Microbiological Degradation of Municipal Solid Waste in Landfills for LFG Generation

Dr. M.J.Khalil, Rimzhim Gupta, Kartik Sharma

***Abstract*— This paper aims to analyze the relationship between gas production, leachate composition and solids decomposition. LFG consists mainly of CH_4, CO_2, and volatile/non-volatile organic matter in trace amount. The change of gas composition from initial stage to the final stage in which methane is formed as a major product and the properties of leachate like pH, BOD, COD, metal content, volatile fatty acids change with change in the property of soil and the composition of gas at every stage of the mechanism of gas generation is discussed. The whole mechanism of LFG involves aerobic and anaerobic process of generation. These processes facilitate the soil with specific microorganism which can survive in presence of oxygen (aerobic) and in absence of oxygen (anaerobic) and then degrade the waste components from their complex molecules to the simpler one.**

A relatively new type of landfill, called a bioreactor landfill, is now days used to optimize the biodegradation of the waste to stabilized products. Landfills with stabilized waste pose little threat to the environment from ozone depleting gases and groundwater contamination. Various factors affecting rate of generation of LFG is also discussed.

***Index Terms*— LFG, Methanogenesis, Landfill bioreactor.**

I. Introduction

The generation of solid waste has become an important global issue because of a drastic growth in world population and thus large increase in waste production. This increase in solid waste generation poses numerous questions concerning the adequacy of conventional waste management systems and their environmental effects. Landfill disposal is the most commonly waste management method worldwide. The safe and reliable disposal of MSW and solid waste residues is an important component of integrated waste management. Solid waste residues are waste components that are not recycled, and remain after processing at a materials recovery facility, or remain after the recovery of conversion products and/or energy. But landfill disposal may have harmful effects towards environment if not treated properly. So new engineered techniques must be used to make it environment friendly and the gas release after the waste is dumped in the landfill might be used for various applications. The LFG obtained is an alternate source of energy. The major constituent of the LFG is methane which a second important Greenhouse gas.

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Since all the surfaces under natural or artificial conditions are covered with the microorganisms so initially when the waste is dumped it has to go thorough different stages of chemical and physical change in the state of waste because of the presence of microorganisms. In presence of oxygen aerobically degradation takes place but as the oxygen depletes in the landfill the degradation continues in the anaerobic manner.

Heat is also evolved in the process because of the action of temperature. Heat is generated as a result of biochemical processes and decomposition of organic components in wastes. Temperature is considered to affect solid waste decomposition in two ways: short-term effects on reaction rates and longer-term effects on microbial population balance. In general, decomposition of wastes increases with increasing temperature up to limiting values. Optimum temperature ranges for maximum gas production from waste is 34-41°C.

II. LANDFILL MICROBIOLOGY

Landfill microbiology is most complex in solid waste due to its chemical composition. ***(NSW EPA, 1996).***

A. Degradation Process

Landfilled wastes are dominated by organic comprising (typically) of 50% cellulose, 15% lignin, 10% hemicellulose, 5% protein as well as starch, pectin and other soluble sugars. ***(Barlaz et al., 1992)***. Microbes degrade these organics into mineral form, principally CO_2, by facilitated chemical oxidation. Landfill waste is initially electron donor rich ***(Blackall and Silvey, 1994)*** causing oxidants to be rapidly depleted. Once electron donor sources are depleted microbes use a combined oxidation/reduction degradation process termed fermentation to further degrade wastes. This produces methane as one of its byproducts.

As redox reactions tend to produce more energy than other types of reactions, microorganisms which utilize these reactions flourish within the landfill. During such reactions, microbes use enzymes and other mechanisms to enhance the rate of such reactions, and to some extent influence the point of equilibrium. As energy is released microbes utilize some of this energy internally in the form of adenosine triphosphate (ATP) an intracellular compound used for further metabolism and reproduction. ***(Amin Kalantarifard, Go Su Yang, IJST,2012)***

B. Phase I - Aerobic Hydrolysis

This phase is characterized by rapid breakdown of complex organics in the presence of water and oxygen into simple

sugars – often termed hydrolysis. Some components, such as lignin, are only effectively broken down during this phase.
The primary product of this breakdown process is glucose but there are secondary compounds formed due to the oxidation other elements such as nitrogen and sulphur as shown in **Fig.1**. This includes such as nitrates, sulphates, chlorinated organics and metal ions which are readily dissolved and transported by leachates.
This phase is characterized by the depletion of O_2 and N_2 due to the production of large quantities of CO_2. It is accompanied by a dramatic drop in redox potential. The large release of energy is also reflected by rapid rise in landfill temperature.

