International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 2, Mar-Apr 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Generation, Management and Utilization of Landfill Gas: A Review

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Abstract

This study investigates landfill gas (LFG) as a complicated mixture of several gases produced by microorganisms inside a landfill. The world has adopted landfilling as its primary method of managing municipal solid waste (MSW) as a result of the rise of MSW globally. However, the majority of countries' use of open dumping practices and unhygienic landfills to manage the majority of their MSW results in increased landfill pollution of the environment. Therefore, as MSW expands internationally, more dump sites are required. Landfills receive over 85% of the MSW produced globally, which result to increased worries about gases released from landfills. These gases have significantly increased anthropogenic greenhouse gas (GHG) emissions, which are bad for the environment.

The physical, chemical, and microbiological processes involved in each stage of the LFG generation process (bacterial breakdown, chemical reaction, and volatilization), as well as the properties of LFG, are taken into account. Effective landfill management is regarded as a crucial facet of integrated waste management, which includes factors like trash composition, oxygen in the landfill, moisture content, temperature, and age of refuse that affect landfill gas production. The paper also discussed the use of LFG as alternatives to traditional energy sources in most developed nations.

Keywords: Greenhouse gases, landfill, solid waste, Anthropogenic, aerobic.

1.0 INTRODUCTION

Municipal Solid Waste (MSW) generation is anticipated to rise as population, urbanization, and global economic growth all increase (FAO, 2016). Urban households produce roughly 1.2 billion tonnes of MSW annually, or 1.2 kilograms per person per day, and by 2025, that number is projected to rise to about 2.2 billion (Hannan, 2015).

Municipal solid waste (MSW) goes through an aerobic (with oxygen) decomposition stage when it is first placed in a landfill, producing little methane. Then, typically in less than a year, aerobic conditions are established, and methane-producing bacteria start to decompose the waste and generate methane (Prince, 2018).

LFG is a naturally occurring byproduct of the breakdown of organic matter in anaerobic (oxygen-free) conditions. Globally, LFG generates around 8% of all greenhouse gas (GHG) emissions.

With the use of several wells and a blower/flare (or vacuum) system, it is removed from landfills. It has a methane content of between 50 and 55 percent, a carbon dioxide content of between 45 and 50 percent, and an organic compound content of less than 1 percent. Methane is a powerful GHG that traps heat in the atmosphere over a 100-year period 28 to 36 times more effectively than carbon dioxide. The primary gases plus a number of gases that are present in very small concentrations make up the majority of the gases in landfill gas (the trace gases). Some of the trace gases, even though they are present in small amounts, might be poisonous and could cause harm. The major gases are created by the decomposition of the organic part of MSW.

With regard to the proper processing of waste materials, waste management focuses on managing all procedures, tools, and facilities, including dumping sites and waste transport trucks, in accordance with health and environmental standards. In recent decades, landfills have frequently accepted garbage. Although garbage disposal is often regarded as the least preferred method of managing solid waste, most nations continue to favor landfill use since it is less expensive in terms of capital outlay and more user-friendly than other methods of managing MSW.

Landfill Gas (LFG) is a complicated mixture of several gases created by the activity of microorganisms inside a landfill. Mismanagement of a landfill can result in unchecked emissions of LFGs like CH_4 and CO_2, which significantly contribute to climate change, as well as strong odors, litter, and dust in the area and seepage of leachate generated in the landfill into ground water and surface water. In 2011, the United States recorded 1908 landfills that produced roughly 1.03 x 10^8 metric tonnes of carbon equivalent of CH_4, accounting for 17.7% of the country's overall CH_4 emissions into the atmosphere. China reported 580 landfills in 2013, and the CH_4 released from these landfills accounted for 13% of the total CH_4 released.

Landfills in Europe were the second-largest source of CH_4 emissions from human activity, accounting for 22% of total CH_4 emissions from waste disposal facilities. Africa is the region of the world that is most susceptible to the effects of unchecked LFG emission. The control of LFG generation is crucial since the potential methane output from Africa in 2012 was 10,496 × 10^6 m^3 (if all the waste produced was dumped on the ground). Most countries throughout the world might benefit from using landfill gas as an alternative source of energy.

2.0 Generation process, characteristics and factor affecting landfill gas production

2.1 LFG Generation process

LFG is mostly produced when organic waste in a solid waste landfill is broken down by microorganisms. Three steps are involved in the formation of LFG in landfills: bacterial degradation, chemical reactions, and volatilization.

2.1.1 Bacteria Decomposition

This is a major process in the process of the main LFG and involves bacterial degradation of organic waste into a variety of gaseous products and by-products (Ehrig, 2011). There are five phases to this initial stage of LFG formation.

Phase I - Initial Adjustment Phase: Phase I is the initial adjustment phase, during which the organic biodegradable components in MSW go through microbial degradation both during and immediately after being disposed of in a landfill.

