World Academy of Science, Engineering and Technology
International Journal of Bioengineering and Life Sciences
Vol:9, No:12, 2015

Comparison of the Effects of Continuous Flow Microwave Pre-treatment with Different Intensities on the Anaerobic Digestion of Sewage Sludge for Sustainable Energy Recovery from Sewage Treatment Plant

D. Hephzibah, P. Kumaran, N. M. Saifuddin

***Abstract*—**Anaerobic digestion is a well-known technique for sustainable energy recovery from sewage sludge. However, sewage sludge digestion is restricted due to certain factors. Pre-treatment methods have been established in various publications as a promising technique to improve the digestibility of the sewage sludge and to enhance the biogas generated which can be used for energy recovery. In this study, continuous flow microwave (MW) pre-treatment with different intensities were compared by using 5 L semi-continuous digesters at a hydraulic retention time of 27 days. We focused on the effects of MW at different intensities on the sludge solubilization, sludge digestibility, and biogas production of the untreated and MW pre-treated sludge. The MW pre-treatment demonstrated an increase in the ratio of soluble chemical oxygen demand to total chemical oxygen demand (sCOD/tCOD) and volatile fatty acid (VFA) concentration. Besides that, the total volatile solid (TVS) removal efficiency and tCOD removal efficiency also increased during the digestion of the MW pre-treated sewage sludge compared to the untreated sewage sludge. Furthermore, the biogas yield also subsequently increases due to the pre-treatment effect. A higher MW power level and irradiation time generally enhanced the biogas generation which has potential for sustainable energy recovery from sewage treatment plant. However, the net energy balance tabulation shows that the MW pre-treatment leads to negative net energy production.

***Keywords*—**Anaerobic digestion, biogas, microwave pre-treatment, sewage sludge.

I. Introduction

THE rapid deployment of renewable resources in various sectors to contribute to the green energy and technology was driven by the ambitious goal of Malaysian government to develop the use of renewable energy and to add it to the national electricity supply in addition to a sustainable socioeconomic development. For instance, the wastewater treatment sector, which has a modern mechanized sewage treatment plant (STP) with anaerobic digesters, has high potential to generate clean energy from the biogas produced as a byproduct during the waste water treatment.

D. Hephzibah, Post-Graduate Student, P. Kumaran, Senior Lecturer and Principal Researcher, N. M. Saifuddin, Professor and Principal Researcher are with the Centre of Renewable Energy, Universiti Tenaga Nasional, Malaysia (e-mail: hephzibahdavid89@gmail.com, kumaran@uniten.edu.my, saifuddin@uniten.edu.my).

At present, anaerobic digesters have been installed in few modern mechanized STPs in Malaysia to generate biogas from the anaerobic treatment of sewage sludge. Currently the average biogas production rate is about 1,150 m^3 daily in a typical modern STP that deploys anaerobic digesters to treat 250,000 population equivalent (PE) sewage solids. The electricity plausible to be generated after a gas engine conversion is approximately 2,900 kWh/day. However, the average plant electricity consumption is 43,503 kWh/day [1]. Therefore, the recovery of energy from biogas will only replace 6.60% of the electricity consumption during the treatment of the wastewater itself. However, it is not economically feasible for commercial implementation due to the quantity of biogas produced presently. Hence, the biogas produced is flared in order to mitigate greenhouse gas emission. Thus, the valuable electricity energy potential of the methane remains untapped. Hence, in order to enhance the biogas production the limiting factors of the anaerobic process needs to be overcome. The anaerobic technology is restricted by certain factors that include the hydrolysis stage, whereby the substrates can be very slow to be degraded due to the molecular structure of the substrates such as high crystalline structure or low surface area, which are poorly accessible to the microorganism and their enzymes [2]. Recent publications have suggested that pre-treatment of substrates prior to anaerobic digestion can be used to overcome this problem [2]-[4]. Literatures also have suggested that secondary thickened sludge (STS) from STP is the most widely studied substrates on pre-treatment application due to low biodegradability [4]. Among the types of pre-treatment are mechanical pre-treatment, thermal pre-treatment, ultrasound pre-treatment, MW pre-treatment acid pre-treatment and others. In this study, MW pre-treatment will be explored.