C. Phase II-Acidogenesis

The process generally involves fermentation (combined oxidation/reduction of organics) of insoluble long chain sugars and thus referred to as solid state fermentation ***(Blackall and Silvey, 1994).*** It produces long carbon chains compounds, as well as other more complex acids and alcohols. Typical reactions for the conversion of glucose to acid and alcohol are:

$$C_6H_{12}O_6 \longrightarrow CH_3C_2H_4COOH + 2H_2 + 2CO_2$$

$$C_6H_{12}O_6 \longrightarrow 2CH_3CH_2OH + 2CO_2$$

Acidogenesis is characterized by increasing CO_2 production shown in **Fig.1**, the appearance of H_2 and a reduction in pH due to the formation and dissolution of organic acid.

A.*Phase III-Acetogenesis*

During this phase acetogenic microbes progressively break down organic acids to acetate through fermentation. Examples include the conversion of butyrate to acetate and ethanol to acetate:

$$CH_3C_2H_4COOH + 2H_2O \longrightarrow 2CH_3COOH + H_2$$

$$CH_3CH_2OH + H_2O \longrightarrow CH_3COOH + 2H_2$$

Acetogens further decrease the pH, the production of hydrogen and dissolution. The production of hydrogen in particular is in part detrimental to the proliferation of acetogens as the reduction of water is energy intensive.

D. Phase IV-Methanogenesis

As soon as acetate product dormant methanogens can being to metabolize methane which is initially produced during acetogenesis. There are 2 main groups of methanogens: those that convert acetate directly to methane and those that combine hydrogen and carbon dioxide. The methanogens that generate acetate are termed acetophilic and do so by facilitating reactions similar to:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

This reaction releases relatively small amounts of free energy. This is just enough to sustain cell growth and the increase in this group of methanogens is accordingly slow. The other main group of methanogens is those that metabolize hydrogen are termed hydrogenophilic and do so according to:

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

$$HCOOH + 3H_2 \longrightarrow CH_4 + 2H_2O$$

Hydrogenophilic methanogens produce slightly more energy thermodynamically and are therefore more favorable when hydrogen is available. This phase also provides substrate for methanotrophic bacteria which converts methane to CO_2 and water in the presence of oxygen. These bacteria can significantly reduce methane emissions.
Methanogens are sensitive to both pH and hydrogen concentrations, yet are dependent upon both. In this manner methanogens are involved in a symbolic relationship with acetogens. Generally the rate of acid and hydrogen formation is matched by their conversion to methane.

E. Phase V – Restoration (Maturation Phase)

Once available organic matter is degraded CO_2 and CH_4 production cases and air diffuses back into the landfill. Exactly how much bioconversion takes place is dependent upon many factors but principally moisture distribution and movement. Moisture is required to facilitate initial hydrolysis into substrates and to form a biofilm over the waste matrix in which microbes thrive. It also provides a vital function in the removal of waste products to allow chemical reactions to continue, and the distribution of vital nutrients.
Often the process of conversion of organic matter to CO_2 and CH_4 is summarized by the following general formula ***(Tchobanoglous et al. 1993***).
Typically waste composition has a formula of $C_{57.1}H_{84}O_{38.5}N_1$.

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \Rightarrow \left(\frac{4a-b+2c+3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

F. Time duration of different phases

Time scale (total time and phase duration) of gas generation varies with landfill conditions (e.g., waste composition and anaerobic state),
Phase I decomposition could last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.
but phase IV is generally reached in less than 1 year. Phase IV landfill gas usually contains approximately 45 percent to 60 percent methane by volume, 40 percent to 60 percent carbon dioxide and 2 percent to 9 percent other gasses, such as sulfide. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill ***(HEYER, 2010)***

III. DISCUSSION AND CONCLUSION

I. Aerobic
II. Anaerobic, Non-Methanogenic
III. Anaerobic, Methanogenic, Unsteady
IV. Anaerobic, Methanogenic, Steady

In Phase I, biological decomposition occurs under aerobic conditions because a certain amount of air is trapped within the landfill.

