 285 million tons of carbon dioxide will be released in 2020 in Malaysia [1]. A key factor for decreasing greenhouse gasses releases comprises in expanding the utilization of alternative energies, for example, bio-methane, which shows ideal environmental indicators [2]. The case study in Lille (town of Northern France), proposes a related evidence of methane utilization for sustainable development by a district. The local community named as Urban Community of Lille (UCL) is approaching to utilize sewage sludge effectively, which is coming from "wattrelos wastewater treatment plant (WTP)" for producing bio-methane fuel supporting town transports. Every day each vehicle requires 100 Nm^3 CH_4 mean energy. Undoubtedly, at the start of 1994, the first European pilot plant had been executed for bio-methane transport fuel generation from the Marquette wastewater treatment plant (France) and by that bio-methane fuel, four means of transport kept running [3].

Considering this as an ideal example, the Malaysian Government is targeting to intensify bioenergy yields, which make productive utilization of sewage sludge coming from the various effluent treatment plants. But, the activated sludge method is right now run with continued air circulation circumstances, bringing about sewage sludge producing low methane. A possibility aimed at enhancing bioenergy yield from anaerobic co-digestion (ACoD) of sewage sludge with different substrates. Petrochemical wastewater (PWW) is especially fascinating as it yields greater methane production, which can easily mix with sewage sludge. But, petrochemical wastewater have some detriments: there may be inadequate lipids for getting access to microbes and unsaturated fatty acids also have some hindering properties.

Kabouris *et al.* [4] considered the ACoD of preliminary and effluent sludge with fats, oil and grease (FOG) collected from WTP; Fountoulakis *et al.* [5] anticipated ACoD of glycerol with sewage sludge; Davidsson *et al.* [6] and Luostarinen *et al.* [7] explored ACoD of sewage sludge with sludge from grease trap. Indeed, semi-continuously operated ACoD remained is possible by adding sludge of grease trap about 10-30 % or 46 % organic feed, yet excessively exorbitant 71 % VS and 55 % lipid content in the feed blend brought about inadequate digestion and the digester acidification with a succeeding reduction in generating biogas [8]. The hindrance in the methanogenesis phase by fatty acids having long-chain have been instigated by over-burdening [1,9].

The ACoD of grease contains wastewater might be increased by various pretreatment procedures, for example, enzymatic hydrolyze, treatment for acid (HCl adding for maintaining pH = 2-2.6) [10]. The methane generation was maximum (0.33 L CH_4/g VS_{added}) that was achieved from the ACoD of microwave pre-treatment of waste activated sludge for 30 min with petrochemical wastewater [11]. Glycerides are initially degraded on hydrolysis into fatty acids and glycerol subsequently converted to higher solubility soaps. Formation of dissolvable soaps from insoluble lipids enhances the interaction in between the microbes and substrate [12]. The presence of hydroxyl (OH^-) groups and carbon-carbon bond chain reduced the harmfulness of multiplexes to micro-flora digester [13]. Saponification has been completed in various trial operations *e.g.*, at 75 °C with excess KOH [14]; at 75 °C temperature and pH = 9 with KOH [15] or at 55-115 and 155 °C with NaOH [16]. Alternatively, alkali treatment (NaOH, 45-405 meq L^{-1}) did not yield considerable slaughterhouse wastewater solubilization comprising fat particles of pork around 2.5 g/L [17]. Lastly, a variety of heat pretreatment has been conducted for sterilizing slaughterhouse wastewater of the industry handling meat at 150 °C for 20 min [18] or at 65 °C for 55 min [19]. In both cases, methane yield reduced because of the development of inhibiting materials.

Pretreatment has been mostly done to advance the performance of ACoD of sewage sludge and some review articles have been published [20]. Among the various pretreatment systems, heat hydrolysis at 155-175 °C has been appeared to enhance both the productivity and the rate of digestion of sewage sludge [21]. Also, heat treatment prompts waste hygiene and change ability of sewage sludge whereas operational expenses is recovered by the generation of biogas [22]. Limited investigations have investigated the heat-soluble sewage sludge pretreatment yet the circumstances included were not fairly the same as like greasy saponification at 120 °C [23], 125 °C [21] or 170 °C [21] or an extended response time for example, 6 h at 50 °C [24] or 10 h at 95 °C [25]. As reported earlier pretreatment of sludge with pH = 10 at 125 °C temperature using KOH yielded a significant increment in methane generation with 165 °C heat pre-treatment [26]. Like various factors, like pH, hydraulic retention time (HRT), C/N ratio, temperature is also important for anaerobic co-digestion procedure [1].

