Engineering e-Transaction (ISSN 1823-6379)
Vol. 7, No.1, June 2012, pp 23-27
Online at http://ejum.fsktm.um.edu.my
Received 27 May, 2012; Accepted 27 June, 2012

CONTINUOUS STIRRED TANK REACTOR APPLICATION FOR RENEWABLE METHANE FROM ANAEROBIC BIODEGRADATION OF PETROCHEMICAL WASTEWATER

M.N.I. Siddique and A.W. Zularisam
Faculty of Civil Engineering and Earth Resources
University Malaysia Pahang (UMP), Lebuhraya Tun Razak
26300 Gambang, Kuantan, Pahang, Malaysia.
Email: zularisam@ump.edu.my

ABSTRACT

Anaerobic digestion using continuous stirred tank reactor (CSTR) as a potentially sustainable technology for petrochemical waste water treatment was investigated by strategic raise in organic loading rate (OLR). The reactor efficiency was observed at 4 to 2d hydraulic retention time (HRT) with OLR 7 to 11 g-COD/Ld. Startup operation of CSTR was closely examined up to 60 days. Masophilic performance of CSTR was studied. Results enclosed that highest COD elimination efficiency was 98±0.5% at 7.5 g-COD/Ld OLR and 4d HRT. Maximum biogas and methane production were 0.80 L/g-$COD_{removed}$ d and 0.60 L/g-$COD_{removed}$ d respectively, comprising average methane of 65.49%. The complete acclimatization took place at 37 ˚C with great process stability. The current work specifies methane productivity of petrochemical waste water under masophilic temperature.

***Key words*:** Anaerobic digestion (AD); Petrochemical waste water (PWW); CSTR; COD; methane.

1. INTRODUCTION

Malaysia is facing two concurrent problems -1) the discarding of wastes produced by manufacturing and 2) the requirement for novel sources of gasoline to meet up the energy necessities of society. Anaerobic co-digestion, a sustainable green technology, extensively applied to various waste treatments, especially animal manure. The anaerobic digestion system among all methods has been renowned as the principal method of an advanced technology for environmental safeguard (Latif *et al*. 2011). To meet up accumulative need for energy and gainful environmental safety, anaerobic digestion bioengineering has become the motivation of global attention (Hanssan *et al.* 2001). In comparison to other treatment methods, the key benefits of anaerobic digestion are minor sludge generation, less costly, elevated energy proficiency and process easiness. Besides, it proposes an optimistic environmental impact as it provides waste stabilization with net energy generation and permits usage of effluent as fertilizer. Nevertheless, there are definite limitations of its application, like as lengthy start-up period and process instability (Nazri *et al.* 2008). Currently, anaerobic digestion has scrupulous attraction for organic waste treatment due to the economic advantages of energy production (Yu *et al.* 2002; Edgar *et al.* 2006; Boha *et al.* 2000). Due to high organic and moisture contents, anaerobic biodegradation is a superior option for PWW treatment. AD has latent of biogas production that can be used for cooking, heating, and electricity generation. Since, PWW contains great quantity of organic matter (Rao *et al.* 2004; Han *et al.* 2005), it is a valuable biomass source for AD. During AD, temperature and pH have somber effect on bacterial activity of the biomass (Mchugh *et al.* 2004). The temperature should be in the range of 30–60˚C (Berand *et al.* 2007). Hence, it is a principle process for tropical climate due to high fluctuation in daily temperature. Optimum pH (values) ranges between 6.8 and 7.2 for most microbial growth, but pH below 4.0 or above 9.5 does not give satisfactory results (Gerardi *et al.* 2003). Methane-producing bacteria need a neutral to lightly alkaline environment to produce maximum methane from food biomass. The feasibility of CSTR conception treating digest-able wastewaters has been adequately described at pilot and full scale (Malina *et al.* 1992). The CSTR is the most commonly used process, with more than 500 installations the world over (Tchobanoglous *et al.* 2003). CSTRs have been effectively applied to treat various wastewater, such as, fruit wastewater, cassava pulp, molasses alcohol slops, domestic and municipal wastewater, palm oil mill effluents, etc. Nevertheless, the application of CSTRs treating PWW has shortly been stated in literature to date. The main objective of this study is to explore the feasibility of mesophilic anaerobic digestion of PWW by using a CSTR reactor. The co objective of this study is to examine the performance of CSTR reactor on PWW at various organic loading rates and temperatures for waste reduction and biogas production.