In Phase II, identified as the transition phase, oxygen is depleted and anaerobic conditions begin to develop. In Phase II, the pH of the leachate, starts to **drop (lower graph of Fig.1)** due to the presence of organic acids and the effect of the elevated concentrations of CO_2 within the landfill.

In phase III, ***(Aik Heng Lee et al., 2010)*** the pH of the leachate, will often drop to a value of 5 or lower **(lower graph of Fig.1)** because of the presence of the organic acids and the effect of the elevated concentrations of CO_2 within the landfill **(upper graph of Fig.1)**. The BOD_5, the COD, and the conductivity of the leachate will increase significantly during Phase III due to the dissolution of the organic acids in the leachate. Also, because of the low pH values in the leachate, a number of inorganic constituents, principally heavy metals, will be solubilized during Phase III. Many essential nutrients are also removed in the leachate in Phase III. If leachate is not recycled, the essential nutrients will be lost from the system.

In phase IV the pH within the landfill will rise to more neutral values in the range of 6.8 to 8. In turn, the pH of the leachate, will rise, and the concentration of BOD_5 and COD and the conductivity value of the leachate will be reduced. With higher pH values, fewer inorganic constituents are solubilized; as a result, the concentration of heavy metals present in the leachate will also be reduced.

General values in a case study are found to be:

Acid phase	**$BOD_5/COD \geq 0.4$**
Intermediate phase	**$0.4 > BOD_5/COD > 0.2$**
Metahnogenic phase	**$BOD_5/COD \leq 0.2$**

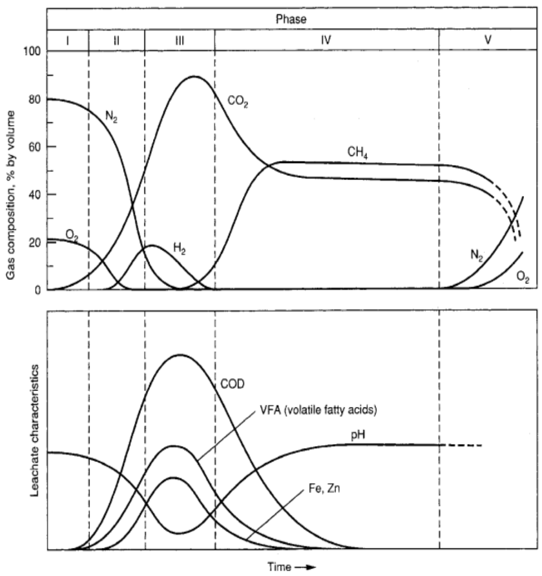

Fig.1 Generalized phases in the generation of landfill gases (I—Hydrolysis, II—acidogenesis, III—Acetogenesis, IV—methanogenesis, and V—Maturation Phase).

During the maturation phase, the leachate often contains higher concentrations of humic and fulvic acids, which are difficult to process further biologically. In very old landfills, when only more refractory organic carbon content remains in the landfilled wastes a second aerobic phase may appear in the upper layer of landfill **(Phase V, Fig.1)**.

In this phase methane production rate is very low and air will start diffusing from the atmosphere giving rise to the aerobic zones and redox potential too high for methane formation.

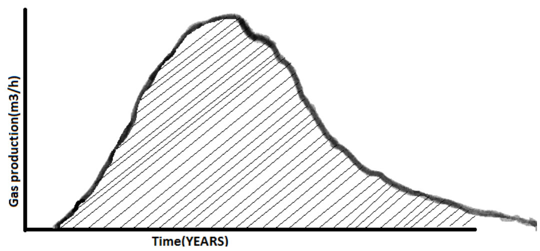

Fig.2 LFG production curve

In **Fig.2** During peak landfill gas production the bulk gas consists typically of 50 to 60% by volume methane and 40 to 50% by volume carbon dioxide. After all biodegradable substrate has been consumed, landfill gas production slows and the gas composition in the waste returns to atmospheric conditions.

Each tonne of degradable waste will produce approximately 6 m^3 landfill gas per year for the first 10 years after deposition ***(EPA, 2000)***. Under optimum conditions, a bulk gas production of 400 - 500 m^3 may theoretically be achieved per tonne of degradable waste ***(EPA, 2000)***. The achievable yield of extracted landfill gas will however be much lower, in the range of 100 - 200 m^3 over the site lifetime ***(EPA, 2000).***

IV. ENHANCEEMNT TECHNIQUES FOR LFG GENERATION

Some enhancement techniques like Leachate recirculation, increased moisture, and higher temperatures increased the first order degradation rates of cellulose and volatile solids. Increased methane production can result when biological reactions in the landfill are accelerated.

