  Water Science & Technology | 64.9 | 2011

Increased biogas production in a wastewater treatment plant by anaerobic co-digestion of fruit and vegetable waste and sewer sludge – A full scale study

Nathan D. Park, Ronald W. Thring, Randy P. Garton, Michael P. Rutherford and Steve S. Helle

ABSTRACT

Anaerobic digestion is a well established technology for the reduction of organic matter and stabilization of wastewater. Biogas, a mixture of methane and carbon dioxide, is produced as a useful by-product of the process. Current solid waste management at the city of Prince George is focused on disposal of waste and not on energy recovery. Co-digestion of fresh fruit and vegetable waste with sewer sludge can improve biogas yield by increasing the load of biodegradable material. A six week full-scale project co-digesting almost 15,000 kg of supermarket waste was completed. Average daily biogas production was found to be significantly higher than in previous years. Digester operation remained stable over the course of the study as indicated by the consistently low volatile acids-to-alkalinity ratio. Undigested organic material was visible in centrifuged sludge suggesting that the waste should have been added to the primary digester to prevent short circuiting and to increase the hydraulic retention time of the freshly added waste.

Key words | anaerobic digestion, biogas, co-digestion, fruit and vegetable waste, full scale

Nathan D. Park
Ronald W. Thring (corresponding author)
Michael P. Rutherford
Steve S. Helle
Environmental Science and Engineering,
University of Northern British Columbia,
3333 University Way,
Prince George,
British Columbia,
Canada V2N 4Z9
E-mail: *thring@unbc.ca*

Randy P. Garton
Wastewater Treatment Center,
City of Prince George,
505 – 4th Avenue,
Prince George,
British Columbia,
Canada V2L 3H2

INTRODUCTION

An estimated 38% of solid food available for retail sale was wasted by Canadians in 2007 (Statistics Canada 2008a). The majority of this organic waste was disposed of in landfills. Issues with landfill space, groundwater contamination, resource sustainability, and greenhouse gas emissions have sparked interest in diversion of waste from landfills. Composting is the most widespread form of organic waste diversion from landfills. Approximately 1.7 million tonnes of organic waste were composted in centralized facilities in Canada in 2002 (Statistics Canada 2008b). Composting produces a valuable resource as a soil amendment, but is an energy consuming process. Also, recent concerns over energy sustainability, energy security, and anthropogenic climate change have sparked great interest in producing energy from waste. Incineration is the most common form of energy generation from waste. However, the high water content in food waste limits its energy production potential.

Anaerobic digestion (AD) is a process in which bacteria consume organic wastes, in the absence of oxygen, to produce methane gas and carbon dioxide. Biogas, as the gas mixture is termed, can be used as fuel like conventional natural gas. The remaining stabilized solids, or biosolids, are beneficial as a nitrogen and phosphorous rich soil amendment. The AD process has been in use for decades to stabilize and reduce the organic solids found in wastewaters. The biogas produced can be used to supplement the energy demands of the wastewater treatment facility. Most AD systems are constructed with excess capacity to account for future population growth and have low organic loading rates due to the low solids content of incoming raw sludge. Total solids (TS) content of the digester sludge at the Lansdowne wastewater treatment plant (LWWTP) is approximately 1.5% and could be increased to the 3–4% range without significant plant modifications (Garton 2010). Biogas yield could be improved, with minimal capital investment, by adding biodegradable matter to increase the digester loading. This process is also known as co-digestion.

Anaerobic digestion of organic wastes is a viable waste disposal method to reduce greenhouse gas emissions (Haight 2005). Due to the sealed and controlled nature of AD, volatile gases are trapped, combusted, and reduced to carbon dioxide.

doi: 10.2166/wst.2011.753

Aerobic treatment of wastes, on the other hand, produces large and uncontrolled emissions of volatile compounds, such as ketones, aldehydes, ammonia and methane (Mata-Alvarez et al. 2000). Methane is of significant importance due to the large amount formed during the decomposition of organic wastes and its potent greenhouse gas warming potential. Anaerobic digestion is therefore advantageous from an emissions standpoint by producing methane in a controlled manner. This methane can then be burnt to produce carbon neutral CO_2 and offset emissions from energy production that may have otherwise come from fossil fuels (Ward et al. 2008).

