

Influence of Continuous Flow Microwave Pre-Treatment on Anaerobic Digestion of Secondary Thickened Sludge for Sustainable Energy Recovery in Sewage Treatment Plant

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Abstract. This work elucidates the effects of pre-treatment of secondary thickened sludge (STS) for enhancement of biogas production that has great potential to generate energy for the utilization of the sewage treatment plant (STP) itself. Microwave pre-treatment has been adopted for this study. Experiment works have been designed and conducted to examine the effectiveness of continuous flow microwave pre-treatment on the solubility of STS, digestibility of STS and biogas production at a power level of 80 W for 5, 10 and 15 minutes. A few characteristics of the sewage sludge were monitored daily to identify the effect of pre-treatment on the sludge. The soluble chemical oxygen demand (SCOD)/total chemical oxygen demand (TCOD) ratio increased by 0.1, 1.0 and 1.8%, while the volatile fatty acids (VFA) concentration of the pre-treated sludge improved by 4.4, 5.1, 5.9% at the irradiation time of 5, 10 and 15 minutes, respectively at a microwave power level of 80 W. Besides that, the digestate also indicates that the pre-treated sludge undergoes efficient VS removal and TCOD removal after anaerobic digestion compared to the untreated sludge. Moreover, the biogas quantity increased by an average of 19.2, 24.1 and 32.2% in 5, 10 and 15 minutes irradiation time respectively compared to the untreated sludge. The additional quantity of biogas generated has shown a great potential for sustainable energy generation that can be utilized internally by the STP.

1 Introduction

The ambitious goal of Malaysia to introduce renewable energy to the national electricity supply mix has motivated the adoption of renewable resources in various sectors such as the wastewater treatment sector.

Currently, anaerobic digesters have been installed in few modern mechanized STPs in Malaysia to generate biogas from the anaerobic treatment of sewage sludge. Presently, in a typical modern STP that deploys anaerobic digesters to treat 250,000 population equivalent (PE) sewage solids the average biogas production rate is about 1,150 m³ daily whereby the electricity plausible to be generated after

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gas engine conversion is approximately 2,900 kWh/day. However, the average plant electricity consumption is 43,503 kWh/day [1]. Thus, the recovery of energy from biogas will replace 6.6% 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 methane gas produced is flared in order to mitigate greenhouse gas emission. Therefore, the valuable electricity energy potential of the methane remains untapped.

In order to enhance the biogas production, the limiting factors of the anaerobic process which includes the hydrolysis stage needs to be overcome. 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 [2,3,4]. Among the types of pre-treatment is mechanical pre-treatment, thermal pre-treatment, ultrasound, pre-treatment, microwave pre-treatment acid pre-treatment and others. In this study, microwave pre-treatment will be explored.

Previously, a study on batch microwave pre-treatment has been conducted and the quantity of biogas produced with and without pre-treatment has been evaluated and compared whereby the microwave pre-treated sludge for 5 minutes and 15 minutes enhances the anaerobic digestibility rate and biogas production by 11.9% and 38.5% respectively compared to untreated sewage sludge [5]. Although, batch microwave pre-treatment shows optimistic effect on the biogas production, it is not feasible to be implemented in the STP. Therefore, a feasible microwave pre-treatment system that can be put into operation in the STP need to be deliberated. Literatures have suggested that STS from STP is the most widely studied substrates on pre-treatment application due to low biodegradability [4]. The aim of this study is to investigate the influence of continuous flow microwave pre-treatment of STS for sustainable energy recovery in STP.

2 Materials and Methods

Two Sartorius Stedim BIOSTAT Aplus bioreactors were filled with 4.3 L of digested sludge from Pantai Dalam STP as inoculum and purged with nitrogen gas to ensure that the digesters are in anaerobic condition. The digesters have been allowed to stabilise for 5 days. After this period the experiment was started for 30 days under mesophilic condition at 35°C and stirred continuously at 200 rpm. The primary thickened sludge (PTS) and STS samples collected from Pantai Dalam STP 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, was used in this study. A 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 untreated, pre-treated and digested sludge was characterised daily for total solid (TS), volatile solid (VS), total suspended solid (TSS), volatile suspended solid (VSS), TCOD, SCOD, VFA and alkalinity. Meanwhile, the quantity and quality of biogas generated was measured by using a graduated eudiometer and COMBIMASS GA-m portable chemical sensor gas analyser.