To the best of our knowledge, the pretreatment of blended waste (sewage sludge and petrochemical wastewater) before its co-digestion has not been studied till to date. The objective of this research study is to assess the effect of heat pretreatment at 165 °C (usually utilized for waste sludge) and combined heat and alkali pretreatment (used usually intended for oily wastewaters) applied to blended waste composed of sewage sludge and petrochemical wastewater. At first, batch tests were done for increasing temperature and pH on mixed effluent produced at volume ratio for PWW:SS of 68:32 and after that pretreatment for heat and alkali staging were assessed through ACoD at semi-continuously and was completed with raw blended samples at volume ratio of 85:15 for SS:PWW. One more operation was supplied with mixed sewage at volume ratio of 65:35 for SS:PWW to consider ACoD by higher presence of lipid content.

EXPERIMENTAL

Sample collection: The activated waste sludge was collected from the Quantum Hydromech Sdn. Bhd., Kuantan, Pahang, Malaysia. It was collected from a prolonged air circulation method having 21 days sludge age. The petrochemical wastewater was accumulated during sludge discharging of the Petronas Penapisan (Terengganu) Sdn Bhd. The properties of sewage sludge and petrochemical wastewater was listed in Table-1. Both sewage sludge and petrochemical wastewater were kept at temperature of 4 °C for 1 month. The inoculum was collected from mesophilic sludge from a sewage processing plant in Kuantan, Malaysia. The sludge carried 25 ± 2 G_{TS} and 17 ± 1 G_{VS} L^{-1}.

TABLE-1
PROPERTIES OF SEWAGE SLUDGE AND PETROCHEMICAL WASTEWATER

Parameters	Sewage sludge	Petrochemical wastewater
Total solids (g/L)	40	43
Volatile solid (g/L)	24	33
COD (g/L)	38	93
HEM[a] (g/L)	1.47	22

[a]Heptane extractable matter.

Analysis: Supernatant is solvable portion of substrate and centrifugation (5 °C, 15 min, 42000 g, Beckman J2 MC) is the particulate portion as the pellets. After centrifugation, total solids (TS) and volatile solids (VS) determination were carried out for substrates as objects, as per standard methods [27]. COD was measured utilizing at 620 nm by HACH spectrophotometer, DR/2000 (HACH Company, Loveland, CO., USA) and Spectroquant® test packs (Merck, Darmstadt, Germany).

Heptane extractable matter (HEM) extracted matter portion, which measured lipid level. Usually, this determination is done by hexane however heptane was chosen due to its lower lethality [28]. Waste specimen volume (pH < 2) was initially treated by H_2SO_4 with a specific goal to keep up unsaturated fats for non-ionic shape. In an extraction pipe, heptane and methanol (half of the heptane volume taken) were put to the sample. In the fluid stage, lipoproteins are kept up by using methanol. Customization of the funnel was like that it gave 40 motions per moment up to 30 min and it was built on an oscillating blender. The heptane stage was then recovered and set in a carafe. HEM was continued till the point it stayed colourless, demonstrating fatigue of the specimen. Roto-evaporator (Rotavapor R, Büchi) evacuated heptane was evacuated under partial vacuum at 80 °C. The weight of extricated lipids was measured after drying for 24 h at 105 °C.

Biogas production amount was measured by column shifting method where at 10 g L^{-1} of NaCl and pH = 2, the fluid becoming water. The correctness of this approximation was ±10 mL for semi-continuous reactors and ±1 mL for clump tests. The biogas composition was determined by a gas chromatography device (Shimadzu GC-8A) equipped with an integrator C-R8A and an attached CTRI column, which was comprised of two segments: 3.18 mm distance across the internal segment, loaded by silica gel, allowed detachment of carbon dioxide from other gasses. A 6.4 mm measurement external column, loaded with a sub-atomic strainer, isolated alternative gasses. Argon gas was used as the carrier gas at 2.7 bar. The stove and injector and detector temperature were 30 and 105 °C respectively. The gaseous material detection was carried out by a heat sensor and the electric current density was kept 75 mA. The volume of injected biogas was 1.5 mL. The standardization was performed with a usual gas made of 24 % carbon dioxide, 6 % hydrogen, 2.5 % oxygen, 9.5 % nitrogen and 58 % methane.