It is the time taken by microbes to adopt their new environment and food as well as sufficient moisture contents developed in landfill ecology (Reinhart and Al-Yousfi, 1996). In the initial adjustment stages easily biodegradable organic fraction of MSW aerobically decomposed by aerobic microbes via consuming free available oxygen that were trapped in cover soil and solid waste porosity (Ehrig, 1983; Christensen and Kjeldsen., 1989; Chiemchaisri et al., 2004).

In landfill ecology, this aerobic decomposition process causes a rise in temperature and the production of carbon dioxide. During this phase, only the compaction of MSW during landfilling and the short-circuiting of external and/or recirculated leachate through water pipe lines of MSW matrices result in the generation of landfill leachate (KJeldsen et al., 2002). The principal source of this microbial community (aerobic and anaerobic) is the soil utilized as a final cover on daily basis. Other sources of the organisms include recycled leachate and digested wastewater treatment plant sludge, both of which are commonly disposed of in MSW landfills.

Phase II – Transition Phase: Phase II, often known as the transition phase, is marked by a reduction in oxygen and the emergence of anaerobic conditions. Nitrate and sulfate could operate as electron acceptors in the oxygen-reduction mechanism that reduces nitrogen gas and hydrogen sulfate when the waste turns anaerobic (Reinhart and Al-Yousfi, 1996). For the reduction of nitrate and sulfate, the reduction/oxidation values should be in the range of -50 to 100 millivolts, whereas for the formation of methane gas, they should be in the range of -150 to -300 millivolts (Tchobanoglous, Theisen and Vigil., 1993). The microbial community responsible for converting the organic material in MSW to methane and carbon dioxide starts the three-step process with the conversion of the complex organic material to organic acid and other intermediate products, as described in phase III, as the oxidation/reduction potential continues to decline.

Anaerobic bacteria would be encouraged to transform organic materials into methane and carbon dioxide gases in the subsequent phase by the continual decline of reduction/oxidation values in the landfill ecology. The presence of a significant amount of chemical oxygen demand (COD), volatile organic acids (VOA), biochemical oxygen demand (BOD), and low pH values in the leachate are the distinctive leachate compositions that demonstrate the transition phase of anaerobic degradation processes (Christensen and Kjeldsen., 1989; Chiemchaisri et al., 2004).

Moreover, during this time, carbon dioxide concentration progressively rises while nitrogen gas concentration drops sharply.

Phase III – Acid Phase:

In phase III, the acid phase, the microbial activity initiated in phase II accelerates with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The process of breaking down complex organic substances (such as lipids, polysaccharides, proteins, and nucleic acids) into their component parts, known as enzyme-mediated transformation or (Hydrolysis), is the first stage of the acid production phase. The second stage of acid creation involves the conversion of hydrolysis products' molecular components into their most basic forms, which are subsequently used by the community of acid-forming microbes (acidogenes) to produce acetic acid (CH_3COOH), fluvic acid, and other complex organic acids. The main leachate features that are produced during this phase are an excessive amount of BOD_5, COD, which may further reduce pH values and raise the levels of heavy metals. Moreover, a significant amount of hydrogen gas and a negligible amount of nitrogen gas were produced (Tamru and Chakma, 2015).

Phase IV – Methane Fermentation Phase: Phase IV, also known as the methane fermentation phase, is characterized by the predominance of a second set of microorganisms that transform the acetic acid and hydrogen gas produced in the acid phase by the acid formers into CH_4 and CO2. The intermediate acids were absorbed at this stage by the methanogens or methane formers, who then turned them into methane and carbon dioxide gases (Christensen and Kjeldsen., 1989). The completion of an excessive concentration of organic acid at this stage enhanced pH values (6.8-8.0) and decreased BOD5, COD, and conductivity concentrations. The other sign of this phase is a decrease in the concentration and mobilization of heavy metals in the leachate as a result of complexation and precipitation brought on by a higher pH value (Kim et al, 2011).

Phase V – Maturation Phase: The MSW anaerobic degradation processes end with this phase. After the readily degradable organic material has been transformed to CH_4 and CO_2 in phase IV, the maturation takes place. The waste fraction of the biodegradable material that was previously unavailable will be transformed when moisture continues to permeate through. Phase V sees a significant reduction in the rate of landfill gas formation because the majority of the available nutrients have been eliminated with the leachate during biodegradable.

The MSW anaerobic degradation process ends at this phase. After the readily degradable organic material has been broken down into CO_2 and CH_4 in phase IV, the maturation takes place. The waste fraction of the biodegradable material that was previously unavailable will be converted when moisture continues to permeate through. Because the majority of the available nutrients have been eliminated with the leachate during biodegradable, the rate of landfill gas formation declines dramatically in phase V.

