STUDY ON BIOENERGY RECOVERY FROM ANAEROBIC CO-DIGESTION OF GLYCEROL RESIDUE AND TREATED PALM OIL MILL EFFLUENT USING ANAEROBIC HYBRID REACTOR

Chinnapong Wangnai[1], Pratin Kullavanijaya[1], Chalermchai Ruangchainikom[2]

[1]Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi (Bang Khun Thian Campus)

[2]Environmental Research and Management Department, PTT Research and Technology Institute

chinnapong.wan@kmutt.ac.th

ABSTRACT

Glycerol residue derived from crude glycerol distillation, relating biodiesel/oleochemical waste utilization and management, is characterized as high-strength waste containing extremely high COD content, inorganic impurities and dark brown color. While treated palm oil mill effluent (treated POME) discharged from biogas plant/wastewater treatment system contains sufficient nutrient source for anaerobic microorganisms growth. Therefore, appropriate mixture of glycerol residue and treated POME could be considered as co-substrates with value added in biogas production. The objective of this study was to investigate feasibility in applying the glycerol residue and treat POME as feedstock for biogas production. The experimental results suggested that the mixture could be applied as high potential feedstock for biogas production with contributing on practical bioenergy recovery and environmental protection.

1. INTRODUCTION

Glycerol residue derived from glycerol refinery is one of major waste discharged from biodiesel/oleochemical industry. The glycerol residue is characterized as caramelized waste containing extremely high COD content, inorganic impurities and dark brown color. Various waste treatment technologies such as incineration, physico-chemical treatment and landfill application have been implemented to deal with this high strength waste. However, practical waste utilizing scheme is unlikely available for biogas recovery, which can be applied as renewable energy, from this glycerol residue. While treated palm oil mill effluent (treated POME) discharged from biogas plant/wastewater treatment system contains sufficient nutrient source for anaerobic microorganisms growth and high alkalinity for a digester buffer capacity. Therefore, appropriate mixture of glycerol residue and treated POME could be considered as co-substrates with value added in biogas production.

High-rate anaerobic reactors; namely, anaerobic filter reactor (AF), anaerobic fixed-film reactor (AFF) (Tanticharoen and Bhumiratana, 1995) and upflow anaerobic sludge blanket (UASB) (Lettinga, 1995) have been studied and developed for treatment and energy recovery from high strength wastewater of agro-industry. Although the efficiency of these reactors is impressive, the troublesome of each reactor is found differently. To solve those problems, anaerobic hybrid reactors with a combination of different anaerobic system features into a single reactor have been studied in treating various industrial wastewaters (Lo et al., 1994; Borja et al., 1996; Surarak et al., 1998; Najafpour et al., 2006). In addition, anaerobic hybrid reactor with combining benefits of an upflow sludge bed reactor and a fixed-film reactor has been developed by PDTI/KMUTT for wastewater treatment and biogas production from agro-industrial wastes since 1995. Currently, several full-scale anaerobic hybrid reactors are implemented for palm oil industry under KMUTT technology transfer program.

The aim of this research was to assess the feasibility of biogas production from co-substrates of glycerol residue and treat POME in the anaerobic hybrid reactor combining fixed-film and sludge bed reactor.

2. EXPERIMENT

2.1 Experimental Apparatus

A laboratory-scale anaerobic hybrid reactor (AHR) applied for this study was made of plastic column with working volume of 10 L (excluding head space). The AHR consisted of two major compartments; top and bottom. The top part (upper 1/2 of the operational level) was filled with bunches of nylon fibers as a packed bed zone, while, the bottom part was set as a sludge bed zone. The nylon fibers were allowed to float upward due to the upflow pattern of the influent and gas bubbles. Fig. 1 shows the schematic flow chart of the AHR used in this research.

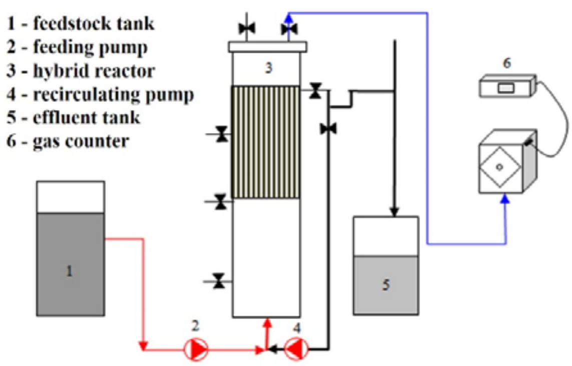

Fig. 1 Schematic diagram of the anaerobic hybrid reactor.

