CHEMICAL ENGINEERING TRANSACTIONS

VOL. 63, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jeng Shiun Lim, Wai Shin Ho, Jiří J. Klemeš

ISBN 978-88-95608-61-7; **ISSN** 2283-9216

DOI: 10.3303/CET1863013

Review on the Characteristic and Feasibility of Leachate for Biogas Production by Anaerobic Digestion

Cassendra P. C. Bong[a,b], Li Yee Lim[a], Chew Tin Lee[a,b,*], Wai Shin Ho[a,b], Chin Siong Ho[b], Jiři J. Klemeš[c]

[a]Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM), 81310, Johor, Malaysia.
[b]UTM Low Carbon Asia Reseach Centre (UTM-LCS), Universiti Teknologi Malaysia (UTM), 81310, Johor, Malaysia.
[c]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 00 Brno, Czech Republic.
ctlee@utm.my

The sound handling of municipal solid waste (MSW) is of high priority to minimise environmental degradation and pollution. MSW can be treated via various technologies including landfilling, incineration, composting, anaerobic digestion (AD) and more. Landfill without landfill gas capturing serves as an enclosed bioreactor to store and stabilise waste. Other technologies such as incineration, composting and AD allow substantial volume reduction and generate value-added products. The treatment for MSW is commonly focusing on the solid part. Organic waste contains high moisture content of 70 - 90 %. The pressing of the water content before entering treatment unit, the release of water during and after the treatment, can generate high strength wastewater, known as leachate. Leachate is rich in organic matter, organic pollutants, pathogens, heavy metals and more, which can lead to severe secondary environmental pollution if not properly treated. Leachate from different treatment units showed certain unique characteristics, such as high Na, high Ca , different species and availability of heavy metals. This review summarised some of the important characteristics of different leachates and the suitability of AD as a mean of treatment. The efficiency of AD to treat leachate was presented in terms of the removal efficiency of chemical oxygen demand (COD) and biogas production. The COD removal efficiency was between 60 - 98 %, following the treatment of different leachates under different reactors and operational parameters. Among the different stream of leachates, the leachate from landfill is most commonly studied as a co-digestion substrate for AD, as compared to leachate from the composting facility.

1. Introduction

The effective management of municipal solid waste (MSW) is a critical element for the sustainable development in many countries. Technologies embedded with the concept of “waste-to-energy” or “waste-to-resource” is ranked high in the waste management hierarchy as compared to traditional landfill or open disposal. These technologies allow the reduction of waste and generates value-added product.

Incineration is the combustion of waste at a minimum temperature of 850 °C which produces heat and energy. Composting and AD are two major biological treatments for organic wastes. Composting takes place under aerobic condition, where the organic matter is decomposed to release metabolic heat, water and CO_2. The end-product is a humus-like compost that can be used as fertiliser or soil amendment to improve soil and plant’s health. AD is the decomposition of organic matter under the absence of oxygen, with biogas, mainly CH_4 and CO_2, and the digestate as the main products.

The characteristic of the waste fed into the system is one of the important factors influencing the performance of the technology. For this paper, the waste of interest is MSW that is characterised as high in solids, organic matter content and moisture content and slightly lower in pH (Dhar et al., 2016). The management and treatment of MSW should be viewed as two parts: mainly the solid part and the liquid part (leachate). The leachate can be produced at several stages while employing the selected technologies to treat the solid part of MSW, such as during collection of MSW (door-to-door collection), dewatering of MSW before entering

Please cite this article as: Cassendra Phun Chien Bong, Li Yee Lim, Chew Tin Lee, Wai Shin Ho, Jiří Jaromír Klemeš, 2018, Review on the characteristic and feasibility of leachate for biogas production by anaerobic digestion, Chemical Engineering Transactions, 63, 73-78 DOI:10.3303/CET1863013

treatment unit (pre-treatment before incineration), leachate production during treatment (composting, landfilling) and after leaving treatment unit. Figure 1 shows the stages where leachate is potentially generated during different MSW treatments including for landfilling, incineration, composting and AD.

