INVESTIGATION OF METHANE PRODUCTION BY ANAEROBIC CO-DIGESTION OF FOOD WASTE, FATS, OIL AND GREASE, AND THICKENED WASTE ACTIVATED SLUDGE USING AUTOMATIC METHANE POTENTIAL TEST SYSTEM

Nikita Bahri, Dr. Antoine Trzcinski
Faculty of Health, Engineering and Sciences
University of Southern Queensland, Toowoomba, Queensland

ABSTRACT: This project investigated the methane production by anaerobic co-digestion using Automatic Methane Potential Test System (AMPTS). Food waste (FW), waste cooking oil- Canola oil (FOG), and thickened waste activated sludge (TWAS) were used as substrates for anaerobic digestion in two sets of experiments. All the substrates were digested individually in the first set of experiments. In the second set, they were combined in different proportions (four combinations) and were co-digested. All the experiments were carried at mesophilic temperature (37˚C). Results obtained from the first set established that FOG is not a suitable substrate for anaerobic digestion. From the second set of experiments, it was found that FOG did not cause inhibition. However, presence of FOG in co-digestion process caused problems which led to decreased yield of methane in all the four combinations.

Keywords: Anaerobic Co-digestion, Methane, AMPTS, Waste

1. INTRODUCTION

Organic waste produced from domestic, industrial and agricultural activities is increasing at a fast pace owing to growth, development, globalisation and increasing competition. Disposing off this waste is becoming a major concern for different industries as it causes pollution if left untreated. Also, burning of fossil fuels for energy is a threat to the environment because of increasing carbon dioxide emissions in the atmosphere. Anaerobic digestion is a way of treating and generating cleaner energy from the waste. A.J. Ward et al. (2008) state that anaerobic digestion can be applied to a variety of feedstock including industrial and municipal waste water, agricultural, municipal and food industry wastes.

Anaerobic digestion of food waste, waste cooking oils and thickened waste activated sludge as co-substrates to produce methane has not been investigated. If methane production is in good quantity, this research would help the food industries to get rid of their food wastes and waste cooking oils, and this waste will help in production of methane which can be used as a fuel. Also, the waste water treatment plants may be able to get rid of the biological solid waste in a constructive way.

Producing methane using individual substrates helped in comparing the methane produced when all three substrates were used. Using different percentages of substrates in combinations of three substrates helped in investigating the optimum composition of these substrates to produce methane.

L. Baere (2006) state that setting up an anaerobic digestion plant involves high investment. Therefore, it would be helpful if the experiments are carried out at laboratory scale to find the optimum percentage of co-substrates and to analyze the methane production potential of substrates.

This study focused primarily on the production of methane using AMPTS from FW, FOG and TWAS. Experiments were conducted for single substrates as well as for all the three substrates together. Results obtained from single substrate digestion and co-digestion were compared with each other and with other studies. This study helped in investigating if co-digestion leads to more production of methane. Also, it helped in investigating if FW, FOG and TWAS could be used together efficiently as co-substrates

2. BACKGROUND

There is a growing interest towards the use of renewable resources of energy. As the non-renewable sources will not last long and because of the environmental concerns due to increasing levels of pollution and carbon dioxide emission level in the environment, there is a need to invest in renewable energy technology. Burning of fossil fuels poses a threat to environment. Therefore, there needs to be a replacement for fossil fuels. R.E. Sims et al. (2003) state that coal is the largest source for electricity generation (38%). 7700 million tons of carbon dioxide per year is released to the atmosphere by global electricity supply sector.

Disposing the organic waste generated from various human activities is also a growing concern. Waste generated from food industries, including waste cooking oils, can be difficult to dispose. J.C. Kabouris et al. (2009) state that restaurants, food service providers and residences are major contributors of food waste. Food waste, especially, waste cooking oils may cause sewer problems by restricting the sewer flow and causing sewer overflows.

S. Chan and J. Schapper (2010) mention that in Australia, every year one person throws away 145kg of food. An illustration of this would be if a person buys five bags of groceries per week, he would end up disposing one bag of grocery. In total, 3.28 million tons of food waste is thrown away by Australian homes and businesses per year.