2.2 Co-substrates and Seed Sludge

In this study, co-substrates as glycerol residue and treated POME mixture was used as the AHR feedstock. The glycerol residue was the bottoms fraction taken from a crude glycerol distillation column of an oleochemical factory in Rayong, Thailand. The treated POME was collected from a wastewater treatment plant of a palm oil mill in Chonburi, Thailand. Initial characteristics of both substrates are shown in Table 1. The mixture of the feedstock was prepared with COD:N:P ratio as 100:0.7:0.1 (Khanal, 2008) by adding NH_4Cl and KH_2PO_4 and was stored in a cold room at 4 °C before feeding.

Table 1 Characteristics of the glycerol residue and treated POME (unit; mg L^{-1}).

Parameter	Glycerol Residue	Treated POME
Total COD	1,050,600	2,252
Soluble COD	1,030,200	1,580
BOD	580,000	1,078
TKN	1,140	37
Total Phosphate	600	37
Sodium	15,680	481
Chloride	<30	3,159
Potassium	18,560	1,838
Oil & Grease	ND	ND
sulfate	7,480	103

Sludge taken from a biogas plant fed with POME at its steady-state was applied as microbial starter. The seed sludge pH value was 7.3 and contained 35.8 g L^{-1} of volatile suspended solid (VSS). The Specific methanogenic activity (SMA) was 0.16 g COD g VSS^{-1} day^{-1}.

2.3 Reactor Operation

The reactor was started with an initial organic loading rate (OLR) of 1.3 kg COD m^{-3} d^{-1} and a hydraulic retention time (HRT) of 10 days. Thereafter, the co-substrates feeding flow was increased stepwise to examine the maximum OLR with the fixed HRT that the AHR could perform with high biogas yield as well as high organic removal.

In order to determine the reactor performance and stability regarding biogas production, the reactor influent and effluent samples were collected and analyzed for pH, total alkalinity (ALK), total volatile fatty acids (VFA), and COD every 2-3 days. Biogas volume and composition were monitored daily.

2.4 Analytical Methods

The operating parameters such as pH, COD, TS, and SS, and VSS were analyzed according to Standard Methods (APHA, 1999). ALK and VFA were determined by titration method (Anderson and Yang, 1992). Gas chromatographs equipped with thermal conductivity detector (Shimadzu Chromatography, Model GC-9A) were used for the determination of biogas compositions.

3. RESULTS AND DISCUSSION

This study was carried out within 160 days of the AHR operation with various OLR and fixed HRT as presented in Fig. 2. The 10 days HRT was set as the shortest retention time that the AHR could run with stability regarding the prior work which glycerol residue fed as single substrate. The reactor has been started with the OLR approximately 1.3 kg COD m^{-3} day^{-1} for more than 6 rounds of HRT to ensure that the seed sludge was acclimated to the feedstock. The reactor could be operated with steady-state at the highest OLR of 2.5 kg COD m^{-3} day^{-1}.

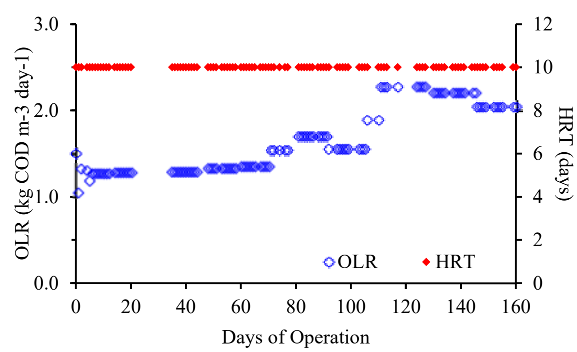

Fig. 2 Profiles of operating OLRs and HRT

In Fig. 3, the variation of operating parameters including pH, alkalinity, and volatile fatty acids indicated that the reactor was likely running with consistency. The system pH and alkalinity was fairly higher that typical operating range relating to remarkable properties of the treated POME. Moreover, the high VFA concentrations in the reactor could be an effect relating the supremacy of acidogens in the seed sludge. The significant change of VFA during the reactor start-up period could be an indicator on the lack of acclimatizing time for the seeding microorganisms to adapt to the feedstock containing glycerol. After the temporary stop on feeding (Day#20-Day#35), the microorganisms were likely recovered and could tolerated for VFA with concentrations higher than 2,000 mg L^{-1} as acetic acid in the reactor.