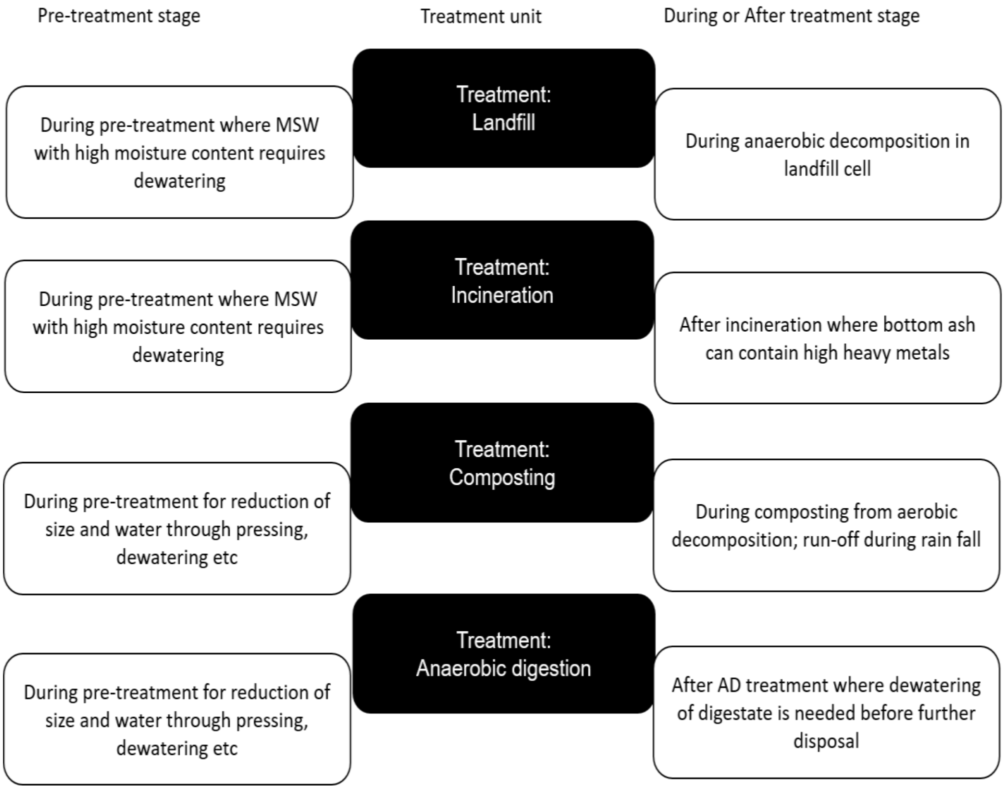

Figure 1: Possible stages where leachate can be generated in different treatment units

Leachate is commonly regarded as high strength wastewater, which is high in chemical oxygen demand (COD), dissolved organic matter (DOM) and with the presence of heavy metals. Treatment for leachate can include biological methods (composting, AD) and physico-chemical methods such as adsorption, coagulation/ flocculation, chemical oxidation and precipitation (Baccot et al., 2017). Leachate generated at different stages varied among different technologies. The characterisation of leachate is important, as there are different requirements for the optimal performances among different technologies. This paper has the aims to (1) review the characteristic of leachate from different sources and their subsequent treatment technologies (2) review on the suitability of leachate, especially composting leachate, as a substrate or microbial inoculum for AD. The main output of this review is to determine the suitability of leachate from several treatment units to be used as substrate or microbial inoculum for the subsequent AD treatment. This could provide a better insight to design a closed-loop, integrated solid waste management scenario employing composting-AD, incineration-composting-AD or landfill-incineration-composting-AD.

2. Methods

This review is based on a literature search using ScienceDirect with the focus on several keywords: leachate from municipal solid waste, leachate from composting, leachate from landfill, leachate for AD and leachate treatment.

3. Characteristics of leachate from different sources and treatment

3.1 Characteristics of leachate from different sources

In this section, the treatment unit considered for managing MSW includes pre-treatment units, composting, landfill and incineration. Due to the nature of MSW and the treatment units, leachate can be produced at different stages along the treatment unit and exhibit different characteristic. Leachate originated from biowaste, food waste or MSW might have high pathogen, salt and heavy metals, which cause operational issues and safety concern. Leachate generated from the dewatering pre-treatment unit might have highly soluble OM as compared to leachate coming out after treatment unit or in matured landfill. Table 1 illustrated the characteristic of leachate from different treatment units.