2. MATERIAL AND METHODS

2.1 Sample collection and characterization

A100 L of PWW sample was collected in plastic containers at the point of discharge in to the main stream and from the receiving stream. Then, transported to the laboratory and preserved at 4˚C for further study were physicochemical analysis and treatment. Effluent pH was maintained at 6.5, using 5N NaOH solution. Alkalinity was maintained between 1400-1800 mg $CaCO_3$/l by $NaHCO_3$. Complementary nutrients like nitrogen (NH_4Cl) and phosphorous (KH_2PO_4) were employed to maintain a COD: N: P ratio of 250:5:1. Table1 explains composition and characteristics of PWW. With a view to eliminate trash materials, the prepared sludge was initially passed through a screen.

Table 1 Composition and Characteristics of PWW

Parameters	CPW
pH	6.5-8.5
BOD	8-32
COD	15-60
TOC	6-9
Total solids	0.02-0.30
Acetic acid	46.60
Phenol	0.36
Total Nitrogen	0.05-0.212
Total Phosphate	0.102-0.227
Volatile fatty acids	93-95

*Except pH and Acetic acid, all parameters in gL^{-1}

2.2 Seeding

Seeding of CSTR was done using anaerobically decomposed sewage sludge collected from municipal sewage treatment plant situated in Kuantan. Collected sludge was initially sieved (<2 mm) to eliminate any fragments and bigger elements before feeding to the reactor. Reactor was fed 50% sludge having suspended solids 3.09 g-TSS/L and 2.09 g volatile suspended solids (VSS) per liter. In order to measure the bacteriological performance of seed sludge, 5 mL of sludge was supplemented to 50.0 mL sucrose and acetate in a 150-mL serum bottle (Minowa *et al.* 1995). The generated biogas was examined after 24 h.

2.3 CSTR Construction and Operation

A stainless steel laboratory-scale CSTR (2160 cm^3) with 2 L effective volume was used in this study (Figure 1). Thermophilic condition was adapted by gradual increase in the temperature from 30 to 55˚C. The granular sludge bed volume was 795 cm^3 (app. 37% portion of total reactor). The feed was introduced by peristaltic pump; with a flow rate of approximately 965 mL/d. $NaHCO_3$ was fed from separate dosing tank to control the acidity. The CSTR was uninterruptedly fed with diluted PWW for 72 days. The CSTR was monitored daily for flow rate, TOC, COD, SS, VSS, volatile fatty acids (VFAs), biogas (CH_4, CO_2, and H_2S) and methane yield, while temperature and pH were monitored quarterly a day. The diluted PWW was uninterruptedly fed into CSTR with gradual increase in organic loading rate from 2.0 to 7.5 g-COD/Ld.

2.4 Analytical Methods

The COD was measured by direct digestion method, using HACH apparatus LR (3–150 COD), HR (20–1500 mg/L COD), and HR plus (20–15,000 mg/L COD and above). Total organic carbon was measured by direct method of low, medium, and high range tests (N tube reagent set), using HACH DBR 200 TOC program in HACH apparatus. Day-to-day gas yield was determined, by a revocable device, having liquid displacement technology. Biogas configuration was determined by a Perkin Elmer gas chromatograph having a thermal conductivity detector. A GC column packed with supelco 100/120 mesh was employed to distinct CH_4 and CO_2. Helium was employed as carrier gas maintaining flow rate 30 mL/ min. The columns sustained at 50˚C. Volatile fatty acids (VFAs) were analyzed using that similar GC, having a flame ionization detector connected to a supelco capillary column. Helium was employed as carrier gas maintaining flow rate 50 mL/ min. Injector and detector temperatures were 200 and 220˚C, individually. The kiln temperature was fixed at 150˚C for 3 min and subsequently amplified to 175˚C. The recognition limit for VFA investigation was 5.0 mg/L.

2.5 Statistical Analysis

Data analysis was performed with Microsoft EXCEL 2010. Regression coefficient (R^2) was calculated to analyze the effect of OLR on COD removal efficiency, biogas, and methane.

