Jurnal
Teknologi

Full Paper

ENHANCING LANDFILL GAS RECOVERY- A REVIEW

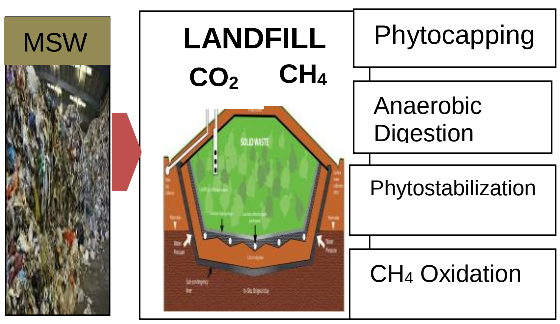
Emmanuel Olisa*, Nasiman Sapari, Amirhossein Malakahmad, Ezerie Henry Ezechi, Ali Riahi

Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS (UTP), 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia

Article history
Received
25 June 2015
Received in revised form
28 September 2015
Accepted
21 December 2015

*Corresponding author
emidear2003@yahoo.com

Graphical abstract



Abstract

Although landfills serve as an easy and very economic means for disposing wastes, it poses threat to the environment as it generates both leachate and greenhouse gases, including methane (CH_4) and carbon dioxide (CO_2). Nowadays, landfills are equipped with gas recovery components thereby making it possible for more methane gas to be collected and used as an alternative source of green energy. Currently, various technologies have been employed in managing landfill sites in order to attenuate environmental degradation; Revegetation technologies, methane oxidation, anaerobic digestion, waste washing and pre-treatment are some of the methods currently used. This review presents an overview of the technologies and methods employed for enhancing landfill gas mitigation and recovery.

Keywords: Landfill gas, Phytocapping, Anaerobic Digestion

© 2016 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

Integrated solid waste management involves various stages of waste handling and the waste hierarchy is pivotal, where waste management operations are categorized in their order of most to least beneficial environmentally or energy generation wise. The hierarchy encourages waste prevention/reduction, reuse, recycling and the eventual disposal of solid waste which is usually done by landfilling. Landfill disposal of solid waste is a very common practice in many cities including cities in Malaysia.

The constant increase in population, growth in social civilization, changes in habit in terms of production and consumerism, more lifestyles of affluence, use of resources, continued industrial evolution has resulted in the rise in the volume of municipal and industrial solid wastes being generated, hence the world is still faced with this problem [1].

In recent years, Malaysia has continuously experienced an upsurge in terms of economic growth, which has also led to population growth especially as a result of the massive inundation of foreign workers into Malaysia. This has consequently led to a rise in the amount of solid waste that is being generated. In 2003, waste generation was averagely at 0.5–0.8 kg/person/day nationwide, even though the value in the cities was higher at about 1.7 kg/person/day [2]. Handling of municipal solid waste is one of the biggest environmental challenges Malaysia is encountering nowadays [3].

Landfills have great impact on climate change which basically has to do with their emissions of CO_2 and CH_4 which are greenhouse gases (GHG) contributing to global warming along with several other gaseous components [4]. Methane and carbon dioxide are the main landfill gases (LFG) with constituent compositions of about 55–60% and 40–45% by volume, respectively [5]. These gases usually escape into the atmosphere through the gas vents or the landfill surfaces. Methane which has been reported to have a global warming potential (GWP) that is 21 times higher than that of carbon dioxide, is the second most abundant greenhouse gas [6]. The processes that lead to the formation of landfill gas are waste degradation by bacteria, series of chemical reactions and volatilisation [7].

Generally, the conventional method of LFG collection is from the waste layer where only about 40–60% (v/v) of the overall landfill gas generated can be recovered via this method as a result of landfill gas variations [8]. More so, sufficiently great amounts of landfill gas unaccounted for still escape from the landfill surface and leachate collection pipes. Organic matter in landfill starts to decompose when water comes in contact with the buried waste. Leachate production and landfill gas emission are enhanced by an increase in the level of moisture in landfills. Production of leachate in landfills causes vegetation damage, surface and ground water pollution, while greenhouse gas emission in form of methane leads to ozone depletion and climate change [9].