During phase V, CH_4 and CO_2 were the main landfill gases that emerged. Small amounts of oxygen and nitrogen may also be present in the landfill gas, depending on the closure procedures used. In the landfill leachate, non-degradable organic fractions like humic and fluvic acid may stay, and sulfate and nitrate may reduce to sulfides and ammonia, according to the post-closure management of the landfill. However, the management claims that oxygen and oxidized species have returned (Tamru and Chakma, 2015).

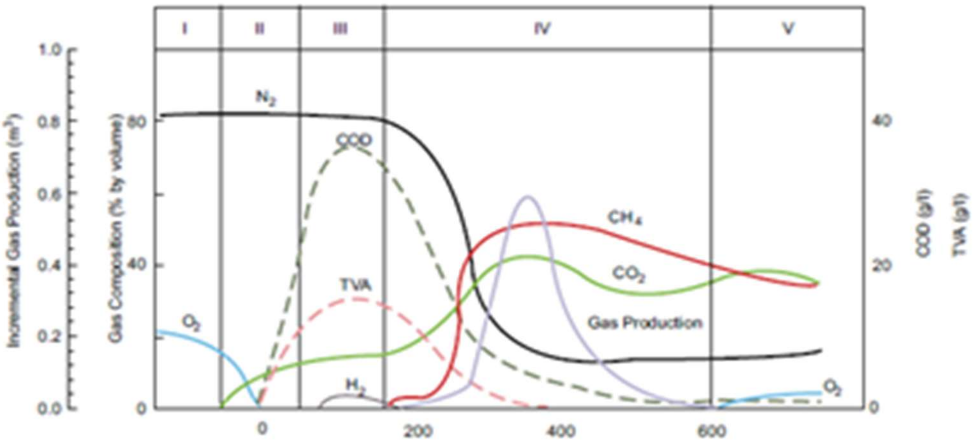


Fig 1: Composition of Landfill Gas with Time (Source: ATSDR, 2016)

2.1.2 Chemical Reaction

In the presence or absence of moisture, oxygen (O_2), and carbon dioxide (CO_2), various chemical components found in landfill garbage can chemically react with one another to produce various types of LFG (LMOP, 2016). For instance, an anhydrous oxidation of aluminum from raw metal waste reacts with oxygen whether or not there is water present.

$2AL + {}^{3}/_{2}O2 \rightarrow AL_2O_3 + \Delta H^{o}_{298}$ (molecular) enthalpy of the oxidation of aluminium = -1675.7KJ/mole (Calder, 2010).

Amphoteric reaction – aluminium reacts with alkaline water at $PH \geq 8$,

$AL + OH^{-+} + 3H_2O \rightarrow [AL(OH^{-1})_4]^{-1} + {}^{3}/_{2} H_2$.

Also, aluminium nitrate can react with water to form ammonium gas;

$ALN + 3H_2O \rightarrow Al(OH)_3 + NH_3$,

the odour of ammonia gas indicates the landfill is alkaline in nature. Aluminium sulphide can react with water to produce hydrogen sulphide with its characteristic pungent odour.

$6H_2O + AL_2S_3 \rightarrow 2AL(OH)_3 + 3H_2S$, these end products are characterized by pungent odour (Haynes, 2014).