3. RESULTS AND DISCUSSION

3.1 Chemical Oxygen Demand

The COD elimination capability with gradual increase in OLR is explained in Figure 1, and influent COD concentration in Table 1. During the first week of experiment, COD concentration was 4 g/L. The lower organic loading rates were, in fact, due to lower COD concentrations at early stages in PWW treatment (Figure 1). Stepwise increase in COD concentration was done in terms of increasing the OLR and reducing the HRT. COD removal efficiency was low in the first week (40–55%), but it recovered during second week (add value) although OLR was enhanced from 2.0 to 5.0 g-COD/L_d. During fourth and fifth week, sudden drop in COD reduction was observed where COD removal efficiency decreased to 62% (R^2 = 0.92). As OLR was further enhanced, COD removal efficiency reached to 98% (R^2 = 0.95) at an OLR of 7.50 g-COD/L_d. Choorit and Wisarnwan (2007) reported 71.10% and 70.32% COD reduction at mesophilic (37˚C) and thermophilic (55˚C) temperatures respectively, treating palm oil mill effluent in continuous stirrer tank. Rittmann and McCarty (2001) investigated that optimum development of microorganisms occurred in a restricted temperature limit and once this limit surpassed, development lowered down quickly. The overall COD removal efficiency of the reactor was found 75%.

3.2 Effect of Organic Loading Rate

Organic loading rate affects several parameters such as COD, biogas, methane, and volatile fatty acids. Stepwise increase in OLR from 1.5.0 to 7.50 g-COD/Ld showed a satisfactory COD removal efficiency with a strong correlation (r = 0.78) which shows that by increasing the organic loading rate, COD removal percentage will be higher as shown in Figure 1. Results indicate that increased organic loading rates produce more biogas and methane (Figure 1). When the organic loading was low, the pH was enhanced steadily up to day 21.

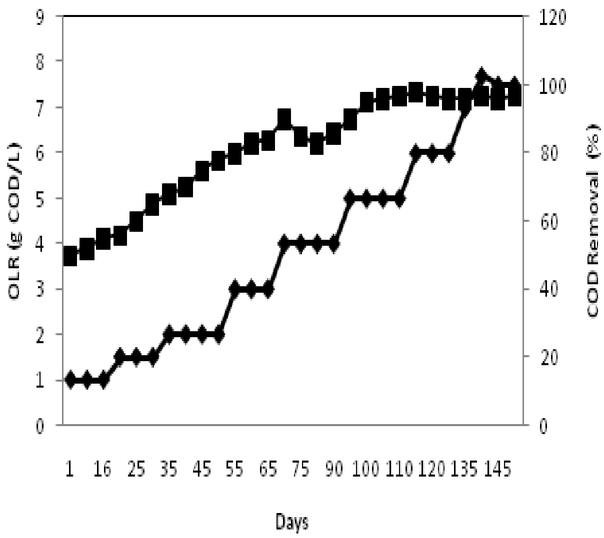

Fig. 1 COD removal efficiency in terms of OLR influence, where ♦ OLR (g COD/L), ■ COD removal %

A reduction in pH value has been observed when temperature was shifted from 37 to 50˚C. This shows that pH affects the COD removal, VFA concentrations, and biogas production due to sudden temperature change. Ivan and Herbert (1998) investigated that the temperature shock causes biomass failure, dropping of the pH, and agglomeration of VFA. Nonetheless, reactor stability was recovered within 7 days through pH adjustment by supplementation of alkaline solution.

Thus, appropriate organic loading rate design is necessary for better reactor performance and process stability. In this study, the OLR was enhanced gradually by dropping HRT from 4 to 2 days (Table 2). Movaedyan *et al.* (2007) maintained OLR up to 1.5 kg-COD/m^3 d for 1 week and then enhanced up to 10 kg-COD/m^3 d for 40 days. Nevertheless, biogas and methane production was low at lower organic loading rates. Michaud *et al.* (2002) and Rincon *et al.* (2006) investigated that lesser OLR caused minor COD removal and biogas yield. The high OLR perhaps created channeling via sludge bed, reverting indigent substrate–biomass contact and minimum digestion of inward COD. These deliver supplementary provision to previous conventions that in plug-flow states, inward influent stays in CSTR, for single retention time, permitting extreme time for adaptation. Moreover, excessive substrate feeding results due to the lack of distribution that may inhibit bacterial activity (Sallis *et al.* 2003). Kalyuzhnyi *et al.* (1998) operated with UASBR for chip processing industry wastewater treatment. For lab scale experimental setup with OLR of approximately 14 kg-COD/m^3 d degradation was more than 75% and 63% for centrifuged and total COD of substrate. Grover *et al.* (1999) used anaerobic baffled reactor, for the treatment of pulp and paper liquors at 35˚C and showed a highest COD degradation approximately 60% at an OLR of 5 kg-COD/m^3 d and 2 days HRT.

