WASTE SETTLEMENT ANALYSIS

IN AN

AEROBIC BIOREACTOR

A Thesis

Submitted in partial fulfillment of the requirements of the award of the degree of

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Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the report title **"WASTE SETTLEMENT ANALYSIS IN AN AEROBIC BIOREACTOR"** in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Environmental Engineering and submitted in Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Shubam Abrol** during a period from August 2017 to March 2018 under the supervision of **Dr. Saurabh Rawat**, Assistant Professor and co-supervision of **Prof Ashok Kumar Gupta**, Head, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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DECLARATION

I hereby declare that the work reported in this report entitled **"WASTE SETTLEMENT ANALYSIS IN AN AEROBIC BIOREACTOR"** submitted at **Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr Saurabh Rawat,** Assistant Professor and co-supervision of **Dr Ashok Kumar Gupta**, Professor and Head. I have not submitted this work elsewhere for any other degree.

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ABSTRACT

Monitoring of MSW degradation in two aerobic simulated landfill bioreactors was done as a function of time during 150 days of operation. Operational characteristics such as leachate recirculation, waste settlement were monitored. In reactor 1, leachate produced is treated with ASP (activated sludge process having BOD and COD removal efficiency of 60% and 50% respectively) prior to its recirculation whereas in reactor 2, leachate is recirculated as collected. Two 54 cm x 54 cm x 54 cm tanks were fabricated using a Plexiglas sheet supported by an aluminum frame. Reactors are equipped with 9 ports; 3 ports are used for drainage and collection of the leachate, 2 ports are used for recirculation of the collected leachate and to control the bioreactor temperature, while the other 4 ports provide air into the bioreactor. A 10 cm aggregate layer is used as the bottom layer of the reactor to prevent the drainage tubes from clogging and regulating the leachate formed in the drainage pipes.

The municipal solid waste used in the reactor is a mixture of organic waste (25 kg) , plastic (5 kg) and paper (5 kg) to form a 25 cm layer. The total weight of the MSW layer used in the experiment is 35 kg with a density of 480.1 kg / m^3. An air pump with a flow rate of 12 L / min is used to create an aerobic condition inside the bioreactor. The leachate is collected and tested every 14 days from the beginning of the experiment. One liter of leachate is used to analyze the pH, the BOD_5 / COD ratio. In this study, the effect of the treated leachate recirculation and the recirculation of the untreated leachate in aerobic conditions on the degradation of urban solid waste is determined. Lab scale activated sludge process was set up for the treatment of leachate prior to its recirculation in one reactor. Two tanks of 6 liters capacity were used as aeration tank and settling tank. The reduction of COD and BOD_5 is 86.6% and 98.1%. This shows that the recirculation of leachate has increased the degradation of MSW. At the end of the experiment, it was found that the MSW settlement was 23.4 cm and 21 cm. Show that consolidation of the MSW layer is greater if the treated leachate is distributed. A variation of the reactor temperature is also observed over time.

Keywords: *Municipal solid waste, Treated Leachate recirculation, Waste settlement, Aerobic condition*

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BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
CAR	Continuous Aerobic Reactor
Cr	Chromium
Cd	Cadmium
Cu	Copper
IAR	Intermittent Aerobic Reactor
TDS	Total Dissolved Solids
Fe	Iron
H_2S_2	Hydrogen Sulphide
TVS	Total Volatile Solids
MSWLF	Municipal Solid waste Landfill
Ni	Nickel
Pb	Lead
VFA	Volatile Fatty Acid
NH_4^+	Ammonia
NO_3^-	Nitrate
Zn	Zinc
ASP	Activated Sludge Process

Chapter 1

INTRODUCTION

1.1 General

Landfills are used for disposing the solid urban waste in India and many other countries. Recently, waste management professionals have focused on use landfills closed for recreational or beneficial purposes (such as parks, golf courses, etc.), using landfill gas for energy production and reducing long-term post-closure monitoring and its associated costs. Even with these interests and concerns that come to the fore, they are still treated as an assistant. That is, they are not specifically addressed during the design phase. Rather, these problems receive more frequently the attention at the end of the process, the moment of the spill closure.

The traditional method of operating bioreactors in landfills entails the acceleration of stabilization of anaerobic waste. Recently, interest in the provision of air into solid waste for aerobic waste degradation has increased. Aerobic bioreactors have been used as a method to improve the stabilization of waste. Studies on these processes of aerobic biodegradation have shown that organic matter present in waste can be degraded in a relatively short period of time compared to anaerobic biodegradation.

The main components of a planned urban solid waste landfill (Figure 1.1) consist of relatively Waterproof bottom eyeliner and top cover systems completed with a lower leachate collection and disposal system to ensure that leachate accumulation never exceeds more than one foot on the lower lining. The leachate generated in the landfill is collected through the leachate collection system (LCS) located at the bottom of the landfill and is handled on site or off-site. Although current design protects the environment, it causes very slow degradation MSW due to low humidity and inadequate distribution of microbes and nutrients inside the MSW, raising environmental concerns for a prolonged period [1]. The slow degradation of MSW also causes a prolonged settlement that exceeds 50 years, it slows down the production of landfill gas and prolongs the monitoring period after closure.

In recent years, bioreactor landfills have emerged as a means of overcoming these problems conventional landfills. The Bioreactor landfills recirculate the leachate generated towards the landfill using different types of leachate recycling systems (LRS), increasing the humidity inside the MSW (Figure 1.2) improves moisture, nutrients and microbes biodegradation of MSW.

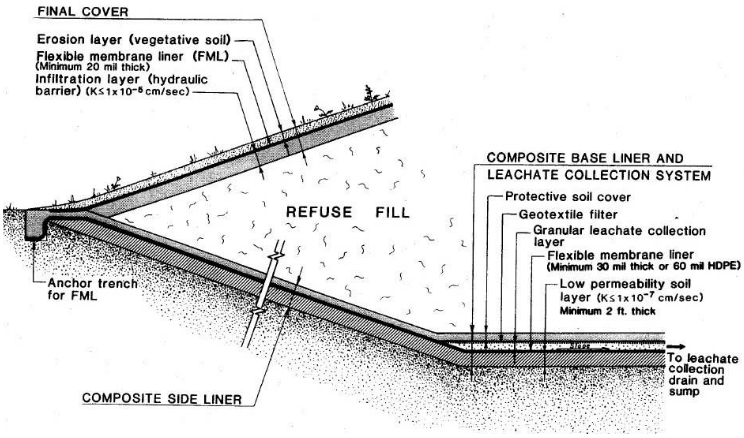

Figure 1.1 Municipal solid waste landfill with liner and final cover (Sharma and Reddy, 2004)

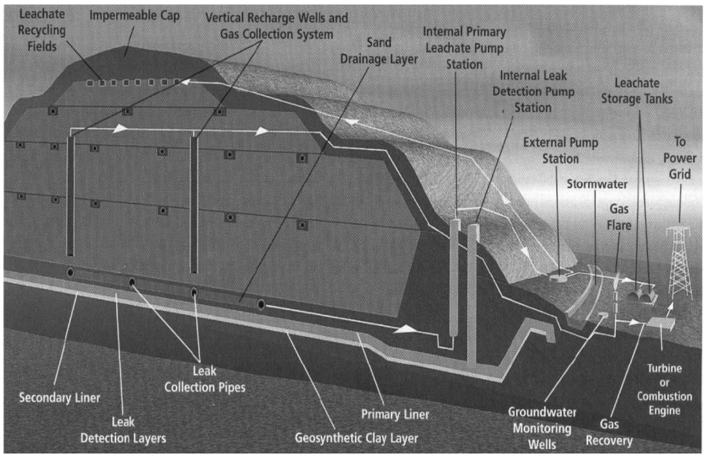

Figure 1.2 Municipal solid waste bioreactor landfill with liner and final cover (Source : Mazen M. and Milind V., 2005)

1.2 Bioreactor Landfill Fundamentals

A modern landfill bioreactor is specially designed for the faster degradation of the biological content in the MSW (typically 5 to 10 years) compared to a traditional landfill (typically 30 to 50 years or more) bioreactor operator dump aims to monitor, control and optimize the process of stabilization of waste rather than simply containing waste as required by regulations. If controlled and managed safe landfill bioreactors can provide a more sustainable and respectful management system with the waste environment than standard procedures. The modern bioreactor landfills are generally used for anaerobic processes in major countries. The anaerobic process in the bioreactor landfill has advanced gas collection system which reduces its chances to degrade the environment. However, the stabilization period of the waste mass is reduced in case of aerobic landfill as compared to anaerobic landfill [2]. In the aerobic landfills, higher settlement rates are expected. This was observed from most of the researches based on conventional aerobic landfills [3]. As underlined the most possible reason for the same is the rapid degradation of waste. The physical properties such as porosity and density are effected by the increased settlement rates of the waste. These parameters directly influence aeration inside a landfill.