According to Q. Wang et al. (2017), average annual production of excess sludge is 3 million wet tons in Australia, and 240 million wet tons in Europe, USA, and China combined. Landfill, agricultural use and incineration are still the common ways for sludge disposal. These methods incur very high costs, $30-$70 per wet ton in Australia. Therefore, anaerobic co-digestion is an effective way of utilizing this sludge for energy production.

2.1 Anaerobic digestion

S. Xie et al. (2017) state that a recent and notable development in anaerobic digestion is to co-digest two or more substrates together. There are some problems associated with single substrate digestion such as lack of micronutrients, imbalanced C/N ratio, a higher biodegradable fraction etc. These inherent problems can be overcome by co-digestion.

A.J. Ward et al. (2008) state that Biogas is produced in the anaerobic digestion process which is a carbon neutral energy source. Carrying out anaerobic digestion in sealed container, will trap the methane gas, which is a greenhouse gas. Also, methane can be used to replace the fossil fuels, which on burning produce carbon dioxide. On the other hand, on combustion, methane releases carbon neutral carbon dioxide which enters the carbon cycle.

With the growing concern for the disposal of waste from various industries, including food industry, in this project food waste was chosen to be one substrate. Another issue which the food industries are facing is the disposal of fats, oils and grease. J.B. Williams et al. (2012) state that fats, oils and grease deposits in sewers are a major problem as they could cause sewer overflows, leading to environmental damage and health risks. On the other hand, FOG enhances the methane production if used as a substrate in co-digestion process.

K. Braber (1995) states that anaerobic digestion occurs in nature by itself where the right typical conditions are present, like, bottom of the lakes, landfills etc. However, when this process is carried in plant, the conditions such as temperature, humidity, microbial activity, and waste properties, are controlled. This leads to a stimulated and accelerated process. Anaerobic digestion is carried out by a consortium of four different types of microorganisms: hydrolytic, fermentative, acetogenic, and methanogenic. K. Braber (1995) also states that anaerobic digestion is a net energy production process (150-250 kWh per ton of input waste) but its commercialization is not yet fully demonstrated.

S. Stromberg et al. (2015) state that AMPTS is a recent development which allows automatic and reliable gas measurements with high resolution and makes an approach based on real-time prediction with mathematical models feasible. AMPTS is a standardized laboratory set-up designed for automatic biomethane potential testing of any biodegradable material. It consists of pre-calibrated flow cells in which gas is measured through water displacement. It gives a signal for every 10mL of produced gas. The gas volume is normalized to 0˚C, 1 atm and dry gas conditions at each measuring point by temperature and pressure sensors.

R.M. Alqaralleh et al. (2016) studied the anaerobic co-digestion of thickened waste activated sludge (TWAS) with fat, oil and grease (FOG) and evaluated the methane production. Volatile solids (VS) in TWAS, FOG and inoculum were 34.5g/Kg, 282.8g/Kg and 14.7g/Kg respectively. Experiments were performed using different percentages of FOG and it was found that with the increase of FOG as substrate up to a specific amount significantly increased the methane production. The control sample, which contained the inoculum and TWAS (0% FOG) produced 316.4 ml methane. Addition of 20%, 40% and 60% (based on TVS) FOG to the co-digestion mixture increased the methane production to 427ml, 451ml, and 491ml respectively. This represents 35.2%, 42.6% and 55.4% increase in methane production in comparison to the control. However, addition of 80% FOG to the co-digestion mixture reduced the methane production to 102ml, which is less than the methane production for the control. Therefore, FOG has an inhibitory effect at 80% composition. Fig.1 depicts the methane production for different percentages of FOG in the anaerobic mixture.

