CHAPTER 2

LITERATURE REVIEW

2.1 Landfill Construction and Operation

Landfill sites construction activities start with routing runoff away from the proposed landfill area, building access roads and weighing facilities, and installing fences to control access to the landfill operation. Excavation and preparation of the landfill bottom and subsurface sides are then conducted. Possible rebound and settlement of subbase of the landfill bottom is examined, especially when the subbase is found to be clayey material (Bagchi, 1992). Excavated material is stockpiled for later use as daily cover or protective soil layers. The landfill bottom is shaped to promote leachate collection before both vadose zone and groundwater monitoring system are placed.

Placement of a low-permeability liner system is the next step, and the liner usually extends up to the excavated wall of the landfill. In case of liner system composed geomembrane overlying compacted clay, the geomembrane should be rapidly covered by soil or the first load of waste after placement, since sun light is able to induce deterioration in polymer structure, which subsequently may lead to its failure as a moisture barrier. Furthermore, the first load of waste to be placed on the geomembrane should be screened for materials capable of puncturing the synthetic liner (Bagchi, 1992).

Typically, the aforementioned construction activities are performed in sections rather than throughout the entire area to reduce exposure of the working surface to possible precipitation, thus minimizing infiltration into the emplaced refuse.

The solid waste placement is commenced from unloading of waste materials from vehicles. Compaction is performed against a compaction face, normally the wall of the excavation. After a given operating period, usually a day, an individual cell of deposited waste is formed. All exposed surfaces of the cell are covered with six inches of native soil or other appropriate materials after each operating period.

A lift is a complete layer of cells over the active area of the landfill. Successive lifts are placed on top of one another along with the installation of gas and leachate collection facilities. After the predetermined height of the landfill is attained, a cover system is applied to the completed landfill section. Vertical gas extraction wells are installed, gas extraction systems are then tied together, and collection of landfill gas begins. In addition, if leachate recirculation is practiced, the final redistribution and/or injection system will be installed.

Due to consolidation and decomposition of the solid waste, differential settlement often occurs, causing damage to landfill surface cover as well as gas and leachate collection networks. Therefore, regrading of settled surface and maintenance of the cover and liners as well as the collection systems must continue not only for the period where filling operation is not completed, but also through post-closure period (30 to 50 years).

2.2 Landfill Stabilization Processes

Landfills can be conceptualized as a batch anaerobic bioreactor (figure 2.1), receiving limited inputs of solid waste and moisture, and producing limited outputs of leachate and gas through a series of chemical, physical, and biological reactions comprising the inherent stabilization processes (Stratakis, 1991). Those reactions include; biological decomposition of degradable material by; either aerobic or anaerobic processes; dissolution and transport of organic and inorganic constituents by leaching; biochemical oxidation of organic portions in solid waste; diffusion and transport of gas; liquid hydraulic transport; diffusive and convective movement of dissolved constituents; and differential settlement of landfill layers resulting from waste degradation and consolidation of materials into void spaces.

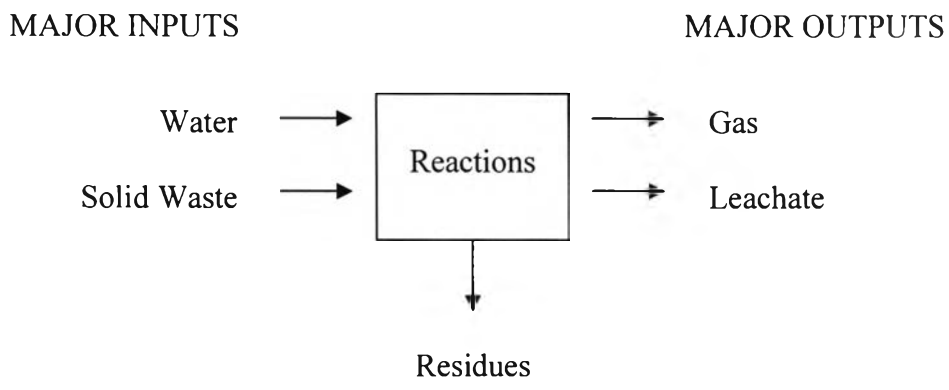

Figure 2.1 Landfill Bioreactor
(**Source:** Stratakis, 1991)