The VFAs composition was measured by a gas chromatography device (Fisons Instruments, GC-8000), which was furnished by a fire ionization indicator and a programmed tester (Fisons Instruments, AS 800). The column segment had a length of 14 m, the width of 0.52 cm and Phase EC™ 1000 film was 1.3 μm named as semi-capillary Econocap FFAP (Alltech). 245 and 270 °C was the temperature for splitless injector temperature and the detector respectively. Within 3 min, the reactor temperature was improved from 85 to 125 °C. At 24 kPa, nitrogen was used as the carrier gas. The injected sample volume was 1 μL. Equipment standardization was prepared by a proper mixing of six types of acids: acetic acid, butyric acid, valeric acid, propionic acid, isovaleric acid and isobutyric acid at 1.0 g L^{-1} individually. Range of standardization was kept 0.25-1.0 g L^{-1} by standard mix dilution. Total VFAs level was measured by core standard technique (fermentation of 50 mL H_3PO_4, 1.0 g of ethyl-2-butyric was corrosive in water of 1.0 L) by a combination of equal volume of the sample and the internal standard solution.

Heat and heat-alkali pretreatment: Initially, pretreatment conditions impact for a batch test of anaerobic processing names as biochemical methane potential (BMP) test for a blended substrate of PWW:SS (68:32) were observed. Pretreatment conditions were selected depending on the earlier works. Heat pretreatment was done 30 min at 165 °C as suggested for the pretreatment of sludge [21]. For petrochemical wastewater, alkaline pretreatment was done 30 min both at 75 and 115 °C [16]. Potassium hydroxide was selected instead of sodium hydroxide because the potassium cations have a less hindering impact than sodium cations. The impact of pH was investigated by three response of pH values (8, 9 and 10). To maintain required pH levels, potassium hydroxide was added after 30 min of treatment and before heat pretreatment. The potassium hydroxide measurements were found 0.13, 0.15 at 75 °C and 0.15, 0.19 at 115 °C. ACoD was operated semi-continuously for the blended substance of SS:PWW with 85:15 mix volume ratio where pretreatment conditions were done 30 min at 75 °C. Blended substance was pretreated in a 2.0 L glass reactor at 75 °C outfitted with a twofold stirrer and coat; high-temperature pretreatments (115 or 165 °C) were done in a Zipperclave reactor having 1.0 L capacity.

Anaerobic Co-digestion (ACoD): By ACoD process, biogas production from various decomposable biological substrates is now considered as a good fit alternative to use for fossil fuel [29]. ACoD was done at 37 °C (mesophilic conditions). The blended substance was prepared from 68 % volume of petrochemical wastewater and 32 % volume of sewage sludge for batch tests of biochemical methane potential (BMP). Every crude test was blended in a plasma bottle having 500 mL volume with oligo-component arrangement, anaerobic inoculum, bicarbonate cradle arrangement *etc*. The inoculum proportion was adjusted to 0.5 g COD of inoculum per gm of anaerobic organics (VS) whose level was 4 g VS L^{-1}. Nitrogen were used for flushing the reactor which was fixed with an elastic plug and afterwards established on a blending table at 37 °C with 100 rpm rotating speed. Biogas generation was quantified by displacement of water column with pH = 2.1. Generation of methane of the substance was assessed and was deducted from generation of methane of the examples. BMP tests were running about 25 days and each investigation was replicated.

Four tank reactors which are magnetically blended having 2.0 L of volume were kept running parallel by semi-continuous way. A temperature of 37 °C was set by aquatic mixing in the two-fold coat. At first, the reactors were at first loaded at 17.95 g VS L^{-1} with 2.0 L inoculum. sewage sludge feeding was done in the one reactor, one was with the blend of SS:PWW by 85:15 pretreatment done at 75 °C where pH was 8.1 and rest two were with the blend of SS:PWW by 85:15 and 55:45. The ACoD with maximum HRT can play an important role for emerging an efficient energy production with waste management [30]. Since blended wastes had a higher concentration of total COD than sewage sludge, so the dilution was done for the three blended waste by distilled water keeping in mind that the end goal was to achieve an indistinguishable total COD from sewage sludge so as to work the four reactors with the same organic loading rate (OLR) and HRT. The HRT was 21 days for this study. The reactors were fed and withdrawn once a day. The load was increased step by step up to 6 weeks, the OLR was kept up at 1.7 g COD L^{-1} d^{-1} fit for 9 weeks [16].