Table 2 CSTR operational design

Runs	Time frame/run (d)	Organic loading rate (g COD/Ld)	HRT (d)	COD_{in} (g/L)
1	7	1	4	4
2	11	1.5	4	6
3	9	2	3.5	7
4	7	3	3	9
5	15	5	2	10
6	13	6	2	12
7	11	7	2	14
8	7	7.5	2	15

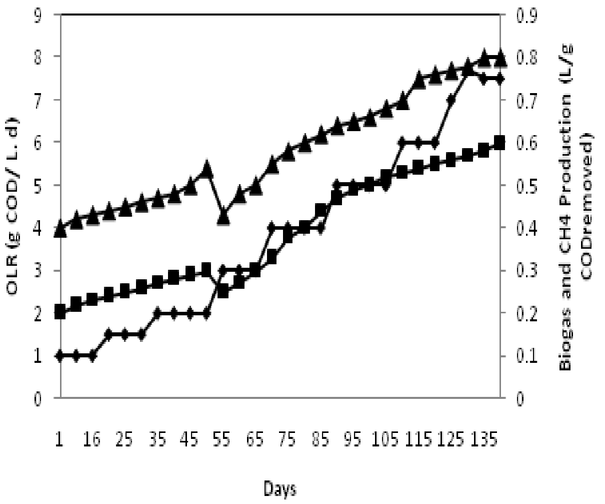

Fig 2. Biogas and CH_4 production in terms of OLR influence, where ♦ OLR (g COD/L), ■ CH_4 production (L/g $COD_{removal}$),▲Biogas production (L/g $COD_{removed}$)

3.3 Biogas and Methane Production

Figure 2 ellustrates the change in biogas and methane production along with organic loading rate. At an OLR of 2.0 g-COD/L_d, biogas and methane production were 0.50 L/g-$COD_{removed}$_d and 0.29 L/g-$COD_{removed}$_d, respectively. The biogas production progressively enhanced thru increasing OLR and mean biogas yield was 0.45 and 0.80 L/g- $COD_{removed}$_d at OLR of 3 and 7.5 g-COD/ L_d, respectively. The methane generation was between 0.25 and 0.60 L/g $COD_{removed}$_d at an OLR of 1.5–7.50 g-COD/L_d, respectively. A strong correlation (r = 0.82) was observed with varing organic loading rate and biogas production during PWW anaerobic treatment in CSTR. Results indicate that high organic loading rates result in more biogas production but the reduction in biogas is caused due to the sudden change in temperature and VFA accumulation in the reactor.

4. CONCLUSIONS

A CSTR reactor is efficient for COD removal and high methane production. A lab scale reactor was constructed to study the mesophilic to thermophilic anaerobic treatment of food waste. VFA accumulation was low, and methane production was comparatively high due to controlled temperature and pH. However, a sudden change in temperature had adverse effect on biogas production and system stability. The high COD loadings in the initial state at 37˚C offer a satisfactory substrate source for succeeding acidogenesis and methanogenesis steps. Thus, at 55˚C temperature and OLR of 7.5 g- COD/L_d with 4 d HRT support a highest biogas generation of 0.6 L/g-$COD_{removed}$_d.

ACKNOWLEDGEMENTS

The authors would like to thank faculty of civil engineering and earth resources, university Malaysia Pahang, for providing continuous laboratory facility. The present research was made possible availing facility provided by RDU-0903113.

REFERENCES

Alper, T.A., Orham, I., Nilgun, A.O., Betul, K. and Bahar, K.I. 2005. Evaluation of performance, acetoclastic methanogenic activity and archaeal composition of full-scale UASB reactors treating alcohol distillery wastewaters, Process Biochemistry. **40**: 1251–1259.

Bernd, L. 2007. Kinetic study of thermophilic anaerobic digestion of solid wastes from potatoes processing. J. Biomas.Energ. **30**: 892–896.