Co-digestion is the AD of two or more organic waste streams. The benefits of co-digestion include: the dilution of toxic compounds, improved balance of nutrients, synergistic effects of organisms, increased load of biodegradable matter, and ultimately an increase in biogas yield (Sosnowski et al. 2003). Much research has been conducted in the laboratory on the co-digestion of various organic wastes (Alatriste-Mondragon et al. 2006; Ward et al. 2008). Lab scale experiments by Zhang et al. (2007) have shown that food waste is a highly desirable substrate for anaerobic digestion due to its high biodegradability and methane yield. Full scale anaerobic co-digestion projects are less widely reported.

Zupancic et al. (2008) increased the organic loading rate (OLR) of digester influent by 25% using the organic fraction of municipal solid waste (OFMSW) in a fully operational wastewater treatment plant. Biogas quantity increased by 80%, electrical energy production increased by 130%, and heat production increased by 55%. The increased volatile solids load also improved degradation efficiency by 10% and there was no significant increase in digester effluent volatile solids content. Bolzonella et al. (2006) have also increased the OLR of a fully operational WWTP by as much as 20% with the addition OFMSW and subsequently increased gas production by 50%. Edelmann et al. (2000) found an increase in biogas production of 27% when the organic loading was increased by codigesting supermarket waste in a relatively small sewer treatment plant.

The full scale study presented here was undertaken to assess the feasibility of using local fruit and vegetable waste to improve biogas production in the anaerobic digesters of the LWWTP in Prince George, British Columbia, Canada. FVW was added to the secondary digester in order to increase the loading of easily biodegradable matter and potentially promote digestion of recalcitrant sludge. The waste was collected from six supermarkets in town; hand sorted, characterised, shredded, and pumped into the secondary digester. Overall digester performance was evaluated during the course of the study.

METHODS

The LWWTP is a secondary wastewater treatment plant that treats wastewater coming from the municipality of Prince George, British Columbia, Canada. The plant is sized for 115,000 PE. Digesters are fed approximately 120 m^3/day of crude sludge (approximately 3.5–4% TS) from two primary clarifiers. The anaerobic digestion system is composed of two digesters, operated in series, each with a maximum volume of 2,986 m^3. The digesters are operated at mesophilic (36 ± 2 °C) temperatures. The combined hydraulic retention time of both digesters is approximately 35–40 days. After the sludge has been stabilized it is dewatered by centrifugation to about 25% dry matter. Methane gas is used in a boiler to produce heat, or cleaned of hydrogen sulphide and siloxanes and combusted by as set of microturbines to produce electricity. The microturbines are used mainly in the summertime when the heating requirements of the LWWTP are low. All in-process measurements were performed by the City of Prince George laboratory staff. Combined digester biogas production was measured continuously and totalled daily. Digester gas carbon dioxide concentration is measured 2–3 times per week using a Fyrite™ gas meter. Methane gas concentration is assumed to make up the remaining balance. Volatile acids and alkalinity of the digester sludge were determined twice per week by the method outlined by Dilallo & Alberton (1961). Digester sludge pH was measured by standard methods (APHA 1998).

Fruit and vegetable waste (FVW) collection and addition

FVW's were collected from Save-On Foods (four locations), Shoppers Wholesale, and Old Town Country Market in Prince George, B.C. Waste was collected every weekday morning (excluding statutory holidays). FVW was then spread out on to a clean concrete pad and visible impurities were removed by hand. The 'clean' FVW was then shovelled into a Vaughn™ 'Veggie Chopper' pump, mixed with water, and shredded for a set time. The shredded waste was then pumped into the sludge heating recirculation line of the secondary digester.