RESULTS AND DISCUSSION

Effects of pretreatment on batch ACoD: The outcomes of heat pretreatment are presented in Table-2 and Fig. 1. Its application to the blended waste made from petrochemical wastewater and sewage sludge prompted a 16 % decrease in the production of methane. The methane generation was measured before and after heat pretreatment due to break down the consequence of 165 °C pretreatment for every particular section of the blended waste. The methane generation capability of the petrochemical wastewater and sewage sludge was measured before and after heat treatment. In this manner, the heat pretreatment prompted an enhancement in the generation of methane by sewage sludge from 191 ± 4 to 242 ± 5 mL CH_4 g^{-1} VS_{added} and reduction in methane potential by petrochemical wastewater from 649 ± 10 to 502 ± 20 mL CH_4 g^{-1} VS_{added}. Optimistic effect of heat pretreatment optimistic effect on sewage sludge for BMP test has been demonstrated by the carbon-based materials solubilization, which were absent in anaerobic microbes [31].

TABLE-2
METHANE PRODUCTIONS IN mL CH_4 g^{-1} VS OF THE MIXED RATIO OF SS:PWW (68:32) WITH AND WITHOUT THERMAL OR THERMO-ALKALINE PRETREATMENT (INCREASE ABOVE REFERENCE)

	Initial pH = 6	pH = 8	pH = 9	pH = 10
Without treatment	541 ± 10 (Ref)	–	–	–
75 °C	–	575 ± 5 (+5 %)	574 ± 10 (+5 %)	575 ± 2 (+5 %)
115 °C	–	566 ± 6 (+5 %)	576 ± 6 (+5 %)	581 ± 10 (+6 %)
165 °C	449 ± 10 (-16 %)	–	–	–

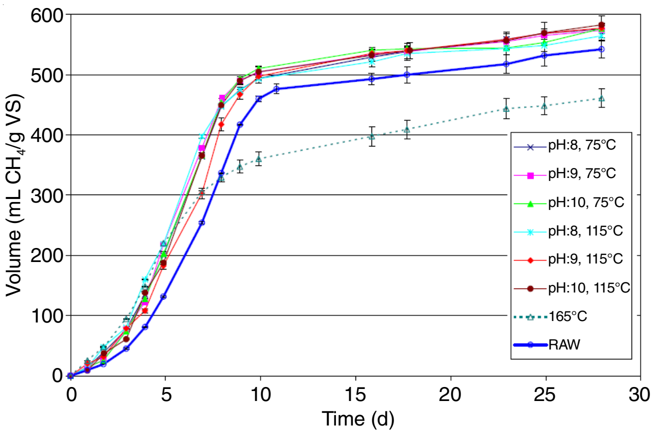

Fig. 1. Methane production from the blend of sewage sludge and petrochemical wastewater with 68:32 mixing ratio without pretreatment and after thermal (165 °C) or thermo-alkaline pretreatments

The adverse effect on the methane potential for the 165 °C pretreatment of petrochemical wastewater was clarified by development of complex materials. The adverse impact of the blended waste happened due to 165 °C pretreatment because the existence of greasy ingredients were readily decomposable and molded complex mixtures at 165 °C. The result reported a decline in the transformation of slaughter house wastewater in production of methane after pretreatment for 20 min, 5 bar and at 146 °C [18]. In slaughter house waste, the percentage of fats are 39 % (dry premise), were eliminated up to 21 % during anaerobic processing of substrate for pretreatment where about 60 % were removed by anaerobic digestion without pretreatment. The remoal of pretreated fats was marginally increased during co-digestion with the carbon-based portion of city wastes yet at the same time remained lower than that of the co-digestion of untreated petrochemical wastewater (31 % contrasted with 75 %). The accumulation of complex materials during heat pretreatment of fat where the presence of lipid is more or the transformation of rapidly decomposable solid to gradually decomposable was detected at 70 °C for 60 min pretreatment of petrochemical wastewater [32].

Heat and alkali pretreatment increased anaerobic degradation of the blended waste rather than warm treatment at 165 °C. Nevertheless, the methane generation impact was moderately low (4.1-7.1 %) pH was extending from 8 to 10 and temperature was extending from 75 to 115 °C. However, heat and alkali pretreatment enhanced anaerobic degradation rates. Certainly, methane generated by the initial 5 days of anaerobic degradation showed 32.5-39.5 % of whole generation for treated substrates rather than 24.5 % of whole generation for the samples without pretreatment. The growth in anaerobic assimilation rate which has no or exceptionally slight the effect on production of methane, which had been seen after saponification of aero flotation fats and cattle dead-bodies fats [33]. This might be clarified by a complete transformation of the substrate in a month of batch anaerobic degradation. As the highest methane generation was achieved by raw waste, the degradation rate improvement is the key impact for pretreatment. Since addition of high potassium hydroxide or high temperature brought no huge change in batch test for methane generation, the least conditions (pH = 8, temperature is 80 °C and compared to 3 g potassium hydroxide per liter) were decided for using in anaerobic digester at semi-continuous way.