1. Air addition: The most special and advanced feature introduced in the aerobic bioreactors is the addition of air. The oxygen present in the air favors the aerobic stabilization of the discharged waste. This process is similar to the traditional waste composting system. The decomposition of waste into an aerobic landfill is a faster process than anaerobic decomposition of waste. This aerobic technology also found to be helpful in cold regions where degradation of solid waste is a major problem.
2. Other factors: adding moisture and adding air are the main technologies to improve the stabilization of waste in bioreactor controlled landfills; sometimes other environmental conditions of landfills are also proposed for monitoring. These include temperature, pH and nutrient level. The optimal temperature conditions are between 34 and 40 ° C for mesophilic microorganisms and up to 70 ° C for thermophilic microorganisms. In cold regions, low temperatures can be problematic, therefore providing aeration to landfill waste helps to heat the reactor in the initial phase of the anaerobic bioreactor. Temperature control in

the operation of an aerobic bioreactor is a critical problem to prevent fires. There are three types of bioreactor technologies:

i. Anaerobic process
ii. Aerobic process
iii. Hybrid process

The three mechanisms provide for the re introduction of the collected leachate to maintain the level of moisture of the waste mass in the landfill. The microorganisms responsible for the degradation of the organic matter are stimulated to decompose at a higher rate in order to minimize harmful emissions. The bioreactor health landfill requires some system designs and changes in its operational characteristics in order to improve and control the stabilization process in the reactor. While recirculation of leachate through the waste mass is the most common liquid supply, other sources of adding moisture to the waste can also be considered.

1.3 Description of Aerobic Bioreactor

The aerobic process includes following reaction:

Degradable waste + oxygen $\longrightarrow$ CO_2 $+H_2O$ + heat + biomass + Acetic Acid + Residuals CO_2 + H_2O $\longrightarrow$ H_2CO_3 (Carbonic Acid)

In aerobic bioreactors, air is supplied to the landfill using vertical and horizontal pipes. The aerobic environment inside the reactor accelerates the rate of decomposition and the amount of VOC, the toxicity of leachate and methane are reduced to a minimum [4]. The bioreactor optimizes the conditions for microbial decomposition and accelerates stabilization and regulation.

•Bacteria present in the aerobic process of biodegradation are very active and decompose cellulose at a faster rate.

• A greater amount of sporogenic bacteria is present in the waste mass of the aerobic landfill; which helps in the constant decomposition of the waste mass even under the effect of environmental changes.

• In the anaerobic landfill, the decomposition of organic waste produces organic acid which results in the decreased growth of bacteria and hence slower stabilization rates.

• The aerobic bioreactor helps in the oxidation of the organic part of the MSW by breathing the bacteria to CO_2 and H_2O, so that the organic nitrogen is mineralized to NH_4 +.

• If there is sufficient amount of the dissolved oxygen (DO) and alkalinity is present, the NH_4 + is then further oxidized to NO_3- by the process of nitrification, which results in lower alkalinity and hence lower pH [5].

Therefore, it is important to create aerobic conditions in a landfill to enhance the process of stabilization of waste mass, as shown in Figure 1.3.

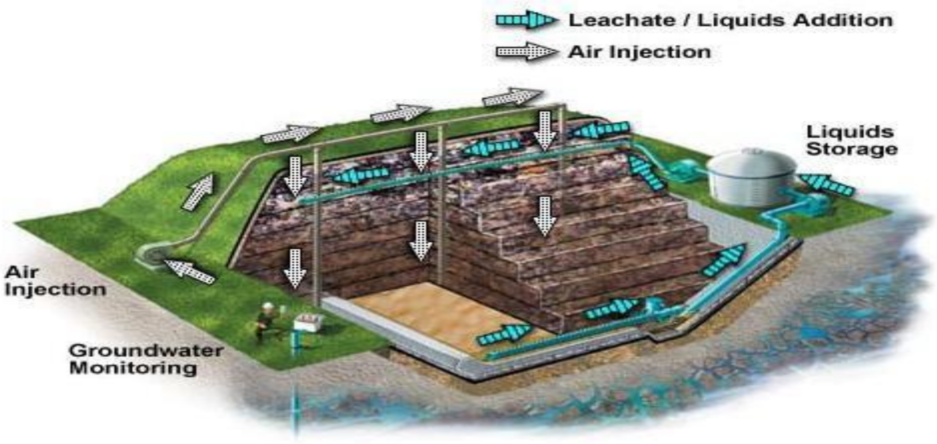

Figure 1.3 Schematic shows aerobic operation
[Source: United States Environmental Protection Agency]

The main difference between the traditional landfill and the aerobic bioreactor is the speed of decomposition. In traditional landfills, waste is buried in large wells and covered as shown in Figure 1.4. The waste is decomposed by bacteria and archaea in the conventional landfills generates many byproducts including sulphide (H_2S), N_2O_2 nitrogen oxide, etc.). Natural gas which is a green house gas produced in a larger proportion inside a landfill. So it is important to eliminate gas from the waste cell to eliminate the threat of explosion. Leaching is a fluid metabolic decomposition product and contains various types of dissolved metal toxins and ions. Leachate can cause health problems in both animals and plants if it escapes into groundwater. With the increasing amount of waste produced, it is very difficult to find the appropriate places for safe storage of waste.

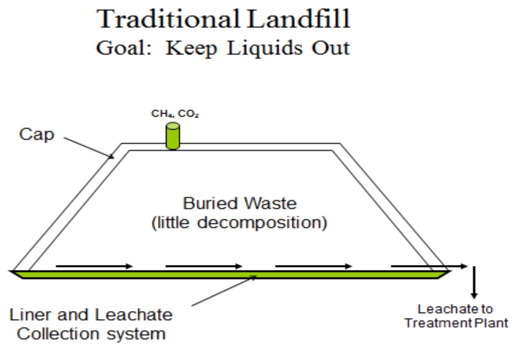

Figure 1.4 Schematic shows traditional landfill

Bioreactor landfills accelerate the decomposition process. As decomposition progresses, more waste space is created. These bioreactor landfills are generally designed so that they can save up to 30% of the landfill space by the faster degradation of the waste. The aerobic landfill bioreactor can provide a meaningful way to maximize landfill space. As this is not only effective, but also for landfills, it is also better for the environment, as shown in Figure 1.5.