FVW laboratory analysis

Five to ten kilograms of FVW were selected by random shovelfuls and combined. Approximately 1 kg of roughly chopped FVW was blended to a thick consistency (2–3 min) using a Krups™ household blender. Blended waste was then

 Water Science & Technology | 64.9 | 2011

stored at 4 °C and analyzed within 48 h. Samples of waste were frozen for COD analysis at the end of the study. The mass of FVW waste inserted was recorded daily. TS, VS, COD, pH, volatile acid concentration, and alkalinity were analyzed in duplicate 3 times per week (randomly). TS, VS, and pH were determined by standard methods (APHA 1998). Sewer sludge (SS) and FVW were diluted 5:1 and 25:1, respectively, with deionised water for COD measurements. COD was determined by the HACH™ colorimetric method (Hach 2010). Volatile acids and alkalinity were determined by the method outlined Dilallo & Alberton (1961).

Statistical data treatment

Mean daily biogas production over the 6 week trial was compared using analysis of variance (ANOVA). When p was significant (<0.05), statistical differences among treatment means were determined using Tukey-HSD test. JMP 8 statistical software (SAS, NC, USA 2010) was used to perform statistical calculations. Microsoft Excel was used to produce the graphs.

RESULTS AND DISCUSSION

Fruit and vegetable addition

The total mass of FVW inserted weekly is shown in Table 1. Impurities were mainly plastic food wrapping, and other garbage. It was removed daily, by hand, and the wet mass was recorded daily.

Supermarket waste proved to be a reliable and consistent waste stream. One cubic meter of waste weighed approximately 460 kg. The TS and VS of the collected waste remained stable over the course of the experiment (Table 1). Source sorted supermarket FVW was found to be extremely low in impurities when compared to similar waste streams. Kubler *et al.* (2000) found food waste originating from canteens to be considerably higher in impurities, 5% by mass respectively.

FVW and SS characteristics

A comparison of the FVW and secondary digester SS characteristics are shown in Table 2.

The high moisture content (MC), approximately 89.6%, of the FVW suggests sufficient water for AD. The high VS content (86% TS) imply a high level of biodegradability. TS and VS (Table 2) of the supermarket waste were found to be similar to waste collected from similar sources. Bouallagui *et al.* (2005) reviewed the characteristics of a number of mixed fruit and vegetable wastes and found it them to have a TS content between 8–10%, a VS content of about 90%, and total COD around 104 g/L. More variable waste streams such as OFMSW were found to be much higher in TS content, approximately 23–35%, and lower in VS, 57–70% when compared to FVW (Kubler *et al.* 2000).The VS solids content of the FVW was approximately 20% higher than the SS. This suggests that the FVW is more degradable than the sewer sludge. The volatile acids concentration of the FVW was quite high suggesting that the FVW may not have had the buffering capacity to maintain optimal pH if anaerobically digested alone (Ward *et al.* 2008). Codigestion with a buffering substrate such as sewer sludge was therefore necessary.

Table 1 | Weekly mass of FVW added to digesters

Week	Mass of FVW (kg)	TS (%)	TS inserted (kg)	VS (% TS)	VS inserted (kg)	Impurities (kg)	Impurities (%)
July 12–16	1,990	12.5	249	90.0	224	5.1	0.26
July 19–23	2,166	12.2	264	89.0	234	1.6	0.07
July 26–30	2,801	9.6	270	79.9	215	2.5	0.09
Aug 3–6	2,391	11.6	277	86.7	240	6.3	0.26
Aug 9–13	2,215	13.0	288	89.7	259	3.6	0.16
Aug 16–20	3,036	9.7	296	81.7	242	6.1	0.20
Total	14,599	NA	1,644	NA	1,416	25.2	NA
Mean	2,433	11.4	274	86.2	236	4.2	0.17
SD	404	1.4	17	4.3	1	2	0.08

Table 2 | Main characteristics of FVW and secondary SS

Parameter	FVW	SS[a]
TS (%)	11.5 ± 2.5	1.42 ± 0.21
VS (% TS)	86.2 ± 7.5	65.8 ± 1.4
pH	4.6 ± 0.4	7.12 ± 0.07
Volatile acids (mg/L)	2,477 ± 445	171 ± 4
Alkalinity (mg/L)	979 ± 359	2,713 ± 52
COD (g/L)	139 ± 39	12.8 ± 0.7[b]

[a]Average values from July 1–August 31, 2009 ([b]average COD determined from 1 sampling of SS).

