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Anaerobic Co-Digestion of Food Waste and Palm Oil Mill Effluent for Phosphorus Recovery: Effect on Reduction of Total Solids, Volatile Solids and Cations

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Abstract

Food waste (FW) and palm oil mill effluent (POME) with significant nutrients contents were successfully digested anaerobically for phosphorus recovery. Anaerobic co-digestion is a treatment that can enhance the reduction of total solid and volatile solid before disposed onto landfill. The presence of sodium and potassium ions may affect phosphorus recovery efficiency either by stimulating the phosphorus release or stabilizing the polyphosphate compounds. Dilution of sodium and potassium ions also can be achieved through this treatment method. The experiment was performed under different composition of FW and POME. The optimum mixing of FW and POME at ratio 70:30 showed the highest solid waste and volatile solid reductions which values were 45% and 41%, respectively. Further study on cations reduction was investigated and the results found that co-digestion process was able to reduce potassium and sodium ions concentration at 85.8% and 92.2%, respectively. The ions reduction may contribute to phosphorus recovery which achieved as high as 247% recovery.

Introduction

Organic compounds such as fiber waste containing in food waste (FW) and palm oil mill effluent (POME) are abundantly available in Malaysia (Abdulrahman *et al.*, 2013; Zihan *et al.*, 2015). Currently, food wastes are disposed onto landfillng for final disposal, while POME is treated in stabilization pond. Previous studies reported that this can directly contributes to the environmental problems for instance, eutrophications. Ironically, these wastes also can be utilized to recover both energy and nutrients (Gomez *et al.*, 2006; Hamatschek, 2010; Li *et al.*, 2014). The nutrients such as phosphorus can be used in fertilizers production which the demand is raising with the increasing of world population.

Anaerobic digestion (AD) is a biological process that can be used not only for treatment but also for resource recovery techniques (Iacovidov *et al.*, 2012). In recent years, there has been an increasing interest in anaerobic co-digestion (co-AD) compared to mono-AD. This process becoming interesting as it can enhance resource recovery efficiency, increase waste reduction and reduce heavy metals concentrations in the samples. In addition, it is considered as the simple and cheap technique as it only uses sludge that contains microorganisms (Tamrat *et al.*, 2013). Co-AD is a process where two or more substrates are put together in one anaerobic treatment process, while mono-AD is a process that only involves one substrate in one treatment process (Kangle *et al.,* 2012). According to Esposito *et al.* (2012), co-AD process can increase the reduction of solid waste before being disposed on landfill. Treating this waste anaerobically can reduce the cost in management significantly. Additionally, this process can trap methane gas in closed space which can be used as a renewable energy. Consequently, the release of green house gases (GHGs) to the environment can be reduced.

FW and POME are high in ions content which could inhibit the productions of phosphorus (P) during AD process. To encounter this problems, co-AD process is applied as it was proved can dilute compounds such as sodium (Na^+) and potassium (K^+) ions in the sample (Mino *et al.,* 1984; Mulkerrins *et al.,* 2004; Fang *et al*., 2011). Several studies have revealed that Na^+ ion presence helps in enhancing the process of co-AD as it is essential in supplying energy to the microorganisms (Mino *et al.,* 1984; Fang *et al.,* 2011). While, potassium ion helps in stabilize the polyphosphate compounds (Rashed & Massoud, 2014). However, when it present in high concentration, it will tends to inhibit the process. In this study, anaerobic batch experiments were performed using both substrates FW (fiber components) and POME to recover phosphorus. The reduction of solid waste and cations will be determined after performing co-AD process.

Materials and Methods

Sample collection and preparation

FW was collected within three days from a local restaurant located in Petagas. In this study, only fiber proportion was used for investigation, including leftover vegetables and fruits. While, POME was collected from the Kinabatangan palm oil factory in Sandakan. Inoculums was collected from Kogopon water treatment plant in Papar. Both substrates were kept in a freezer at 4^{o}C prior to use (Li *et al.,* 2014).

Analytical methods

The Total solid (TS), volatile solid (VS) and pH values of both samples were determined according to the method described by APHA, (2005). Cations concentration was determined by using inductively coupled plasma atomic emission spectrometer (ICP-AES) according to the method described by Manu *et al.* (2013). The samples were prepared in the following way: 1mL of sample were mix with 50mL of 2% of hydrochloric acid (HCl). While phosphorus determination was carried out by using a UV-spectrophotometer.