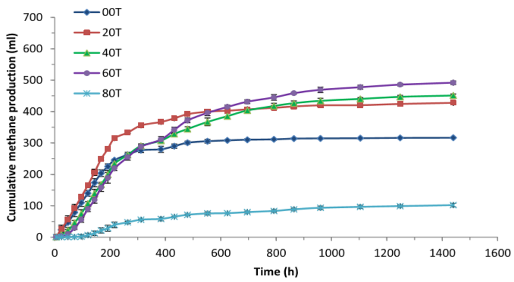

Fig.1 Cumulative methane production for different percentages of FOG in co-digestion mixture (Alqaralleh et al. 2016)

S. Xie et al. (2017) conducted sets of experiments to study the anaerobic digestion. Food waste, paper pulp reject and primary sludge were anaerobically digested individually. Co-digestion of combination of food waste (FW) and primary sludge (PS) and combination of paper pulp reject (PPR) and sewage sludge (PS) was also performed. It was found that the process performance enhanced when co-digestion was performed. Cumulative methane production from co-digestion of food waste and primary sludge and paper pulp reject with food waste was more than the production from mono-digestion. Fig.2 depicts enhancement of methane production with co-digestion.

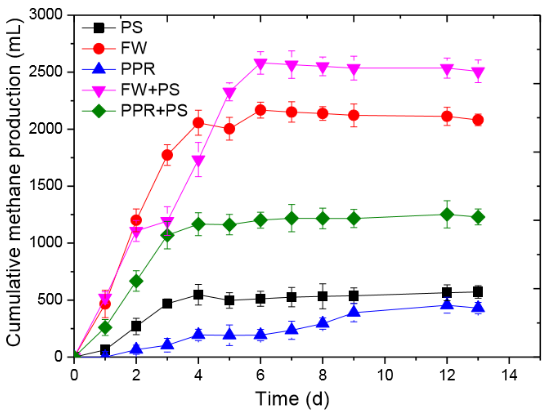

Fig.2 Cumulative methane production from mono-digestion and co-digestion of Primary sludge with organic wastes (Xie et al. 2017)

3. METHODOLOGY

The food waste and waste cooking oil used in the experiments were obtained from the University of Southern Queensland Refectory, Toowoomba, Australia. The food waste comprised of a mixture of chips, bacon, fruits and their peals, and bread. This food waste was grinded to form a slurry. Thickened waste activated sludge was obtained from the Wetalla Wastewater Treatment plant in Toowoomba. The inoculum was obtained from the pond at a piggery farm located in Lockyer Valley in Queensland, Australia. The inoculum is important for enabling the digestion process.

Characterization analysis was performed for the substrates and inoculum. Total solids, total volatile solids, COD, total organic carbon, total nitrogen were measured. A bio-medium was prepared as directed by W.F. Owens et al. (1979), which provides the essential micro-nutrients to the microbes. It contains ammonium carbonate which is essential for regulating the pH in the AMPTS bottles.

Two set of experiments were conducted for analyzing methane production at mesophilic temperature range (37ºC) using the AMPTS. In the first set of experiments, single substrate digestion experiments were performed. In the second set of experiments, all the substrates were combined in different proportions and were co-digested. 100ml of inoculum and 100ml of bio-medium were added to each of the AMPTS bottles, along with the substrates. Three controls consisting of 100g Inoculum and 100ml of bio-medium each were used in both sets.

Fig.3 AMPTS set-up

In the set 1 of experiments, 50g of food waste was added to three bottles as triplicates, 50g FOG and 10g FOG were added to two bottles each and triplicates for 50g TWAS were used. S/I ratio for each of them is mentioned in Table 1 below.

Table 1 Set 1 of experiments

Number	Substrate	I/S ratio
1	50g of FW	0.741
2	50g of FOG	0.101
3	10g of FOG	0.51
4	50g of TWAS	13.2
5	Control	-

In the set 2 of experiments, the three substrates were co-digested in different combinations as shown in Table 2. This set of experiment helped in determining if co-digestion with FOG produces more methane.

Table 2 Set 2 of experiments

Number	Substrate	I/S ratio
1	50g FW + 25g FOG+ 25g TWAS	0.16
2	50g FW + 10g FOG+ 25g TWAS	0.29
3	25g FW + 10g FOG+ 50g TWAS	0.37
4	25g FW + 25g FOG+ 50g TWAS	0.18
5	Control	-

4. RESULTS

4.1 Characterisation results

Characterisation analysis was performed to calculate total solids (TS), total volatile solids (TVS), ash content, chemical oxygen demand (COD), total organic carbon (TOC) and total nitrogen (TN). The characterisation results are shown in the Table 3 and 4 below.