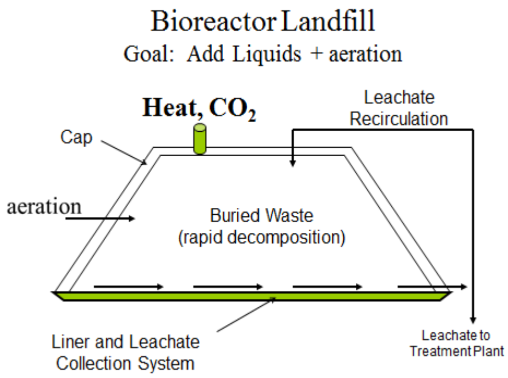

Figure 1.5 Schematic shows bioreactor landfill

In addition, most landfills have been in limits to reduce its impact on the surrounding through its emission from the last few decades. On the contrary, the new technologies are so developed that no monitoring should be required for a period of 10 years or even more. Therefore, the closed landfills can be used for other purposes like parks, parking etc. Furthermore, the reuse of the percolate to moisten the landfill is filtered as shown in Figure 1.6. Therefore, it makes the process more efficient by reducing the time and energy required for the processing of leachate.

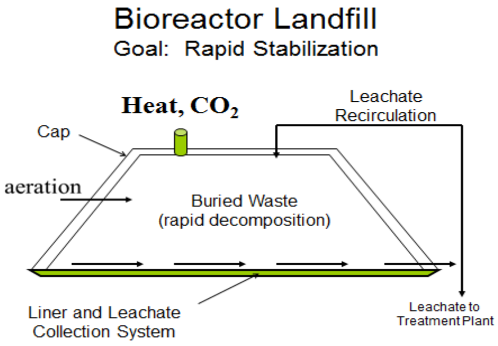

Figure 1.6 Schematic shows rapid stabilization

The aerobic process includes the following advantages over other processes:

- Working or closed landfills can be used as permanent community recycling facilities.
- The carbon contained in the waste combines with O_2 in the air to produce CO_2 and heat. The production of methane ceases.
- The aerobic process is 30 to 40 times faster than the anaerobic process.
- Leachate leaving the landfill is recycled back to the site, which minimizes the opportunity to break the design of the protection system to contain it.
- The percolates contain dissolved organic substances, which are processed by aerobic bacteria, which significantly improve the quality of the leachate, in particular the BOD level.
- Because the process generates substantial heat, most of the leachate is discharged into the atmosphere in the form of water vapor. This effectively reduces the amount of leachate and minimizes the possibility of a failure of the safety system.

1.4 Landfill Bioreactor Operation

There are many parameters that can be adjusted to increase the stabilization rates in a bioreactor landfill.

- Moisture content
- Addition of Nutrients
- Temperature
- Oxygen
- Frequency of recirculation
- Addition of buffers

1) **Moisture content**: Recommend that the moisture content is 25% and 40-65% for optimal degradation. If the moisture content exceeds 65%, the anaerobic condition will prevail due to the low level of airspace. If the moisture content is less than 40%, the activity of the micro-organism is inhibited.
2) **Proportion of carbon in nitrogen**: Nutritional requirements are generally met by the organic fraction of MSW. Microorganisms use carbon to produce energy and growth and nitrogen for protein synthesis and reproduction. C: N ratio is between 25: 1 to 30: 1. Phosphorus has been limiting in the subsequent stages of degradation.
3) **Temperature**: In general, the rate of degradation increases with increase in temperature. Up to an optimal temperature, specific for that particular microbe. It reported 40 ° C as optimal with a significant inhibition of more than 55 ° C. Oxygen: the aerobic conditions in the first stage would be the supply of air to the landfill. The aerobic micro-organism in the landfill would have rapidly metabolized the easily degradable organic.
4) **Circulation frequency**: The main advantage of the percolate recycling is that it increases the moisture content of the waste mass and reduces the quantity of leachate mainly due to evaporation. The other advantage is the treatment of leachate.
5) **Adding buffers** : Buffers are mainly important in the initial stages of the process when the chances of production of acids are high and pH values can

drop more quickly. Usually the pH is the problem. Alkalinity increases with the addition of lime or sodium to the leachate during storage.

1.5 Phases of Waste Decomposition

To understand the process of waste mass degradation in a landfill bioreactor it is necessary to know the principles of waste decomposition in the conventional landfills. Degradation of solid waste can be increased significantly by increasing the moisture content of the waste mass and concentrations of its components can be decreased in both aerobic and anaerobic landfills. Through percolation recirculation and degradation, the quality of the percolate of a bioreactor can rapidly improve, reducing the costs of leachate removal. The waste decomposition has five different phases, as shown in Figure 1.7. The quality and quantity of leachate and landfill gas has been characterized in each phase, thereby marking a remarkable change in microbial processes within the landfill [6].

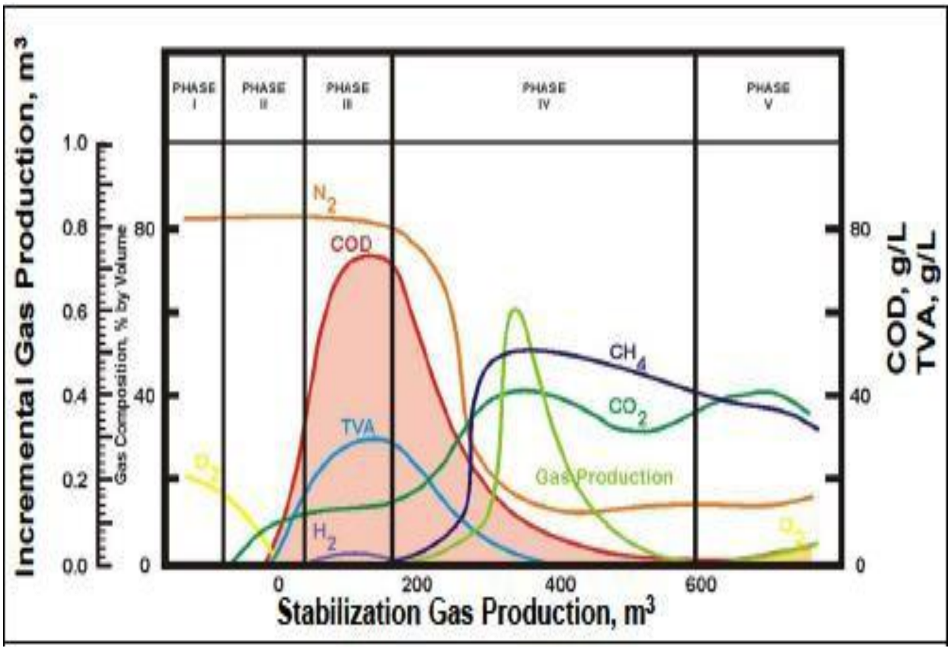

Figure 1.7 Waste decomposition phases taken from draft

(Source: Pohland and Harper, 1986)

Phase I (lag phase) is a period of acclimatization and the moisture present inside begins to gather and the aerobic bacteria starts consuming oxygen which is deposited in the waste cell.

Phase II (transition phase):this phase is reached when the moisture content inside the landfill increased to a significant level and due to the absorption of the oxygen the aerobic conditions starts to change into anaerobic conditions. The significant increase in the total volatile acids (TVA) and the chemical oxygen demand (COD) in the leachate signifies the growth of anaerobic bacteria inside the landfill.

Phase III (acid phase) : In this phase there is a significant decrease in the pH of the leachate due to the conversion of residues into TVA due to the presence of acidogenic bacteria. In this phase easily degradable organic compounds are produced in the form of liquid which initiates the process of hydrolysis. This rapid degradation process makes acidic conditions and a lower pH is observed and metals present inside starts to percolate with the leachate. Volatile organic compounds also percolate with the leachate. In this phase the values of BOD and COD in the leachate reaches to the maximum.

Phase IV In this phase the methanogenic bacteria converts the acidic compounds produced into methane and gaseous carbon dioxide. In this phase, the pH conditions become neutral from acidic conditions and there is a significant reduction in the metals and concentration of VOC. There is maximum production of landfill gas in this phase. Landfill gas production and the COD / BOD cycle follow similar first-order biodegradation constants.