Table 1: Leachate from different sources and their subsequent treatment

Reference	Source	COD (mg/L)	pH	Used for	Remark
Liu et al., 2010	Fresh leachate from MBT treated MSW	60,000 - 70,000	3.8 - 6.3	Substrate for AD after MBT	Significantly higher COD than composting leachate; MBT is often followed by composting, incineration or landfill.
Kim and Kang, 2015	Leachate from food waste	N/A	~ 7	Co-substrate of AD	Leachate is lacking biodegradable organics and high salt content; Require additional co-substrate other than fresh leachate.
Luo et al., 2015	MSW leachate from landfill	8,500 - 117,000	3.8 - 8.1	Co-substrate for AD	Rich with various heavy metals, NH_3, labile OM.
Baccot et al., 2017	MSW leachate from landfill	12, 890	~ 7.35	Co-substrate for AD	The suitability for biogas production is influenced by the degree of humification, regardless of the age of leachate; Leachate with high transphilic-like compounds is suitable for methanisation than hydrophilic-like compounds.
Hassan and Abbas, 2016	Leachate from composting	140 - 4,200	7.5 - 8	Complementary treatment of pre-anaerobic-aerobic treated composting leachate	AD is capable to treat the leachate till requirement of standard.
Dang et al., 2014	Leachate from MSW incineration plant	70,390 - 75,480	4.58 - 6.42	Substrate for AD	High Ca (i.e. 5,000 mg/L) concentration present leads to decreasing growth and survival of microbial community.

Municipal solid waste consists of high moisture content, especially for biowaste such as food waste, which consists of 70 - 90 % of water (Kim and Kang, 2015). MSW with high moisture requires pre-treatment to remove excess water before entering the composting unit or the addition of bulking agent. MSW is well-known for its heterogenous nature, which contains waste with uneven size and biodegradability. Simple pre-treatment such as the uses of pressers and extruders were found to be effective for size reduction and dewatering (Micolucci et al., 2016).

Composting is the aerobic stabilisation of organic matter that produces a humus-like material that could be used as fertiliser or soil conditioner. One of the major concerns for composting is the management and treatment of leachate with high strength of organic load (Trujillo et al., 2006). The generation of leachate from composting include: (1) along the composting process, including the microbial decomposition of OM and possible runoff due to heavy rainfall; (2) at the beginning of the composting process through the dewatering pre-treating unit, such as pressing and mechanical-biological treatment (MBT).

Pre-treatment for dewatering is needed if the composting material has moisture content higher than 60 %. 1 t of organic fraction of MSW (OFMSW) processed was reported to have 70 % solid material, with the remaining 30 % being the press water generated (Nayano et al., 2010). The commonly reported heavy metals included Fe > Mn > Ni > Zn > Cu > Co > Pb > Cr > Cd for press water from the raw composting material (Nayono et al., 2010), Ca > Na > Mg > Fe > Mn > Zn > Pb > Ni from the leachate of a MSW incineration plant (Dang et al., 2014), Ca > Fe > Zn > Mn > Cu > Zn > Pb > As > Ni from the fresh leachate of a raw compost (Liu et al., 2010). Lim et al. (2017) reported that composting could effectively reduce the bioavailability of heavy metals through the buffering effect of high pH and binding of humid acid.

The generation of fresh leachate during the early dumping of MSW is a major issue as the leachate contains high organic matters, NH_3-N, heavy metal and inorganic salts (Luo et al., 2015). Baccot et al. (2017) categorised the landfill leachate into three categories: young (aerobic, high biodegradability and acidic), intermediate and mature/stabilised (low biodegradability, methanogenic).

Incineration with complete combustion, allows significant reduction on the waste volume. The solid residual is the bottom ash, fly ash and air pollution control residues, containing high amount of heavy metals, inorganic salts and some organic compounds (Ibáñez et al., 2000). The leachate can be generated by weathering effect, such as during rainfall, acid precipitation (Chow and Chai, 2007) when the bottom ash is dumped to landfill or other disposal options. The leachate from incineration plant consists relatively similar amount of COD as compared to the leachate from composting and landfill. Dang et al. (2014) reported a high Ca concentration of greater than 5,000 mg/L in the leachate from a MSW incineration plant In China. The high concentration of Ca resulted in the potential clogging due to precipitation as $CaCO_3$. High concentration of Ca and $CaCO_3$ precipitation were found to inhibit microbial activity.

Leachate from the treatment units with MSW could be the feed material consisted of high COD, with a minimum COD of 140 mg/L from composting to the maximum of 117,000 mg/L from landfill leachate. Table 1 summarises different types of leachate with their respective COD and pH, and their subsequent reused found in several studies.

3.2 Anaerobic digestion (AD) as a mean for effective leachate treatment

AD has been popular in treating high strength wastewater. Leachate generated from the MSW treatment units can be characterised as high strength wastewater due to their high COD (~ 10,000 mg/L). Table 2 illustrates the COD removal efficiency using AD to treat leachate.