Because oxygen entering the landfill during solid waste filling operations is rapidly depleted after capping, the majority of stabilization processes during the active life of a landfill proceeds anaerobically. Therefore, complex and/or insoluble organic materials are initially hydrolyzed and liquefied to less complex soluble materials of sizes and forms that are capable of penetrating bacterial cells for use as energy or carbon sources. Extracellular hydrolytic enzymes produced and excreted by the bacterial population for the specific purpose accomplish this step. Yet, not all organic compounds can be broken down to simpler soluble materials because of structure, inaccessibility, and complex non-hydrolytic linkages of the parent compounds (Parkin and Owen, 1982). The rate of hydrolysis also varies for each type of compounds under different conditions of operation. This would suggest that the overall rate of stabilization could be limited by the ability of microbial communities to hydrolyze the complex materials normally found in solid wastes.

Acidogenesis, is a conversion of hydrolysis products to simple intermediates. Long-, medium-, short-chain volatile organic acids, alcohols, as well as methane and carbon dioxide are produced in this step. Obligate anaerobic acidogens were observed by Torien and coworkers (1967) to be an important group responsible for this conversion. This finding confirmed the significance of establishing and maintaining anaerobic conditions for successful waste conversion. The biological conversion of organic matter is thought to occur in three steps (Figure 2.2). The first step in the process involves the enzyme-mediated transformation of higher-molecular-mass compounds into compounds suitable for use as a source of energy and cell carbon. The second step involves the bacterial conversion of the compounds resulting from the first step into identifiable lower molecular-mass intermediate compounds. The third step involves the bacterial conversion of the intermediate compounds into simpler end products, principally methane and carbon dioxide (Holland, Knapp, and Shoesmith, 1987)

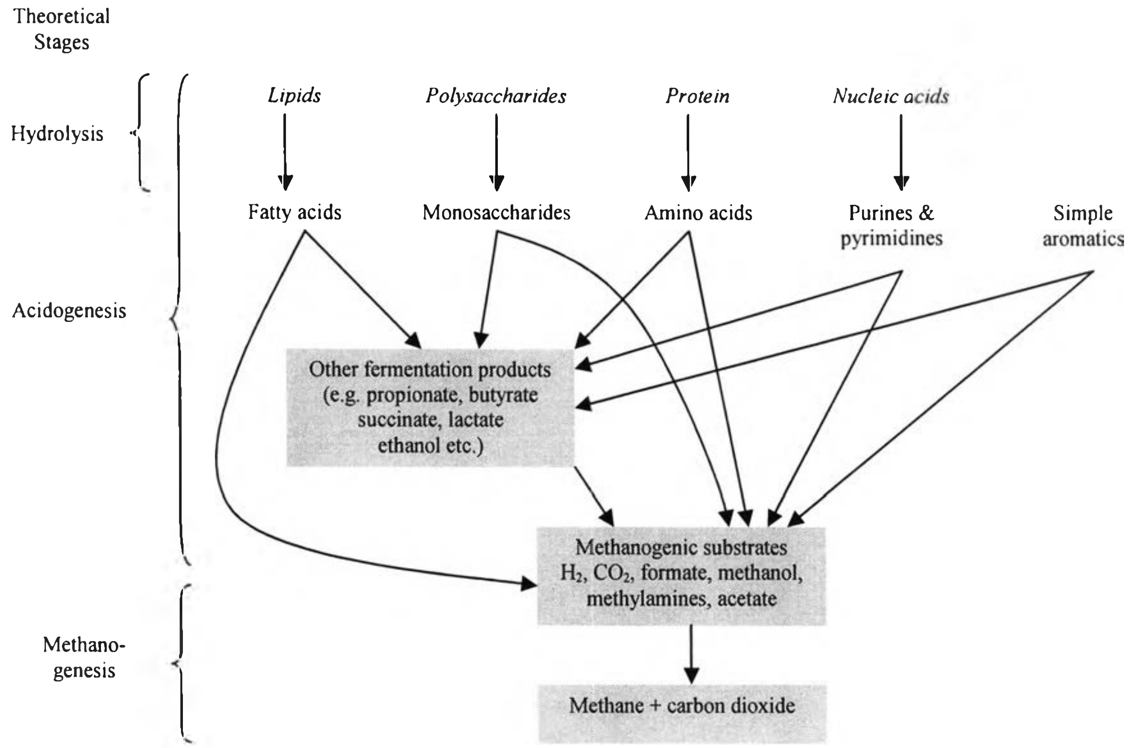

Figure 2.2 Schematic diagram of the patterns of carbon flow in anaerobic digestion (**Source:** Holland, Knapp, and Shoesmith, 1987)