Digester performance and response

Average daily biogas production for the study period under investigation (July 12–August 20, 2010) was compared to the historical biogas production during the same period (Figure 1) and was found to be significantly greater than 2008, 2007, and 2006, but not 2009. More stable gas production was observed during addition of FVW than in previous years. Addition of co-digestate may have helped to stabilize gas production by providing easily digestible matter and possibly other trace nutrients that may have been lacking in the secondary sewer sludge.

The average weekly biogas concentrations for 2010 were 8–17% higher than the historical weekly average. Not enough FVW could have been added to account for all of the increased biogas. Other factors may have contributed to the increase in biogas production. Sosnowski *et al.* (2003) suggest that besides added biodegradable matter codigestion can improve biogas yield by dilution of toxic compounds and improving the balance of nutrients inside the digester. The most important parameter that contributes to biogas production is the volume of crude sludge that flows into the digesters. Sludge volume flow into the digesters, over the last year, was directly proportional to an increase in biogas production (data not shown). The average daily crude flow of sludge into the plant was not significantly higher in 2010, during the study period, than any of the previous years (data not shown). Therefore, the increase in biogas production in 2010 can not simply be accounted for by an increase in sludge flow alone.

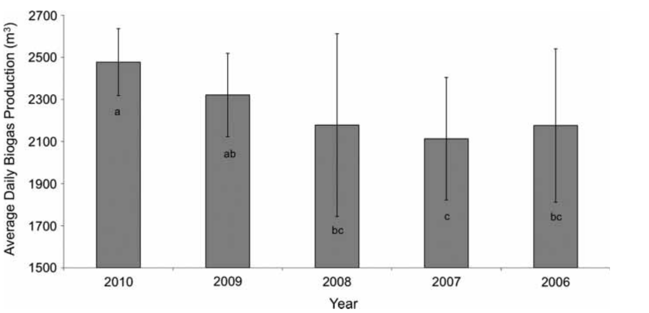

Figure 1 | Average daily biogas production during the addition of FVW (July 12–August 20, 2010) compared to previous years without addition. (Means with the same letter are not significant at $p < 0.05$.)

Digester pH remained relatively stable over the course of the study (data not shown). The secondary digester's pH declined slightly when compared to the primary digester. This was most likely due to the addition of fresh organic matter. Highly biodegradable matter such as FVW can cause acidification of the digester due to rapid hydrolysis, acidogenisis, and subsequent increase in volatile acids concentration of the sludge (Ward *et al.* 2008). However, only a small amount FVW was added and the strong buffering capacity of the SS would have prevented any large shifts in pH.

As seen in Figure 2, there is an increase in the secondary digester carbon dioxide concentration after addition of FVW to the digester. This increase may have been due to the increased hydrolysis and acidogenisis occurring because of the addition of fresh waste. Addition of FVW was from Mondays to Friday; thus the drop in carbon dioxide concentrations on the weekends.

Volatile acid concentration of the secondary digester generally followed the trend of the primary, but was overall lower. Alkalinity remained stable. Lower VS content of the secondary digester decreases the formation of volatile acids when compared to the primary digester. Digester health is often determined by the ratio of volatile acids to total alkalinity. Ratios of 0.3–0.4 are indicative of digester upset. (Water Environment Federation 2008). The volatile acids to alkalinity ratio of both digesters remained stable (0.06–0.08) throughout the study due to the high alkalinity and buffering capacity of the sewer sludge (Table 2). This suggests that more waste could have been added without subsequent digester acidification.

