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Research Article

Methane Recovery Technologies from Landfills for Energy Generation and Leachate Reduction-an Overview

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Abstract: The literature has been critically reviewed in order to assess the current various techniques applied in controlling landfill gas emission and leachate generation in landfills, while also taking into cognizance the methods applied in generating energy from biomass and the energy generation potency from landfills. Landfills serve as a simple and very economic means of disposing solid waste, but they also have negative impact on the environment, which includes the emission of Greenhouse Gases (GHG) such as methane (CH_4) and carbon dioxide (CO_2) and leachate generation. Various technologies have been employed to enhance the quality of emissions from landfills in order to reduce the environmental as well as the social impact caused by landfills. There has been an increased practice of revegetation on landfill sites in order to enhance environmental sustainability and in turn trees further serve as sources of biomass used for energy generation. This study presents a review of the various techniques applied in controlling landfill gas emission and leachate generation in landfills, taking also into cognizance the methods applied in generating energy from biomass and the energy generation potency from landfills. Phytocapping, phytostabilization, anaerobic digestion, pretreatment of solid wastes and waste co-digestion are other technologies that have been used to enhance the recovery of biogas from solid wastes.

Keywords: Biomass, greenhouse gas emission, phytocapping, revegetation, solid waste

INTRODUCTION

Landfill disposal of solid waste is a very common practice in many cities around the world. The constant increase in population, Growth in social civilization, changes in habit in terms of productivity and consumption, increasingly affluent lifestyles and resources use, continued industrial development, has been accompanied by the rapid generation of municipal and industrial solid wastes, which create the adamant absurdity around the world (Anwar *et al*., 2012). Table 1 highlights the current data of waste generation as well as projected amount of solid waste to be generated by 2015.

Landfills have great impact on climate change, they generate carbon dioxide (CO2) and methane (CH4) which are greenhouse gases (GHG) contributing to global warming along with several other gaseous components. These gases are by-products of anaerobic decomposition of organic waste, a process which converts organic waste biologically in the absence of oxygen (Renou *et al*., 2008). CH_4 and CO_2 being the major Landfill Gases (LFG) have relative amounts of 40-45% and 55-60% by volume, respectively (Raco *et al*., 2010) although some authors put the values at 50-60% and 30-40% by volume (Wang-Yao *et al*., 2006). The Potential of CH_4 as a greenhouse gas is 21 times higher than CO_2 in terms of its potential to cause global warming (Ayalon and Avnimelech, 2009). Several factors influence methane generation in landfills. They include; composition of the waste and availability of readily biodegradable organic matter, the age of the waste, moisture content, pH and temperature (Machado *et al*., 2009). The processes that lead to the formation of landfill gas are bacterial decomposition, volatilization and chemical reactions (ATSDR, 2001).

Conventionally, landfill gases are collected from the solid waste layers, where only about 40-60% (V/V) of the total landfill gas generated can be collected due to escape of gases from landfill surfaces and leachate collection pipes (Spokas *et al*., 2006). Organic matters in landfill start 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 is involved in ozone depletion and climate change (Lamb *et al*., 2014).

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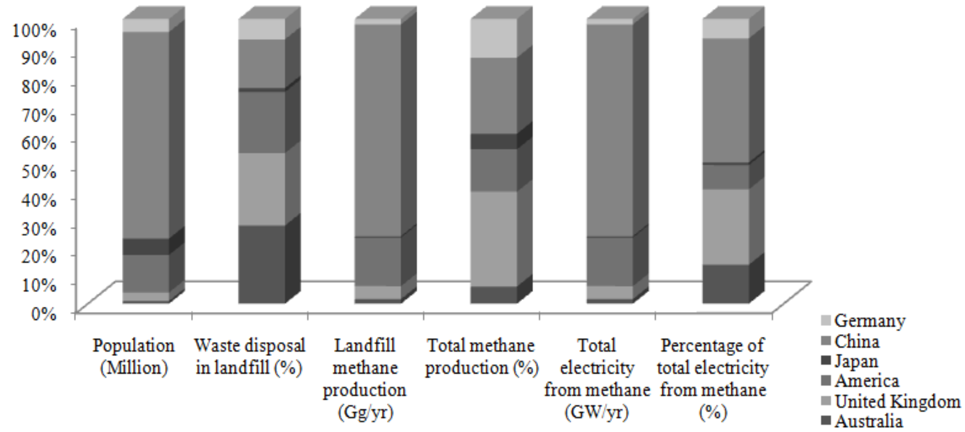

Fig. 1: Potential of methane production and electricity from landfills in various countries

Table 1: Projected solid waste generation around the regions of the (World Bank, 2012)

		Current available data		Projections for 2025			
		Urban waste generation		Projected population		Projected urban waste	
Region	Total urban population (millions)	Per Capita (kg/capita/day)	Total (Tons/day)	Total population (millions)	Urban population (millions)	Per Capita (kg/capita/day)	Total (tons/day)
AFR	260	0.65	169, 119	1, 152	518	0.85	441, 8400
EAP	777	0.95	738, 958	2, 124	1,229	1.5	1, 865, 379
ECA	227	1.1	254, 389	339	239	1.5	354, 810
LAC	399	1.1	437, 545	681	466	1.6	728, 392
MENA	162	1.1	173, 545	379	257	1.43	369, 320
OECD	729	2.2	1, 566, 252	1031	842	2.1	1,742, 417
SAR	426	0.45	192, 41	1938	734	0.77	567, 545
Total	2, 980	1.2	3, 532, 252	7644	4285	1.4	6, 069, 703

AFR-Africa, EAP-East Asia and Pacific, ECA: East Central Asia; LAC-Latin America and Caribbean, MENA-Middle East and North Africa, OECD-Organization for Economic Co-operation and development, SAR-South Asia

During the process of municipal solid waste degradation by anaerobic systems, various phases such as hydrolysis, acidogenesis, acetogenesis and methanogenesis are observed. As the methanogenic phase approaches, a large fraction of the digested organic matter of the waste are converted into gas with less amount of liquid produced, hence making more biogas available for energy production and less cost and energy used for leachate treatment (Iglesias *et al*., 2000; Daniel and Maria, 2012).