Phase V marks the final stage of the process and the nutrients present inside starts limiting and there is a significant reduction in the biodegradable matter. In this phase there is a significant reduction in the production of landfill gas as well as in the leachate production, the leachate characteristics reach to a stable level and a slow degradation of waste mass is observed.

1.6 Thesis Organization

The first chapter of the thesis offers a brief introduction to the concept of aerobic waste landfill bioreactor. Several stages of decomposition of waste are also mentioned in this chapter.

The second chapter concerns the review of the available literature on landfill improvement techniques and the experimental studies that have been carried out for the study of landfills worldwide. The objectives and purpose of this study are also mentioned in this chapter.

The third chapter analyzes the step-by-step fabrication of the aerobic laboratory bioreactor reactor and a ASP setup. It includes the methodology used to configure the load, the positioning of the waste, the leachate collection system and the recirculation method of the cast for the bioreactor. This chapter also deals with the different experimental methods used to study the characteristics of the leachate. The effect of the leachate recycling in the MSW is also discussed in this chapter. The chapter also helps to analyze the general performance of the bioreactor with respect to the determined objective.

The fourth chapter concerns the results obtained from laboratory tests. Temperature variation and regulation over time is also discussed in the chapter.

The fifth chapter emphasizes the conclusions that can be drawn from the results on the characteristics of the leachate and the effect of leachate recirculation in the MSW. The reasons for the variation of the experimental results of the literature are also discussed.

Chapter 2

Literature Review

2.1 General

This chapter includes a complete review of the literature on aerobic bioreactors in landfills. The chapter deals with different landfill technologies, as well as techniques for improving aerobic fillings and several experimental studies on the aerobic landfill bioreactor. Although the current landfill project under research is environmentally friendly, but the solid waste degradation due to low humidity and inadequate distribution of microbes and nutrients within the MSW, raising environmental concerns for more than one time periods [1]. Also the slow degradation of MSW causes a prolonged settlement that exceeds 50 years, reduces the production of landfill gas and stretches the follow-up period after closure.

2.2 Bioreactor Landfills

A large-scale underground liquid injection model has been designed for bioreactor and dump sites. This model was used to understand the liquid distribution in the mass of waste when a drainage layer (DB) was used as recirculation of the percolate system (LRS) [7]. Vary the saturated hydraulic conductivity of the MSW underlying the DB and the liquid injection pressure heads understand the evolution of the degree of saturation (presented in terms of volumetric moisture content) and extension of the wetting face. The physical model of the unsaturated flow was 86 cm long, 30 cm wide and 56 cm high. A DB measuring 50 cm in length, 30 cm in width and 2 cm in thickness, with gravel as filling material, installed 17 cm from the top of the model. To measure the developed pressure and humidity levels in the landfill model, the researchers equipped with pressure transducers and humidity sensors inside the DB and in different locations throughout the MSW. Sand with saturated hydraulic conductivity that varies from 10^{-2} to 10^{-3} cm / s was used to simulate MSW in the dump under the cover, and the researchers explained that the range for the hydraulic conductivity of the sand would have generated the pressure head inside the model.

The leachate collection system was simulated using a perforated pipe and gravel of washed peas placed on a slope of 3% to collect the percolate. Because of recirculation of the leachate in the DB, presented the results of the effects of conductivity of the underlying soil in the pressure head and the degree of saturation, the effects of injection into the developed pressure head and the level of saturation in the soil, and the mode of leachate injection into the moisture distribution DB. During the experiment, they varied injection rate of the percolate from 80 cm^3 / sec to 150 cm^3 / sec and the saturation profile (presented in terms of volumetric moisture content).

The results indicate that the initial moisture content before the recirculation of the percolates was 100%. The capillary barrier effect in the deep layers of sand caused the initial humidity to migrate to the deep layers that cause that saturated condition. They recirculated the percolate until reaching equilibrium state (86 hours for coarse sand with saturated hydraulic conductivity of 10^{-2} cm / s, and 43 hours for fine sand with saturated hydraulics conductivity of 10^{-3} cm / s). The saturation profiles clearly indicate that it is time to reach the the steady state varies according to the saturated hydraulic conductivity and the percolation injection rate in the landfill model, although the initial humidity level in both arenas was the same. These results are useful for validating the numerical model, since it is also possible to implement numerical modeling the transient flow scenario in an unsaturated sand.

In recent years, bioreactor landfills have emerged as a means of overcoming these problems in conventional landfills. Percolated recirculation bioreactor fillers generated back to the filler using different types of leachate recirculation (LRS), increasing the humidity inside the MSW. The increase in moisture, nutrients and microbes improves the biodegradation of MSW. The increased degradation increases the production of landfill gas, making waste processing projects into energy are feasible, accelerating the landfill settlement and makes the projects then revealed to be less problematic, reduces or eliminates the cost of recirculated leachate treatment because with the need of the treatment of leachate on site or elsewhere, and stabilizes faster MSW, reduce the threat to public health and the environment.

In literature, landfills entailed circulation of leachate are called stramazzi leachate recirculation while landfills involving injection of leachate and other liquids (liquid sludge and modified hex) selected are known as bioreactor barriers. Although different types of injection fluids can be used, the ultimate goal of accelerating the biodegradation of MSW is the same. Therefore, the use of the term "bioreactor dumps" regardless of the type of liquid injected is valid and is used in this thesis. Bioreactor landfills are generally classified into three groups: aerobic, anaerobic and hybrid. Aerobic bioreactors involve air recirculation, while the anaerobic bioreactor leachate recirculation system generated in LCS through an LRS. On the other hand, the hybrid system uses the sequential recirculation of leachate and air in landfill accelerate the biodegradation of MSW. Of these options, the anaerobic bioreactor is more common used compared to the other two types of landfill systems. During pre-wetting, surface spray, surface ponds, vertical injection shafts (VW), horizontal ditches (HT) and drainage blankets (DB) are all used in practice.

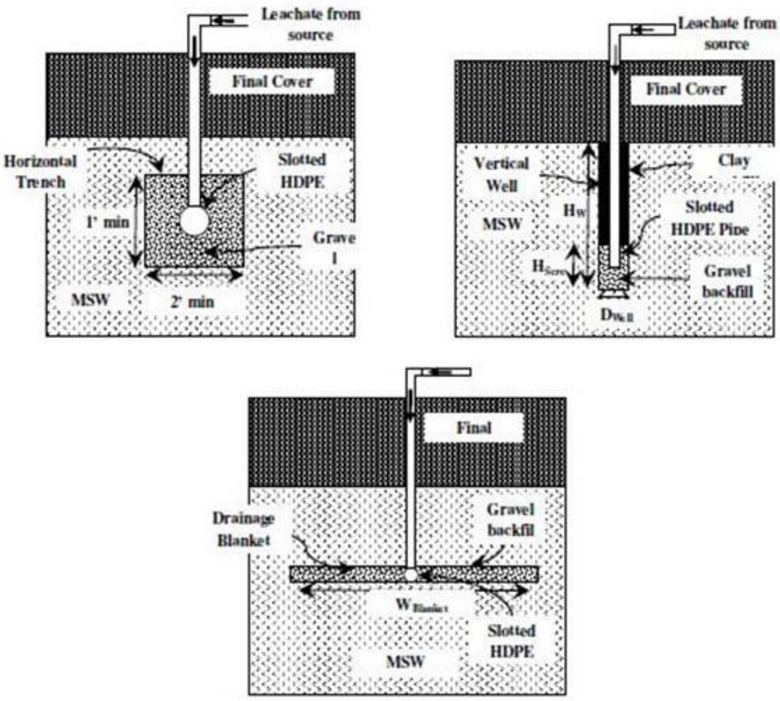

Figure 2.1 Commonly used leachate recirculation systems

(Source : Mazen M. and Milind V., 2005)

Of these leachate recirculation methods, VWs, HTs and DBs are most commonly used (Figure 2.1).