Table 3 Physical characterisation results

Property	Inoculum	FW	FOG	TWAS
TS (g/g)	0.11	0.17	0.96	0.009
TVS (g/g)	0.05	0.14	0.96	0.008
Ash Content (g/g)	0.05	0.03	0	0.0013
Moisture %	89.4	83.1	3.8	99.1
TVS/TS (%)	47.6	80.2	100	85.7

Table 4 Chemical characterisation results

Property	Inoculum (g/L)	FW (g/L)	FOG (g/L)	TWAS (g/L)
COD	31.6	55.4	-	4.36
TOC	-	37.6	-	0.16
TN	-	2.9	-	0.06

4.2 AMPTS RESULTS

4.2.1 Set 1 Results

In the set 1 of experiments, all the substrates were digested individually. Table 5 shows the methane production results from each of the substrates. Duration of the experiments was 63 days.

Table 5 Methane yield results from set 1 of experiments

Substrate	Methane yield (Nml/g VS)	Cumulative Methane yield (Nml)
FW (50g)	673.7 ± 38.3	4634 ± 263
FOG (50g)	4.2 ± 0.06	200 ± 3.2
FOG (10g)	44.6 ± 2.6	429 ± 24.5
TWAS (50g)	163.4 ± 50.5	63.7 ± 19.7

It was observed that maximum methane production was obtained when food waste was digested, followed by TWAS, 10g FOG and finally 50g FOG. Maximum lag phase was observed when FOG was digested, followed by FW. No lag phase was observed in TWAS digestion. It was found that higher the content of FOG (Canola oil), lower is the methane yield. It can be concluded that FOG is not a suitable substrate due to its low biodegradability which leads to low methane yield. It was also found that FOG was not inhibitory.

4.2.2 Set 2 Results

Second set of experiments involved methane production from different combinations of substrates. Duration of the experiment was 48 days. Methane production plateaued after 16 days for the case 1, whereas it continued to be produced in other cases. Table 6 shows the methane production results from anaerobic co-digestion for all the combinations of substrates and Fig.4 shows the methane production in graphical form.

Table 6 Methane yield results from set 1 of experiments

Case	Substrate	Methane yield (Nml/g VS)	Cumulative Methane yield (Nml)
1	50g FW + 25g FOG+ 25g TWAS	66.2	468.2
2	50g FW + 10g FOG+ 25g TWAS	311.2	2201.4
3	25g FW + 10g FOG+ 50g TWAS	669.7	2564.7
4	25g FW + 25g FOG+ 50g TWAS	219.6	841.1

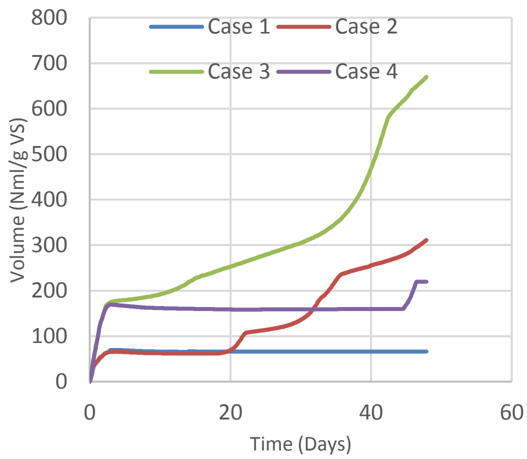

Fig.4 Methane yield from co-digestion experiments

Case 3 came out as the best proportion for maximum methane yield. However, as proposed, in previous studies, by A. Grosser et al. (2017), C. Li et al. (2011), R.M. Alqaralleh et al. (2016), S. Xie et al. (2017) that co-digestion enhances the methane production, increased methane yield was not observed with co-digestion in this study, except slight enhancement in Case 3 with co-digestion. It was established by set 1 experiments that FOG gives a low methane yield. Low yield in set 2 experiments due to presence of FOG re-affirmed that it is not a suitable substrate for methane production.