In most of the EU countries and in America, the energy potential from landfill gas as an alternative source of energy has been greatly utilized (Eleni *et al*., 2012). Figure 1 shows some countries that have greatly harnessed the energy potential from landfill gas.

Bolan *et al*. (2013) Sustainable landfilling has become one of the main concerns of modern waste management concepts (Cossu, 2010), especially when considering the technology for controlling both gaseous and leachate emissions and addressing issues on climate change. Leachate contains a large amount of organic and inorganic compounds and their concentrations depend on the type of waste, landfill environment, filling technique and age of the landfill site (Campagna *et al*., 2013). If leachate is not properly controlled it may enter underlying groundwater thus causing a serious groundwater pollution. The environmental impact of a landfill by leachate percolation may occur over a long period of time, possibly up to 20 years (Hussein *et al*., 2008). It is therefore necessary that landfill leachate be managed properly so that it does not become a threat to the future of our environment.

Current practice of solid waste disposal in a landfill involves placement of solid waste layer on a plastic liner to prevent leachate flow into groundwater. Accumulated leachate above the liner is channeled into a leachate collection/stabilization pond through a leachate collection pipe. This leachate is commonly very concentrated with organic pollutant having COD up to 40000 mg/L (Guo *et al*., 2004). Thus the collection pond often becomes anaerobic and producing methane gas that escapes to the environment thus contributing to global warming problems (Ferrey, 2007). Methane is generated in landfills and open dumps as biodegradable component of the waste contained in them decomposes under anaerobic conditions (Tasneem *et al*., 2012). This review, therefore, focuses on the various current methods through which energy has been recovered from landfills in form of enhanced collection of the greenhouse gases it generates. Techniques for the mitigation of leachate generation in landfills, were also highlighted and examined.

METHODOLOGY

Current trends in landfill operations: Recent development in landfill operations have moved towards aerobic or semi-aerobic methods, where air either naturally diffuses or is injected into the decomposing wastes (Aziz *et al*., 2010). Usually semi-anaerobic landfills consist of a large diameter main pipe that is joined with other small diameter pipes at the bottom for leachate collection so that air moves easily into the waste matrix through the main pipes with large openings (Threedeach *et al*., 2012). Leachate from semi-anaerobic landfills still contains high concentration of organic materials that can be converted into methane (Aziz *et al*., 2010). This gas can be recovered for green energy through a proper gas piping system design. However because large quantity of the degradable organic materials are removed together with leachate into the leachate pond, the gas collection from the existing gas pipe is not optimum. More gas can be generated by the landfill if the organic material in the leachate can be further broken down into methane gas at the bottom of the landfill before it is discharged into the leachate collection pond.

Environmental issues from landfills: Several environmental concerns have been raised over the years from the use of landfill as means of solid waste disposal. During degradation of solid wastes in landfills, gases such as CH_4, CO_2, nitrogen (N_2, N_2O) and sulfur (SO_2 and H_2S) and a range of other trace gases are generated, with CH_4 being the most dominant gas in landfill sites produced through microbial methanogenic process involving *methanobacterium* (Penza *et al*., 2010).

Gas generated and emitted from landfills have led to an upsurge in greenhouse gas emissions globally, hence the waste sector is considered as a significant contributor to greenhouse gas emissions, emitting about 5% of global greenhouse gas budget (Lou and Nair, 2009) (Table 1). The following expression has been used by Salomon and Silva (2009) to estimate the total quantity of CH_4 production potential (MPP) by anaerobic degradation of organic residues from landfill sites Eq. (1):

$$MPP_{landfills} = Pop_{urb} + rateRSU \; x RSUf x \; FCMx \; CODx \; CODFx \; Fx \; 16/12 \quad (1)$$

where,

- Pop_{urb} = Urban population (inhabitants)
- rate RSU = Rate of urban residue generation (kg RSU/yr/person)
- RSUf = Fraction of urban solid waste disposed in landfills (%)
- FCM = CH_4 correction factor (%)
- COD = Degradable organic carbon in urban solid waste (gC/g RSU)
- CODF = Fraction of COD that is actually degraded (%)
- F = Fraction of CH_4 in the landfill gas (%)

16/12 C to CH_4 conversion factor. 788 Gg CH_4 emissions from landfill sites in Brazil which represents about 4.59% of the total CH_4 production was estimated. This expression has been applied to other countries and CH_4 production was found to be in the range of 0.12 Gg in Switzerland to 3801 Gg in China (Table 1). The value indicates that CH_4 emission from landfill sites makes a major contribution to the total Green House Gas emission.