Gas collection and recovery is therefore an economic imperative which also enhances environmental protection, hence the need for improvement in the collection systems.

2.0 ENVIRONMENTAL CONCERNS WITH LANDFILLS

Landfilling is the most commonly used method of disposal for municipal solid wastes. This method is generally the simplest, most flexible, reliable and economical means of disposing municipal solid wastes. The problem with landfilling, however, is leachate generation [10]. Disposing of wastes via landfilling while ensuring environmental sustainability is one of the major challenges of modern waste management techniques [11]. This is so especially when considering the incorporation of positive features applied previously in landfill designs and operations and a long-term technology to mitigate gaseous emissions and leachate generation. Landfill leachate comprises of large amount of organic and inorganic compounds, whose concentrations depend largely on the kind of waste, filling technique, landfill environment and the landfill age [12]. Therefore leachate may become a serious threat to the surrounding water quality. If leachate is not properly controlled it may seep into underlying groundwater thus causing a serious groundwater pollution. Accumulated leachate above the liner in the landfill is channeled into a leachate collection pond through a leachate collection pipe. This leachate is commonly very concentrated with organic pollutant with chemical oxygen demand (COD) up to 40000 mg/l [13]. Thus the leachate collection pond often becomes anaerobic and produces methane gas which escapes into the environment and contributes to the global warming problems [14]. Methane gas as well as other greenhouse gases such as carbon dioxide is produced in landfills and open dumps as the organic fractions of the waste degrades under anaerobic conditions [15].

3.0 TRENDS IN LANDFILL DESIGN

Generally, landfills can be classified into aerobic, anaerobic sanitary landfill with daily cover and semi-aerobic landfill with natural ventilation and leachate collection facilities [16, 17]. Many developed and developing countries still manage their solid wastes by the use of landfills as seen in Figure 1.

Malaysia has adopted the semi-aerobic method for the construction of landfills as seen in Bukit Tagar, Kuala Langkat and a few other locations as approved by the Department of Environment (DOE) [18]. Usually semi-anaerobic landfills consist of a large diameter main pipe that is joined with other small diameter pipes at the bottom for collecting the leachates. Atmospheric air can easily transport into the waste matrix through the main pipes, because they have large diameters or openings [18].

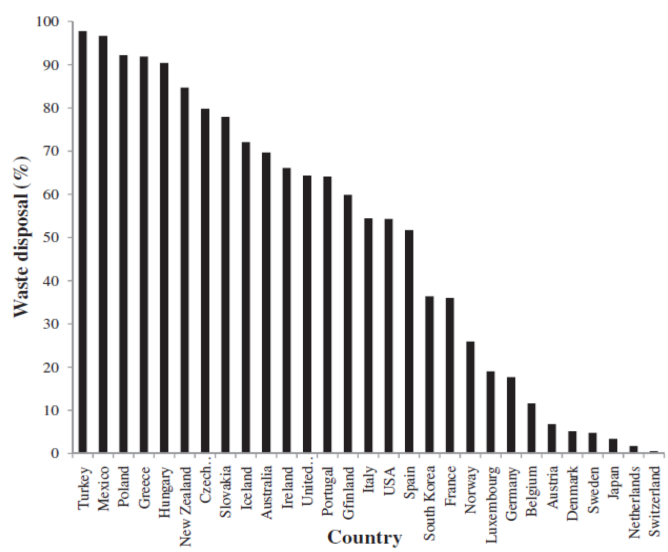


Figure 1 The use of landfills for waste disposal by various countries [32]

Semi-anaerobic landfills have been reported to generate leachate containing high concentration of organic matters that can be converted into methane [19]. This gas can be recovered for green energy through a proper gas piping system design. However, because large quantities of the degradable organic materials leave the landfill with the leachate into the leachate pond, the gas collection from the existing gas pipe is not optimum. Higher volume of methane gas can be generated by the landfill if the organic material in the leachate can be broken down into methane gas inside the bottom of the landfill itself before it is discharged into the leachate collection pond [15].