Semi-continuous anaerobic runs: Four numbers of reactors were kept running semi-continuously so as to look at the execution of ACoD of sewage sludge, the blended substance of SS:PWW with mix ratio of 85:15 with and without heat and alkali pretreatment and the blended substance of SS:PWW with 55:45 mix ratio. The blended SS:PWW were made to achieve an identical COD fixation from sewage sludge. The four substances qualities and digester vents after adjustment are listed in Table-3. The reactor operations are listed in Table-4. The reactor performance affirmed the less decomposability of sewage sludge (21 % TS removal and 34 % VS removal), little production of methane (117 mL CH_4 g^{-1} VS_{added}) and enthusiasm of its co-digestion with petrochemical wastewater. The removal of VS enrichment with high petrochemical wastewater substance demonstrated that sewage sludge was less decomposable than petrochemical wastewater. Moreover, lower percentage of TS removal was due to high presence of minerals in sewage sludge (39 % TS). It ought to be highlighted that all reactors performance was steady for 4 months duration with higher presence of petrochemical wastewater. In fact, 3.1 and 7.2 g L^{-1} were HEM fixations and biological substances produced from petrochemical wastewater in the blends SS:PWW for 85:15 and 55:45 volume mix ratio represented 14 and 49 % respectively. Regarding COD, the portions generating from petrochemical wastewater were 31 and 74 %. The eliminations of HEM were 88-90 % in two blends and VFAs levels stayed low in every one of the digesters throughout four months operation period without showing any hindrance in methane generation steps.

Pretreatment by alkaline prompted methane generation 59 % more with respect to similar blend but raw. Semi-continuous reactor operation has higher effect comparatively than in batch test for BMP (just +6 %). It might be clarified by specific contrasts in pretreated energy and crude substrates. Indeed, by pretreatment, the degradation rate change prompted instead of an intensification in producing methane. All through the BMP tests, the microbes growth period was enough to change all decomposable compounds. Conversely, the retention time was so low that it can't allow change the decomposable constituents in raw wastewater during reactor operation. The elimi-

TABLE-3
CONFIGURATION OF SEMI-CONTINUOUS DIGESTER INFLUENT AND EFFLUENT (MEAN ± STANDARD DEVIATION OF THREE VALUES)

Substrate	Raw sewage sludge	SS/PWW (85/15)		Raw SS/PWW (55/45)
		Raw	Pretreated	
Influent				
TCOD (g O_2 L^{-1})	38	38	38	38
TS (g L^{-1})	40	35	32	30
VS (g L^{-1})	24	22	18	19.5
HEM (g L^{-1})	1.5	3.2	2.8	7.2
Effluent				
TCOD (g O_2 L^{-1})	22.0 ± 1.2	19.8 ± 1.2	14.7 ± 0.5	15.9 ± 0.6
SCOD (g O_2 L^{-1})	0.7 ± 0.11	0.57 ± 0.02	0.95 ± 0.05	0.51 ± 0.05
VFA (g L^{-1})	0	0	0.01 ± 0.02	0
TS (g L^{-1})	30.9 ± 0.3	26.9 ± 0.2	24.9 ± 0.3	20.9 ± 0.4
TSS (g L^{-1})	28.9 ± 0.7	25.9 ± 0.6	21.9 ± 0.2	19.9 ± 0.2
VS (g L^{-1})	14.9 ± 0.4	12.9 ± 0.3	9.9 ± 0.4	9.9 ± 0.2
VSS (g L^{-1})	13.9 ± 0.5	12.9 ± 0.3	8.9 ± 0.2	9.9 ± 0.1
HEM (g L^{-1})	0.11 ± 0.01	0.45 ± 0.02	0.10 ± 0.01	0.77 ± 0.02

TABLE-4
OUTCOMES OF SEMI-CONTINUOUS DIGESTERS (MEAN ± STANDARD DEVIATION OF THREE VALUES)