Leachate contains a variety of chemical compounds derived from the solubilization of the materials deposited in the landfill and from the products of the chemical and biochemical reactions occurring within the landfill (Tchobanoglous *et al*., 1993). A wide range of contaminants, such as dissolved gases, heavy metals and xenobiotic compounds are mainly constituents of landfill leachates (Kulikowska and Klimiuk, 2008).

During reduction condition in landfills, SO_4^{2-} reduces to sulfide species and thereby limits the solubility of heavy metals by forming insoluble metal sulfide minerals such as ZnS, CuS, PbS) (Barrett and Mcbride, 2007) also, many studies have indicated the possibility for arsenic (As) and chromium (Cr) to be present in landfill leachate and aquifers impacted by leachate and because of the composition of landfill waste streams, a lot of organic pollutants have been observed in landfill leachates as well as in associated groundwater, some of the most prevalent organic pollutants in landfill leachates include pesticides, BTEX (Benzene, Toluene, ethyl benzenes and Xylenes), chlorinated aliphatic hydrocarbons and chlorinated benzene compounds (Slack *et al*., 2005). More so, a range of emerging compounds including flame retardants, pharmaceutical and perfluronated compounds and nanomaterial's has been reported at very high concentrations in landfill leachate and associated groundwater (Scheutz and Kjeldsen, 2005).

DISCUSSION

Benefits of landfill operation:

Electricity generation from methane gas: In years past CH_4 from landfills have been collected, recovered and utilized for several purposes such as electricity generation and as a direct source of fuel. Methane recovery, although an expensive technology, is being implemented and adopted in many countries (Table 2).

Landfill gas collection and recovery system's practicability is greatly dependent on the type of gases and the amount of CH_4 emitted by the landfill. In developed countries like in the USA, there has been a dramatic increase in the number of landfill gas to energy projects. In 1999, there were only 300 operational landfill gas to energy facilities which later increased in 2010 to 555 of such facilities generating

Table 2: Potential estimated quantities of methane and electricity production from landfills in various countries (Lamb *et al*., 2014)

Region	Country	Population (million)	Waste disposal from landfills (%)	Landfill methane production (Gg/yr)[a]	Total methane production (%)	Total electricity from methane (GWh/yr)[b]	Percentage of total electricity from methane (%)
Oceania	Australia	17.46	69	81.92	1.35	405	0.16
	NewZealand	3.519	84	20.06	1.53	99	0.23
America	USA	238.7	54	872.3	3.34	4314	0.10
Europe	Mexico	107.8	96	696.5	11.4	3445	1.32
	Brazil	137.9	85	788.8	4.59	3901	0.84
	UK	54.02	64	233.7	7.46	1156	0.31
	Switzerland	3.563	0.5	0.12	0.05	1	0.0009
	Poland	38.16	92	236.7	7.10	1171	0.77
	Greece	11.02	91	67.49	19.4	334	0.54
	France	63.00	36	152.6	4.15	755	0.14
	Norway	4.591	26	8.00	1.00	40	0.03
	Germany	82.51	18	98.27	3.04	486	0.08
	Belgium	10.37	12	8.10	1.60	40	0.04
	Austria	8.171	6.8	3.30	0.81	16	0.02
	Denmark	5.390	5.1	1.85	0.51	9	0.03
	Sweden	9.029	4.8	2.92	0.54	14	0.01
Asia	Japan	103.9	3.4	23.77	1.22	118	0.01
	South Korea	38.70	36	94.78	6.23	469	0.11
	Turkey	67.23	98	442.4	14.4	2188	1.12
	India	1080	15	1090	3.92	5392	0.60
	China	1313	43	3801	5.99	18801	0.51

[a]Eq. (1): (Salomon and Silva, 2009); [b]Electricity from methane (GWh/yr) = landfill methane produced [a](Gg/yr) * (100/20.22) (GWh/Gg)

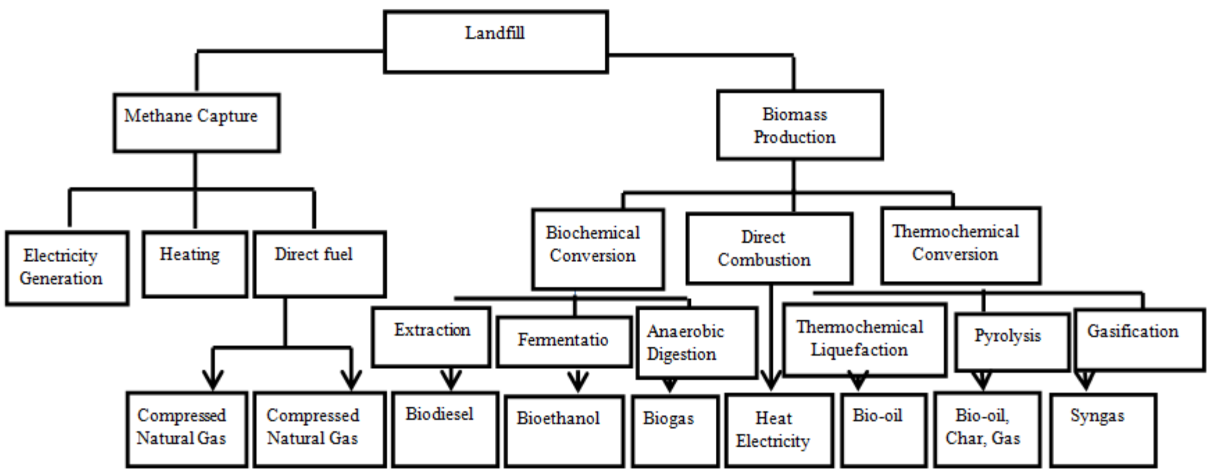

Fig. 2: General routes of conversion of biomass and landfill wastes into fuels and products (Bolan *et al*., 2011)

electricity estimated at 14 TWh (USEPA, 2011). Table 2 gives the potential amount of electricity produced from CH_4 emission from landfill sites. The data suggests that if all the CH_4 from landfill sites is harvested it could be a considerable source of electricity.