4.0 LEACHATE GENERATION AND LANDFILL GAS (LFG) REDUCTION TECHNOLOGIES

4.1 Application of Revegetation Technologies in Landfill Management (Phytocapping)

The fundamental reason for the design and management of landfills is to dispose of solid waste, limit or reduce gaseous emissions into the environment and also prevent water contamination. Landfill covers mitigate infiltration of precipitations, and hence assuaging groundwater pollution from leachate generated. Landfill covers minimize percolation and infiltration by adding layers with low permeability (e.g. geo-synthetic liners and compacted clay soils). However, this is often not achieved. It is due to the cracks being formed as landfills become old. This has prompted the current practice of growing vegetation over constructed caps in order to avert the effect of direct exposure to environmental factors which causes the decomposition of the top layers. This also enhances water storage in the soil as well as evapotranspiration from the vegetation [20]. Phytocapping (Figure 2) is an alternative landfill cover technology which has to do with the capability of plants to manage water movement in landfill caps. The process of phytocapping involves transpiration and root growth in soil layers which behaves like sponge that immobilizes pollutants and reduces leaching by initially holding back precipitations which are later pumped out of the landfill caps through evapotranspiration thereby maintaining the cap's retention capacity and controlling erosion. Vegetative caps are sometimes called evapotranspiration landfill covers or alternative covers [21]

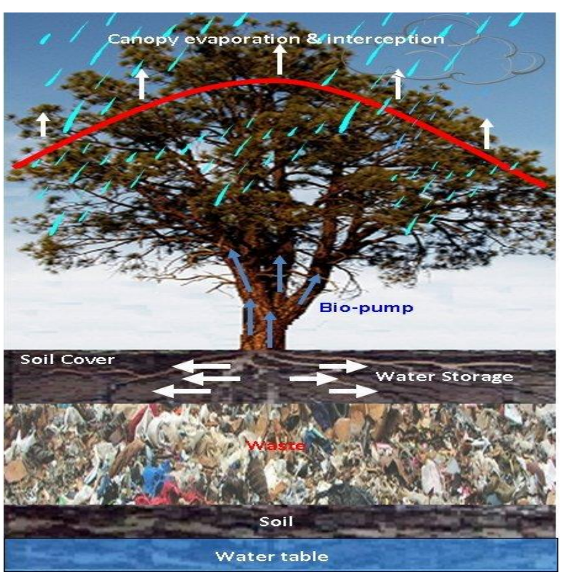


Figure 2 Phytocapping of landfills [28]

This alternative technology although initiated primarily for the prevention of surface emission, it also promotes the aesthetic qualities of landfills especially landfills that are mostly adjacent to urban communities and introduces economic benefits such as biomass generation for energy, timber and fodder [22].

4.2 Phytostabilization

This is another revegetation technology which is also employed to provide or serve as a vegetative cover on the surface of polluted landfills with the primary objective of limiting the movement of pollutants (e.g heavy metals) within the unsaturated zone of the cover soil through accumulation or confinement by roots within the rhizosphere, thereby minimizing offsite pollution [20]. Phytostabilization is a generally accepted method of remediation as a result of its cost effectiveness and practicability especially as pollutants are immobilized in soil layers via accumulation by plant roots and absorption [23].

4.3 Methane Oxidation

A prospective or alternative means for CH_4 control or mitigation is to enhance the rate of methane oxidation through a novel design which provides a favourable environment for methanotrophic activity to occur within the landfill cover [24]. Although conventionally, clay and soil are being used as landfill cover materials, however some artificial and biological covers have also been utilised as alternative landfill covers, for example horticulture soil, mechanical-biological treatment (MBT) residues, peat, sand, agricultural soil and composting, but the application of some more cost-effective bio-cover materials is encouraged especially obtaining them directly from landfills and old refuses. This could be a viable alternative material used for the control of CH_4 emissions as reported by [25]. He described aged refuse as the residues of the disposed wastes which include sewage sludge and municipal solid waste in landfills after a long period of stabilization. It also consists of the macro and micro-nutrients as well as enormous microbes and lots of humus.

4.4 Anaerobic Digestion

Anaerobic digestion is a process in which the solid wastes are stabilized through biological activities in a bioreactor in the absence of atmospheric oxygen, which eventually results in the generation of methane (CH_4), carbon dioxide (CO_2) and other trace gases commonly referred to as biogas [26]. Anaerobic digestion involves bacteria fermentation of organic wastes without oxygen. This fermentation leads to the breakdown of complex biodegradable organics in a four phase process namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis [15].