In most of the countries there are two main bioreactors used in the MSW management; one is the bioreactor in the containers and the other one is the bioreactor landfill. The discussion here is based on the bioreactor landfills.

The disposal of waste in a conventional landfill slows down the degradation process by reducing the entry of moisture, while the bioreactors accelerate the degradation process by controlling the entry of moisture (ie recirculating the leachate) and improving the cycle of nutrients and bacterial populations [8]. There are four methods of recycling leachate for bioreactors;

- Direct application
- Spray irrigation
- Surface application
- Subsurface application.

Surface application uses a pond like surfaces which is used to hold the leachate and recirculate it through the waste mass. In subsoil application, vertical injection wells or horizontal injection wells are used and pipes are installed inside the waste mass in a well defined manner. In bioreactor landfills, the goal is to achieve optimal biostabilization of waste. The landfill emissions from a Bio-destabilized waste would not be as much that can cause a threat to the environment [9]. The main components of the bioreactors are the leachate collection system, the leachate and the air injection, the landfill gas collection and the upper part of the geomembrane. In bioreactor landfills, as a result, the amount of leachate produced is lower than conventional landfills.

2.3 Aerobic Landfill Enhancement Techniques

The improvement of biological activity in a waste cell is primarily done by the increase in the quantity of leachate. In anaerobic systems it is achieved by adding nutrients, enzymes or other chemicals [10]. In past, only leachate recirculation is the effective method used for increasing the moisture content of the waste by most of the researches. As a result of early hydrolysis and the acidogenesis, leachate produced have high concentrations of acids. Changes in the leachate by means of nutrient integration, enzyme changes, temperature adjustments and accumulation of toxic compounds before recirculation of the leachate, which helps the biodegradation process to have significantly less attention. The literature concerning the increase in leachate is distinguished; additional buffers are added along with the addition of nutrients and sludge. The leachate from old landfill sites are used to enhance the process. The addition of mud is the most common practice among all other techniques. It was found that the degradation of lignin is increased significantly when additional enzymes are added to the waste deposited in landfills. However, the informed research was conducted for anaerobic conditions [10].

The improvement of the aerobic phase of a waste cell can be achieved in different ways; biocell temperature control, leachate growth and bioventilation. Techniques to improve aerobic composting, such as microbial inoculation, seed inoculation and the addition of mature compost can also be used for aerobic waste cells if experimentally proven [11].

2.4 Experimental Studies

A large-scale underground liquid injection model has been designed for bioreactor and dump sites, this model was used to understand the liquid distribution in the mass of waste when a drainage layer (DB) was used as leachate recirculation system (LRS). They varied the saturated hydraulic conductivity of the underlying MSW to the DB and the liquid injection pressure heads understand the evolution of the degree of saturation (presented in terms of volumetric moisture content) and extension of the wetting face [7].

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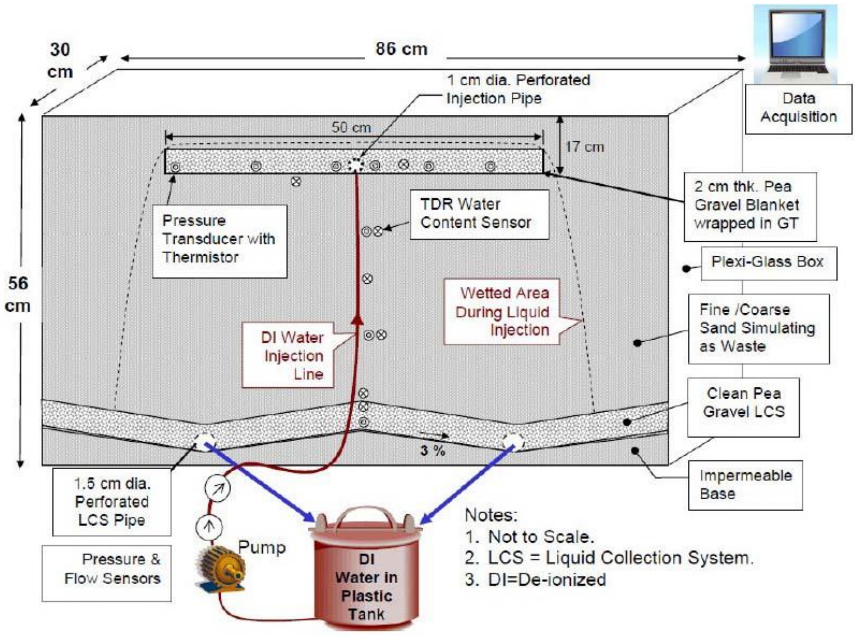

Figure 2.2 Schematic of the laboratory scale landfill model

(Source : Mukherjee and Khire, 2011)

The results indicate that the initial moisture content prior to the leachate recirculation was 100%. The capillary barrier effect in the deep layers of sand caused the initial moisture to migrate into the deep layers causing that saturated condition. They recirculated the leachate until the steady state was reached (86 hours for coarse sand with saturated hydraulic conductivity of 10^{-2} cm/s, and 43 hours for fine sand with saturated hydraulic conductivity of 10^{-3} cm/s). The saturation profiles indicate clearly that the time to reach the steady state varies with the saturated hydraulic conductivity and the leachate injection rate in the landfill model, although the initial moisture level in both the sands were same. These results are useful to validate the numerical model, since the numerical modeling can also be implemented to the transient flow scenario in an unsaturated the sand.

In recent years, bioreactor landfills have emerged as a means of overcoming these problems conventional landfills. The Bioreactor landfills recirculate the leachate generated towards the dump, using different types of leachate recycling systems (LRS), increasing the humidity within the MSW. The increase in moisture, nutrients and microbes improves the biodegradation of MSW. Improved degradation increases the production of landfill gas, which causes the energy generated by waste feasible projects, accelerate the liquidation of the landfill after closure less problematic development projects, reduce or eliminate the cost of leachate treatment recirculation it is not necessary to treat the leachate on site or off site and stabilize the Faster MSW, reducing the threat to public health and the environment.

The uniform and adequate distribution of humidity due to the recirculation of the leachate is of utmost importance for the further degradation of solid urban waste (MSW) in bioreactor landfills [1], [12], [13]. There are different types of leachate recycling systems, mostly horizontal ditches, vertical wells and draining blankets. Unfortunately, there are no rational methods for the design and operation of methods of recirculation of the leachate, which lead to a wide range of performances in field sites. the moisture distribution depends on the moisture retention properties of the MSW, however, only some studies inform about the moisture retention properties of the MSW and the moisture distribution in the bioreactor landfills. This chapter provides a general description of the literature that reports laboratory studies, field observations and numerical models on the moisture retention properties of the MSW and the moisture distribution in the MSW due to the recirculation of the leachate.

An assessment on the field of water infiltration through land cover and the generation of leachate in a landfill not long after its construction was conducted. This study summarizes the results of measurements of the moisture content carried out using neutron probes for a period of one year. These probes were located on the ground cover at depths ranging from 10 cm to 100 cm. The MSW samples were collected annually by drilling wells into two different cells at the depth of 2 m and 4 m below the lower limit of the ground cover. In each well there were two samples taken in every depth. The samples were mixed together and a representative measure of the moisture content of the MSW was taken. The results indicate that high infiltrated moisture soil, generating leachate in the landfill. Figure 2.3 shows the annual humidity variation calculated by the researchers in the landfill cell collected for a period of six years. Obviously, the the moisture content (expressed as a percentage of wet weight) has increased due to the initial moisture content and annual rainfall in the landfill. However, this study is missing information on the leachate collection system and its effectiveness in eliminating leachate process [14.]