Energy from biomass: Bridgewater has defined biomass as any source of renewable fixed carbon emanating from wood, wood residues, agricultural plants and their residues, industrial and municipal wastes are also considered as biomass for their high percentage output of food waste and fiber (Bridgwater, 2012). Biomass is produced in landfill sites and can be used in many ways including energy and bio-char production. If the landfill sites are properly managed for the production of biomass, it will have both economic potentialities as well as environmental benefits.

WAYS OF SOLID WASTE TRANSFORMATION

There exist several methods and processes for the management and transformation of solid wastes. Solid waste at landfills can be transformed into fuels and carbon-based products mechanically, biologically or thermochemically (Fig. 2). Thermochemical methods for transformation of biomass or solid waste are more attractive and have quite a number of advantages which include; high productivity, complete utilization of feed stocks leading to the generation of multiple products, its applicability to a wide variety of feed stocks, independent of climatic conditions and better control over the process as compared to biological processes (Verma *et al*., 2012) also, some of these technologies can be mounted in- situ on landfill sites to produce bioenergy. The various thermochemical transformation processes, such as pyrolysis, liquefaction and gasification are applicable for conversion of both biomass with low moisture (pyrolysis and gasification) and high moisture contents (liquefaction). These systems have their own considerations, one of which is the requirement of particle size uniformity before the biomass is fed into the reactors; hence some type of blending, grinding and pelletizing is done. In the case of dry gasification systems, uniform particle size is important to the peak temperature propagation rates; smaller particles have a larger surface per unit volume thereby leading to faster burnout and an increase in reactor temperature, more so, much energy is needed to operate reactor plants, as well as very high temperatures are reached for complete burn out of biomass.

Over the years, different countries have adopted various methods of waste disposal for various reasons, reasons which may be attributed to the amount and type of waste generated, waste collection method, availability of land mass and environmental regulations practiced. In very large countries like Australia with low population density, landfill is the most commonly used method of disposal of solid wastes; whereas in Japan, incineration (thermal conversion method) is mostly employed for waste disposal, because of lack of space in country with land scarcity (Bolan *et al*., 2013). Interestingly, in many developed countries, high tax rates have been imposed on landfilling thereby discouraging landfill waste disposal and hence encouraging alternative waste management practices such as recycling of waste become more attractive, especially in the EU countries such as Switzerland, Germany, the Netherlands, Sweden, Austria, Denmark and Belgium landfill disposal below 5% in the year 2009 have been reported due to higher landfill taxes imposed on disposal by landfilling (Eurostat, 2012). Although there has been a significant increase in the reduction, reuse and recycling of solid waste, but still disposal to landfill unavoidably remains the most widely used waste management method (OECD, 2012).

LANDFILL GAS EMISSION ANDLEACHATE REDUCTION

Use of vegetation to enhance environmental sustainability: The fundamental reason for landfill design and management is to contain solid waste materials and reduce gaseous emissions into the environment as contaminants; hence landfill covers are used to reduce water percolation, thereby assuaging groundwater contamination due to the risk of leachate production. Conventionally, landfill covers are designed to minimize percolation and infiltration through the addition of layers with low permeability (e.g., compacted clay caps and geo-synthetic liners) however this is often not achieved as a result of cracks being formed as landfills age due to drying and wetting cycles associated with seasonal changes in rainfall and temperature. 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 degradation of the barrier layers and also to enhance water storage in the soil and evapotranspiration from the vegetation (Lamb *et al*., 2014). Caps are often vegetated by laying down topsoil as rooting substrate and sowing grass seeds i.e., phytocapping. Even though the fundamental management objective is to grow vegetation cover in order to enhance evapotranspiration and assuage cap exposure, high yielding crop species may be established as well. Increasingly, phytocaps are being considered for use at a range of waste disposal sites in many countries especially in the west and America.

The process of phytocapping involves transpiration and root growth that immobilizes pollutants by reducing leaching, controlling erosion, creating an aerobic environment in the root-zone of the plant and adding organic matter to the substrate that binds the pollutant. 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 (Carrington and Diaz, 2011).

Phytostabilization is another revegetation technology which is also employed to provide cover to plants on the surface of contaminated landfill sites with the aim of reducing the mobility of pollutants within the vadose zone through accumulation by roots or immobilization within the rhizosphere, thereby reducing offsite contamination (Bolan *et al*., 2011).

Phytocapping and phytostabilization are very promising technologies or methods through which surface emissions of biogas from landfills can be efficiently and greatly reduced, but these above highlighted technologies have not provided suitable means that will care for the gaseous emissions from the leachate that eventually percolates through the landfill.