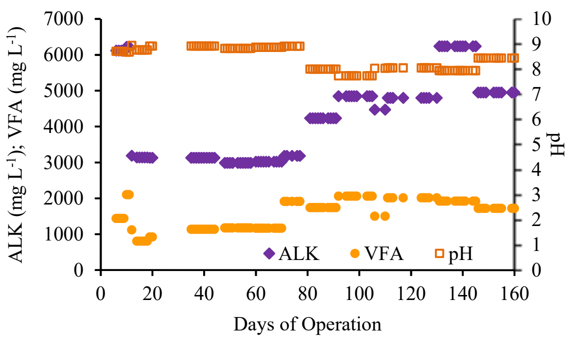

Fig. 3 Variation of the operating pH, ALK, and VFA.

3.1 Feasibility on Biogas Production

The feasibility study on biogas production from the co-substrates was investigated in terms of biogas yield and biogas compositions. Fig. 4 shows the profiles of main gas contents; methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S) in the biogas produced during the study.

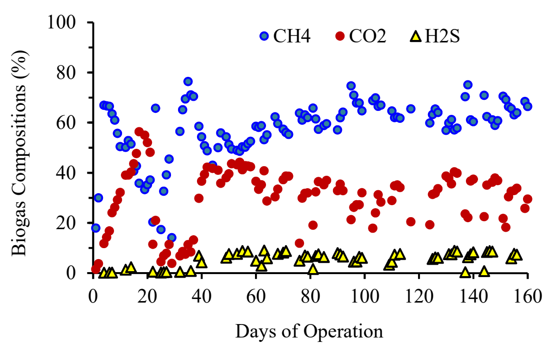

Fig. 4 Variation of the main biogas compositions during this study.

It was clear that biogas generated from the co-substrates feeding contained significant proportion of methane gas, which was higher than 60% in average. Nevertheless, the monitored H_2S content in the biogas also high. In general, this biogas could be an alternative fuel for direct combusting applications. In order to use the biogas as fuel substitute to run engines, H_2S clean-up units are compulsory required to avoid engine malfunction and massive corrosion.

Fig. 5 illustrates the tendency of biogas production over COD removed in term of biogas yield. The average biogas yield was found in a range of 0.5-0.6 m^3 kg^{-1} COD removed, which was similar to the theoretical yield comparatively. These results on biogas production could firmly support an idea on using this waste glycerol to produce renewable energy.

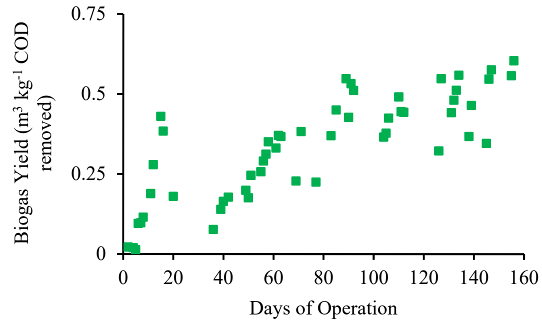

Fig. 5 Variation of the biogas yields

3.2 Organic Removal Efficiency

The COD reduction efficiency was monitored throughout this study in order to examine the performance of the AHR on organic matter conversion. Fig. 6 depicts the profile of COD reduction regarding the days of operation with different OLRs. At the early stage of the study, the reactor performed poorly on decreasing COD content in the glycerol residue and treated POME mixture. Similar to the fluctuation of VFA mentioned above, the microbial starter required certain period of time for feedstock acclimation. When the seeding sludge likely adapted to the co-substrates, the reactor could impressively remove organic matter in the form of COD. The AHR efficiency on COD removal when it was fed continuously with the co-substrates at maximum OLR was approximately 80%.