Operation startup for Mono-AD and Co-AD

The anaerobic digestion experimental work was set-up using Duran bottle with a volume 2.0 L. The digestion tests were performed at different FW (fiber) to POME ratio at mesophilic conditions (37^{o}C) for 30 days. Inoculums was added at ratio 1.5:1.0 (sample: inoculums) to boost up the anaerobic digestion process (Kangle *et al.,* 2012). The Duran bottles were charged with 100% FW (fiber), 100% of POME for mono-AD, and 70:30% of FW:POME and 30:70% of FW:POME for co-AD. Any gas produced was released once in three days to avoid explosion during the test. The pH value was controlled at range pH6.8 and 7.2 which is the optimum pH for AD process. Any reduction or increasing of pH throughout the test was controlled by using 1.0M NaOH and 1.0M HCl.

Result and discussion

Total solid (TS) and volatile solid (VS) reduction

The results obtained from the analysis are shown in Table 1. It was found that the percentage of TS reduction was at range 14-45% throughout different ratios of FW to POME. These results values were similar to the values reported by previous studies (Kangle *et al.*, 2012; Tamrat *et al.*, 2013). The highest TS value reduction achieved up to 45.0% when co-AD was performed at ratio 70:30% (FW:POME), while the lowest was 100% of POME with 14.2% reduction. At ratio 30:70% (FW:POME) and 100% FW, the reduction values were 31.5% and 23.5%, respectively. The results suggest that both mono-AD and co-AD can help in reducing TS content, and achieved the highest when FW was used as the main substrate and co-digested with POME at ratio 70:30. Thus, by performing AD on waste, the amount of TS content can be reduced before being disposed onto landfill (Kangle *et al.*, 2012).

Table 1. Reduction of TS and VS after mono-AD and co-AD processes.

Parameters	Reduction of TS (%)	Reduction of VS (%)
POME; 100%	14.2	27.4
FW; 100%	23.5	32.3
FW:POME; 70:30%	45.0	41.2
FW:POME; 30:70%	31.5	37.7

For VS, the reduction percentage ranged from 27-41% (Table 1). The highest value of reduction was at ratio 70:30% of FW:POME which was 41.4%, followed by 30:70% of FW:POME, 100% 9-FW and 100% POME which values were 31.5%, 23.5% and 14.2%, respectively. The results were similar to TS reduction where the highest VS reduction was achieved when FW was the main substrate in co-AD. The reduction of VS illustrates the removal of nutrient and organic content from waste after AD. Similar findings were found by Tamrat *et al.,* (2013).

Cations reduction (K^+, Na^+) enhanced P recovery

(a) Sodium ion (Na^+)

It is reported that the presence of Na^+ at certain concentrations may inhibits phosphorus (P) production during AD process (Table 2). In this study, the concentrations of Na^+ ranged between 58-131mg/L, thus suggests AD was safe from inhibition. From other perspective, the presence of Na^+ can help in stimulating P release. According to Fang *et al.* (2011), Na^+ ion used by anaerobic microorganisms in the formation of adenosine triphosphate (ATP) or oxidation of NADH, to produce polyphosphate (Figure 1). A similar observation was reported by Ye *et al*. (2008).

Table 2. Concentrations level of cations that can inhibit AD process (Fang *et al*., 2011).

Parameters	Stimulate process of AD	Moderate inhibitor of AD	Strongly inhibitors of AD
Na^+	100-200mg/L	3500-5500mg/L	>8500mg/L
K^+	200-400mg/	2500-3500mg/L	>12000mg/L