Table 2: COD removal efficiency and biogas production through AD of leachate

Reference	Source	COD removal (%)	Biogas production	Remark
Liu et al., 2010	Fresh leachate from MBT treated MSW	88 - 97	6.0 L/L.d	OLR to be kept under 30 kg COD/m^3.d to have COD removal efficiency of ~ 90 %; Efficient COD removal was due to efficient hydraulic mixing to ensure constant optimal contact.
Luo et al., 2015	MSW leachate from landfill	60 - 96	N/A	Higher nutrients, complicate composition, suitable for methanogenesis inhibition and low temperature.
Nayono et al., 2010	Pressed off leachate from MSW	60	270 m^3 CH_4/ t COD_{added}	Press water from MSW produced high biogas even at high loading rate
Baccot et al., 2017	MSW leachate from landfill	N/A	4,257 mL/ g DOC, 56 % CH_4	Leachate with high transphilic-like compounds is suitable for methanisation than hydrophilic-like compounds.
Dang et al., 2014	Leachate from MSW incineration plant	89 - 98	N/A	Ca concentration of > 5,000 mg/L resulted in a 10 % decrease of COD removal efficiency; High Ca concentration reduces alkalinity by binding with free carbonates, decreasing the buffering capacity against VFA (Ye et al., 2011).
Lei et al., 2016	Leachate from MSW incineration plant	~ 80 - 90	8.9 - 11.5 L/d	The use of carbon cloth allows 34.2 % increase in OLR
Micolucci et al., 2016	Leachate from biowaste	N/A	0.79 - 0.90 m^3 biogas/kg VS, 66 - 68 % CH_4	Thermophilic temperature gave higher production; Low level of heavy metals and pathogens; digestate from thermophilic system had lower level of pathogens than mesophilic system.

The leachate from composting unit is relatively lower, due to the high waste stabilisation capability of active microbial degradation during the composting process. Pressed leachate, which is produced from the dewatering process of pre-treatment unit and fresh run-off from composting pile could exhibit higher COD.
As AD is a dynamic biological process where the operational parameters such as organic loading rate (OLR), pH, volatile fatty acids (VFA), COD, biological oxygen demand (BOD), NH_3-N, temperature and more are interacting among each other, the characterisation of leachate is important as it would influence the four stages of AD. AD is also governed by several microbial communities that dominate the process successively. The four main stages of AD are hydrolysis, acidogenesis, acetogenesis and methanogenesis, each governed by the respective microbial groups with different optimal surviving environment.
Leachate contains high biodegradable OM and lower pH, rapid hydrolysis of such OM will lead to acid accumulation, which does not favour methanogenesis. This requires additional stream of substrate to complement the missing nutrients or to dilute the toxicity of the inhibitory compounds. The presence of N source has shown a 53.3 % increase in biogas yield during the AD of fruit-vegetable waste with meat residue (Garcia-Peña et al., 2011) but resulted in a decrease of 50.8 % during the AD of food waste (Sheng et al., 2013). High Ca (Dang et al., 2014) and Na (Kim and Kang, 2015) in certain leachate stream had been reported to cause low biogas production. Most stream of leachate consisted considerable amount of heavy metals. The presence of certain heavy metals had been shown to increase biogas production by stimulating better enzymatic activities under high VFA condition (Banks et al., 2012).
The COD removal efficiency is significantly high, around 80 – 90 % while treating leachate generated from different treatment units, with the exception of the leachate generated from MSW landfill and pressed-off leachate from MSW. Lower pH and potential toxicity from the heavy metals could be hindering the microbial degradation. The threshold for the heavy metals to act as either nutrients or toxicants is dependent on the solubility of heavy metals in the leachate (Aquino and Stuckey, 2007). Due to the anaerobic nature of OM decomposition in landfill, the young landfill leachate consisted less NH_3-N (Luo et al., 2015) but rich in sulphate, as compared to the fresh leachate from aerobic composting.

4. Conclusion

The leachate generated from the treatment facilities treating MSW serves as a suitable nutrient source for AD for biogas generation. The COD removal efficiency and the biogas production could be hindered by high biodegradability, high COD, high salinity, high Ca, low pH and high VFA, NH_3 toxicity and heavy metals. Depending on the type of AD reactor and operational parameters, the COD removal efficiencies was around 60 - 98 %, showing the capability of AD to treat high strength leachate. AD has been commonly used to treat the leachate from MSW landfill, but few were reported for leachate from composting. Future work on characterising the leachate from composting and their feasibilities to serve not only as nutrient source, but also as inoculum source, is worth studying. Leachate from composting might contain diverse microbial community that is readily adapted to the high labile OM and low pH environment of MSW or food waste. The study of methane-producing community from the leachate, to be used as inoculum for anaerobic digestion, remains limited.