During acetogenesis, the higher volatile organic acids are converted to acetic acid, carbon dioxide and hydrogen. There are two basic types of acetogenic bacteria involved; the hydrogen-producing acetogens which obtain energy for growth by completely dissimilating alcohol of greater complexity than methanol and volatile acids of longer chain than acetic acids, into acetic acid, hydrogen, and occasionally carbon dioxide, as well as the hydrogen-consuming acetogens which catabolize carbohydrate, hydrogen, and carbon dioxide or one-carbon compounds into acetic acid (Chynoweth and Mah, 1977). Hydrogen has been shown to be a key factor in regulating the consumption and production of volatile organic acids. According to

Pohland and Harper (1986), the partial pressure of hydrogen must be maintained at low level by hydrogen utilizing acetogens or carbon dioxide-reducing methanogens in order that the conversion of long-chain volatile acids to acetic acid becomes thermodynamically favorable.

During methanogenesis, acetic acid, carbon dioxide, and hydrogen are converted to methane. There are three major groups of bacteria recognized for methane production in this step; aceticlastic bacteria which produce methane and carbon dioxide via acetate cleavage, carbon dioxide-reducing methanogens that utilize hydrogen to reduce carbon dioxide to methane, and a group of bacteria capable of utilizing formic acid and methanol to produce methane. As indicated in Figure 2.3, approximately 72% of the methane formed in the anaerobic digestion of wastewater sludges comes from acetate cleavage, and the remaining 28% of the methane is produced by carbon dioxide reduction, with 13% of the 28% originating from propionic acid and 15% of the 28% coming from other intermediates (McCarty, 1964). Methane gas generated in this stage is not very soluble and tends to escape from the liquid phase. As a consequence, the majority of waste stabilization takes place during the methane forming phase.

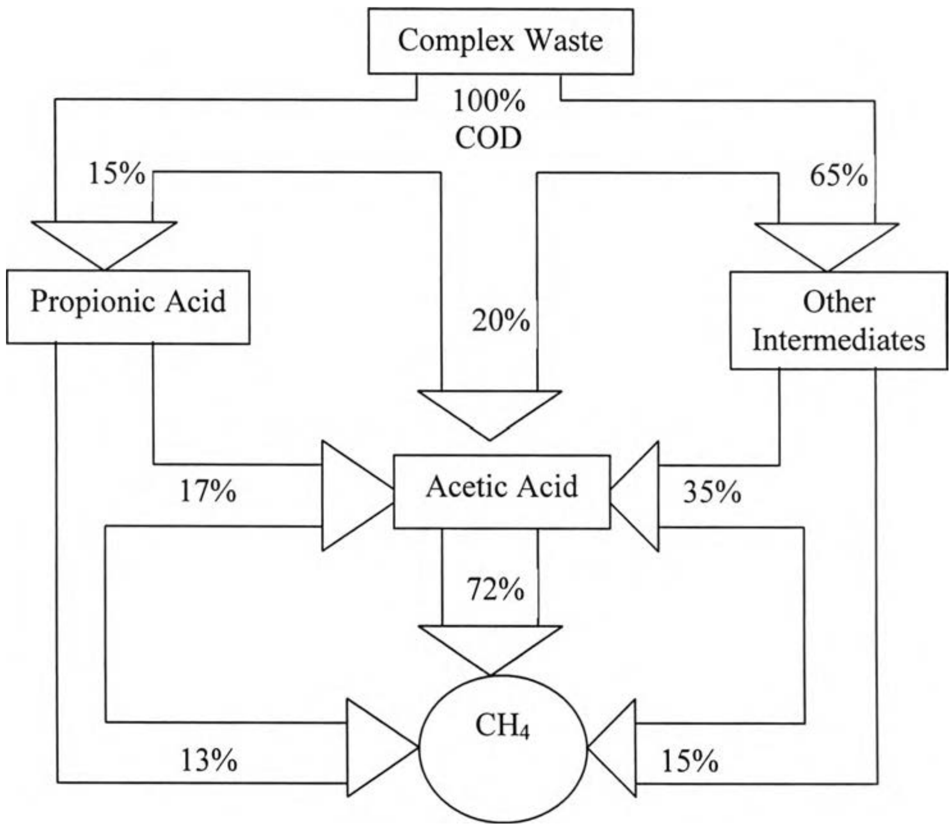

Figure 2.3 Pathways for Methane Fermentation of Complex Wastes
(**Source:** McCarty, 1964)