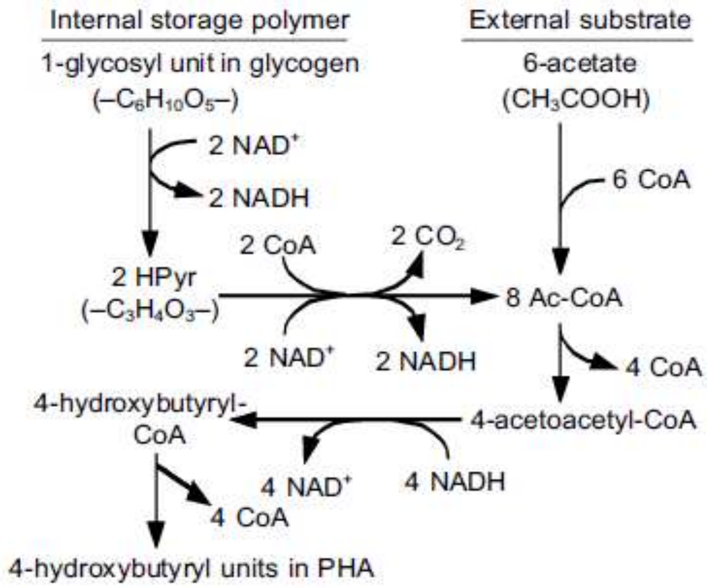

Figure 1. Illustration on the use of Na^+ ion by anaerobic microorganisms in the formation of adenosine triphosphate (ATP) or oxidation of NADH (Mino *et al.*, 1984).

The highest reduction of Na^+ by co-AD at ratio 70:30% (FW:POME), with 92.2% (±0.45), illustrates that the removed Na^+ was used in releasing P and recover 247% phosphorus while the lowest reduction 11.2% (±2.12) found when mono-digestion using 100% POME was used and recovered 77% of P. When 100% FW was digested, 67% Na^+ was reduced in recovering 89% P, indicates that FW as a single substrate contributed more in recovering P compared to single POME. However, when co-AD 30:70% (FW:POME) was carried out, Na^+ reduction was not significant in P recovery. This is because the reduction was low at 37%, but still recovered high P up to 182% (Table 3).

Table 3. Cations reduction and phosphorus recovery in 30 days.

Parameters	**Na^+ reduction (%)**	**K^+ reduction (%)**	**P recovery (%)**
POME (100%)	11.2± 2.12	90.4± 0.52	77.7 ± 1.76
FW (100%)	67.7± 2.01	51.2± 2.48	89.8± 1.88
FW:POME (70:30%)	92.2± 0.45	94.1± 1.24	247.4± 2.78
FW:POME (30:70%)	37.1± 2.56	97.2± 0.52	182.6 ± 2.89

(b) Potassium ion (K^+)

In this study, the concentration of K^+ was 5236.00 mg/L (±0.08). Based on the information given in Table 3, this concentration may inhibit P recovery. However, the information may insignificant for current study as the P recoveries were always high for both mono-AD and co-AD (77-247%) (Table 3). The percentage of K^+ reduction were found varies for all tests (51-97%), consequently suggest that phosphorus recovery was not affected by K^+ reduction. This also leads to a conclusion that the presence of K^+ at even high concentration may not cause phosphorus inhibition. This finding supported by previous study Mulkerrins *et al.* (2004), which stated an excess of K^+ can enhance phosphorus removal as it helps in stabilize the phosphate groups (Figure 2).

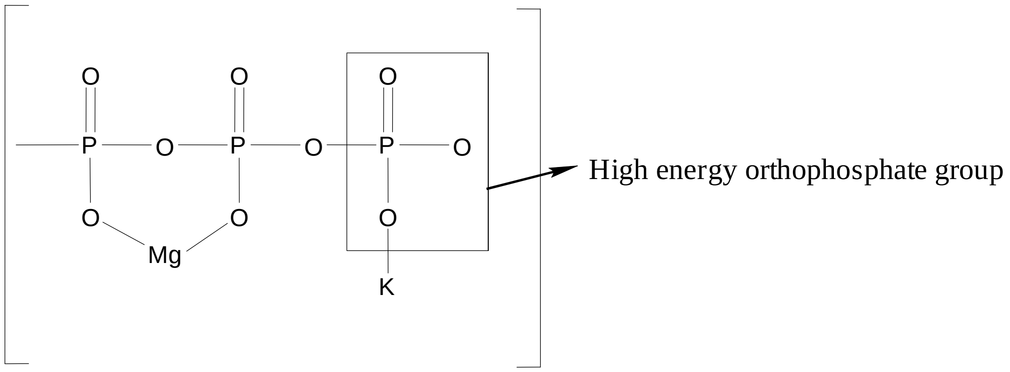

Figure 2. Structure of polyphosphate that stabilized by co-tansportation of K^+ ion (Rashed & Massoud, 2014).