Operation and maintenance

The only mechanical problem that arose was the clogging of the hose that ran from the chopper pump to the sludge recirculation line. FVW often plugged this line. It then had to be manually cleared. Increasing the pump chopping time, decreasing the amount of waste per batch, as well as increasing the rinse cycle may have decreased clogging. Overall there were no other mechanical problems with pumps or clogging downstream from the waste addition. Edelmann

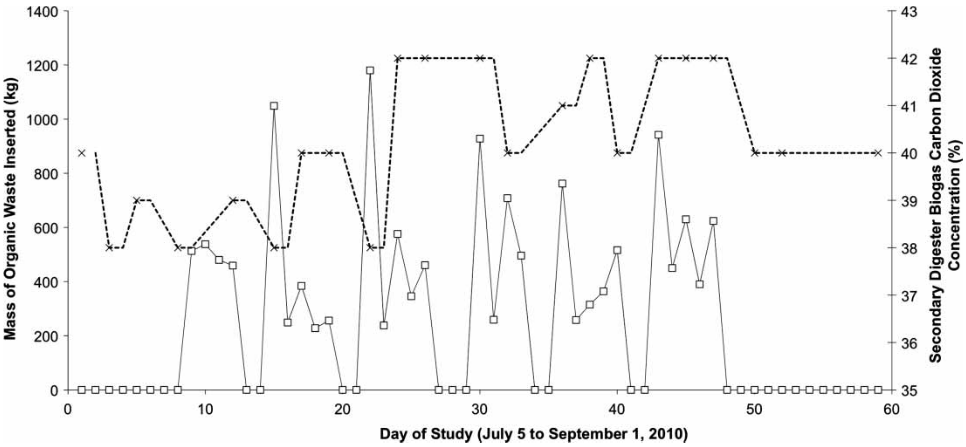

Figure 2 | Primary and secondary digester biogas carbon dioxide concentration over the course of the study (July 12–August 20, 2010). Dashed line represents carbon dioxide concentration. Solid line indicates the mass of FVW inserted.

Figure 3 | (Left) Pre experiment biosolids and (Right) biosolids centrifuged during the course of the experiment.

et al. (2000) also found no negative impact on mechanical operation of anaerobic digesters at a sewer treatment plant treating similar amounts of supermarket waste. The authors did however notice accumulation of fibrous scum build-up near the floating roof of the digester. This was not noticeable at the LWWTP. Most likely because the digester in this study was much larger in volume (2,986 m^3 compared to 240 m^3) and the study period was much shorter (6 weeks compared to 14 months).

Biosolids quality

Biosolids collected during the study period were visibly higher in impurities such as elastic bands, 'twist ties', and other plastic (Figure 3). The British Columbia Ministry of Environment (2008) Land Application Guidelines for the Organic Matter Recycling Regulation and Soil Amendment Code of Practice suggest no more than 1% foreign material in biosolids used for land application. Increased addition of FVW may cause regulatory problems with land application. A more thorough pre-treatment process may be necessary to reduce the addition impurities. Visible undigested organic matter, possibly corn husks, were also found in dewatered sludge. This undigested matter suggests that some of the added waste passed through the secondary digester without fully decomposing. Addition of waste to the primary digester may have improved the digestion of more difficult to digest components by increasing the retention time and preventing 'short-circuiting' of waste when sludge was removed for centrifugation.

CONCLUSIONS

- FVW is a consistent, reliable, and clean organic waste stream.
- FVW can be disposed of in a fully operational WWTP with no digester disruption.

- FVW contributed to an increase in biogas production.
- Co-digestion may have been more complete if FVW was inserted into primary digester instead of secondary.
- Anaerobic co-digestion of organic waste and sewer sludge is a possible alternative to landfilling.

ACKNOWLEDGEMENTS

The authors wish to recognize the City of Prince George for their support. The following grocery stores, namely; Save-On Foods, Shoppers Wholesale Cash and Carry, Old Town Country Market were very generous for supplying the fruit and vegetable waste. The authors would also like to thank to Fikre Debela, Stacey Shantz, Gord Everitt, Tyler Olsen, and Joanne Logie for their assistance. This research was funded by the National Science and Engineering Research Council (NSERC) of Canada.