Substrate	Raw WAS	WAS/PWW (85/15)		Raw WAS/PWW (55/45)
		Raw	Pretreated	
Specific methane production (CH_4 g^{-1}VS)	117 ± 5	173 ± 12	272 ± 7	363 ± 15
Methane production enhancement (%)	–	+49	+134 (WAS) +59 (WAS/PWW (85/15)	+213
CH_4 in biogas (%)	67 ± 2	71 ± 2	75 ± 2	72 ± 5
Removal of total solids (%)	21 ± 1	22 ± 2	21 ± 2	29 ± 2
Removal of volatile solid (%)	34 ± 2	37 ± 3	43 ± 3	47 ± 3
Removal of HEM (%)	94 ± 3	88 ± 3	97 ± 4	90 ± 5

nation of HEM without pretreatment was enhanced from 88 % to a practically total evacuation 97 % after alkaline treatment. Methane generation acquired in the digester (117 CH_4 g^{-1} VS) was less than at BMP batch test (191 CH_4 g^{-1} VS) because BMP tests are suitable to anaerobic degradation and evade kinetic constraints. Generation of methane from petrochemical wastewater, designed with a fixed precise generation from sewage sludge in all digesters (117 mL CH_4 g^{-1} VS of sewage sludge included), was 590 mL CH_4 g^{-1} VS for SS:PWW (85:15) and 668 mL CH_4 g^{-1}VS for SS:PWW (55:45). These rough esteems indicating that petrochemical wastewater was quicker in decomposable than sewage sludge.

Financial feasibility of heat and alkali pretreatment: The results proved 59 % enhancement in generating methane by the blended substrate SS:PWW (85:15) because of the heat and alkali pretreatment (75 °C). Nonetheless, the evaluation of the financial viability of such pretreatment is critical. An approximate financial feasibility analysis has been shown in Table-5. Heat prerequisites for pretreatment are shown at Table-6. They can take participate in producing a small amount of methane. Transformation of methane into warm was measured as 35,823 kJ per m^3. Prerequisites for heat pretreatment were evaluated by total required energy required to increase substrate temperature from 20 to 80 °C, presuming the specific heat of substance deferment in water can be adjusted to the specific heat for water (4.19 kJ kg^{-1} $°C^{-1}$). The total required energy for treating 1 ton of VS is therefore significantly reliant on the VS of the wastewater. In the laboratory experiment, VS was around 20 kg m^{-3} at where in a commercial reactor, it is 61 kg m^{-3}, probably achieving 91 kg m^{-3} after heat pretreatment [21]. The prerequisite of methane for heat pretreatment are demonstrated in Table-5, which more noteworthy than the extra methane generated only after the feeding level is 90 kgVS m^{-3}. The recuperated of energy from heat by the pretreated wastewater is done by this way and [34] revealed 81 % recuperation of heat can be achieved from sludge which are pretreated by heat. So, the net methane generation is expectant while presuming 81 % heat recuperation from the pretreated blended substrate.

TABLE-5
ECONOMIC FEASIBILITY EVALUATION

Parameter	WAS/PWW (85/15)
System cost (USD)	490505
Yearly income (USD)	223642
Yearly cost (USD)	91965
Yearly benefits (USD)	131676
Payback periods (yrs)	3.86

In addition, the potassium hydroxide is also linked with cost of the pretreatment. ICIS reports the cost outline for each ton of potassium hydroxide ranging from the US $ 675 to $ 780 [3]. On the premise of measurement, the potassium hydroxide cost drives up to 87-100 $. The fuel cost must be weighed by this cost that is supplanted by the additional methane generation. On the premise of $ 1.35 per liter of diesel, extra methane generation improvement is predicted at $ 124 and $ 138 at the point when the substrate level is, separately, 61 and 91 kgVS m^{-3}, even though the achievement is more than chemical expenses. The distinction is so little that it can

TABLE-6
ENERGY VALUATION OF THERMO-ALKALINE PRETREATMENT
(75 °C, 0.15 g KOH g VS^{-1}) OF MIXED SUBSTRATE WAS/PWW (85/15)

Asking heat for pretreatment			
VS concentration in feed (kg m^{-3})	21	61	91
Asking^a Heat (kjton^{-1} VS)	12,790,802	4,430,801	3,037,467
Asking^a Heat with 80 % heat recovery (kjton^{-1} VS)	2,558,163	886,164	607,494
Asking^a methane (m^{3}ton$^{-1}{}_{VS}$)	358	126	86
Asking^a methane with 80 % heat recovery (m^{3}ton^{-1} VS)	72	26	18
Methane generated			
Methane generated (m^3 ton^{-1} VS)	–	273	–
Increase^b in Methane (m^3 ton^{-1} VS)	–	100	–
Net Methane generation (m^3 ton^{-1} VS)	-260	-25	15
Net Methane generation with 80 % heat recovery (m^3 ton^{-1} VS)	29	75	83
Net Methane generation with 80 % heat recovery (L eq diesel ton^{-1} VS)	31	83	91

[a]To increase heat from 20 to 80 °C; [b]Compared to anaerobic digestion with no pretreatment.

make such pretreatment financially viable, though the expenses of apparatus were not considered in this investigation. As the fundamental expenses of pretreatment is linked with the use of potassium hydroxide, the cost can be minimized by replacing NaOH instead of using KOH [35].