2.2.1 Phases of Landfill Stabilization

The solid waste stabilization processes in most Municipal Solid Waste (MSW) landfills have been shown to occur in five more or less sequential phases, encompassing; Initial Lag or Adjustment, Transition, Acid Formation, Methane Fermentation, and Final Maturation. These phases are identified and characterized by the changes in leachate and gas composition and production rates with time as shown in Figure 2.4.

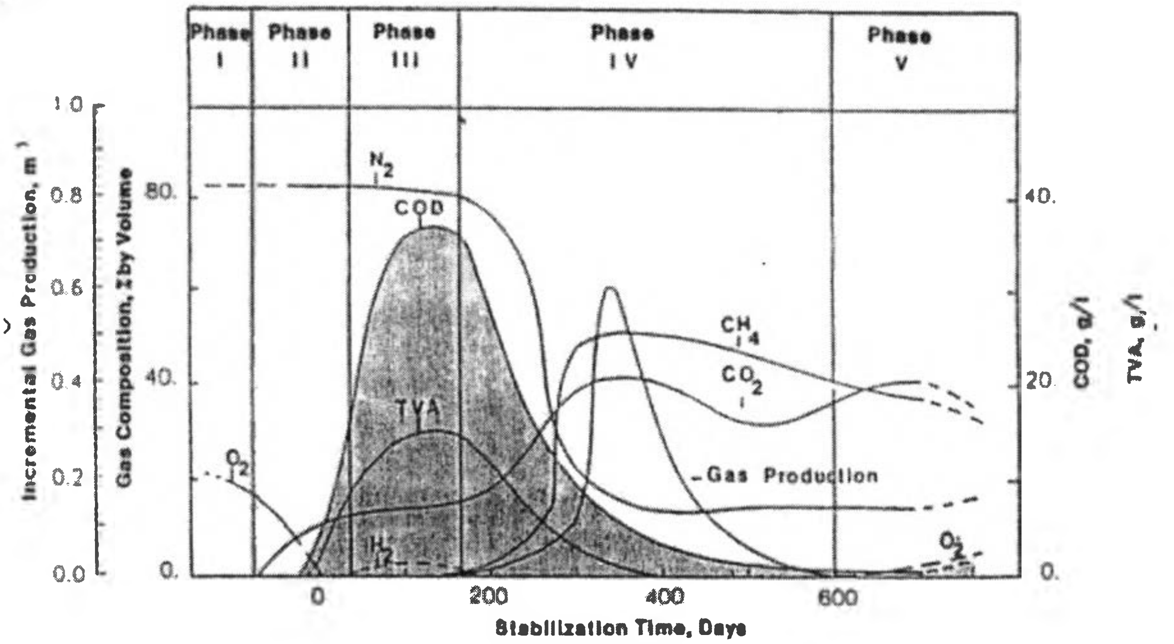

Figure 2.4 Changes in Selected Indicator Parameters During the Phases of Landfill Stabilization

Initial Lag or Adjustment is the first phase of waste stabilization and commences from the time of initial waste placement. In this phase, decomposition of waste material proceeds aerobically until the oxygen available and entrapped within the void spaces of solid wastes during filling operation is depleted. Moisture begins to accumulate and initial subsidence of each landfill compartment as well as changes in environmental parameters reflecting the onset of stabilization are observed.

Field capacity or a certain quantity of liquid that can be contained against the pull of gravity in a landfill cell is exceeded in Phase Two or the Transition Phase. Consequently, leachate is generated. During this phase, the primary electron acceptor shifts from oxygen to nitrate and sulfate and then to carbon dioxide. A transition from initial aerobic to facultative and anaerobic microbial stabilization occurs (Pohland, 1975). Intermediate products such as volatile organic acids first appear and increase in concentration in the leachate.