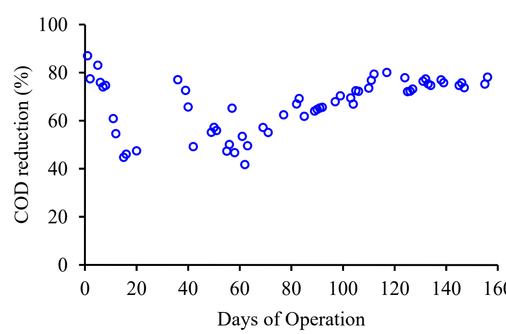

Fig. 6 Variation of the COD reduction.

4. CONCLUSION

After 160 days of the investigation, the highest OLR was reported as approximately 2.5 kg COD m^{-3} day^{-1} corresponding to the stable HRT of 10 days. The average biogas yield was approximately 0.5-0.6 m^3 kg^{-1} COD removed. Methane content in the produced biogas was varied in a range higher than 60%. The percentage of COD removal at maximum OLR was approximately 80% for continuous co-substrates feeding operation. These results suggested that the mixture of glycerol residue and treated POME could be applied as high potential feedstock for biogas production with contributing on practical bioenergy recovery and environmental protection.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support from the PTT Public Company, Thailand.

REFERENCES

APHA, AWWA, and WEF. Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA, AWWA and WEF, Washington, DC., U.S.A., 1999.

Anderson, G.K. and Yang, G., Determination of bicarbonate and total volatile acid concentration in anaerobic digesters using a simple titration, Water Environ. Res., vol. 6, no. 6, pp. 53-59, 1992.

Borja, R., Banks, C.J., Khalfaoui, B. and Martin, A., Performance evaluation of an anaerobic hybrid digester treating palm oil mill effluent, J. of Environ. Sci. Health A, vol. 31, no. 6, pp. 1379-1393.

Khanal, S.K. Anaerobic Biotechnology for Bioenergy Production: Principles and Applications. Wiley-Blackwell., John Wiley & Sons, Inc., Singapore, 2008.

Lettinga, G., Anaerobic digestion and wastewater treatment systems, Antonie van Leeuwen hoek Int. J. Gen. Mol. Biol., vol. 67, pp. 3-28, 1995.

Lo, K.V., Liao, P.H. and Gao, Y.C., Anaerobic treatment of swine wastewater using hybrid UASB reactors, Bioresour. Technol., vol. 47, pp.153-157, 1994.

Najafpour, G.D., Zinatizadeh, A.A.L., Mohamed, A.R., Hasnain Isa, M. and Nasrollahzadeh, H., High-rrate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge-fixed film bioreactor, Process Biochem., vol. 41, pp.370-379, 2006.

Surarak, B., Wangnai, C., Chaiprasert, P. and Tanticharoen, M., Performance of an anerobic hybrid reactor combining a filter and a sludge bed, The 10th Annual General Meeting of Thai Society for Biotechnology for a Self-Sufficient Economy, 25-27 November 1998, Sol Twin Towers Hotel, Bangkok, Thailand, pp. 94-102, 1998.

Tanticharoen, M. and Bhumiratana, S., Waste treatment plants, Narosa Publishing House, New Delhi, 1995.

Chinnapong Wangnai received the B.Sc. (1991), M.Sc. (1995), and PhD. (2006) in the field of chemical engineering from the University of Queensland, Australia.

He is a researcher in Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi. His Current interests include anaerobic hybrid reactor application on wastewater treatment and biogas production from high-strength organic wastewater, bioenergy recovery from solid biowastes co-digestion, and hydrogen sulfide removal from biogas using bioprocesses.

Pratin Kullavanijaya received the B.Eng. (1997), M.Eng. (2005) in the field of environmental engineering from King Mongkut's University of Technology Thonburi.

He is a researcher in Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi. His Current interests include biogas technology, anaerobic digestion, biofilm, and biowaste utilization.

Chalermchai Ruangchainikom received the B.Eng. (2001), M.Sc. (2003), and PhD. (2006) from National Research Center for Environmental and Hazardous Waste Management, Chulalongkorn University, Bangkok, Thailand.

He is a researcher in Environmental Research and Management Department, PTT Research and Technology Institute. His Current interests include renewable energy (biogas system), water/wastewater treatment and reclamation, contaminated soil and groundwater remediation, and advanced oxidation processes.