Conclusion

This study suggests that when anaerobic digestion performed by using two different substrates (co-AD), the efficiency of the technique can be improved, in terms of phosphorus recovery and reduction of waste amount. The reduction of waste amount can be represented by total solids (TS) and volatile solids (VS) reduction, which provide information on degradation of solids and organic contents, respectively, during the AD process. Anaerobic co-digestion at ratio 70:30 (FW:POME) was able to reduce higher TS and VS, with 45% and 41% reductions, respectively. Therefore, this would save some spaces if landfill disposal technique was applied. For cations reduction, Na^+ was reduced the highest at 92%, when FW (fiber) was used as the main substrate (70:30%). The existence of Na^+ ions may not inhibit the process, but can helps in stimulating the P release, hence increased P recovery up to 247%. While for K^+ its high presence at high concentration may not cause phosphorus inhibition, because the existence can help in stabilize the phosphate groups, thus increase P recovery. It was also found that the reduction of K^+ has no significant effect on P recovery at different substrates ratio.

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References

[1] Abdurahman N. Y., Rosli Y. M. & Azhari, N. H. (2013). The performance evaluation of anaerobic method for palm oil mill effluent (POME) treatment : A review. *In:* Quinn, N. W. T. (Ed). *International Perspectives on Water Quality Management and Pollutant Control*. InTech.

[2] APHA. (2005). *Standard Methods for the Examination of Water and Wastewater* (21st edition). American Public Health Association.

[3] Fang, C., Boe, K. & Angelidaki, I. (2011). Anaerobic co-digestion of desugared molasses with cow manure:focusing on sodium and potassium inhibition. *Bioresource Technology*, **102**(2), 1005-1011.

[4] Rashed, E. M. & Massoud, M. (2014). The effect of effective microorganism (EM) on EBPR in modified contact, stabilization, system. *HRBC Journal*, **11**(3), 384–392.

[5] Esposito,G., Frinzo, L., Giorgano, A., Liotta, F., Panico, A. & Pirozzi, F. (2012). Anaerobic co- digestion of organic waste. *Reviews in Environmental Science and Bio/Technology*, **11**(4), 325-341.

[6] Gomez, X., Cuetos, M. J., Cara J., Moran, A. & Garcia, A. I. (2006). Anaerobic co-digestion of primary sludge and fruit and vegetable fraction of the municipal solid wastes: Condition for mixing and evaluation of the organic loading rate. *Renewable Energy*, **31**(12), 2017-2024.

[7] Hamatschek, E. (2010). Current practice of municipal solid waste management in Malaysia and the potential for waste-to-energy implementation. *ISWA World Congress 2010*. 15 - 18 November, 2010, Hamburg, Germany.

[8] Iacovidov, E., Dieudonne, G. O. & Nikolas, V. (2012). Food waste co-digestion with sewage sludge – Realising its potential in the UK. *Journal of Environmental Management*, **112**(15), 267-274.

[9] Kangle, K. M., Kore, S. V., Kore. V. S. & Kulkarni G. S. (2012). Recent trends in anaerobic codigestion: A Review. *Universal Journal of Environmental Research and Technology*, **2**(4), 210 - 219.

[10] Li, H. L., Guo, X. L., Cao, F. F. & Wang Y. (2014). Process evolution of dry anaerobic co-digestion of cattle manure with kitchen waste. Chemical & Biochemical Engineering Quarterly, **28**(1), 161-166.

[11] Manu, M. K., Kumar, R. & Garg, A. (2013). Physical and chemical characterization of yard waste. *International Journal of Applied Engineering Research*. **16**(16), 1891-1896.

[12] Mino, T., Kawakami, T. & Matsuo, T. (1984). Location of phosphorus in activated sludge and function of intracellular polyphosphates in biological phosphorus removal process. *Water Science & Technology*, **17**(2-3), 93-106.

[13] Mulkerrins, D., Dobson, A. & Colleran, E. (2004). Parameters affecting biological phosphate removal from wastewater. *Environment International*, **30**(2), 249-259.

[14] Tamrat, A., Mebeaselassie, A. & Amare, G. (2013). Co-digestion of cattle manure with organic kitchen waste to increase biogas production using rumen fluid as inoculums. *International Journal of Physical Sciences*. **8**(11), 443-450.

[15] Chen, Y., Cheng, J.J. & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: A review. *Bioresource Technology*, **99**(10), 4044-4064.

[16] Zihan, Y., Yulin, D., Xu, Z. & Tianwei, T. (2015). Anaerobic co-digestion of food waste and straw for biogas production. *Renewable Energy*, **78**, 527-530.