Acid formation, the third phase, is the period when significant amounts of volatile organic acids are produced by the continuing hydrolysis and fermentation of waste and leachate constituents. The accumulation of high quantities of volatile acids results in pH depression. Mobilization and complexation are found to be the principal mechanisms for increasing concentrations of heavy metal species in the leachate. Essential nutrients, nitrogen and phosphorus are released from waste and utilized at a rate commensurate with biomass development. Hydrogen gas is also produced and influences microbial metabolism and the types of intermediary products being formed (Chian and DeWalle, 1976; Pohland and Harper, 1986).

Methane Fermentation is the fourth phase of the stabilization processes in landfills. During this phase, the pH of leachate increases to neutral as the volatile organic acids are converted principally to methane and carbon dioxide, and carbonate-bicarbonate buffer system is again re-established. Oxidation-reduction potentials in the Methane Fermentation phases are highly negative and are indicative of highly reducing condition. Removal of heavy metals from leachate by precipitation and complexation with sulfide and carbonate anions proceeds. Excess sulfates and nitrates are reduced to sulfides and ammonia (Pohland, 1975). Leachate organic strength, as measured by chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and total organic carbon (TOC), drastically decreases as a result of volatile acids consumption. The methane percentages, as well as the rate of gas production are at their highest during this period.

Phase Five, final maturation, occurs after the readily available organics in the waste and leachate are depleted by the active waste transformation occurring in Phase Four. The rate of gas production diminishes significantly, since most of the available nutrients are consumed and the substrates that remain in the landfill are slowly biodegradable. Principal gases evolved are still methane and carbon dioxide (Chian and DeWalle, 1976). An increase concentration of nitrogen and oxygen may be found, as well as a reappearance of more natural environmental conditions. During this phase, the leachate is often observed to contain humic and fulvic substances. These microbially-resistant organic materials tend to form complexes with heavy metals, thereby remobilizing concentrations of heavy metals in the leachate.

The duration of the individual phase varies and is a function of climatological conditions, operation variables, management options, and landfill control facilities. Because solid waste is normally deposited in a landfill at different times as the elements of the landfill containment system are developed, the phases of stabilization discussed tend to overlap. In addition, the rate of stabilization is also different for each compartment of landfill. Hence, no landfill has a single "age", but rather a group of different ages associated with various compartments or cells within the landfill complex and their corresponding progress toward stabilization. Furthermore, the rate of progress through theses phases may vary depending on the physical, chemical, and microbiological conditions developed within each section with time (Pohland, Cross, Gould and Reinhart, 1993). For example, acid conditions established during acid formation may preclude the onset of active methane fermentation, microbial inhibition may be induced by the presence of toxic substances, or high compaction may restrict the movement and distribution of moisture as well as nutrients throughout the refuse mass (Pohland and Harper, 1986).

2.2.2 Factors Affecting Landfill Stabilization

Microbially-mediated waste stabilization in landfills, as in separate anaerobic digestion processes, is affected by a number of factors such as pH, temperature, availability of nutrients, the presence of inhibitory substances, moisture content, and preprocessing techniques. The effects that such variables have on stabilization processes usually manifest themselves in terms of leachate and gas characteristics throughout the active life of the landfill. The divergence from normal patterns of waste stabilization can be observed and related to changes in environmental factors, either individually or collectively.

pH, a measurement of hydrogen ion concentration, is a crucial parameter in anaerobic waste conversion. The normal operational range is 6.5 to 7.6, with an optimum pH between 7.0-7.2 (Parkin and Owen, 1982; McCarty, 1964). The pH of an anaerobic system is a function of both volatile organic acids and alkalinity concentrations, as well as the partial pressure of carbon dioxide evolved during stabilization (McCarty and Smith, 1986). During the Acid Formation phase, the carbonate-bicarbonate alkalinity buffer system is displaced by the volatile acid buffer system, resulting in a reduction in pH. This reduction to low pH does not only affect the rates of hydrolysis, liquefaction, and gas production, but also encourages mobilization of heavy metals that may be capable of inhibiting the overall conversion process.

Anaerobic processes usually function in either mesophilic (30 to 38 °C) or thermophilic (50 to 60 °C) temperature ranges (Kotze and Thiel, 1969). Ham, Hartz, and Klink (1983) studied the rate of methane generation from solid waste within the temperature range of 21 to 48 °C, and indicated that the optimum range was 41°C. The optimum temperature range for mesophilic anaerobic digestion reported by McCarty (1964) is 30-32 °C. Parkin and Owen (1982) recommended that a temperature as close to 35 °C as possible be maintained during anaerobic process start-up and recovery from upset. Regardless of operational temperature chosen, consistency of temperature is considered to be important for maximizing stabilization process performance. Nevertheless, temperature fluctuation in landfills is expected, since landfill temperature is not regulated and usually exhibits the influence of atmospheric temperature and insulation provided by surrounding cells as well as cover layers.