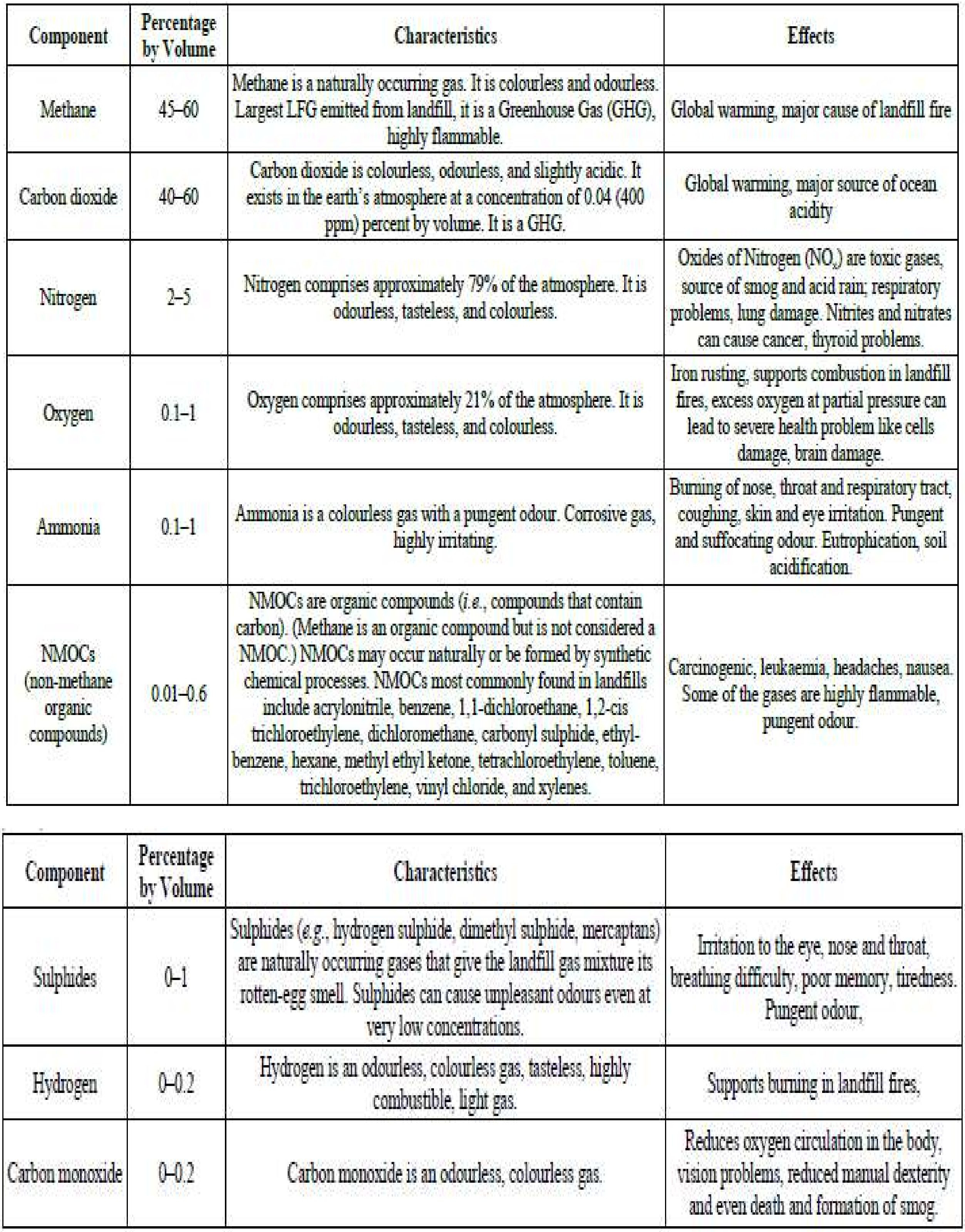
2.1.3 Volatilization

From a solid or liquid state, chemical compounds vaporize or sublime into the environment. Low boiling points are a common characteristic of these chemical compounds. According to a study, landfill sites contain volatile chemicals like hydrocarbons, aromatic molecules, oxygenated, chlorinated, and sulphur compounds (FAO, 2016). According to a study, a landfill included similar volatile substances including benzene and trim ethylbenzene. The study came to the further conclusion that the landfill's primary source of the volatile chemical compound was polystyrene plastic debris (Urase, 2008).

2.2 Characteristics of landfill gases

LFG typically has a density that is similar to air, but if the carbon dioxide content is high, it may tend to settle in culverts, chambers, and poorly ventilated regions due to the increased density. Any entry into such places on or near a dump site must only be made after carefully weighing the hazards to one's health and safety and after analyzing the atmosphere with a suitable portable gas meter. Since there is a chance that LFG could be lethal, reliable and efficient gas control is essential to landfill management. Carbon dioxide typically makes up 45% to 60% of landfill gas by volume. Small amounts of non-methane organic compounds (NMOCs), such as trichloroethylene, benzene, and vinylchloride, as well as nitrogen, oxygen, ammonia, sulfides, hydrogen, and carbon monoxide are also found in landfill gas.

Table 1: Shows the composition, characteristics and, health and environmental effects of landfill gas



Component	Percentage by Volume	Characteristics	Effects
Methane	45–60	Methane is a naturally occurring gas. It is colourless and odourless. Largest LFG emitted from landfill, it is a Greenhouse Gas (GHG), highly flammable.	Global warming, major cause of landfill fire
Carbon dioxide	40–60	Carbon dioxide is colourless, odourless, and slightly acidic. It exists in the earth's atmosphere at a concentration of 0.04 (400 ppm) percent by volume. It is a GHG.	Global warming, major source of ocean acidity
Nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odourless, tasteless, and colourless.	Oxides of Nitrogen (NO$_x$) are toxic gases, source of smog and acid rain; respiratory problems, lung damage. Nitrites and nitrates can cause cancer, thyroid problems.
Oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odourless, tasteless, and colourless.	Iron rusting, supports combustion in landfill fires, excess oxygen at partial pressure can lead to severe health problem like cells damage, brain damage.
Ammonia	0.1–1	Ammonia is a colourless gas with a pungent odour. Corrosive gas, highly irritating.	Burning of nose, throat and respiratory tract, coughing, skin and eye irritation. Pungent and suffocating odour. Eutrophication, soil acidification.
NMOCs (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (*i.e.*, compounds that contain carbon). (Methane is an organic compound but is not considered a NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis trichloroethylene, dichloromethane, carbonyl sulphide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.	Carcinogenic, leukaemia, headaches, nausea. Some of the gases are highly flammable, pungent odour.
Sulphides	0–1	Sulphides (*e.g.*, hydrogen sulphide, dimethyl sulphide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulphides can cause unpleasant odours even at very low concentrations.	Irritation to the eye, nose and throat, breathing difficulty, poor memory, tiredness. Pungent odour,
Hydrogen	0–0.2	Hydrogen is an odourless, colourless gas, tasteless, highly combustible, light gas.	Supports burning in landfill fires,
Carbon monoxide	0–0.2	Carbon monoxide is an odourless, colourless gas.	Reduces oxygen circulation in the body, vision problems, reduced manual dexterity and even death and formation of smog.