5.0 WASTE PRE-TREATMENT TECHNOLOGIES

There exist several other methods of pre-treating wastes before they are either disposed into landfills or digested anaerobically.

5.1 Mechanical Biological Treatment (MBT)

Recently, (MBT) has been considered as an alternative to waste incineration, basically because of its wider positive public acceptance. MBT of waste procedure include: (i) mechanical pre-processing of waste sorting of recyclable materials like metals, plastics and glass, and, (ii) biological phase which involves reduction and stabilization of the organic substances under controlled anaerobic and/or aerobic conditions [27].

5.2 The Presssure Extrusion Method/Technology

This is another form of pre-treatment method for municipal solid waste. It is a mechanical process that is utilised in solid waste treatment plants and has yielded appreciable result indicating its efficiency in gas and leachate generation and emission from landfills when wastes are eventually disposed in landfills. This pre-treatment technology guarantees the separation of the organic fraction of municipal solid waste from the waste stream and aids its degradation when treated under anaerobic conditions [28].

Other pretreatment technologies employed include; (i) washing of the wastes, which is applied to control the leachable fraction of the waste and prevent relevant impact [29, 30], (ii) micro-aeration pre-treatment are used basically to enhance hydrolysis of anaerobic digestion [31], (iii) sonolysis, and (iv) ozonation, which have been shown by previous research to have greatly affected the solubilization of organic solid waste thus improving anaerobic digestion yield [32].

Fat, oil and grease waste from sewage treatment plants (STP-FOGW) have been reported to be commonly disposed of in landfill. Co-digesting the organic fraction of municipal solid waste (OFMSW) enhances the valorisation of STP-FOGW which results in an increase in biogas produced during anaerobic digestion, especially as lipid rich wastes have been observed to be viable substrate for anaerobic digestion because of their high theoretical methane potential, hence in Martin-Gonzalez *et al*., (2010) [33] study on STP-FOGW was examined as a co-substrate in wet anaerobic digestion of OFMSW under mesophilic conditions (37°C). Batch experiments which were carried out at different co-digestion ratios, showed an improvement in methane production related to STP-FOGW addition.

The co-digestion of cattle manure and food waste has also been shown to have enhanced the biogas production and the methane yield in the organic fraction of municipal solid waste (OFMSW) [34]. Research has indicated that, the particle size of organic waste in an anaerobic digester does not change the specific biogas yield, but it does affect the performance of the digester [35]. Apart from landfill disposal, composting can be used to recycle municipal organic waste which leads to reduction in cost of transportation and waste treatment [36].

6.0 CONCLUSION

Although landfilling presents a simple and flexible method to dispose waste, it has negative effects on the environment, such as production of leachate and greenhouse gas emissions in the form of methane gas and carbon dioxide. Landfills having gas recovery systems can be utilised in capturing CH_4 as a source of fuel. Furthermore, advanced revegetation techniques such as phytocapping as well as all the other techniques discussed in this article, aids the recovery of landfill gas collection as well as the mitigation of landfill gas emission into the environment and they also help in the reduction of leachate generation in landfills as well as the prevention of all forms of pollutants getting into the environment from landfills. The use of of an in-situ leachate treatment facility in the landfill that will help to degrade organics in leachate before discharge thereby reducing the pollutant in the leachate as well as converting them into methane gas, is highly recommended.

Acknowledgement

The authors are grateful and deeply appreciate the management of the University Technology PETRONAS for their immense support financially in the form of graduate assistanceship (GA) scheme and provision of the Fundamental Research Grant Scheme (FRGS) (No. 0153AB-I09) and otherwise.

References

[1] Johari, A., Ahmed, S. I., Hashim, H., Alkali, H., Ramli, M. 2012. Economic And Environmental Benefits Of Landfill Gas From Municipal Solid Waste In Malaysia. *Renewable And Sustainable Energy Reviews*. 16: 2907-2912.