Efficient operation of anaerobic waste stabilization cannot be achieved without adequate supplies of nutrients. Macronutrient, nitrogen and phosphorus, are needed in larger amounts, whereas micronutrients such as iron, nickel, cobalt, sulfur, calcium, molybdenum, tungsten, selenium, and some organics are required in minute quantities for bacterial cell maintenance and synthesis (Chian and DeWalle, 1976). Nitrogen is needed for the production of protein, enzyme, ribonucleic acid (RNA), and deoxyribonucleic acid (DNA). Phosphorus is used to synthesize energy-storage compounds (adenosinetriphosphate – ATP) as well as RNA and DNA. Chian and DeWalle (1977) concluded that the upper limits of leachate COD:P and COD:N were 4360:1 and 39:1, respectively. However, a COD:P ratio of 2200:1 was determined sufficient for anaerobic digestion of fatty acids by McCarty and Speece (1963).

The presence of inhibitory substances is another concern. Conditions such as accumulation of volatile organic acids, high concentrations of ammonia nitrogen, sulfide, and heavy metals, or the presence of toxic substances are common causes of failure in many anaerobic digester operations. The extent of toxicity of each substance is associated with concentrations and forms, contact time, as well as acclimation ability of microbial consortia (Parkin and Owen, 1982; McCarty, 1964).

Ammonia is normally the decomposition product of urea or protein. Ammonia, a source of nitrogen for anaerobic bacteria, is stimulatory to the biological reactions.

However, at high concentrations, it may be detrimental to microorganisms. Soluble ammonia gas, which constitutes the majority of ammonia nitrogen at a pH higher than 7.2, is inhibitory at considerably lower concentrations than the ammonium ion. Inhibitory effects have been observed for an ammonia nitrogen concentration of 1,500mg/L, and concentrations above 3,000 mg/L have caused termination in gas production regardless of pH (Pohland, Cross, Gould et al., 1993).

Sulfide in anaerobic treatment originates from the reduction of sulfate or sulfur-containing inorganic compounds or the introduction of sulfide with wastes. Sulfides in soluble form have been reported to cause cessation in gas production at concentrations in excess of 200 mg/L, while concentrations of soluble sulfide varying from 50 to 100 mg/L can be tolerated in anaerobic treatment with little or no acclimation required (Parkin and Owen, 1982). The presence of heavy metals such as iron can lessen this effect, since metal sulfides can be formed and easily removed from solution by precipitation.

Small concentrations of heavy metals are necessary for proper functioning of bacterial enzyme systems. On the other hand, excess concentrations may lead to damage due primarily to the binding of metals with functional groups on proteins or replacing naturally occurring metals in enzymes (Parkin and Owen, 1982). Heavy metals can combine with sulfide, carbonate, or hydroxide to form precipitates. Nonetheless, their mobility is also dependent on pH and the extent of sorption and desorption, ion exchange, as well as chelation reactions taking place within refuse mass. Usually, only heavy metals that exist in free cation forms at concentrations above threshold are harmful to microbial life (Mosey, 1976).

Moisture content is considered important in anaerobic waste stabilization processes, since most physical and biochemical reactions occur in liquid phase or at the interface between phases. Liquid also serves as a transport medium for microorganisms and substrate, providing contact opportunity for reactions to proceed. Sufficient moisture content is critical for rapid stabilization within landfills, and the optimum ranges for maximum methane production were observed by Dewalle and Chian (1976) to vary between 60 and 78%. Typically, 25% moisture is a lower limit required for decomposition to begin. Major sources of moisture in landfill are from rainwater or snowmelt infiltrating final covers, water entering with solid waste, and water contained in various types of cover materials. After being placed in landfills, moisture content of solid waste is a function of its composition, state of decomposition, and the overburden to which the solid waste is subjected (Blight, Ball, and Blight, 1992). Moisture is excess of the holding capacity of the waste becomes leachate.