Source: (ATSDR, 2016)

LFG is also characterized by saturated moisture content, specific gravity of 1.02-1.06, high heating value of 400-550 Btu/sft^3, molecular mass of 27.2kg/kmol, Explosive limits of 5-15% v/v, Relative density of 0.94 and temperature of 100-120°F. However, the gas temperatures at several hundred °C increase abruptly and systematically and the primary gas ratio ($CH_4 : CO_2$) decreases systematically and substantially when the gas temperature increased abruptly (Craig, 2017).

2.3 Factors Affecting the Production of Landfill Gas

The rate and amount of landfill gas produced at a particular site depends on the waste's characteristics (such as the waste's composition and age) and a number of environmental conditions (e.g. the presence of oxygen in the landfill, moisture content and temperature).

2.3.1 Waste Composition

The amount of organic waste in a landfill determines the amount of landfill gas that is produced by bacterial decomposition. Nutrients like sodium, potassium, calcium, and magnesium are found in some types of organic waste and are essential for the growth of bacteria. Landfill gas production rises in the presence of these nutrients. Alternately, when waste has high salt concentrations, producing bacteria can be inhibited.

2.3.2 Oxygen in the Landfill

The production of methane by bacteria doesn't start until the oxygen is depleted. The lower aerobic bacteria can breakdown garbage in phase I, the more oxygen there is in a landfill. More oxygen is accessible if garbage is loosely buried or often disturbed, allowing bacteria that depend on oxygen to live longer and create carbon dioxide and water for extended periods of time. However, if the trash is substantially compacted, methane production will start sooner because in phase III, anaerobic bacteria that produce methane will take the place of the aerobic bacteria.

Methane gas starts to be produced by the anaerobic bacteria only when the oxygen in the landfill is used up by the aerobic bacteria; therefore, any oxygen remaining in the landfill will slow methane production. Barometric highs have a tendency to add air oxygen to the surface soils in the shallower parts of a landfill, which could change the bacterial activity. In this case, trash in phase IV, for example, can briefly transition to phase I before the oxygen is completely consumed once more.

2.3.3 Moisture Content

A landfill produces more gas when there is a specific level of water present because moisture promotes bacterial development and spreads bacteria and nutrients throughout the dump. Maximum gas generation is encouraged by a waste moisture content of 40% or more, based on the wet weight of the trash (e.g. in a capped landfill). Because garbage compaction makes landfill materials denser and slows down water infiltration, it demonstrates methane production. If additional water is introduced into a landfill by heavy rains, permeable landfill covers, or both, the rate of methane production will increase.

2.3.4 Temperature

Bacterial activity rises in warm environments, which in turn accelerates the creation of landfill gas. Lower temperatures prevent bacteria from growing. Below 50^0F, bacterial activity typically decreases sharply. In shallow landfills, the impact of weather variations on gas output is much larger. This is because, in contrast to deep landfills where the garbage is covered by a thick layer of soil, the bacteria are less protected against temperature variations. A covered landfill typically keeps its temperature steady, boosting gas production. Although temperatures as high as 158^0F have been recorded, bacterial activity emits heat that keeps a landfill's temperature between 77^0F to 113°F stable. Increases in temperature also encourage chemical reactions and volatilization. Emission of NMOCs typically doubles for every 18^0F rise in temperature.

2.3.5 Age of Refuse

Waste buried more recently will release more gas than waste buried earlier. Usually within one to three years, landfills start to release noticeable amounts of gas. Usually 5 to 7 years after waste is placed, gas production reaches its peak. However, a landfill may continue to leak minor amounts of gas for 50 or more years. Nearly all gas is created within 20 years of the material being dumped. However, a low-methane yield scenario predicts that slowly decomposing waste will start to emit methane after 5 years and continue to do so for the next 40 years. Depending on when the waste was originally deposited in each region, different parts of the landfill may be going through different phases of the decomposition process at the same time. The amount of organic material in the waste is an important factor in how long gas production lasts.

3.0 Landfill Gas collection, management and treatment

3.1 Collection of landfill gas

LFG collection normally starts once a "cell" (or section of the landfill) is closed to the addition of new material. LFG is extracted from landfills utilizing a blower/flare (or vacuum) system and a network of wells. Depending on the gas's intended purpose, this system delivers the gathered gas to a central location where it can be processed or treated. Both horizontal trenches and vertical well configurations are possible for collection systems.