Previously, a study on batch continuous MW pre-treatment has been conducted and the quantity of biogas produced with and without pre-treatment has been evaluated and compared whereby the MW pre-treated sludge for 5 minutes and 15 minutes enhances the anaerobic digestibility rate and biogas production by 11.90% and 38.50% respectively compared to untreated sewage sludge [5]. Although, batch process MW pre-treatment shows optimistic effect on the biogas production, it is not feasible to be implemented in the STP. Therefore, study needs to be undertaken to incorporate a feasible MW pre-treatment system STP. The aim of this study is to investigate the influence of continuous flow MW pre-treatment of STS with different intensities for sustainable energy recovery in STP through anaerobic digestion.

II. Methods

Primary thickened sludge (PTS) and STS samples were collected from a STP. The experiments were conducted at different time due to the limited experimental setup. Thus, the samples were standardized to 4% concentration prior being fed into the digester. A domestic SHARP R-298H (S) microwave oven with maximum power output of 800 W was modified to accommodate the continuous flow heat exchanger. 150 ml of digestate is drawn out from the digesters daily at a fixed time and fed with 150 ml of PTS for the first 15 days until the quantity of biogas generated start to be in steady state. Subsequently, from day 16 onwards STS was fed into the digesters daily by gradually increasing the volume by 10% in which one digester was fed with untreated STS while the other received pre-treated STS. The STS sample was pre-treated at 240 W and 400 W for 5, 10 and 15 minutes. The untreated, pre-treated and digested sludge was characterized daily for total solid (TS), volatile solid (VS), total suspended solid (TSS), volatile suspended solid (VSS), total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), volatile fatty acids (VFA) and alkalinity. Meanwhile, the quantity and quality of biogas generated was measured by using a graduated eudiometer and COMBIMASS GA-m portable gas analyzer. Besides that, the energy used during the pre-treatment was measured using an EFERGY energy monitoring meter.

III. Results and Discussion

A. Sludge Solubilization

The efficiency in the solubilization of STS was examined by determining the organic matter contents such as sCOD/tCOD ratio and VFA concentration. Previous studies had reported that the MW pre-treatment is able to disintegrate the floc structure of the sludge, thus, the solubilization of the organic matters was enhanced [6], [7]. Due to the disintegration of the floc structure, it releases the extracellular and intracellular materials from the cells into aqueous phase [8], [9].

The results shows that the MW pre-treated STS significantly changed the sCOD/tCOD ratio. Fig. 1 illustrates the increment of the solubility of COD of STS at different MW pre-treatment intensities compared to the untreated STS. The results also demonstrate that as the pre-treatment intensity varies, the solubility of COD also changes. As per this study, the sCOD/tCOD ratio increases as the MW power level and time increases. The solubility ratio of COD of STS increases by 0.92, 0.93 and 0.97% at MW power level of 240 W for 5, 10 and 15 minutes, respectively compared to the untreated STS. Similarly, for the power level of 400 W with 5, 10 and 15 minutes irradiation time, the sCOD/tCOD ratio released is higher by 1.02, 1.84 and 3.15 % for 5, 10, and 15 minutes, respectively compared to the untreated STS. The experimental data were similar to the results reported in a study whereby the COD solubility was enhanced by the increased level of MW power and the longer irradiation time [10].

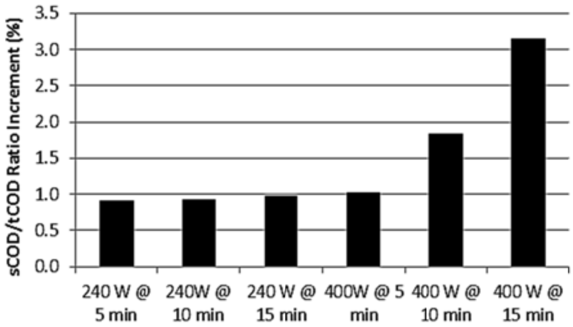

Fig. 1 Effect of MW pre-treatment of STS at different intensities on the increment of solubility of COD