Use of novel bio-cover to enhance methane oxidation: A prospective or alternative means for CH_4 control or mitigation is to enhance the methane oxidation rate through a special design which provides a favourable environment for methanotrophic activity to occur in landfill cover (Perdikea *et al*., 2008). Conventionally, clay and soil are being used as landfill cover materials, some manmade and biological covers have also been applied as alternative landfill covers, such as agricultural soil, horticulture soil, compost, sand, peat and mechanical biological treatment residue. But the application of some more cost-effective bio-cover materials is encouraged especially obtaining them directly from landfills and aged refuses might be one of such promising alternative materials used for the control of CH_4 emissions. Lou *et al*. (2011) described aged refuses as the residues of the disposal materials which include; municipal solid waste and sewage sludge in landfills (Lou *et al*., 2011). Aged refuses consist of the macro, micro-nutrients as well as abundant microorganisms and lots of humus. Methanotrophs which are the bacteria responsible for methane oxidation are usually accumulated significantly in aged refuses in the long-term stabilization process hence could be applied as contributory materials for landfill bio-cover. The use of aged refuse as landfill bio-cover could serve a dual purpose, which firstly mitigates methane gas emission from landfills and also preserves the void space and increases the landfill life meanwhile. Lou *et al*. 2011) examined a novel bio-cover technology where aged refuses from landfill was used and the optimum bio-cover composition, the types of aged refuses and the operation parameters (i.e., the moisture, organic matter content and Eh values) were proposed in the end (Lou *et al*., 2011).

The novel simulated bio-cover was developed to improve the biological methane oxidation process using both aged refuse and aged sludge from landfill. He observed that 78.7 and 66.9% of CH_4 could be removed using both processes respectively, with the aged refuse: aged sludge (w/w %) ratio 7:3 and 6:4 in bio-cover system accordingly. The optimum CH_4 removal rate could attain 100% if the aged refuse with the disposal time of more than 14 years were applied in bio-cover. Some controlled factors for the methanotrophic activity, i.e., moisture, Eh and organic matter content, were also investigated. The CH_4 oxidation rate increases greatly when the moisture content and organic matter were increased respectively. The optimum conditions for bio-cover system were found to be as follow: aged refuse: aged sludge ratio of 7:3, the moisture content of 8-9%, Eh of 104-108 mV and organic matter of 9.5%.

As in the case of phytocapping and phytostabilization, the application or use of bio-cover in landfills is also very efficient as seen from previous studies, but it also have its draw backs and inadequacies, especially as touching leachate generation and discharge in landfill sites.

Anaerobic digestion of the OFMSW: The organic fraction of municipal solid wastes can be digested an aerobically in order to satisfy the European Parliament's directive on solid waste (EUROPA, 2006). Anaerobic digestion process has been adopted by many European countries for many years yielding good results (Daniel and Maria, 2012). It is a process in which the solid wastes are stabilized through biological activities in a bioreactor in the absence of air, which eventually results in the generation of methane (CH_4), carbon dioxide (CO_2) and other trace gases commonly referred to as biogas (Tasneem *et al*., 2012). The fermentation results in the breakdown of complex biodegradable organics in a four phase process include:

- Large protein macromolecules, fats and carbohydrate polymers (such as cellulose and starch) are broken into water soluble monomers (amino acids, long-chain fatty acids and sugars). This is brought about by exo-enzymes (hydrolase) found in facultative and obligatory anaerobic bacteria.
- These products are then fermented during acidogenesis to form short-chain (C1-C5) 'volatile fatty acids', mainly lactic, propionic, butyric and valeric acid.
- In acetogenesis, homoacetogenic microorganisms consume these fermentation products and generate acetic acid, carbon dioxide and hydrogen.
- Methanogenic organisms, which are strictly anaerobic, consume the acetate, hydrogen and some of the carbon dioxide to produce methane.

Theoretically, methane formation follows an exponential equation:

$$VB = C1\ (1-e^{-C2tB}) \quad (1)$$

where,

VB = The biogas yield (m^3/d)
tB = The residence time in the bioreactor (d)
C1 and C2 = Constants (Tasneem *et al*., 2012)

Anaerobic digestion is a self-driven process by nature; hence the optimization of several parameters and conditions associated both directly and indirectly with the performance of the reactor is essential in order to achieve good waste management yielding high volume of biogas.

Some of the sensitive aspects which have to be considered for a successful operation of an anaerobic digestion process for obtaining biogas are highlighted below:

- Specific surface of the substrate
- C/N ratio
- Dilution
- Temperature
- Ph
- Loading rate
- Retention time
- Toxicity
- Mixing/Agitation
- Pathogens
- Light
- Solid residue/Slurry (Tasneem *et al*., 2012)

Direct landfilling of municipal solid waste is known to cause lasting negative impacts on the environment such as the consequential emissions to the atmosphere, the risk experienced in landfill stability and unavailability of land. Since landfill is regarded as an integral part of solid waste management, it is observed that waste treatment prior to landfilling is imperative as it significantly enhances waste stabilization and reduces the emissions. In this regard, biological pre-treatment of waste like anaerobic digestion is an attractive method especially in Asian countries because of its suitable waste characteristics (Nguyen *et al*., 2007).