Vertical well is the most common method of LFG collection. By using a blower or vacuum induction system, it entails digging vertical wells in the waste and connecting those wells to the waste piping that delivers the gas to a collection header.

Horizontal extraction well (trench) is another type of LFG collection system which uses horizontal piping laid in trenches in the waste. In locations of active filling and deeper landfills, horizontal trench systems are helpful. Some collection methods combine horizontal collectors with vertical wells. Both types of systems can effectively collect LFG if they are well-designed. The site-specific variables and installation settings of the LFG collecting system influence the design that is adopted.

Figure 2 (a) illustrates the design of a typical LFG extraction well and figure 2 (b) shows a typical horizontal extraction well.

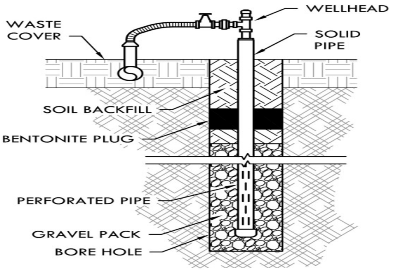


Figure 2 (a) Vertical Extraction Well

(Source: GMI, 2012)

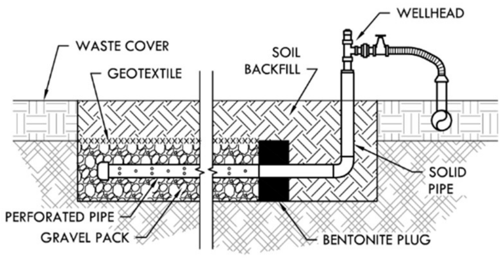


Figure 2 (b) Horizontal Extraction Well

3.2 Landfill Gas Management

Due to the potentially lethal threats posed by landfill gas (LFG), reliable and efficient gas control is essential to waste management. The goal of waste management is to effectively manage all steps and resources involved in processing waste materials, from maintaining waste transport trucks to operating dumping sites in accordance with health and environmental standards (Rushton, 2013).

Waste materials are often treated by being buried in the ground or burned using thermal energy. From an environmental standpoint, each method has pros and downsides. However, toxicity connected to dioxin would be the worst aspect of incineration. For the purpose of preventing the greenhouse effect, the urgent issue that needs to be resolved is the landfill gas associated to global warming (Park, 2015).

Monitoring landfill gas is done to ascertain its composition and look for traces of constituents that could be hazardous to human health or the environment. Methane and carbon dioxide, which make up the majority of landfill gas, are monitored so that they are not released into the environment as greenhouse gases. The recycling system, which consists of power generating, refrigeration, and incinerating plants, collects this gas via a blower system and transports it there.

3.2.1 Techniques for the Monitoring of Landfill Gas

Monitoring methods have been developed since landfill gases can sometimes be dangerous and also valuable. Methane and total volatile organic compound (VOC) levels can both be measured using flame ionization detectors. There are several types of monitoring done, including surface, subsurface, and ambient air monitoring. According to the Clean Air Act of 1990, many big landfills in the United States are obliged to construct gas collection and control systems, which implies that the facilities must at the very least collect and flare the gas.

3.2.1.1 Surface Monitoring

This is used to check the quality of waste cap integrity and monitor boreholes. It might provide early warning signs of gas migration off-site. Methane is often regulated to a volumetric limit of 500 parts per million (ppm).

There are two types of surface monitoring: integrated and immediate. To do immediate monitoring, a person must walk across the landfill's surface while holding a flame ionization detector (FID). The process of integrated monitoring entails strolling around the landfill's surface while pumping a sample into a bag. The sample is then either sent to a lab for comprehensive analysis or read with a FID. The typical integrated regulatory limit is 50 ppm or less.

3.2.1.2 Subsurface Monitoring

Gas probes, often referred to as perimeter or migration probes, are used for subsurface monitoring and identify local gas concentrations. At a same site, numerous probes may occasionally be utilized, each at a different depth. A landfill is often surrounded by a ring of probes. Although it varies, the space between probes almost never surpasses 300 meters. The standard regulation limit for methane in this country is 50,000 ppm by volume, or 1.5% more carbon dioxide and 1% more methane than the UK's geological background values.

3.2.1.3 Ambient Air Monitoring

In order to check for excessive levels of methane and other gases in the air around a landfill, ambient air samples are taken. The main odoriferous substances are volatile organic acids and hydrogen sulphide, which is poisonous and causes the majority of people exposed to levels above 5 parts per billion to complain (WHO, 2000).

3.2.1.4 Collection System Monitoring

This system is used to examine the characteristics of the landfill gas that the gas extraction system is collecting. Either the power plant or the individual gas extraction well may do monitoring (or flare). In each scenario, users are keeping an eye on temperature, pressure, flow rate, and the gas composition (CH_4, CO_2, O_2, and Balance Gas). There are three different ways to quantify collected gas.