A. Waste Composition

Waste composition is one of the most important parameters affecting bioreactor landfill performance. Especially the easily biodegradable components such as food waste, paper, garden cutting. While plastic, wood, rubber etc. is examples of hardly biodegradable material. Normally, higher gas yield could be achieved from easily biodegradable wastes compare to hardly biodegradable materials. Percentage of easily biodegradable material is depending on the solid waste management program. At this stage, recycle program takes an important role.

B. Seeding of microorganisms

Normally, seeding of microorganisms in anaerobic process has primary objective in accelerating waste degradation by increasing the population of slow-growing microorganisms such as methanogenic bacteria. Favorite seeding that gains the positive effect are digested sewage sludge and old anaerobically degraded refuses. However, negative effect can occur if using low pH septic tank sludge.

C. Buffering capacity

Acidogenic step will result in accumulation of acid. Naturally, the process is self-recovery but take a long period of time. In order to avoid excessive accumulation of acid, buffer substances can be added to prevent the inhibition of methanogenic activities. Calcium carbonate ($CaCO_3$), sodium carbonate (Na_2CO_3) and potassium carbonate (K_2CO_3) were found to be effective in maintaining buffering capacity in landfill.

D. Shredding/ Size Reduction

Reduction of particle size influences the process by increasing the ratio of surface area to mass, providing more uniformity of wastes by which the biodegradation could be enhanced. In addition, size reduction also support the hydrolysis and acidogenic step to quicker release acid to the system. Thus size reduction should take place concurrently with buffering and/or seeding. On the other hand, ***Buivid et al. (1981)*** reported negative impact of size reduction by suggested that methanogenic activities could be inhibited by the release of some chemicals from newspaper wastes.

E. Compaction

Higher compaction under well-mixed static landfill condition yielded higher methane gas volume ***(Buivid et al., 1981).*** But, in the case of leachate recirculation, a looser material is more advantageous for distribution purposes. At critical high compaction, increased channeling of recycled leachate through MSW landfill might occur, severely limiting any beneficial effects of enhancement. The operation of landfill with low compaction or no daily cover could also promote the degradation. In the case of high moist waste, lower density operation helps increasing the degradation rate.

F. Cover soil

Application of daily cover soil is often prescribed to improve the hygienic and aesthetic standard of the landfill. The use for daily and final cover soil is the principal source of organisms responsible for the decomposition of refuse. Exceptional, positive effect of cover soil might be expected by providing buffering capacity to the landfill. However, leachate concentrations were higher from shallow lysimeters having covered soil.

G. Leachate Recirculation

Leachate recirculation helps reducing organic strength of leachate, maintaining moisture content in landfill and diluting toxic. It can also recycle nutrients and microorganisms back into the landfill cell. The frequency of recirculation depends upon the balance between biological processes of waste degradation and hydrologic capacity of the wastes. In full-scale practice, the recirculation should be more frequent du ring the operation and less during post-closure period. This is to avoid high compaction of wastes, leachate ponding, side seeping and interference with gas collection.

Moisture content below 25% (WET MASS), especially below 20% WM could be considerably limit the anaerobic degradation processes but also have restrictive effects on aerobic degradation processes.

H. Treatment of Wastes

The provision of waste pretreatment by aerobic condition (composting) prior to landfill helps reducing those easily biodegradable substances and preventing excessive acid accumulation in the landfill. It can also be performed after completion of landfill by providing aeration to re-circulating leachate.

I. Temperature.

Warm temperatures increase bacterial activity, which in turn increases the rate of landfill gas production. Colder temperatures inhibit bacterial activity. Typically, bacterial activity drops off dramatically below 50° Fahrenheit (F). Weather changes have a far greater effect on gas production in shallow landfills. This is because the bacteria are not as insulated against temperature changes as compared to deep landfills where a thick layer of soil covers the waste. A capped landfill usually maintains a stable temperature, maximizing gas production. Bacterial activity releases heat, stabilizing the temperature of a landfill between 77° F and 113° F, although temperatures up to 158° F have been noted. Temperature increases also promote volatilization and chemical reactions. As a general rule, emissions of NMOCs double with every 18° F increase in temperature.

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