There exist several other methods of pre-treating wastes before they are either disposed into landfills or digested an aerobically. Mechanical-Biological Treatment (MBT) has been recently considered as an alternative to residual municipal solid waste incineration, basically because of its wider positive public acceptance. In many developed countries, especially in Europe this has become a very well accepted technology, for example, currently in France, six full-scale plants are already in operation with numerous other projects are under development. MBT aims to reduce biogas and leachate generation, minimize odors during the waste deposal operations, reduce landfill settlement and reduce the duration of the landfill site aftercare; MBT is also be considered as a pre-treatment technology employed to improve the beginning of biogas production. MBT of residual MSW include:

- Mechanical pre-processing stages to sort out recyclable materials such as paper, metals and plastics
- Biological stages to reduce and stabilize the biodegradable organic materials under controlled anaerobic and/or aerobic conditions (Bayard *et al*., 2010).

The pressure extrusion method/technology is another form of pre-treatment method for municipal solid waste, it is a mechanical process that is recently employed in waste treatment plants in waste handling 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 undesired materials from the flow of the organic fraction of municipal solid waste and at the same time, simplifies its degradation when treated in anaerobic conditions (Daniel and Maria, 2012).

Several other pre-treatment methods have been carried out on solid waste prior to landfilling. Integration of these various methods into the manner with which various forms of the organic fraction of municipal waste were handled, have shown very positive impact in the system, in terms of reduction in generation and emission of both leachate and biogas. Some of such technologies implemented include; washing of the wastes, which indicates a feasible pre-treatment method focused on controlling the leachable fraction of residues and relevant impact (Raffaello and Tiziana, 2012; Raffaello *et al*., 2012), micro-aeration pre-treatment are used basically to enhance hydrolysis of anaerobic digestion (Lim and Wang, 2013), sonolysis and ozonation have been shown by previous research, to have greatly affected the solubilization of organic solid waste thus improving anaerobic digestion yield (Alessandra and Vincenzo, 2013).

Despite the various options that have been proposed for the handling of food waste, which includes; incineration, composting, the use of Food Waste Disposal units (FWDs) and anaerobic digestion; anaerobic digestion has enchanted more interest, especially in policy making, because of its potential for energy production. However, food waste is highly variable as a result of factors such as; its source and because its composition might vary significantly from one location to another, which can bea factor militating against to its successful and efficient digestion, Eleni *et al*. (2012), suggested an approach which aims to overcome the limitation by using food waste as a co-substrate in sewage sludge digestion, a process known as co-digestion. Co-digestion involves the digestion of two substrates together as a way to improve digestion efficiency and increase the energy output.

Fat, oil and grease waste from Sewage Treatment Plants (STP-FOGW) have been reported to be commonly disposed of in landfill, co-digestion of the Organic Fraction of Municipal Solid Waste (OFMSW) enhances the valorization of STP-FOGW which results in a higher biogas yield throughout anaerobic digestion process, especially since lipid rich wastes have been observed to be valuable substrate for anaerobic digestion because of their high theoretical methane potential, hence in Martín-González *et al*. (2010) study, STP-FOGW was evaluated as a co-substrate in wet anaerobic digestion of OFMSW under mesophilic conditions (37°C) and batch experiments carried out at different co-digestion ratios showed an improvement in methane production related to STP-FOGW addition.

Study on the effect of the combination of various operational parameters on the decomposition of Municipal Solid Waste (MSW) in a simulated anaerobic bioreactor landfill was carried out, the parameters considered were aeration with addition of aerobic microbial culture, mixing of gravel, sludge addition, intermediate soil cover and variation in leachate recirculation rate, as against the usual practice of combining two or three parameters in a reactor. The study showed that there was increase in the production of methane gas by 25% (Mali *et al*., 2012).

Anaerobic co-digestion of food waste and cattle manure has also been shown to have enhanced the biogas production and the methane yield in the Organic Fraction of Municipal Solid Waste (OFMSW) (Zhang *et al*., 2013).

Research has indicated that, the particle size of organic waste in an anaerobic digester does not change the specific biogas yield, but does affect the performance of the digester (Zhang and Banks, 2012).

Apart from landfill disposal, Home Composting systems (HC) can be used to recycle municipal organic waste and hence resulting in reducing, collection, transportation and treatment costs and energies. Nevertheless, HC configurations must limit gaseous emissions to levels comparable to other treatment methods (Bijaya *et al*., 2013).

Leachate can be collected from solid waste via the use of wells or drains and collected leachate can then either be treated and disposed of or reintroduced into the landfill through an artificial recharge system, a process usually referred to as leachate recirculation, which may be employed in order to optimize gas production as it enhances the decomposition of the waste by raising the water content and transportation of bacteria, nutrients and potentially inhibitory waste products, it can also serve as a means used to manage the load on a leachate treatment plant due to the fact that recirculation results in the storage of leachate within the landfill in comparison with fully drained down conditions. The re-introduction or recirculation of leachate back into the waste plays an important role in landfill management also (White *et al*., 2011).

One of the most revolutionary and applauded methods of leachate treatment is the reintroduction of high strength leachate back to the landfill, by reintroducing or recirculating the leachate, the organic component of the leachatecan be reduced by the active biological communities within the refuse mass (Sinan *et al*., 2007), therefore leachate recirculation increases the moisture content in a controlled reactor system and enhances the transportation of nutrients and enzymes between methanogens (Haleh *et al*., 2012).