- **Handheld, single reading monitoring** – giving point readings from individual gas collection wells. There are two companies that provide the large majority of these type of metres, LANDTEC and Elkins Earthworks
- **Wired, continuous reading monitor** – these hard wired monitors can typically be found at either the flare or the landfill gas-to-energy plant. There are a number of companies that provide wired, continuous reading monitors.
- **Wireless, continuous reading monitor** – theses wireless monitors can typically be found installed on individual landfill gas collection wells but can be installed anywhere on the gas collection system. Loci controls is currently the only company that provide wireless continuous reading monitors.

3.2.2 Other Ways of Managing Landfill Gas

As well as monitoring of landfill gas, the gas can also be properly managed through the following ways;

- Capping: Timely installation of synthetic liners or engineered clays is paramount in minimizing uncontrolled emissions or ingress of air.
- Overtipping: An overtip plan must be prepared to minimize odour release and ensure effective gas control is maintained.
- Daily cover: Careful removal of daily cover is the only way to prevent movement of gases and liquids and odour problem.

In general, landfill gas frequently contains strong corrosives such hydrogen sulfide and sulfur dioxide, which will reduce the lifespan of the majority of monitoring equipment when they react with moisture (this is also problem of landfill gas utilization schemes). Effective landfill management must therefore take into account a number of variables, including the kind of waste that is brought to a site, the filling technique, the daily cover choice, the design of the phasing, the landfill engineering, the leachate management system and leachate strategy, the gas system design and operation, and the weather.

3.3 Treatment of landfill gas

LFG typically needs to be treated before being used in an energy recovery system to get rid of extra moisture, particles, and other contaminants. The kind of energy recovery system used and the LFG features unique to the site determine the type and scope of therapy. In general, boilers and the majority of internal combustion engines need little maintenance (usually dehumidification, particulate filtration and compression). After the dehumidification process, several internal combustion engines, as well as many gas turbine and micro-turbine applications, call for siloxane and hydrogen sulfide removal using absorption beds, biological scrubbers, and other existing technologies.

Fig 3. presents a diagram of an LFG energy project that includes LFG collection, a sizable treatment system, and an energy recovery system that generates both electricity and heat. While a growing number of combined heat and power (CHP) systems can produce both electricity and heat, most LFG energy projects only do one or the other.

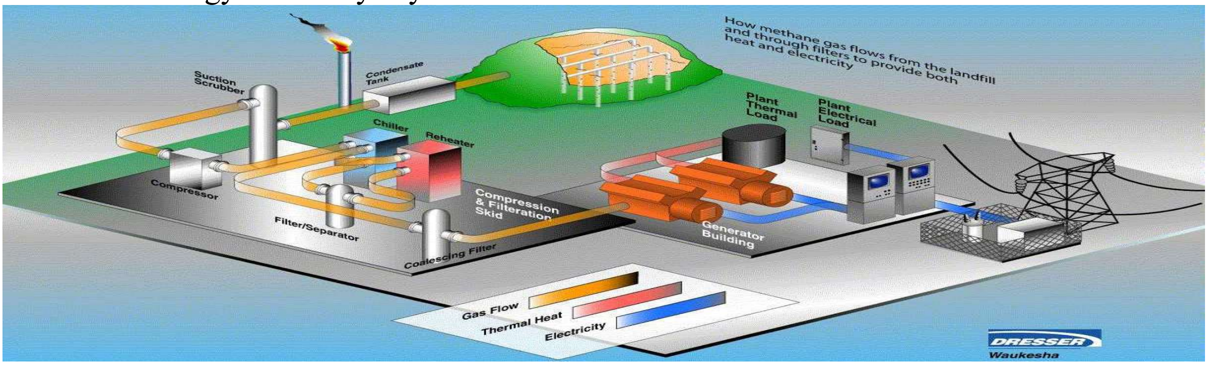


Figure 3. LFG collection, treatment and energy recovery (source: EPA, 2016)

The cost of gas treatment is determined by the end-use application's criteria for gas purity. The cost of a system that must also remove contaminations like siloxane and sulphur that are present at elevated levels in some LFG is significantly higher than the cost of a system that simply filters the gas and removes condensate for direct use of Medium-Bill gas or for the generation of electricity.

Flares are also a part of each energy recovery option since they may be required to manage LFG emissions during startup and shutdown of the energy recovery system as well as to manage gas that is too much for the energy conversion equipment. A flare is both a tool for lighting and burning LFG and a practical approach to gradually expand the energy production system at an operating landfill. The flare is used to manage surplus gas between energy conversion system upgrades (for instance, before the addition of another engine), preventing methane from being discharged into the atmosphere when additional garbage is dumped in the landfill and the gas collection system is extended.