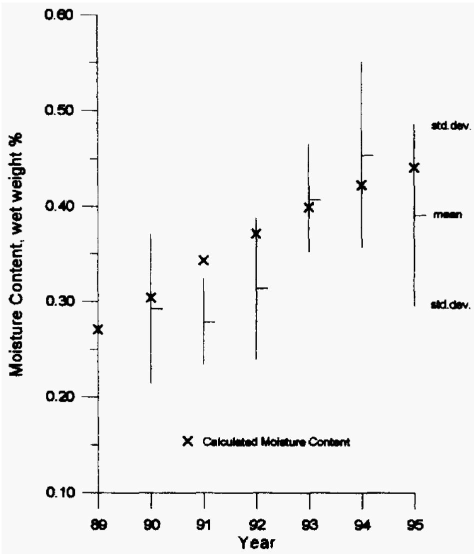

Figure 2.3 Total moisture content, mean, standard deviation measured in the municipal solid waste sample (Source: Bendz et al., 1997)

The first ever aerated landfill was developed by in the city of Fukuoka, Japan in 1975 [15]. This method of landfill is known as Fukuoka method. In this method air was injected through leachate collection tubes. These leachate collection pipes provide proper ventilation throughout the waste mass. The Fukuoka concept is illustrated in Figure 2.4 and a schematic diagram of a typical site is shown in Figure 2.5. Comparison between between semi-aerobic fillers and anaerobic fillers has been done experimentally [16]. The aerobic landill is found to have greater tendency of decomposing biochemical oxygen demand (BOD) as compared to anaerobic landfillls. In a semi-aerobic landfill, total nitrogen in the lower part decomposed by the nitrification and denitrification process. But in anaerobic landills there is no sufficient amount of oxygen present in the lower place and no nitrification could occur. This produces leachate containing a high concentration of nitrogen. Except in the lower layer, the overall amount of change in BOD was greater in the semi-aerobic fill type.

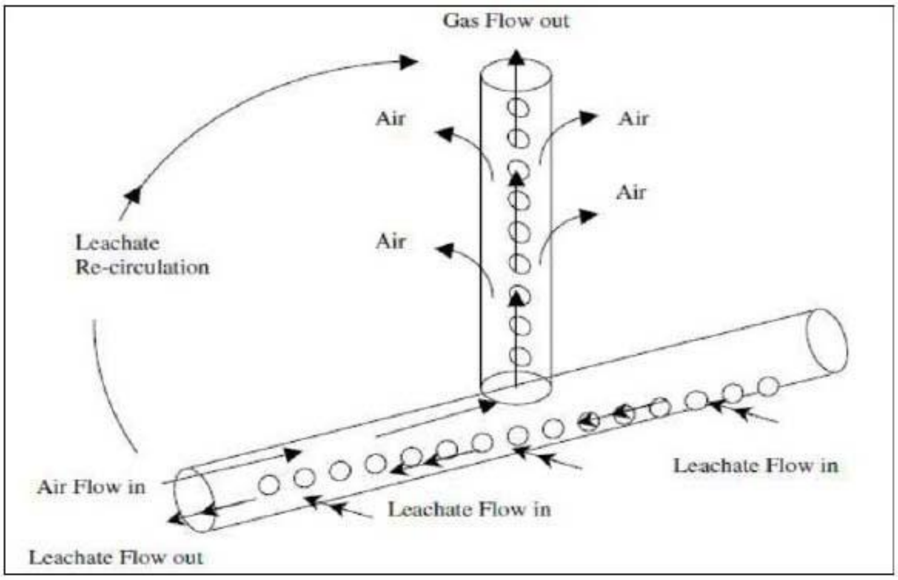

Figure 2.4 Fukuoka method concept (Source: Chong et al., 2005)

Another consideration worth analyzing is the effect of leachate recirculation in an aerobic landfill. A laboratory-scale model was developed to compare the parameters of the effect of leachate recirculation in an aerobic landfill and an anaerobic landfill. Water circulates to obtain the same moisture content for all scenarios [17]. They concluded that the introduction of air into landfills has accelerated the degradation of organic matter. Therefore, it helps landfills to stabilize first and reduces the weight of leachate treatment. Even at a relatively low recirculation rate, it was observed that the chemical oxygen demand (COD) of the leachate decreased significantly. Furthermore, the reduction of ammoniacal nitrogen (NH3-N) was more pronounced among the parameters of the percolate, by recirculating the percolate through a semi-aerobic filler [17]. The improvement of the aerobic phase of a waste cell can be achieved in different ways; control of the biocell temperature, increase in leachate and bioventilation. Improvement of aerobic composting also techniques such as inoculation of microbes, seed inoculation and addition of mature compost be used for aerobic waste stacks if tested experimentally [11].

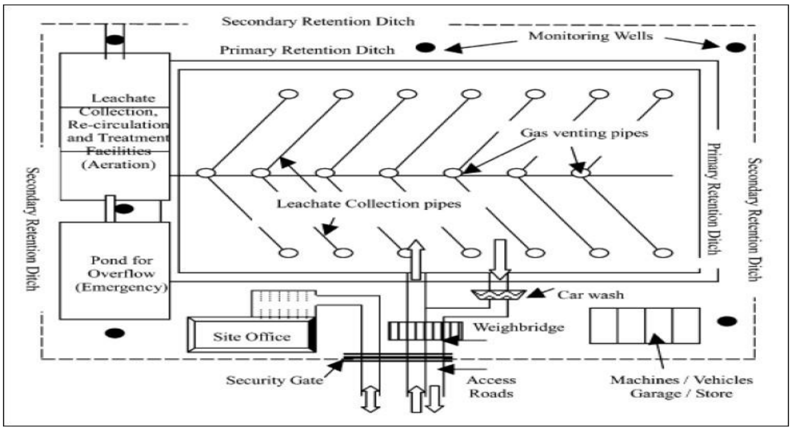

Figure 2.5 Semi-aerobic landfill site concept (Source: Chong et al., 2005)

Six methods were evaluated for measuring in situ humidity variation landfills: the neutron probe, the electrical resistance sensors, the electromagnetic, electrical techniques resistivity tomography, portioned gas detectors and fiber optic sensors. This study describes the intensive field application for each of these methods, including its operational principles and Limitations As cited by other researchers, these researchers emphasize the limits of use the neutron probes; you need extra care and requires a lot of documentation to get permission from the safety and environmental regulatory agencies to use it in the field [18].

The researchers also cite the extensive application of electrical resistance sensors for blankets composed of permeable drainage discussing examples of studies at the Yolo County dumps in California and a test site a Michigan. Based on data from resistivity sensors presented in the Yolo County literature Landfills, researchers illustrate weak correlations between sensor readings and humidity content of nearby waste. In general, they find that electrical resistance sensors can evaluate the infiltration of moisture in the MSW mass that originates in the injection pits, but it is not possible to estimate the moisture content in the MSW [19].

On the other hand, electromagnetic (EM) techniques such as EM waves, the domain of time reflectometry (TDR) and transmittivity in the time domain (TDT) have been developed specifically for estimate the moisture content Researchers also present the application of EM techniques in the field citing the Michigan test site applied. In general, they report that the EM techniques are temperature sensitive and have precise wiring for the instrumentation and a leached front The field application of electrical resistivity tomography (ERT) is also mentioned [20].

Researchers, who used an example of moisture routing through horizontal (HT) in ditches a French bioreactor landfill (Figure 2.6). The resistivity changes in Figure 2.6 indicate changes in moisture in the landfill where the negative resistivity indicates higher humidity content. In general, researchers see the utility of ERT mapping as a means of routing leached into the field in a bioreactor dump. Partition Trace Gas Testing (PGTT) involves the circulation of two tracers under constant gas flow conditions in the MSW.