CONCLUSION

Recently, there has been an upsurge in the number of factories and processing industries operational around the globe. This expansion in turn, results in an overwhelming generation of solid waste. Predictions for years ahead are indicative of an increasing trend in solid waste generation and subsequently in leachate infiltration into groundwater. Today, the increasing discrepancy and finite success of landfill gas recovery and reduction of leachate generation in field practices have raised concerns over the use of the conventional recovery of landfill gas through vents and wide diameter pipes used for leachate collection in semi-aerobic landfill, especially as research has shown that landfill gas escapes into the environment through the collection pipes. Although various limitations and challenges are associated with most of the methods applied in gas recovery from landfills, a widespread and huge progress in this area is anticipated in the future.

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REFERENCES

Alessandra, C. and B. Vincenzo, 2013. Sonolysis and ozonation as pretreatment for anaerobic digestion of solid organic waste. Ultrason. Sonochem., 20: 931-936.

Anwar, J., I.A. Saeed, H. Haslenda, A. Habib and R. Mat, 2012. Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. Renew. Sust. Energ. Rev., 16(5): 2907-2912.

ATSDR, 2001. Landfill Gas Primer: An Overview for Environmental Health Professionals. Department of Health and Human Services Agency for Toxic Substances and Disease Registry Division of Health Assessment and Consultation, Atlanta, GA.

Ayalon, O. and Y. Avnimelech, 2009. Solid waste treatment as a high priority and low-cost alternative for greenhouse gas mitigation. Environ. Manage., 27(5): 697-704.

Aziz, S.Q., H.A. Aziz, M.S. Yusoff, M.J. Bashir and M. Umar, 2010. Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study. J. Environ. Manage., 91: 2608-2614.

Barrett, K. and M. Mcbride, 2007. Dissolution of zinc-cadmium sulfide solid solutions in aerated aqueous suspension. Soil Sci. Soc. Am. J., 71: 322-328.

Bayard, R., J. de Araújo Morais, G. Ducom, F. Achour, M. Rouez and R. Gourdon, 2010. Assessment of the effectiveness of an industrial unit of mechanical-biological treatment of municipal solid waste. J. Hazard. Mater., 175(1-3): 23-32.

Bijaya, K.A., T. Anne, B. Suzelle, M. José and D. Mylène, 2013. Gas emissions as influenced by home composting system Configuration. J. Environ. Manage., 116: 163-171.

Bolan, N.S., J.H. Park, B. Robinson, R. Naidu, K.Y. Huh, 2011. Phytostabilization: A green approach to contaminant containment. Adv. Agron., 112: 145-204.

Bolan, N.S., R. Thangarajan, B. Seshadri, U. Jena, K.C. Das *et al*., 2013. Landfills as a biorefinery to produce biomass and capture biogas. Bioresource Technol., 35: 578-587.

Bridgwater, A., 2012. Review of fast pyrolysis of biomass and product upgrading. Biomass. Bioenerg., 38: 68-94.

Campagna, M., C. Mehmet, F. Yaman and O. Bestamin, 2013. Molecular weight distribution of a full-scale landfill leachate treatment by membrane bioreactor and nanofiltration membrane. Waste Manage., 33: 866-870.

Carrington, L. and A. Diaz, 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.

Cossu, R., 2010. Technical evolution of landfilling. Waste Manage., 30: 947-948.

Daniel, N. and C. Maria, 2012. Anaerobic digestion of extruded OFMSW. Bioresource Technol., 104: 44-50.

Eleni, I., O. Dieudonné-Guy and V. Nikolaos, 2012. Food waste co-digestion with sewage sludge-Realising its potential in the UK. J. Environ. Manage., 112: 267-274.

EUROPA, 2006. Directive 2006/12/EC of the European Parliament and Council on Waste. EU Law and Publications, Europe.

Eurostat, 2012. Municipal Waste Metadata. [Online] Retrieved from: http://appsso.eurostat.ec.europa.eu/nui/show.do?Dataset=env_wasmunandlang=en. (Accessed on: August 20, 2012)

Ferrey, S., 2007. Converting brownfield environmental negatives into energy positives. Boston College Environ. Affairs Law Rev., 34(3): 417.

Guo, H., P. He, L. Shao and G. Li, 2004. Removal of high concentrated ammonia nitrogen from landfill leachate by landfilled waste layer. J. Environ. Sci., 16: 5.

Haleh, S., W. Mostafa, H. Mohamed and J. Kevin, 2012. Effect of leachate recirculation on mesophilic anaerobic digestion of food waste. Waste Manage., 32: 400-403.

Hussein, T.M., O.A. Loni and A.M. Alrehaili, 2008. Geo-environmental assessment of a landfill site southeast of Riyadh, Saudi Arabia. Proceeding of the 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum. Riyadh, Saudi Arabia.

Iglesias, R.J., C.L. Pelaz, M.E. Maison and S. Andres, 2000. Biomethanation of municipal solid waste in a pilot plant. Water Res., 34(2): 447-454.

Kulikowska, D. and E. Klimiuk, 2008. The effect of landfill age on municipal leachate composition. Bioresource Technol., 99: 5981-5985.

Lamb, D.T., K. Venkatraman, N. Bolan, N. Ashwath, G. Choppala *et al*., 2014. Phytocapping: An alternative technology for the sustainable management of landfill sites. Crit. Rev. Environ. Sci. Technol., 44(6): 561-637.

Lim, J. and J. Wang, 2013. Enhanced hydrolysis and methane yield by applying microaeration pretreatment to the anaerobic co-digestion of brown water and food waste. Waste Manage., 33(4): 813-819.

Lou, X. and J. Nair, 2009. The impact of landfilling and composting on greenhouse gas emissions-a review. Bioresource Technol., 100: 3792-3798.