3 Results and Discussion

3.1 Sludge Solubilization

The SCOD/TCOD ratio was used to evaluate the efficiency of sludge solubilization of STS. The SCOD/TCOD ratio for the untreated STS shows no significant differences, leading to conclusion that no substantial fluctuations in the STS characteristics although the samples were collected at different time. Thus, any observed enhancement of anaerobic digestion will be due to the alteration in the structure of the STS and not due to the difference in the amount of organics fed into the digester. The microwave pre-treated STS significantly change the averaged SCOD/TCOD ratio as depicted in Table

1. The results show that the SCOD/TCOD ratio increased by 0.1, 1.0 and 1.8% at the irradiation time of 5, 10 and 15 minutes, respectively, at a microwave power of 80 W compared to the untreated. The increase in SCOD/TCOD ratio is the result of the disruption of the complex STS floc structure and the release of the extracellular and intracellular materials from the cells into aqueous phase [6,7]. However, the extent of sludge floc disruption by microwave pre-treatment is influenced by the irradiation time as presented in Table 1. At a shorter irradiation time, the structural change was minimal enough, while when the contact time increases, the floc structure were disrupted completely [8].

Table 1: SCOD/TCOD ratio of untreated and pre-treated STS

SCOD/TCOD Ratio (%)	80 W @ 5 min	80 W @ 10 min	80 W @ 15 min
Untreated STS	0.6827	0.7129	0.6944
Pre-treated STS	0.6836	0.7201	0.7069

Table 2: VFA concentration of untreated and pre-treated STS

VFA Concentration (mg/L)	80 W @ 5 min	80 W @ 10 min	80 W @ 15 min
Untreated STS	142.9402	142.6435	142.7030
Pre-treated STS	149.2104	149.9053	151.1545

Besides that, total VFA also represents the essential organics in anaerobic digestion. The averaged total VFA that was analysed is included in Table 2 for the untreated and microwave pre-treated STS. The concentration of the measured total VFA increased significantly due to the microwave pre-treatment [6]. The total VFA concentration increased by 4.4, 5.1, 5.9% at the irradiation time of 5, 10 and 15 minutes, respectively, at a microwave power of 80 W. The VFA concentration is also affected by the irradiation time of the microwave pre-treatment [8].

3.2 Sludge Digestibility

Figure 1 represents the removal efficiency of VS in digesters fed with untreated and microwave pre-treated STS at different pre-treatment condition which is affected by microwave pre-treatment. The VS removal efficiencies of the untreated STS for each condition were averaged for comparison purpose. The VS removal efficiency increased to the range of 41.2% and 43.4% 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. From day 16 onwards, it can be observed that the VS removal efficiency decreases steadily as the volume of STS fed into the digester increases. However, the VS removal efficiency of the microwave pre-treated STS from day 16 onwards was higher compared to the untreated STS. The VS removal efficiency also increases as the irradiation time increases [9]. The average VS removal efficiency, when STS was fed 100% into the digester from day 25 onwards, at the irradiation time of 5, 10 and 15 minutes are 14.9, 17.1, and 18.9%, respectively.

Meanwhile, Figure 2 illustrates the TCOD removal efficiency of the untreated and microwave pre-treated STS at different pre-treatment condition. The pattern of TCOD removal efficiency is almost similar to the VS removal efficiency. For the first 15 days, the TCOD removal efficiency increases due to the PTS sample being fed into the digester. However, from day 16 onwards, the TCOD removal efficiency decreases slowly. On the other hand, the pre-treated STS shows greater TCOD removal compared to the untreated STS. Meanwhile, the TCOD removal efficiency is also affected by the pre-treatment condition. As the irradiation time increases, the TCOD removal efficiency increases too [8]. The average TCOD removal efficiency for 5, 10 and 15 minutes irradiation time at the last 5 days when 100% STS was fed into the digester is 7.2, 7.9 and 8.1%, respectively. The improved VS and TCOD removal compared to the untreated strongly indicates that solubilization by microwave pre-treatment converted a portion of organic materials which are difficult to be biodegraded into materials which are more easily biodegradable [9].