Conclusion

The experimental study proposes a unique way to deal with the investigation of ACoD of sewage sludge with petrochemical wastewater by examining semi-ceaseless ACoD by application of thermo-antacid pretreatment to blended substance. It demonstrates that ACoD of sewage sludge and greasy water effluent from eateries is possible, even at a great amount of greasy wastewater (volume 40 %, VS 49 % and COD 73 %, relating to lipids convergence of 7 g L^{-1}). This co-digestion prompted increment methane creation, 363 mL CH_4 g^{-1} VS, though sewage sludge distant from everyone else delivered 117 mL CH_4 g^{-1} VS. Besides, basic pretreatment (30 min, pH = 8, temperature = 75 °C) of a blended waste (SS:PWW with 85:15 mix ratio) demonstrated compelling in intensifying generation of methane in reactors (+ 58 %) semi-continuously. Even having a less effect on BMP esteems, it demonstrated an improvement in the anaerobic assimilation rate.

ACKNOWLEDGEMENTS

The authors are thankful to School of Ocean Engineering, University Malaysia Terengganu (UMT) and Faculty of Engineering Technology at the University of Malaysia, Pahang (UMP) for allowing continuous access to their laboratory services. The present study was made possible by the UMP RDU160315 grant.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. S. Krishnan, L. Singh, P. Mishra, M. Nasrullah, M. Sakinah, S. Thakur, N.I. Siddique and Z.A. Wahid, *Environ. Technol. Innov.*, **8**, 360 (2017); https://doi.org/10.1016/j.eti.2017.08.005.
2. R. Doornbosch and R. Steenblik, Biofuels: Is the Cure Worse than the Disease?, Round Table on Sustainable Development, Unclassified SG/SD/RT(2007)3/REV1, Paris, 11-12 September (2007).
3. H. Carrere, Y. Rafrafi, A. Battimelli, M. Torrijos, J.P. Delgenes and C. Motte, *Chem. Eng. J.*, **210**, 404 (2012); https://doi.org/10.1016/j.cej.2012.09.005.
4. J.C. Kabouris, U. Tezel, S.G. Pavlostathis, M. Engelmann, J. Dulaney, R.A. Gillette and A.C. Todd, *Bioresour. Technol.*, **100**, 3701 (2009); https://doi.org/10.1016/j.biortech.2009.02.024.
5. M.S. Fountoulakis, I. Petousi and T. Manios, *Waste Manage.*, **30**, 1849 (2010); https://doi.org/10.1016/j.wasman.2010.04.011.
6. Å. Davidsson, C. Lövstedt, J. la Cour Jansen, C. Gruvberger and H. Aspegren, *Waste Manage.*, **28**, 986 (2008); https://doi.org/10.1016/j.wasman.2007.03.024.
7. S. Luostarinen, S. Luste and M. Sillanpää, *Bioresour. Technol.*, **100**, 79 (2009); https://doi.org/10.1016/j.biortech.2008.06.029.
8. F.-M. Pellera and E. Gidarakos, *Waste Manage.*, **68**, 103 (2017); https://doi.org/10.1016/j.wasman.2017.06.026.
9. T. Xie, S. Xie, M. Sivakumar and L.D. Nghiem, *Int. Biodeter. Biodegrad.*, **124**, 155 (2017); https://doi.org/10.1016/j.ibiod.2017.03.025.
10. S.A. Neshat, M. Mohammadi, G.D. Najafpour and P. Lahijani, *Renew. Sustain. Energy Rev.*, **79**, 308 (2017); https://doi.org/10.1016/j.rser.2017.05.137.
11. M.N.I. Siddique, M.S.A. Munaim and Z.B.A. Wahid, *J. Clean. Prod.*, **145**, 303 (2017); https://doi.org/10.1016/j.jclepro.2017.01.061.
12. Y. Ma, Y. Yin and Y. Liu, *Bioresour. Technol.*, **241**, 448 (2017); https://doi.org/10.1016/j.biortech.2017.05.154.
13. L. Singh, M. Siddique and A. Zularisam, *Int. J. Civ. Eng. Geo-Environ.*, **3**, 71 (2012).
14. S. Facchin, P.D.D. Alves, F.F. Siqueira, T.M. Barroca, J.M.N. Victória and E. Kalapothakis, *Open J. Ecol.*, **3**, 34 (2013); https://doi.org/10.4236/oje.2013.31005.
15. A.H. Mouneimne, H. Carrère, N. Bernet and J.P. Delgenès, *Bioresour. Technol.*, **90**, 89 (2003); https://doi.org/10.1016/S0960-8524(03)00091-9.
16. A. Battimelli, M. Torrijos, R. Moletta and J.P. Delgenès, *Bioresour. Technol.*, **101**, 3388 (2010); https://doi.org/10.1016/j.biortech.2009.12.043.
17. L. Masse, K.J. Kennedy and S. Chou, *Bioresour. Technol.*, **77**, 145 (2001); https://doi.org/10.1016/S0960-8524(00)00146-2.
18. M.J. Cuetos, X. Gómez, M. Otero and A. Morán, *Waste Manage.*, **30**, 1780 (2010); https://doi.org/10.1016/j.wasman.2010.01.034.
19. S. Luste and S. Luostarinen, *Bioresour. Technol.*, **101**, 2657 (2010); https://doi.org/10.1016/j.biortech.2009.10.071.
20. V.K. Tyagi and S.-L. Lo, *Rev. Environ. Sci. Bio/Technol.*, **10**, 215 (2011); https://doi.org/10.1007/s11157-011-9244-9.
21. H. Carrère, C. Dumas, A. Battimelli, D.J. Batstone, J.P. Delgenès, J.P. Steyer and I. Ferrer, *J. Hazard. Mater.*, **183**, 1 (2010); https://doi.org/10.1016/j.jhazmat.2010.06.129.