Lou, Z., W. Li and Z. Youcai, 2011. Consuming un-captured methane from landfill using aged refuse bio-cover. Bioresource Technol., 102: 2328-2332.

Machado, S.L., M.F. Carvalho, J.P. Gourc, O.M. Vilar and J.C.F. Do Nascimento, 2009. Methane generation in tropical landfills: Simplified methods and field results. Waste Manage., 29: 153-161.

Mali, S., K. Khare and A. Biradar, 2012. Enhancement of methane production and bio-stabilisation of municipal solid waste in anaerobic bioreactor landfill. Bioresource Technol., 110: 10-17.

Martín-González, L., L. Colturato, X. Font and T. Vicent, 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 Manage., 30: 1854-1859.

Nguyen, P., P. Kuruparan and C. Visvanathan, 2007. Anaerobic digestion of municipal solid waste as a treatment prior to landfill. Bioresource Technol., 98: 380-387.

OECD, 2012. OECD Environmental Data Compendium 2006-2008. [Online] Retrieved from: OECD, (2007) Organization for Economic Cooperation and Development. OECD environmental datahttp://www.oecd.org/dataoecd/22/58/41878186.pdf. (Accessed on: June 18, 2012)

Penza, M., R. Rossi, M. Alvisi and E. Serra, 2010. Metal-modified and vertically aligned carbon nanotube sensors array for landfill gas monitoring applications. Nanotechnology, 21: 105-501.

Perdikea, K., A. Rotra and J. Hettiaratchi, 2008. Study of Thin Bio-Covers (TBC) for oxidizing uncaptured methane emissions in bioreactor landfills. Waste Manage., 28(8): 1364-1374.

Raco, B., R. Battaglini and M. Lelli, 2010. Gas emission into the atmosphere from controlled landfills: An example from Legoli landfill (Tuscany, Italy). Environ. Sci. Pollut. R., 17: 1197-206.

Raffaello, C. and L. Tiziana, 2012. Washing of waste prior to landfilling. Waste Manage., 32: 869-878.

Raffaello, C., L. Tiziana and P. Kostyantyn, 2012. Waste washing pre-treatment of municipal and special waste. J. Hazard. Mater., 207-208: 65-72.

Renou, S., J.G. Givaudan, S. Poulain, F. Dirassouyan and P. Moulin, 2008. Landfill leachate treatment: review and opportunity. J. Hazard. Mater., 150(3): 468-493.

Salomon, K. and L. Silva, 2009. Estimate of the electric energy generating potential for different sources of biogas in Brazil. Biomass Bioenerg., 33(9): 1101-1107.

Scheutz, C. and P. Kjeldsen, 2005. Biodegradation of trace gases in simulated landfill soil cover systems. J. Air Waste. Manage., 55: 878-885.

Sinan, B., D. Ahmet and O. Bestamin, 2007. Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes. J. Hazard. Mater., 143: 177-183.

Slack, R., J. Gronow and N. Voulvoulis, 2005. Household hazardous waste in municipal landfills: Contaminants in leachate. Sci. Total Environ., 337: 119-137.

Spokas, K., J. Bogner, J.P. Chanton, M. Morcet, C. Aran *et al*., 2006. Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? Waste Manage, 26: 516-525.

Tasneem, A., S. Tauseef and S. Abbasi, 2012. Anaerobic digestion for global warming control and energy generation-An overview. Renew. Sust. Energ. Rev., 16: 3228-3242.

Tchobanoglous, G., H. Theisen and S. Vigil, 1993. Integrated Solid Waste Management: Engineering Principles and Management Issues. 2nd Edn., McGraw-Hill, Singapore, pp: 978.

Threedeach, S., W. Chiemchaisri, T. Watanabe, C. Chiemchaisri, R. Honda and K. Yamamoto, 2012. Antibiotic resistance of Escherichia coli in leachates from municipal solid waste landfills: Comparison between semi-aerobic and anaerobic operations. Bioresource Technol., 113: 253-258.

USEPA, 2011. An Overview of Landfill Gas Energy in the United States-Landfill Methane Outreach Program (LMOP). USEPA, Washington, DC.

Verma, M., S. Godbout, S.K. Brar, O. Solomatnikova, S.P. Lemay *et al*., 2012. Biofuels production from biomass by thermochemical conversion technologies. Int. J. Chem. Eng., 2012: 18.

Wang-Yao, K., S. Towprayoon, C. Chiemchaisri, S.H. Gheewala and A. Nopharatana, 2006. Seasonal variation of landfill methane emissions from seven solid waste disposal sites in Central Thailand. Proceeding of the 2nd Joint International Conference on Sustainable Energy and Envir, Bangkok, Thailand.

White, J., R. Beaven, W. Powrie and K. Knox, 2011. Leachate recirculation in a landfill: Some insights obtained from the development of a simple 1-D model. Waste Manage., 31: 1210-1221.

World Bank http://siteresources.. Org/in turban development/ Resources/ 336387-1334852610766/What_a_Waste 2012_Final.pdf

Zhang, C., G. Xiao, L. Peng, H. Su and T. Tan, 2013. The anaerobic co-digestion of food waste and cattle manure. Bioresource Technol., 129: 170-176.

Zhang, Y. and C. Banks, 2012. Impact of different particle size distributions on anaerobic digestion of the organic fraction of municipal solid waste. Waste Manage., 33(2): 297-307.