There are two types of flare designs: open (or candlestick) flares and enclosed flares. Although more expensive than open flares, enclosed flares may be preferable (or required by state regulations) because they allow for stack testing, offer greater control over combination conditions, and may even achieve slightly higher combustion efficiencies (higher methane destruction rates) than open flares. They can also reduce noise and light nuisances.

(a) Open flares (b) Enclosed flares

Figure 4. Types of flare (Source: SEPA)

4.0

Uses of Landfill Gases

Gases generated from landfill sites or produced within a landfill can be collected and flared or used in several ways including;

4.1 **Source of electricity**

A million tons of landfill waste typically emits 434,000 cubic feet of LFG each day, which is sufficient to generate 0.80MW of power. This means that the gas can be utilized as fuel for power generation, which can produce electricity from a steam engine up to 45 megawatts (Willumsen, 2001) . Electricity can be generated on site through the use of reciprocating internal combustion engine, use of gas or steam turbine, power plant with organic ranking cycle, stirling cycle engine, molten carbonate fuel cells and solid oxide fuel cells; the selection of method is owed to several conditions (Bove, 2006). This form of utilization has shown to be reliable, environmentally and economically friendly to its users. (GMI, 2016). The Durban LFG facility in South Africa's Ethekwini municipality is a good example.

The advantages of this method include its potential for use as an electricity source, as a means of generating cash for the government through the sale of electricity produced, and as a means of maximizing the yield of LFG when it is collected from landfill sites. In the opposite situation, the approach has a relatively high operating cost, necessitates a high degree of experience and technology, and its cost may be insignificant in nations with cheap electricity.

4.2 Boiler system

A boiler or other form of combustion device can use the LFG directly on site to generate heat. LFG is a fuel source used by boilers to create steam and hot water. Additionally, the process produces steams that can be utilized to heat buildings, hospitals, schools, and even major manufacturing companies (pulp and paper industries). The Gaoantun landfill in Beijing, China, and the Three Rivers Regional Landfill in South Carolina, USA, are two examples of landfills that use LFG for their boiler systems (GMI, 2016).

This method uses the maximum quantity of LFG collected, is very inexpensive, doesn't process much LFG, and can be utilized as a heating source. However, the price is based on the length of the pipe lines, and endorsers must be accessible.

4.3 **Source of vehicle fuel**

LPG is compressed and utilized as a fuel source for powering vehicles. Borray (1998) asserts that raw LFG can be utilized as fuel for vehicles after collection, purification, drying, and compression to a suitable pressure gauge. Due to the high cost of converting the raw LFG gathered into motor fuels, this technique is not favorable in all countries. For instance, the Global Infrastructure Based Company completed a project in the South African municipality of Ekurhuleni to transform LFG into fuel for fleet cars. The undertaking took a full year and cost $5 million (Basel, 2017).

However, the method has advantages because, when sold, it serves not only as a fuel source for cars and trucks but also as a cash stream for the government.

4.4 Source of natural gas

This process involves the upgrading of LFG into natural gas quality (Willumsen, 2001). The LFG is sold offsite, sent into natural gas pipeline and processed into pipeline quality majorly by removing various contaminants and components. According to Sabri's (2011) research, LFG can be enhanced to have a methane concentration of 87.9+2.0% by employing a high pressure gas absorption approach. Thus, the residential use of the refined LFG via the natural gas network is possible. Developed countries like the US and Europe commercially substitute LFG for the traditional fuel that has been utilized for home purposes (GMI, 2016).

However, the method offers benefits such as being utilized in domestic cooking and in industries as a source of heat, as well as being used in natural gas pipes to generate cash for the government. However, it is somewhat pricey and calls for LFG expensive processing methods.

4.5 Furnace, dryers and kilns

This involves the direct use of raw LFG from landfills as a source of fuel directly from the kilns (Willumsen, 2001). Manufacturing companies that produce cements, ceramics, iron, wood and steel use LFG straight from the landfill site as a source of fuel for infrared heating mechanism. With an efficiency of up to 93%, infrared heating can achieve temperatures of 8000°C to 1000°C (GMI, 2016).

However, this procedure is cheap and simple to set up. Additionally, in some production firms, the raw LFG can be used straight from the kilns. However, if employed seasonally, LFG use may be limited.

5.0 Conclusion

According to the study, landfill gas is a complex mixture of several gases created by microorganisms inside a landfill. It was discovered that CO_2 and CH_4, both of which are greenhouse gases, make up the majority of LFG. The improper management of the landfill led to the unchecked emission of LFGs, which has a significant impact on climate change.

The stages involves in the generation process, factors affecting the production of LFG as well as how the unintentional spreading of the gas into the atmosphere is controlled and properly managed are also considered as a critical aspect of this study.

The study also considered the possibility that landfill gas emissions could serve as useful alternatives to traditional energy sources in most developed nations. Its various uses include leachate evaporation (furnaces, dryers, and kilns) and source of power, boiler system, source of vehicle fuel, source of natural gas, all of which are more crucial in some engineering projects.

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