[2] Kathirvale, S., Muhd, M. N., Sopian K., Samsuddin, A. H., 2003. Energy Potential From Municipal Solid Waste In Malaysia. *Renewable Energy*. 29: 559-67.

[3] Saeed, M. O., Hassan, M. N., Abdul, M. M. 2009. Assessment Of Municipal Solid Waste Generation And Recyclable Materials Potential In Kuala Lumpur, Malaysia. *Waste Management*. 29: 2209-13.

[4] Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F., Moulin, P. 2008. Landfill Leachate Treatment: Review And Opportunity. *J. Hazard. Mater*. 150: 468-493.

[5] Raco, B., Battaglini, R. & Lelli, M. 2010. Gas Emission Into The Atmosphere From Controlled Landfills: An Example From Legoli Landfill (Tuscany, Italy). *Environmental Science And Pollution Research*. 17: 1197-206.

[6] Hoornweg, D., Bhada-Tata, P. 2012. *What A Waste: A Global Review Of Solid Waste Management*. World Bank Publications, Washington, DC.

[7] Raco, B., Battaglini, R., Lelli, M. 2010.Gas Emission Into The Atmosphere From Controlled Landfills: An Example From

Legoli Landfill (Tuscany, Italy). *Environmental Science And Pollution Research*. 17: 1197-206.

[8] Spokas, K., Bogner, J., Chanton, J. P., Morcet, M., Aran, C., Graff, C., Moreau-Le Golvan, Y., Hebe, I. 2006. Methane Mass Balance At Three Landfill Sites: What Is The Efficiency Of Capture By Gas Collection Systems? *Waste Manage*. 26: 516-525.

[9] Lamb, D. T., Venkatraman, K., Bolan, N., Ashwath, N., Choppala, G., Naidu, R. 2014. Phytocapping: An Alternative Technology For The Sustainable Management Of Landfill Sites. *Critical Reviews In Environmental Science And Technology*. 44: 561-637.

[10] Fred, L. And Jones L. 2004.Superfund Site Remediation By Landfilling—Overview Of Landfill Design, Operation, Closure, And Postclosure Issues. *Remediation Journal*. 14(3): 65-91.

[11] Cossu, R. 2010. Technical Evolution Of Landfilling. *Waste Manage*. 30: 947-948.

[12] Campagna, M., Mehmet, C., Yaman, F. & Bestamin, O. 2013. Molecular Weight Distribution Of A Full-Scale Landfill Leachate Treatment By Membrane Bioreactor And Nanofiltration Membrane. *Waste Management*. 33: 866-870.

[13] Guo, Hui-Dong, H. E. Pin-Jing, Shao, Li-Ming, L. I. Guo-Jian. 2004. Removal Of High Concentrated Ammonia Nitrogen From Landfill Leachate By Landfilled Waste Layer. *Journal Of Environmental Sciences*. 16: 5.

[14] Ferrey. 2007. Converting Brownfield Environmental Negatives Into Energy Positives. Boston College Environmental Affairs Law Review. 34.

[15] Tasneem, A., Tauseef, S. M., Abbasi, S. A. 2012. Anaerobic Digestion For Global Warming Control And Energy Generation—An Overview, *Renewable And Sustainable Energy Reviews*. 16: 3228-3242.

[16] Carrington, L. P., Diaz, A. 2011. An Investigation Into The Effect Of Soil And Vegetation On The Successful Creation Of A Hay Meadow On A Clay-Capped Landfill. *Restor. Ecol*. 19: 93-100.

[17] Bolan, N. S., Park, J. E., Robinson, B., Naidu, R., Huh, K. Y. 2011. Phytostabilization: A Green Approach To Contaminant Containment. *Adv. Agron.* 112: 145-204.

[18] Chong, T. L., Matsufuji, Y., Hassan, M. N. 2005. Implementation Of The Semi-Aerobic Landfill System (Fukuoka Method) In Developing Countries: A Malaysia Cost Analysis. *Waste Management*. 25: 702-711.

[19] Ghazali, M. A. Z., Sapari, N., Olisa, E., Jusoh, H. 2015. Landfill Gas Detection In Leachate Pipe: A Consideration For Design Improvement Of Leachate Piping And Gas Venting System. *Applied Mechanics And Materials*. 699: 607-612.