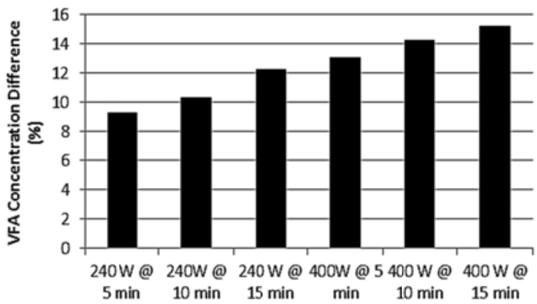

Fig. 2 Effect of MW pre-treatment of STS at different intensities on the increment of VFA concentration

Moreover, the total VFA concentration of STS increased significantly, for the pre-treated compared to the untreated STS sample. It indicated that VFA concentration increased gradually and these rates increased with the MW power level and irradiation time as depicted in Fig. 2. At a power level of 240 W, the VFA concentration increases by 9.30, 10.30 and 12.30% at 5, 10 and 15 minutes, respectively compared to the untreated STS. Consequently, the VFA concentration at 400 W also escalates by 13.05, 14.22 and 15.22% for irradiation time of 5, 10 and 15 minutes, respectively. Solubilization of WAS in terms of VFA concentration due to MW irradiation have been reported previously [7], [9].

The increase in solubility can be explained by the hydrolysis of the large organic molecules, the lysis of cell walls and disintegration of the sludge floc which was intensified by the applied MW pre-treatment [10]. At short MW power level and irradiation time, the floc structure becomes relatively unfettered and some bacteria are exposed during this alteration, however, the structural change was minimal. The floc structure was disrupted completely and extracellular and intracellular matters were released from the sludge flocs into the soluble phase when the MW intensities increased. [7], [11]-[13]. Besides that, it could be concluded that temperature was the most influential parameter in sludge disintegration because as the MW intensities increases, the sludge temperature also hikes [14].

B. Sludge Digestibility

The MW pre-treatment has accelerated the hydrolysis process which is the rate limiting step and improved the anaerobic digestion process compared to the untreated STS. Fig. 3 shows the VS removal efficiency of the digesters fed with untreated and MW pre-treated STS at different MW intensities. The VS removal efficiency increased to the range of 41.00 to 46.00% gradually in the first 15 days of the digestion time due to the effect of PTS sample which is high in strength compared to STS sample. From day 11 onwards, as the digester was fed with STS, it was observed that the VS removal efficiency decreases slowly. The VS removal efficiency of the MW pretreated STS also increases as the MW power level and irradiation time increases. For instance, at a power level of 240 W, the averaged VS removal efficiency of the untreated STS increased from 13.78% to 23.46, 24.78 and 26.21% at 5, 10 and 15 minutes respectively when the digester was fed with 100% STS from day 25 onwards. Comparatively, at 400 W, the VS removal efficiency hikes to 27.15, 28.75 and 30.64% for 5, 10 and 15 minutes respectively compared to the untreated STS. Moreover, the TCOD removal efficiency of the pre-treated STS sample also improved compared to the untreated STS sample. Fig. 4 presents the TCOD removal efficiency of untreated and MW pre-treated STS at different intensities. A first observation is that the TCOD removal efficiency increased to the range of 15.30 to 17.00% gradually in the first 15 days of the digestion time due to the effect of PTS sample which is high in strength compared to STS sample. When the digester was fed with STS from day 11 onwards, it was observed that the TCOD removal efficiency decreases slowly. From the results, it is so clear that TCOD removal efficiency improves as the MW pre-treatment intensity intensifies. At 240 W, the TCOD removal efficiency when the digester was fed with 100% STS reaches around 8.64, 9.30 and 9.82% for 5, 10 and 15 minutes respectively compared to the untreated digester which was only 6.37%. Meanwhile, improvements in the TCOD removal efficiencies of the MW pre-treated with respect to the control was approximately 10.3, 10.9 and 11.4% at a power level of 400 W at 5, 10 and 15 minutes irradiation time correspondingly.