The questions cited here include surveys carried out in the Yolo County landfills. PGTT measures the fraction of water in the pores of MSW, allowing the moisture content to be calculated While this test can estimate the moisture content, the expenses documented in the two sites, suggests that the number of hours spent by the staff needed to perform the test significantly affects the application of this field test.

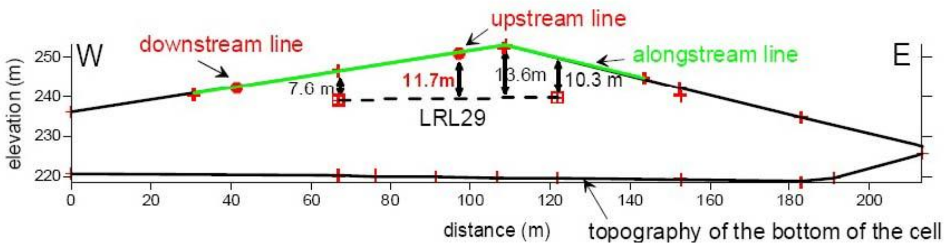

Figure 2.6 Topography of the cell above leachate recirculation line

(Source : Grellier et al., 2006)

Fiber-optic sensors, on the other hand, are inexpensive and can measure quickly temperature variations in MSW landfills. The researchers implemented fiber-optic monitoring system in two landfills in Finland to control temperature, leachate movement due to leachate recirculation, leakage through the surface sealing layer, the location of the filtration path and water table. Figure 2.6 illustrates the variation of the temperature levels measured in the Ammort rubbish dump. The smallest temperature increase, shown in the dark blue region, indicates the symbol higher content of volumetric humidity. Researchers indicate that the use of fiber-optic sensors I would estimate the variation in humidity in a bioreactor landfill. However, it is not validated for Measurement of moisture content So even if among all the methods that have been tested, the ERT and fiber-optic methods are the most effective for measuring in situ moisture content, both The methods must be evaluated for accuracy.

The effect of the leachate recycling on the behavior of the different options available for the sanitary landfill was studied. In this study, the quality of the percolate is studied by measuring pH, alkalinity, oxidation reduction potential, TDS, conductivity, chloride, COD, TKN and ammonia nitrogen. The author used an aeration flow rate of 0.06 l / (min kg). With this study, he concluded that the leached aerobic filler shows the lowest emissions of leachate, with low concentrations of COD, ammonia and TKN. The main difference between the recirculated leachate and the non-recirculated leachate was determined in its quantity [21].

The effect of age and seasonal variations of the municipal sanitary landfill on the characteristics of leachate was studied. The document discusses the effect of age and seasonal variations in the characteristics of leachate generated by the municipal waste disposal site (MSW) of Ludhiana City, Punjab (India). Percolate samples were collected and various physico-chemical parameters were examined to estimate their potential for contamination. The landfill of municipal solid waste is an open low-level landfill without design. It has no bottom coating or percolate treatment and collection system. Therefore, the leachate generated by waste finds its way to the environment. No leachate collection system has been tested in the landfill. In this study, samples of leachate were taken from the solid waste base where the leachate was drained by gravity. It has been found that the percolate contains high concentrations of organic and inorganic components above permitted limits. While, the concentration of heavy metals was in traces because the nature of the waste is domestic. The data presented in this study indicate that with the passage of time and with seasonal variations, mainly during the rainy season, the values of different parameters have increased, because the solid waste material has been degraded and the waste components have penetrated together rainwater [22].

The effect of air imports on the stabilization of waste was studied. The average airflow velocity was 18 L / min. Rates of oxygen utilization and biodegradation of percentages of organic matter showed that aerobic biodegradation was possible and adequate to proceed in an aerobic tipping bioreactor. It was observed by the study that the aerobic bioreactor can eliminate over 90% of COD and almost 100% of BOD. The percolated recirculation reduced the concentration of heavy metals aerobic process stops the production of methane, which is desirable for the region where the collection of methane is not feasible [23].

After understanding the waste degradation model and the composition of the individual methanogenic groups, it is essential to know the microbiology of landfills. The main objective was to characterize and evaluate the methanogenic range of Archaea in an intermittent aerated bioreactor dump filled ashes with incineration and shredded waste incombustible as a function of time using 16S rRNA based Hybridization, cloning and sequencing analysis membrane. The results indicated that rapid stabilization of solid waste is possible with the aerobic tipping bioreactor at various oxygen levels and oxidation reduction potential. The results of hybridization of slots transfer samples of leachate collected aerobic bioreactor landfill showed archaic and bacterial activities increased stabilization and increased bacterial populations including almost 95% of all microorganisms [24].

The dynamics and performance of the microbial population in conventional landfill was also studied, anaerobic and aerobic laboratory scale bioreactors for high organic waste content. It was found that the respective volumes of final waste at day 138 of conventional, anaerobic and aerobic reactors were 75%, 65% and 60% of the initial volumes. The recirculation of the percolate in the anaerobic bioreactor has accelerated the biochemical reactions and promoted the production of methane. However, leached by the anaerobic bioreactor showed concentrations of TOC and NH4 + -N that were as high as those of the conventional reactor. Aeration reduces the production of leachate and the concentration of methane and reduces the organic matter in solid waste and leachate. Furthermore, the MPN value of the amoA gene reached 105 MPN copies / g-dry in the aerobic bioreactor, in which nitrogen was removed from solid and leached organic waste. During the first 72 days, the MPN value of the aerobic bioreactor of the 18S rDNA fungal was the highest among the reactors, but decreased gradually. All reactors showed similar MPN values of 16S rDNA, nirS, and eubacteric nirK [25].

The rate of energy consumption in the aerobic landfill bioreactor is very high. Researches provided the solution to reduce the rate of energy consumption by providing intermittent ventilation to the landfill bioreactor. He studied the effects of intermittent aeration and continuous aeration on accelerated stabilization and on the dynamics of microbial populations in landfill bioreactors. Three reactors were operated without aeration, with cyclic aeration of 6 hours and absence of aeration of 6 hours and with continuous aeration. IAR's performance was the highest among the reactors. The organic compounds of carbon and nitrogen in the IAR and CAR scenarios showed significant reductions compared to those of CR. There have been important investigations on the assessment of the fate of nitrogen in biological treatment processes and in landfill leachate. However, only a limited number of these were made in situ disposal of ammonia in bioreactor landfills, although many researchers have suggested that ammonia nitrogen is the most important long-term pollution problem when considering full stabilization. and post-closure monitoring [26].

Evaluation of in situ removal of ammonia in an aerated waste bioreactor was done. The results confirmed the feasibility of rapid aerobic bioesthesia in an air-borne bioreactor operated at different ORP levels (from 400 to 150 mV). BOD5 decreased more rapidly than TOC and fell below 10 mg / l after day 120. Thereafter, it remained fairly constant until the end of the operating period. This rapid degradation of BOD5 in the aerated bioreactor in landfills has increased the possibility of nitrification by promoting nitrifying bacteria with high oxygen affinities. It is also very important to keep the pH close to neutral and the bicarbonate alkalinity could help. This was called "alkalinity generated by metabolism" within cells. Degradation of the cation that releases organic nitrogen compounds (proteins) could double the alkalinity concentration generated during protein biodegradation in organic solid waste. On the other hand, the alkalinity of the AGV contributes to the damping of H2CO3, but it is transient since the AGV varies and, therefore, can not be invoked in a coherent way. Therefore, adequate alkalinity or buffer capacity is required to maintain a stable pH in the digester for optimal biological activity [27].