Bohn, I., Bjornsson, L., and Mattiasson, B. 2000. The energy balance in farm scale anaerobic digestion of crop residues at 11–378C. J. Process Biochem. **42**: 57–64.

Choorit, W. and Wisarnwan, P. 2007. Effect of temperature on the anaerobic digestion of palm oil mill effluent. E. J. Biotechnol. **10**: 376–385.

Edgar, F.C.M., Diego, E.C., and Victor, A.A. 2006. Study of the operational conditions for anaerobic digestion of urban solid wastes. J. Waste Manag. **26**: 546–556.

Gerardi, M.H. 2003. *The microbiology of anaerobic* digesters. 5th ed. USA: Wiley.

Grover, R., Marwaha, S.S. and Kennedy, J.F. 1999. Studies on the use of an anaerobic baffled reactor for the continuous anaerobic digestion of pulp and paper mill black liquors. J. Process Biochem. **39**: 653–657.

Han, S.K., Kim, S.H. and Shin, H.S. 2005. UASB treatment of wastewater with VFA and alcohol generated during hydrogen fermentation of food waste. J. Process Biochem. **40**: 2897–2905.

Hanssan, M.N., Chong, T.L., Rehman, M., Salleh, M.N., Zakaria, Z. and Away, M. 2001. Solid waste management with special attention to Malaysia, Malaysia: University of Putra.

Ivan-Lau, W.C. and Herbert-Fang, H.P. 1998. Effect of temperature shock to thermophilic granules, J. Wat. Rese. **31**: 2626–2632.

Kalyuzhnyi, S., Santos, L. and Martinez, J.R. 1998. Anaerobic treatment of raw and preclarified potato-maize wastewater in a UASB reactor. J. Biores. Technol. **66**: 195–199.

Latif, A.F., Ghufran, R., Zularisam, A.W., Ahmad, A. 2011. Integrated application of UASBR for the treatment of waste waters. Wat. Res. **45**: 2683-4699.

Malina, J.F.J. and Pohland, F.G. 1992. *Design of anaerobic processes for the treatment of industrial and municipal wastes.* Pennsylvania: Technomic Publishing Company, Inc.

McHugh, S., Carton, M., Collins, G., and O'Flaherty, V. 2004. Reactor performance and microbial community dynamics during anaerobic biological treatment of wastewater at 16–37 8C. J. FEMS Microbiolo. Ecolo. **48**: 369–378.

Michaud, S., Bernet, N., Buffiere, P., Roustan, M. and Moletta, R. 2002. Methane yield as a monitoring parameter for the start-up of anaerobic fixed film reactors. Wat. Rese. **36**: 1385–1391.

Movahedyan, H., Assadi, A. and Parvaresh, A. 2007. Performance evaluation of an anaerobic baffled reactor treating wheat flour starch industry wastewater. Iran J. Environ. Health. Sci. Eng. **4**: 77–84.

Nadzri, Y. 2008. Overview of solid waste management in Malaysia. Workshop on carbon finance and municipal solid waste management in Malaysia (p. 4.)

Rao, M.S. and Singh, S.P. 2004. Bioenergy conversion studies of organic fraction of MSW: Kinetic studies and gas yield-organic loading relationships for process optimization. J. Biores. Technol. **95**: 173–185.

Rincon, B., Raposo, F., Borja, R., Gonzalez, J.M., Portillo, M.C. and Saiz-Jimenez, C.J. 2006. Performance and microbial communities of a continuous stirred tank anaerobic reactor treating twophases olive mill solid wastes at low organic loading rates. Biotechnol. **121**: 534–543.

Rittmann, B.E. and McCarty, P.L. 2001. *Environmental biotechnology: Principles an applications*. New York: McGraw-Hill Book Co., 768. ISBN 0–072-34553–5.

Sallis, P.J. and Uyanik, S. 2003. Granule development in a spilt-feed anaerobic baffled reactor. J. Biores. Technol. **89**: 255–265.

Tchobanoglous, G., Burton, F.L., and Stensel, H.D. 2003. Wastewater engineering: *Treatment and reuse.* 4th ed. New York: McGraw Hill.

Yu, H.W., Samani, Z., Hanson, A., and Smith, G. 2002. Energy recovery from grass using two phase anaerobic digestion. J. Waste Manag. **22** : 1–5.