As discussed in the earlier section, MW pre-treatment effectively solubilizes the sludge and thus increasing the readily biodegradable portion of the sludge. This ultimately leads to enhanced sludge digestibility as shown in the VS and TCOD removal efficiency. Although the VS and TCOD removal efficiency of the MW pre-treated samples increased, the control performed less efficiently and these sludge digestibility effects have been reported previously [15].

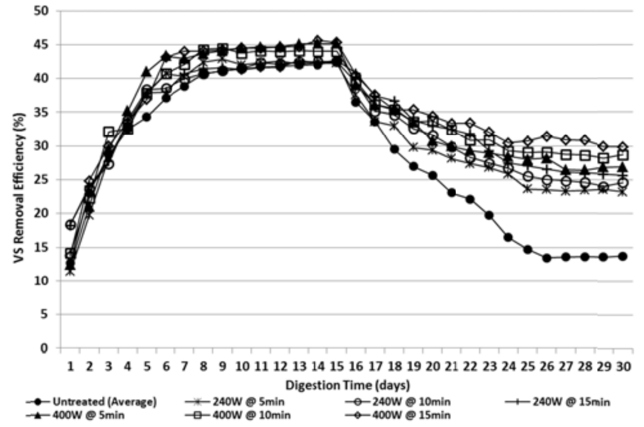

Fig. 3 VS removal efficiency of untreated and MW pre-treated STS at different intensities

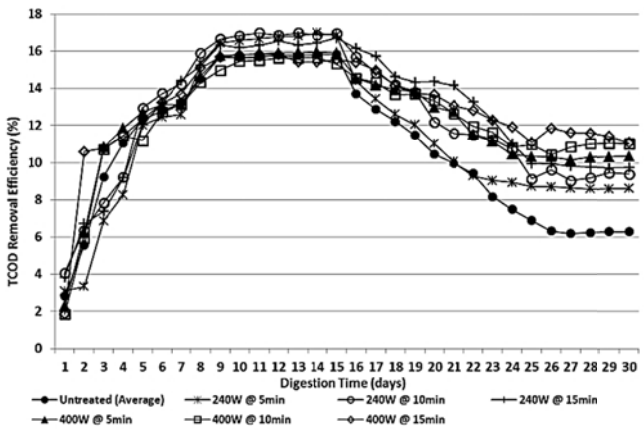

Fig. 4 TCOD removal efficiency of untreated and MW pre-treated STS at different intensities

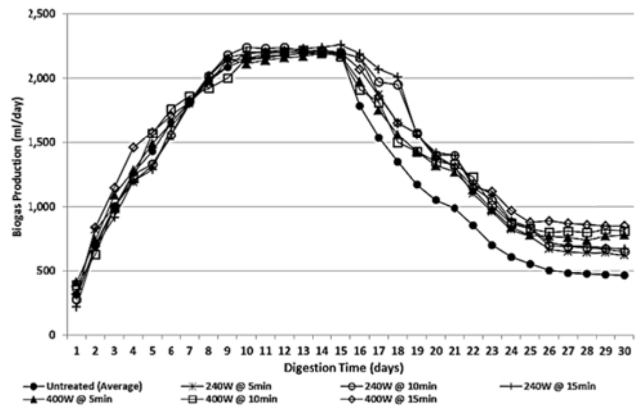

Fig. 5 Daily biogas production of the untreated and MW pre-treated STS at different intensities

C. Biogas Production

The biogas production in both digesters is illustrated in Fig. 5. In this study, the biogas production escalates to approximately 2,200 ml until day 15 as the digester was only fed with PTS which is high in strength. The biogas fluctuates slowly as STS was being introduced in the digester. It can be observed that the biogas production in the MW pre-treated digester was significantly higher compared to the untreated digester. The quantity of biogas generated in the 5, 10 and 15 minutes MW pretreated at 240 W increased by 164, 172, 210 ml at 240 W when the digester was fed with 100% STS. Meanwhile, at 400 W the increment was 274, 319 and 374 ml. Moreover, the methane concentration in the biogas from the digesters did not defer and remained constant approximately 65-69%.