[20] Kwon-Rae K., Gary O. 2010. Potential For Enhanced Phytoremediation Of Landfills Using Biosolids – A Review. *Journal Of Environmental Management*. 91: 791-797.

[21] Kim, K-R., Owens, G. 2010. Potential For Enhanced Phytoremediation Of Landfills Using Bio-Solids – A Review. *Journal Of Environmental Management*. 91(4): 791-797.

[22] Carrington, L. P., Diaz, A. 2011. An Investigation Into The Effect Of Soil And Vegetation On The Successful Creation Of A Hay Meadow On A Clay-Capped Landfill. *Restor. Ecol.* 19: 93-100.

[23] Pérez-Esteban, J., Escolástico, C., Moliner, A., Masaguer, A., Ruiz-Fernández, J. 2014. Phytostabilization Of Metals In Mine Soils Using Brassica Juncea In Combination With Organic Amendments. *Plant Soil.* 377: 97-109.

[24] Jing, W., Fang-Fang, X., Yun Bai., Cheng-Ran, F., Dong-Sheng, S., Ruo, H. 2011. Methane Oxidation In Landfill Waste Biocover Soil: Kinetics And Sensitivity To Ambient Conditions. *Waste Management*. 31: 864-870.

[25] Islam, T., Jensen, S., Reigstad, L.J., Larsen, O., Birkeland, N. K. 2008. Methane Oxidation At 55ºc And Ph 2 By A Thermoacidophilic Bacterium Belonging To The Verrucomicrobia Phylum. *Proc. Natl. Acad. Sci.* 105: 300-304.

[26] Tasneem, A., Tauseef, S. M., Abbasi, S. A. 2012. Anaerobic Digestion For Global Warming Control And Energy Generation—An Overview. *Renewable And Sustainable Energy Reviews*. 16: 3228-3242.

[27] Tasneem, A., Tauseef, S. M., Abbasi, S. A. 2012. Anaerobic Digestion For Global Warming Control And Energy Generation. An Overview, *Renewable And Sustainable Energy Reviews.* 16: 3228-3242.

[28] Daniel, N. Maria, C. Z. 2012. Anaerobic Digestion Of Extruded OFMSW. *Bioresource Technology*. 104: 44-50.

[29] Raffaello, C. Tiziana, L. 2012. Washing Of Waste Prior To Landfilling. *Waste Management*. 32: 869-878.

[30] Raffaello, C., Tiziana, L., Kostyantyn, P. 2012. Waste Washing Pre-Treatment Of Municipal And Special Waste. *Journal Of Hazardous Materials*. 207-208: 65-72.

[31] Lim, J. W., Wang, J. Y. 2013. 2012. Enhanced Hydrolysis And Methane Yield By Applying Microaeration Pretreatment To The Anaerobic Co-Digestion Of Brown Water And Food Waste Wastemanagement. Http://Dx.Doi.Org/10.1016/J.Wasman.11.013.

[32] Alessandra C., Vincenzo B. 2013. Sonolysis And Ozonation As Pretreatment For Anaerobic Digestion Of Solid Organic Waste. *Ultrasonics Sonochemistry*. 20: 931-936.

[33] Martín-González L., Colturato L. F., Font X., Vicent T. 2010. Anaerobic Co-Digestion Of The Organic Fraction Of Municipal Solid Waste With FOG Waste From A Sewage Treatment Plant: Recovering A Wasted Methane Potential And Enhancing The Biogas Yield. *Waste Management*. 30: 1854-1859.

[34] Mali, S. T., Khare, K. C., Biradar A. H. 2012. Enhancement Of Methane Production And Bio-Stabilisation Of Municipal Solid Waste In Anaerobic Bioreactor Landfill. *Bioresource Technology*. 110: 10-17.

[35] Cunsheng, Z., Gang, X., Liyu, P., Haijia, S., Tianwei, T. 2013. The Anaerobic Co-Digestion Of Food Waste And Cattle Manure. *Bioresource Technology*. 129: 170-176.

[36] Zhang, Y., Banks, C. J. Impact Of Different Particle Size Distributions On Anaerobic Digestion Of The Organic Fraction Of Municipal Solid Waste.