Distribution of moisture is also an important aspect. In a system with good moisture distribution, longer contact time between microorganism and substrate as well as greater amounts of accessible substrate are expected, resulting in higher waste conversion efficiency. This is evident for landfills where leachate recirculation is employed, since this technique is realized to promote a more thorough distribution of moisture throughout the refuse mass (Pohland, 1980; Pohland and Harper, 1986; Leckie, Pacey, and Halvadakis, 1979).

Mechanical volume reduction methods including shredding, milling, and grinding decreases the size of solid waste materials and increases the surface areas where bacteria can attach and proliferate, thus aiding in decomposition processes. Baled solid waste tends to retard the flow of water and may cause uneven distribution of moisture, leading to less complete and slower biodegradation (Pohland, Gould, and Ghosh, 1985). Sorting and recycling divert nonbiodegradable portions of the solid waste, minimize channeling and short-circuiting, and maximize effective exploitation of landfill space (Chian and DeWalle, 1976).

2.2.3 Parameters Indicative of Landfill Stabilization

There are certain traditional indicator parameters that can be used to indicate and describe the presence, intensity, and longevity of each phase of landfill stabilization. Both gas and leachate parameters are monitored and analyzed for this purpose.

Chemical Oxygen Demand (COD) is a chemical parameter indicative of the organic strength of leachate in terms of the amounts of oxygen needed to obtain oxidation of the chemically oxidizable fractions contained within the waste. The concentration of volatile organic acids (VOA) is closely related to the biodegradability portion of the leachate constituents, since during the Acid Forming

Phase, the majority of the COD is composed of VOA. pH and Oxidation reduction potential (ORP) are physical-chemical parameters and indicative of the oxidation-reduction and acid-base condition, respectively. Availability of essential nutrients, nitrogen and phosphorus, are assessed through the analyses of leachate ammonia nitrogen and orthophosphate, which are the readily available forms of both elements (Chian and DeWalle, 1976).

The abundance of methane, carbon dioxide, nitrogen, and oxygen in landfill gas is also characteristics of stabilization. Therefore, when considered along with aforementioned parameters, the manifestation of phases is obtained. Gas production data are also used to evaluate the extent of waste transformation as organics are converted to carbon dioxide and methane.

The intensity of these parameters is dependent upon the prevailing phase of landfill stabilization and is also influenced by operational management strategies, i.e., moisture management, buffer addition, and removal of inhibitory compounds; the nature of the waste; and closure and post-closure methods eventually applied (Pohland, Cross, Gould et al., 1993).

2.3 Compositions of Leachate

Leachate is defined as liquid that has percolated through solid waste and extracted dissolved or suspended material. The characteristics of leachate are reported in Table 2.1.

Table 2.1 Typical data on the compositions of leachate from new and mature landfills (**Source:** Tchobanoglous, Theisen, and Vigil, 1993)

Constituent	New landfill (less than 2 years)		Mature landfill
	Range	Typical	(greater than 10 years)
BOD_5 (mg/L)	2,000-30,000	10,000	100-200
TOC (mg/L)	1,500-20,000	6,000	80-160
COD (mg/L)	3,000-60,000	18,000	10-150
Total suspended solids (mg/L)	200-2,000	500	100-400
Organic nitrogen (mg/L)	10-800	200	80-120
Ammonia nitrogen (mg/L)	10-800	200	20-40

Nitrate (mg/L)	5-40	25	5-10
Total phosphorus (mg/L)	5-100	30	5-10
Ortho phosphorus (mg/L)	4-80	20	4-8
Alkalinity (mg/L as $CaCO_3$)	1,000-10,000	3,000	200-1,000
pH	4.5-7.5	6	6.6-7.5
Total hardness (mg/L as $CaCO_3$)	300-10,000	3,500	200-500
Calcium (mg/L)	200-3,000	1,000	100-400
Magnesium	50-1,500	250	50-200
Potassium (mg/L)	200-1,000	300	50-400
Sodium (mg/L)	200-2,500	500	100-200
Chloride (mg/L)	200-3,000	500	100-400
Sulfate (mg/L)	50-1,000	300	20-50
Total ion (mg/L)	50-1,200	60	20-200

The biodegradability of the leachate varies with time. Changes in the biodegradability of the leachate can be monitored by checking the BOD_5/COD ratio initially, the ratio will be in the range of 0.5 or greater. Ratios in the range of 0.4 to 0.6 are taken as an indication that the organic matter in the leachate is readily biodegradable. In mature landfills, the BOD_5/COD ratio is often in the range of 0.05 to 0.2. The ratio drops because leachate from mature landfills typically contains humic and fulvic acids, which are not readily biodegradable.