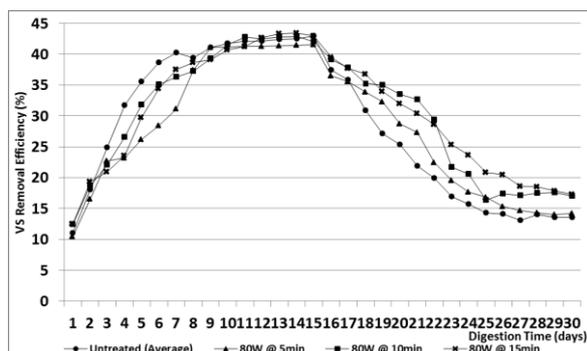


Figure 1: VS removal efficiency of digesters fed with untreated and microwave pre-treated STS at different pre-treatment condition

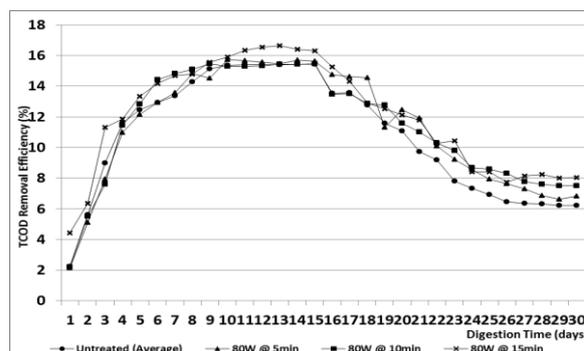


Figure 2: TCOD removal efficiency of digesters fed with untreated and microwave pre-treated STS at different pre-treatment condition

3.3 Biogas Production

The total biogas production in the digesters is as illustrated in Figure 3. It was seen that the biogas production in the microwave pre-treated digester was significantly higher compared to the untreated digester. The biogas quantity increased by an average of 97, 112 and 172 ml when the digesters were fed with 100% STS for 5, 10 and 15 minutes irradiation time respectively compared to the untreated.

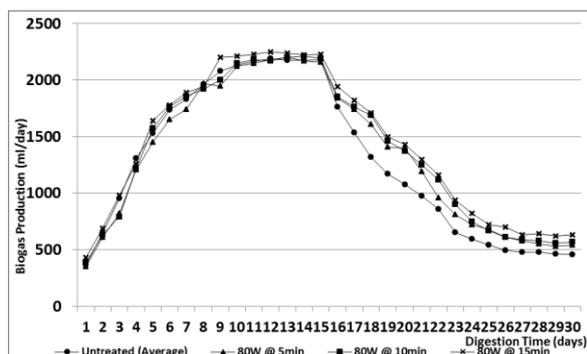


Figure 3: Daily biogas production of the untreated and microwave pre-treated STS at different pre-treatment condition

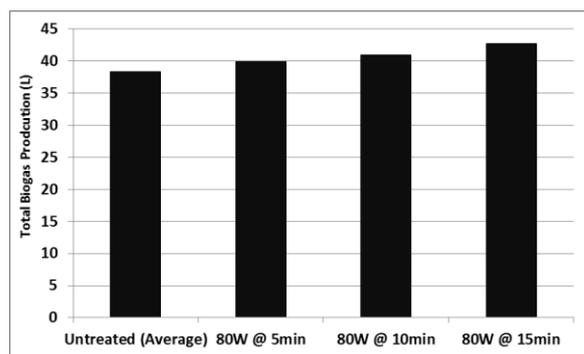


Figure 4: Total biogas production of the untreated and microwave pre-treated STS at different pre-treatment condition

Besides that, the total biogas production of the untreated and pre-treated STS at different pre-treatment condition is illustrated in Figure 4. The averaged total biogas generated by the untreated sample is approximately 38.3 L. Meanwhile, for the pre-treated samples, the total biogas generated is around 39.9, 41.0 and 42.6 L for 5, 10 and 15 minutes irradiation time respectively. The results show an averaged increment in total biogas production by 19.2, 24.1, and 32.2% for 5, 10 and 15 minutes irradiation time respectively compared to the untreated.

Besides that, the methane content of the produced biogas was in the range of 65-69%, which is suitable for electricity generation by using a gas engine. The additional quantity of biogas which is highly potential to be generated after microwave pre-treatment will be able to increase the potential of energy recovery from the biogas. Therefore, the biogas production pattern suggests that the pre-treatment increased the amount of material available for biodegradation as discussed earlier [6,7]. Moreover, it can be observed that as the irradiation time increases, the enhancement of biogas production is greater [8,9].

4 Conclusions

In this study the effect of continuous flow microwave pre-treatment was investigated on the STS sludge solubilization, digestibility and biogas production after anaerobic digestion. The results show that microwave pre-treatment is an efficient and rapid technique to disintegrate the sludge to enhance the digestibility of the sludge which leads to increase in biogas generation. The biogas production from STP is considered as one of the most promising methods to generate renewable energy from the wastewater which can sustain the electricity consumption of the STP after converting the gas to electricity. However, further research is recommended to identify the optimum microwave power and irradiation time for the pre-treatment and to perform cost-benefit analysis.

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