REFERENCES

Alatriste-Mondragon, F., Samar, P., Cox, H. J., Ahring, B. & Ironpour, R. 2006 Anaerobic codigestion of municipal, farm, and industrial organic wastes: a survey of recent literature. *Water Environment Research* **78** (6), 607–636.

American Public Health Association/American Water Works Association/Water Environment Federation (APHA/AWWA/WEF) 1998 *Standard Methods for the Examination of Water and Wastewater*. 20th edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA.

Bolzonella, D., Battistoni, P., Susini, C. & Cecchi, F. 2006 Anaerobic codigestion of waste activated sludge and OFMSW: the experiences of Viareggio and Treviso plants (Italy). *Water Science and Technology* **53** (8), 203–211.

Bouallagui, H., Touhami, Y., Ben Cheikh, R. & Hamdi, M. 2005 Bioreactor performance in anaerobic digestion of fruit and vegetable wastes. *Process Biochemistry* **40**, 989–995.

British Columbia Ministry of Environment 2008 *Land Application Guidelines for the Organic Matter Recycling Regulation and Soil Amendment Code of Practice*. Available from: http://www.env.gov.bc.ca/epd/industrial/regs/codes/soil_amend/pdf/land-app-guide-soil-amend.pdf (accessed 10 December 2010).

DiLallo, R. & Alberton, O. E. 1961 Volatile acids by direct titration. *Journal Water Pollution Control Federation* **33** (4), 356–365.

Edelmann, W., Engell, H. & Gradenecker, M. 2000 Co-digestion of organic solid waste and sludge from sewage treatment. *Water Science and Technology* **41** (3), 213–221.

Garton, R. 2010 *Chief Wastewater Treatment Plant Operator at the Lansdowne Wastewater Treatment Plant*. Prince George, B. C., CA. Personal communication. (10 December 2010).

Hach 2010 *Procedure Method 8000, Oxygen Demand, Chemical, Ultra High Range*. Available from: http://www.hach.com/fmmimghach?/CODE%3AOXYGENCOD_NONE_HIGH_2091%7C1 (accessed 12 December 2010).

Haight, M. 2005 Assessing the environmental burdens of anaerobic digestion in comparison to alternative options for managing the biodegradable fraction of municipal solid wastes. *Water Science and Technology* **52** (1–2), 553–559.

Kubler, H., Hoppenheidt, K., Hirsch, P., Kottmair, A., Nimmrichter, R., Nordsieck, H., Mucke, W. & Swerev, M. 2000 Full scale co-digestion of organic waste. *Water Science and Technology* **41** (3), 195–202.

Mata-Alvarez, J., Mace, S. & Llabres, P. 2000 Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology* **74**, 3–16.

Sosnowski, P., Wieczorek, A. & Ledakowicz, S. 2003 Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes. *Advances in Environmental Research* **7**, 609–616.

Statistics Canada 2008a *Human Activity and the Environment: Food in Canada*. Available from: http://www.statcan.gc.ca/daily-quotidien/090609/dq090609a-eng.htm (accessed 2 September 2010).

Statistics Canada 2008b *Study: Composting Organic Waste*. Available from: http://www.statcan.gc.ca/daily-quotidien/080327/dq080327c-eng.htm (accessed 12 December 2010).

Ward, A., Hobbs, P., Holliman, P. & Jones, D. 2008 Optimisation of the anaerobic digestion of agricultural resources. *Bioresource Technology* **99**, 7928–7940.

Water Environment Federation 2008 *Operation of Municipal Wastewater Treatment Plants*, Volume 1: Management and Support Systems, 6th edition, Water Environment Federation, USA.

Zhang, R., El-Mashad, H., Hartman, K., Wang, F., Lui, G., Choate, C. & Gamble, P. 2007 Characterisation of food waste as feedstock for anaerobic digestion. *Bioresource Technology* **98**, 929–923.

Zupancic, G., Uranjek-Zevart, N. & Ros, M. 2008 Full-scale anaerobic co-digestion of organic waste and municipal sludge. *Biomass and Bioenergy* **32**, 162–167.

First received 5 April 2011; accepted in revised form 24 June 2011