2.4 Related Works

Pohland, Cross, Gould et al. (1993) employed liquid management strategies at field-scale landfills that can be separated into two major types. The first type restricted water infiltration and allowed for single pass leaching. Moreover, the other treatment option employed in-situ containment, collection and recirculation of leachate through the refuse mass, thereby converting the landfill into a large fixed film anaerobic biological reactor capable of attenuating pollutional constituents. Leachate recirculation has been proven be an economical means of pretreating leachate by accelerating inherent waste stabilization processes occurring in the landfill.

Pohland (1975) research investigations included two experimental simulated landfill columns (one single pass and one recycle) loaded with shredded municipal solid waste. The experimental results indicated that the recycle column produced more gas than the single pass column. In contrast, leachate from the single pass column, which contained much of the gas production potential in the form of volatile organic acids, was removed from the system. Thus, leachate was not discarded from the recycle column and the gas production potential was not lost. However, if the interval of initial recirculation of high-strength leachate was too frequent, a delay in methane gas production could result.

Reinhart and Al-Yousfi (1996) obtained emerging data from full-scale recirculating landfills and these data support observations made from pilot- and laboratory- scale investigation, for instance; an acceleration of stabilization processes, leachate management opportunities and enhancement of gas production.

Komilis, Ham, and Stegmann (1999) suggested that controlled leachate recirculation, moisture and waste composition could result in a balanced anaerobic ecosystem. Leachate recirculation and addition of inoculum appeared to be effective if used in combination with nutrient and buffer addition.

Turajane (2001) investigated solid waste degradation behavior. Comparison of methane production efficiency from high solid anaerobic digestion with and without leachate recycle was performed. Batch anaerobic digestion was operated for 200 days. Initial conditions, such as quantities and compositions of solid waste as well as of anaerobic sludge seeded, were kept the same for both reactors. There were three phases of leachate recirculation depending on the volume of leachate applied. The amount leachate recirculation in the first phase was up to ten percents of the moisture available in the reactor. The volume of leachate recycled in the second and the last phases were 25 and 50 percent, respectively. Initial amount of waste was 45 kg with density of 450 kg/m^3. Increasing the recycle ratios from 10, 25, and 50 percent resulted in rising biogas production of 25.74, 156.2, and 129.14 liters, with percent methane content in off-gas of 40.88, 48.61, and 52.45 percent, respectively. Therefore, leachate recycle system was beneficial and enhanced a more complete conversion of organic waste to methane than a system with no recycle of leachate.

Šan and Onay (2001) studied the impact of various leachate recirculation regimes on municipal solid waste degradation, two landfill reactors, one with leachate recycle and one without, were constructed and placed at a constant room temperature

(34 °C). Both reactors were filled with 13 kg of municipal solid waste mixtures re. Leachate recirculation volume and frequency were changed periodically. The results showed that increased frequency of leachate recirculation accelerated the stabilization rate of waste matrix. About 2 L of recirculated leachate and four times per week recirculation strategy were found to provide the highest degree of waste stabilization. Additionally, the results confirmed that leachate recirculation is a very feasible way for in situ leachate treatment.

Rachdawong (1994) studied on the potential for using waste carpets as part of cover and liner system at municipal solid waste landfills. Two simulated landfill reactors were constructed, one with leachate recycle and one without. Both reactors were filled with a food waste to assure accelerated stabilization, establish the identity and maximize the homogeneity of the refuse. The results showed that the leachate recirculation management strategy employed enhanced waste stabilization processes occurring in the simulated landfill in terms of the time period required for stabilization and the extent of stabilization obtained, as reflected in gas volumes produced, gas production rates, gas composition, and leachate indicator parameters. The recycle reactor, whose leachate was contained, buffered, and recycled, provided a promoted contact opportunity for biomass with substrate, nutrients, and moisture that can be used for microbial growth and proliferation as opposed to the single pass reactor, whose leachate was continuously removed from the system. In addition, leachate generated from landfills practicing single pass leaching would pose a greater treatment challenge and the possibility of more adverse environmental impact if it was to migrate from landfill boundaries.