4.2.3 Discussion

In the present study, FOG did not inhibit the methane process. This is evident from instant methane production in set 1 as well as in all four cases of co-digestion (set 2), and even 50g of FOG in set 1 produced methane. It was not inhibitory even when it constituted 86.3% of the total VS load (case 4). However, due to low biodegradability of FOG, low yield of methane was obtained in set 1 experiment. In co-digestion experiment (set 2), along with low bio-degradability, other problems arose due to FOG:

- Lack of proper mixing in the AMPTS bottles. The substrates were not uniformly mixed which led to low methane yield. Access of substrates to microbes was difficult.
- FOG was accumulated at the top of the surface of the solution in the AMPTS bottles as shown in Fig. 5. This led to formation of a scum layer. It was difficult for methane produced and accumulated in the AMPTS bottles to escape in the gaseous form due to this layer.
- Combination of all the substrates and inoculum led to formation of a thick solution. Due to high thickness, mass transfer of substrates to the microbes was improper.
- FOG coated the bodies of microbes as well substrates.

Fig.5 FOG accumulation on the top surface of solution in AMPTS bottle

These reasons explain the maximum methane yield from Case 3, followed by Case 2, Case 4 and the least methane yield from Case 1. Also, above problems did not allow enhancement of methane production in co-digestion experiment than that obtained in anaerobic digestion of single substrates. Therefore, to obtain high methane yield, anaerobic digestion of FOG (Canola oil), which is mainly non-biodegradable, must be avoided.

5. CONCLUSION

The project investigated methane production by anaerobic co-digestion of food waste, fats, oil and grease and thickened waste activated sludge using Automatic Methane Potential Test System. Two sets of experiments were conducted. In the first set, the substrates FW, FOG and TWAS, were anaerobically digested individually. In the second set, they were combined in different proportions and were digested to investigate the most optimum combination and if co-digestion increases the methane production. Special emphasis was given to the percentage of FOG which could be inhibitory. All the experiments were carried out at mesophilic temperature range (37ºC).

In the first set of experiments, maximum methane yield was obtained from 50g FW (673.7 ± 38.3 Nml/g VS FW), followed by 50g TWAS (163.36 ± 50.49. Nml/g VS TWAS). 10g FOG produced 44.63 ± 2.55 Nml/g VS FOG whereas 50 FOG generated just 4.16 ± 0.06 Nml/g VS FOG. Methane production plateaued after 63 days for food waste, 15 days for 50ml waste cooking oil, 37 days for 10ml waste cooking oil, and 17 days for

TWAS. Maximum methane production was observed in the first day for FW and TWAS and second day with FOG. This was because of more balanced C/N ratio, I/S ratio and enzymes in the beginning.

From the second set of experiments it was found that maximum methane yield was obtained from Case 3- 25g FW_10g FOG_50g TWAS (669.7 Nml/g VS), followed by Case 2- 50g FW_10g FOG_25g TWAS (311.2 Nml/g VS), and Case 4- 25g FW_25g FOG_50g TWAS (219.6 Nml/g VS). Least amount of methane was generated from Case 1- 50g FW_25g FOG_25g TWAS (66.2 Nml/g VS). It was determined that co-digestion did not increase methane yield in comparison to individual substrate digestion, except slight enhancement in case 3- 25g FW_10g FOG_50g TWAS.

From both set of experiments, it was established that FOG (Canola oil) is not a suitable substrate for anaerobic co-digestion due to its low biodegradability. However, it can be further investigated if the yield can be improved if a higher I/S ratio and more bio-medium is used with FOG. Better mixing in AMPTS bottles could also lead to a higher methane yield. Thick substrate and inoculum solution prevents proper mass transfer from substrates to microbes, hence, thick solutions must be avoided if the experiment is carried out using AMPTS. Canola oil used in this study did not inhibit the digestion process but reduced the methane yield. However, use of other type of waste cooking oil may give different results. Therefore, investigation with other type of oil may be useful.