Acknowledgments

The authors would like to acknowledge the research grants from the Universiti Teknologi Malaysia (UTM) with the grant no. Q.J130000.2546.14H65 and the Ainuddin Wahid Scholarship. The authors also acknowledged the funding and support by the EU project Sustainable Process Integration Laboratory – SPIL, funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research, Development and Education, Priority 1: Strengthening capacity for quality research.

Reference

Aquino S.F., Stuckey D.C., 2007, Bioavailability and toxicity of metals nutrients during anaerobic digestion, Journal of Environmental Engineering, 133, 28-35.
Baccot C., Pallier V., Feuillade-Cathalifaud G., 2017, Biochemical methane potential of fractions of organic matter extracted from a municipal solid waste leachate: Impact of their hydrophobic character, Waste Management 63, 257-266.
Banks C.J., Chesshire M., Heaven S., Arnold R., 2011, Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance, Bioresource Technology 102, 612-620.
Chow J.D., Chai W.L., 2007, The influences on leachate from landfill of incineration residuals by acid precipitation, Journal of Hazardous Materials, 142, 483-492.Dang Y., Zhang R., Wu S., Liu Z., Qiu B.,

Fang Y., Sun D., 2014, Calcium effect on anaerobic biological treatment of fresh leachate with extreme high calcium concentration, International Biodeterioration & Biodegradation, 95, 76-83.

Dhar H., Kumar P., Kumar S., Mukherjee S., Vadiya A.N., 2016, Effect of organic loading rate during anaerobic digestion of municipal solid waste, Bioresource Technology, 217, 56-61.

Garcia-Peña E.I., Parameswaran P., Kang D.W., Canul-Chan M., Krajmalnik-Brown R., 2011, Anaerobic digestion and co-digestion processes of vegetable and fruit residues: Process and microbial ecology, Bioresource Technology, 102, 9447-9455.

Hassan H., Abbas K., 2016, Complete treatment of compost leachate using integrated biological and membrane filtration processes, Iranian Journal of Chemistry and Chemical Engineering, 35, 81-87.

Ibáñez R., Andrés A., Viguri J.R., Ortiz U., Irabien J.A., 2000, Characterisation and management of incinerator waste, Journal of Hazardous Materials, 79, 215-227.

Lei Y., Sun D., Dang Y., Chen H., Zhao Z., Zhang Y., Holmes D.E., 2016, Stimulation of methanogenesis in anaerobic digesters treating leachate from a municipal solid waste incineration plant with carbon cloth, Bioresource Technology, 222, 270-276.

Lim L.Y., Lee C.T., Lim J.S., Klemes J.J., Chin Siong Ho, Mansor N.N.A., 2017, Feedstock amendment for the production of quality compost for soil amendment and heavy metal immobilisation, Chemical Engineering Transactions, 56, 499-504.

Liu J., Zhong J., Wang Y., Liu Q., Qian G., Zhong L., Guo R., Zhang P., Xu Z.P., 2010, Effective bio-treatment of fresh leachate from pre-treated municipal solid waste in an expanded granular sludge bed bioreactor, Bioresource Technology, 101, 1447-1452.

Luo J., Qian G., Liu J., Xu X.P., 2015, Anaerobic methanogenesis of fresh leachate from municipal solid waste: A brief review on current progress, Renewable and Sustainable Energy Reviews, 49, 21-28.

Micolucci F., Gottardo M., Cavinato C., Pavan P., Bolzonella D., 2016, Mesophilic and thermophilic anaerobic digestion of the liquid fraction of pressed biowaste for high energy yields recovery, Waste Management, 48, 227-235.

Nayono S.E., Winter J., Gallert C., 2010, Anaerobic digestion of pressed off leachate from the organic fraction of municipal solid waste. Waste Management, 30, 1828-1833.

Sheng K., Chen X., Pan J., Kloss R., Wei Y., Ying Y., 2013, Effect of ammonia and nitrate on biogas production from food waste via anaerobic digestion, Biosystems Engineering, 116, 205-212.

Trujillo D., Font X., Sanchez A., 2006, Use of Fenton reaction for the treatment of leachate from composting of different waste. Journal of Hazardous Materials, 138, 201-204.

Ye J., Mu Y., Cheng X., Sun D., 2011, Treatment of fresh leachate with high-strength organics and calcium from municipal solid waste incineration plant using UASB reactor, Bioresource Technology, 102, 5498-5503.