Enhancement of biogas production due to MW pre-treatment has been reported previously by various literatures [8], [9], [15]. The improvements in the sludge solubilization and sludge digestibility of the MW pre-treated STS compared to untreated STS are a strong reason for the improvement of the biogas production. Besides that, it also can be concluded as the MW intensities increases, the biogas production hikes.

D.Energy Calculation

The energy contained in the additional amount of biogas produced from MW treated sludge was compared to the energy utilized during the MW treatment. Table I summarizes the energy balance of the MW pre-treatment and the extra biogas generated for a sludge volume of 150 ml. The energy content of extra biogas production was calculated based on the average increase in biogas production while the MW energy applied was obtained from the energy monitoring socket

TABLE I
ENERGY BALANCE CALCULATION

Pre-treatment condition	Average increase in biogas production (mL)	Energy content of extra biogas (kJ)	MW energy applied (kJ)	Net energy production (kJ)
240 W, 5 min	172.04	1.74	226.80	-225.06
240 W, 10 min	210.37	2.13	270.00	-267.87
240 W, 15 min	223.70	2.26	327.60	-325.34
400 W, 5 min	273.70	2.77	442.80	-440.03
400 W, 10 min	318.70	3.22	529.20	-525.98
400 W, 15 min	373.70	3.78	612.00	-608.22

The results show that for each pre-treatment condition, the net energy production is negative, which means that the system is not self-supporting. Similar effects were reported in a literature [9]. Thus, further optimization of the MW pre-treatment is needed. For instance, the configuration of the heat exchanger in terms of volume, mass, geometry and spatial configuration through the microwave chamber shall be subjected to further investigation. Subsequently, these configuration parameters might impact on the microwave absorption efficiency as explained by other studies [16].

IV. CONCLUSION

This paper studied the application of a MW pre-treatment at different intensities. It was seen that the pre-treatment resulted in significant sludge solubilization. Solubilization of COD and VFA of MW pre-treated sludge was higher than the untreated sludge. In addition, the VS and TCOD removal efficiency also increased considerably as the MW power level and irradiation time increases. Moreover, the biogas production of the MW pre-treated STS was higher compared to the untreated STS, without a significant difference in methane content of the biogas. The biogas produced is a promising renewable resource that can generate renewable energy from the wastewater which can sustain the electricity consumption of the STP after converting the gas to electricity. However, the energy balance calculation shows that the pre-treatment leads to negative net energy production. With regard to that, further study is recommended to optimize the MW pre-treatment technology.

ACKNOWLEDGMENT

The authors would like to acknowledge the contributions of Indah Waster Konsortium (IWK) management for providing us their support in completing this research. We would like to convey our sincere gratitude to all the research assistants and laboratory staffs of the Department of Mechanical Engineering in Universiti Tenaga Nasional (UNITEN), Department of Civil Engineering in UNITEN and the management of UNITEN for their support and direct involvement in this study.

REFERENCES

[1] Yew, L. (2012) *Energy and Resource Baseline Analysis of a Sewage Treatment Plant*. Undergraduate. Universiti Tenaga Nasional.

[2] Montgomery, L. and Bochmann, G. (2014). *Pretreatment of Feedstock for Enhanced Biogas Procution*. Energy from Biogas. IEA Bioenergy.

[3] Appels, L., Baeyens, J., Degrève, J. and Dewil, R. (2008). Principles and Potential of the Anaerobic Digestion of Waste-activated Sludge. *Progress in Energy and Combustion Science*, 34 (6), pp. 755-781.

[4] Carlsson, M., Lagerkvist, A. and Morgan-Sagastume, F. (2012). The Effects of Substrate Pre-treatment on Anaerobic Digestion Systems: A Review. *Waste Management*, 32(9), pp.1634-1650.