There was no lag phase observed in anaerobic digestion of TWAS and hence, it is a useful substrate. Food waste has a high potential of generating methane. Therefore, anaerobic digestion plants may co-digest food waste and sludge for generating methane. It will be an efficient source of renewable energy generation and utilization of excess amount of waste produced in the world.

6. ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my supervisor Dr. Antoine Trzcinski for his support and motivating guidance throughout this project. I would also like to thank Alan Skerman and Dr. Christopher Pratt, from Department of Agriculture and Fisheries, Toowoomba, for their help and for allowing me to use the essential equipment at the department required for this project.

Finally, I would like to thank my family for supporting and encouraging me throughout this endeavour.

7. REFERENCES

Alqaralleh, RM, Kennedy, K, Delatolla, R and Sartaj, M, 2016, 'Thermophilic and hyper-thermophilic co-digestion of waste activated sludge and fat, oil and grease: Evaluating and modeling methane production', *Journal of Environmental Management*, vol. 183, pp.551-561.

Baere L, 2006, 'Will anaerobic digestion of solid waste survive in the future?', *Water Science and Technology*, vol. 53, no. 8, pp. 187-194.

Braber, K, 1995,'Anaerobic digestion of municipal solid waste: a modern waste disposal option on the verge of breakthrough', *Biomass and bioenergy*, vol. 9, no.1-5, pp.365-376.

Chan, S and Schapper, J, 2010, 'Food waste in Australia', *Food Australia*, vol. 62, no. 7, p.307.

Grosser, A, Neczaj, E, Singh, BR, Almås, ÅR, Brattebø, H and Kacprzak, M, 2017,'Anaerobic digestion of sewage sludge with grease trap sludge and municipal solid waste as co-substrates', *Environmental research*, vol. 155, pp.249-260.

Kabouris, JC, Tezel, U, Pavlostathis, SG, Engelmann, M, Dulaney, J, Gillette, RA and Todd, AC, 2009,'Methane recovery from the anaerobic codigestion of municipal sludge and FOG', *Bioresource technology*, vol. 100, no. 15, pp.3701-3705.

Li, C, Champagne, P and Anderson, BC, 2011,'Evaluating and modeling biogas production from municipal fat, oil, and grease and synthetic kitchen waste in anaerobic co-digestions', *Bioresource technology*, vol. 102, no. 20, pp.9471-9480.

Owen, WF, Stuckey, DC, Healy, JB, Young, LY and McCarty, PL, 1979,'Bioassay for monitoring biochemical methane potential and anaerobic toxicity', *Water research*, vol. 13, no. 6, pp.485-492.

Sims, RE, Rogner, HH and Gregory, K, 2003, 'Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation', *Energy policy*, vol.31, no.13, pp.1315-1326.

Strömberg, S, Nistor, M and Liu, J, 2015,'Early prediction of Biochemical Methane Potential through statistical and kinetic modelling of initial gas production', *BioresourceTechnology*, vol. 176, pp.233-241.

Wang, Q, Wei, W, Gong, Y, Yu, Q, Li, Q, Sun, J and Yuan, Z, 2017, 'Technologies for reducing sludge production in wastewater treatment plants: State of the art', *Science of the Total Environment*, vol. 587-588, pp. 510-521.

Ward, AJ, Hobbs, PJ, Holliman, PJ and Jones, DL, 2008, 'Optimisation of the anaerobic digestion of agricultural resources', *Bioresource Technology*, vol. 99, no. 17, pp.7928-7940.

Williams, JB, Clarkson, C, Mant, C, Drinkwater, A and May, E, 2012, 'Fat, oil and grease deposits in sewers: Characterisation of deposits and formation mechanisms', *Water research*, vol. 46, no. 19, pp.6319-6328.

Xie, S, Wickham, R, and Nghiem, LD, 2017, 'Synergistic effect from anaerobic co-digestion of sewage sludge and organic wastes', *International Biodeterioration & Biodegradation*, vol. *116*, pp.191-197.