22. C. Bougrier, J.P. Delgenès and H. Carrère, *Biochem. Eng. J.*, **34**, 20 (2007); https://doi.org/10.1016/j.bej.2006.11.013.
23. C. Park, C. Lee, S. Kim, Y. Chen and H.A. Chase, *J. Biosci. Bioeng.*, **100**, 164 (2005); https://doi.org/10.1263/jbb.100.164.
24. N.-H. Heo, S.-C. Park, J.-S. Lee and H. Kang, *Water Sci. Technol.*, **48**, 211 (2003); https://doi.org/10.2166/wst.2003.0471.
25. A.G. Vlyssides and P.K. Karlis, *Bioresour. Technol.*, **91**, 201 (2004); https://doi.org/10.1016/S0960-8524(03)00176-7.
26. N.I. Siddique, M.S.A. Munaim and Z.A. Wahid, *J. Clean. Prod.*, **91**, 229 (2015); https://doi.org/10.1016/j.jclepro.2014.12.036.
27. E.W. Rice, R.B. Baird and A.D. Eaton, Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Water Works Association, Water Environment Federation, edn 23 (2017).
28. M.N.I. Siddique and Z.A. Wahid, *J. Clean. Prod.*, **194**, 359 (2018); https://doi.org/10.1016/j.jclepro.2018.05.155.
29. M. Nasrullah, M.N.I. Siddique and A. Zularisam, *Asian J. Chem.*, **26**, 4281 (2014); https://doi.org/10.14233/ajchem.2014.16134.
30. M.N.I. Siddique, M.S.A. Munaim and Z. Ab. Wahid, *J. Clean. Prod.*, **133**, 504 (2016); https://doi.org/10.1016/j.jclepro.2016.05.183.
31. H. Carrère, C. Bougrier, D. Castets and J.P. Delgenès, *J. Environ. Sci. Health Part A*, **43**, 1551 (2008); https://doi.org/10.1080/10934520802293735.
32. S. Luste, S. Luostarinen and M. Sillanpää, *J. Hazard. Mater.*, **164**, 247 (2009); https://doi.org/10.1016/j.jhazmat.2008.08.002.
33. A. Battimelli, H. Carrère and J.-P. Delgenès, *Bioresour. Technol.*, **100**, 3695 (2009); https://doi.org/10.1016/j.biortech.2008.12.029.
34. B.R. Dhar, G. Nakhla and M.B. Ray, *Waste Manage.*, **32**, 542 (2012); https://doi.org/10.1016/j.wasman.2011.10.007.
35. G. Jard, D. Jackowiak, H. Carrère, J.P. Delgenes, M. Torrijos, J.P. Steyer and C. Dumas, *Chem. Eng. J.*, **209**, 513 (2012); https://doi.org/10.1016/j.cej.2012.08.010.