[5] Hephzibah, D., Kumaran, P. and Saifuddin, N. (2014). Pre-Treatment of Sewage Sludge to Enhance Biogas Production to Generate Green Energy for Reduction of Carbon Footprint in Sewage Treatment Plant (STP). In: *Green Energy for Sustainable Development (ICUE), 2014 International Conference and Utility Exhibition*. (online) Pattaya City: IEEE, pp.1-5. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6829007&isnumber=6828886 (Accessed 15 Jun. 2015).

[6] Bougrier, C., Delgenès, J. and Carrère, H. (2008). Effects of thermal treatments on five different waste activated sludge samples solubilisation, physical properties and anaerobic digestion. *Chemical Engineering Journal*, 139(2), pp.236-244.

[7] Eskicioglu, C., Kennedy, K. and Droste, R. (2006). Characterization of soluble organic matter of waste activated sludge before and after thermal pretreatment. *Water Research*, 40(20), pp.3725-3736.

[8] Tyagi, V. and Lo, S. (2013). Microwave irradiation: A sustainable way for sludge treatment and resource recovery. *Renewable and Sustainable Energy Reviews*, 18, pp.288-305.

[9] Appels, L., Houtmeyers, S., Degrève, J., Van Impe, J. and Dewil, R. (2013). Influence of microwave pre-treatment on sludge solubilization

and pilot scale semi-continuous anaerobic digestion.*Bioresource Technology*, 128, pp.598-603.
[10] Beszédes, S., László, Z., Horváth, Z., Szabó, G. and Hodúr, C. (2011). Comparison of the effects of microwave irradiation with different intensities on the biodegradability of sludge from the dairy- and meat-industry. *Bioresource Technology*, 102(2), pp.814-821.
[11] Feng, X., Lei, H., Deng, J., Yu, Q. and Li, H. (2009). Physical and chemical characteristics of waste activated sludge treated ultrasonically. *Chemical Engineering and Processing: Process Intensification*, 48(1), pp.187-194.
[12] Eskicioglu, C., Kennedy, K. and Droste, R. (2007). Enhancement of Batch Waste Activated Sludge Digestion by Microwave Pretreatment. *Water Environment Research*, 79(11), pp.2304-2317.
[13] Park, W., Ahn, J., Hwang, S. and Lee, C. (2010). Effect of output power, target temperature, and solid concentration on the solubilization of waste activated sludge using microwave irradiation. *Bioresource Technology*, 101(1), pp.S13-S16.
[14] Yu, Q., Lei, H., Yu, G., Feng, X., Li, Z. and Wu, Z. (2009). Influence of microwave irradiation on sludge dewaterability. *Chemical Engineering Journal*, 155(1-2), pp.88-93.
[15] Park, W. and Ahn, J. (2011). Effects of microwave pretreatment on mesophilic anaerobic digestion for mixture of primary and secondary sludges compared with thermal pretretament. *Environmental Engineering Research*, 16(2), pp.103-109.
[16] Hosahalli, S. and Manguang, L. (2011). Influence of system variables on the heating characteristics of water during continuous flow microwave heating. *International Journal of Microwave Science Technology*, 2011.

Hephzibah David obtained her bachelor's degree in Mechanical Engineering from Universiti Tenaga Nasional, Malaysia. She is currently a master's degree student under the supervision of Ir. Dr. Kumaran Palanisamy and Prof. Dr. Saifuddin Normanbhay. Her research is centered on the design and development of microwave assisted pre-treatment system for enhancement of biogas production in sewage treatment plant (STP).

Ir. Dr. Kumaran Palanisamy a graduate mechanical engineer from Purdue University is a senior lecturer at Universiti Tenaga Nasional. He has 10 years working experience in electric power generation in a multinational electricity utility corporation in Malaysia, Tenaga Nasional Berhad. Currently, he is dedicated to energy related green research, specifically alternative renewable energy, energy efficiency and environment conservation.

Prof. Dr. Saifuddin Normanbay obtained his bachelor's degree and master's degree in Science from University Malaya. He received his PhD from University Malaya through his research work on protein structure and enzymology. He have been lecturing since 1991.He has been actively involved in the research field of the microwave assisted reactions, biocatalyst immobilization and biodiesel/bioethanol production.