The characterization of leachate and assessment of the impact on groundwater quality in the landfill area was done. An experimental study was conducted to understand the characteristics of landfill leachate and groundwater in the area near the landfill. samples of landfill leachate and groundwater Narela-Bawana (New Delhi, India) are collected. high concentrations of various physico-chemical parameters are observed in the collected samples, including heavy metals (Cr, Cu, Fe, Ni, Fe and Zn). This study deals with the assessment of potential concentrations of hazardous pollutants in groundwater over a period of time due to the discharge of pollutants from such landfill leachates into the soil nearby and, ultimately, groundwater. The results clearly indicated that groundwater contamination due to landfill leachate released. The results are compared with the Bureau of Indian Standards for drinking water. The presence of contaminants in the water table, particularly near landfills, warns quality and, therefore, makes the water table unreliable for domestic water supply and other uses [28].

The BOD COD report of landfill leachate of a mature surveyed over a period of six years to determine the indicator to be used to predict the characteristic leachate generated in the landfill. The results of the research show that the BOD: COD ratio is a good indicator of the degradation of organic matter in landfills. It can be used as an indicator of degradation of the organic substance in acetogen phase difference in methanogenic phase in this landfill. Temperature also plays an important role in stabilizing the landfill (Wang, Y. et al., 2012) have studied the effects of temperature on waste mode of long-term degradation, Emissions and post-closure dumps based management simulators. Pilot demonstration was used with seven anaerobic simulators (LSR) dumps to study the impact of temperature in the range of 20-46 ° C on emissions, features and long-term filling trends, due to a clear lack of knowledge in this area . The pilot has more than 1400 days. Higher temperatures accelerated waste degradation and gas generation, but also led to higher concentrations of COD and NH4-N leachate, prolonging the post-treatment period to meet effluent discharge limits. The temperature coefficient of the gas generation differs greatly from a few values reported in landfill simulation studies, but according to the relative hydrolysis solubilization behavior and provides more detailed information on the behavior of different landfill temperatures. Simulator results were applied in typical European conditions in a large landfill containing predominantly organic material, which gives the post-treatment duration over 200 years to reach the effluent discharge limits. Within the post-treatment period (around 200 years), mesophilic conditions engaged in high gas production and concentrations of leachate closer. The leachate pre-treatment process from the landfill and a specific leachate management system that are essential to achieve further profitable and shorter landfill cures. The results provide new information for assessing and modeling long-term landfill control strategies under various environmental conditions. [29]

2.5 Summary of Literature Review

Aerobic bioreactors have been studied all over the world in different pilot and field dumps. But in all of those studies leachate is recirculated without any pre treatment. The bioreactors optimize the conditions for microbial decomposition and improve the stabilization rate, allowing additional or faster re-use of the soil. To improve the decomposition of organic and inorganic matter, various techniques have been developed, such as the addition of additional water / leaching, shredding of waste, compaction of waste and regulation of pH. It has been found that the rate of degradation under aerobic conditions is faster and could reduce stabilization time and increase mass sedimentation rates of MSW. The leachate recirculation increases the moisture content and provides better contact between the microorganisms, the soluble nutrients and the insoluble substrate. It can also reduce the cost of leachate treatment. Aeration in the reactor interrupts the production of methane, which is desirable in the area where gas collection is not feasible. In the aerobic bioreactor, nitrification and denitrification can occur simultaneously, which helps eliminate ammonia from the leachate. The main difference between the recirculation and non-recirculation aerobic operations is determined by the amount of leachate. The impact of treated leachate recirculation on the MSW is still unknown.

2.6 Objectives

Based on the literature review, the project objectives were determined.

- To investigate the effect of treated leachate recirculation on degradation of MSW layer in a lab scale aerobic bioreactor.
- To carry out a comparative study between MSW degradation under treated and untreated leachate recirculation.
- To examine the leachate characteristics.

2.7 Scope of the Project

In the literature review, it was found that there are very limited researches regarding recirculation of treated leachate. Regarding studies carried out all over the world, there is no pre treatment of leachate prior its recirculation. During the bioreactor operation, gas emissions are observed. The study of these gases helps to better understand the decomposition of waste through different phases that occur over time. It is also noted that the gas generation from a bioreactor also depends on factors including the composition of the waste, the age of the waste, the pH, the temperature, the moisture content and the size of the waste particles. Therefore, this could be an area of study for future researchers. The recirculation of the leachate increases the moisture content inside the reactor. Increasing the moisture content can reduce the structural stability of the landfill by increasing the interstitial water pressure inside the waste. Thus, it is possible to study the effects of moisture content on bioreactor performance. The slope stability analysis can also be performed to study the structural stability of the bioreactor and, consequently, of landfills. Furthermore, leachate treatment with activated sludge process is found to have a positive impact on biodegradation of waste, thus there is a lot of scope and this type of laboratory as well as field studies can be done in a large scale to better understand the effect of leachate treatment prior its recirculation.

Chapter 3

Methodology

3.1 General

The materials used for fabrication of the aerobic landfill reactor are presented in this chapter. This chapter also discusses the effect of leachate recirculation on the degradation of MSW. The chapter focuses on the experimental test done to characterize the leachate. The experimental methodology of each experiment is discussed separately. The response of MSW on leachate recirculation is also covered within this chapter.

3.2 Materials

3.2.1 Municipal solid waste

35 kg of MSW were added to the reactor. Organic waste was collected from Jaypee University and other wastes were collected from the municipal solid waste landfill in the nearby area. This residue was manually separated and ground before being added to the reactor. Crushed waste provides a large surface for digestion. Waste shredding is performed to homogenize by reducing size and mixing, increasing the specific surface of the waste components for biodegradation and increasing permeability by reducing the impermeable materials and facilitating water distribution [30]. The final composition of bioreactor waste is shown in table 3.2.

Table 3.1 MSW composition in the landfill bioreactor

	Organic	**Paper**	**Plastic**	**Total**
Weight (kg)	25	5	5	35
Percentage (%)	71.43	14.28	14.28	100

3.2.2 Aggregate

Aggregates of different grades were used in the reactor. Grades of 10mm, 12mm, and 16 mm were used. Sieve analysis was done for the grading of aggregates. Grading of the aggregates was carried out to ensure two conditions:

1) Uniform distribution of the leachate.

2) Provide adequate drainage path for the leachate produced from degradation of MSW.

3) Specific gravity of aggregates with different grades was calculated to find out the exact quantity of the aggregates of different grade required in the aerobic bioreactor as shown in table 3.1.

Table 3.2 Specific gravity of aggregate (IS 2386 Part 4 1963)

Grade of Aggregate	Specific Gravity	Weight of Aggregate
10mm	2.41	15.0 kg
12mm	2.58	16.0 kg
16mm	2.50	15.6 kg

3.3 Lab scale aerobic bioreactor setup

Fig. 1 and Fig. 2 shows the schematic diagrams of two lab-scale setup of aerobic reactors used in this study. The simulated aerobic bioreactor consisted of a 158 L tank made of Acrylic (0.54 x 0.54 m).

Two tanks of dimensions 54 cm x 54 cm x 54 cm were fabricated. The Perspex sheet is used to build a laboratory-scale bioreactor. An aluminum frame is provided along the joints. A 5-liter capacity tank was installed on the bottom of the bioreactor to collect and store the leachate. Figure 1 shows that the leachate collected from the bottom of the reactor is transferred to the ASP tank for its treatment. The treated leachate is then injected on the top layer of MSW from the port provided at the top of the reactor.

The leachate is recirculated and sprayed on the upper layer of the MSW. The air was injected into the bioreactor using four vertical perforated tubes at each corner while the excess gas accumulated at the top and escapes from the port provided at the top of the reactor. The reactor is equipped with 9 ports; 3 ports are used for drainage and collection of the leachate, 2 ports are used for recirculation of the collected leachate and to control the bioreactor temperature, while the other 4 ports provide a constant flow of air into the bioreactor. PVC pipes were used for reactor accessories. Half-inch PVC pipes were used for the drainage system. To regulate the leachate formed in the drainage pipes and prevent the drainage pipes from becoming clogged, a layer of 10 cm aggregates is used as the bottom layer of the reactor.

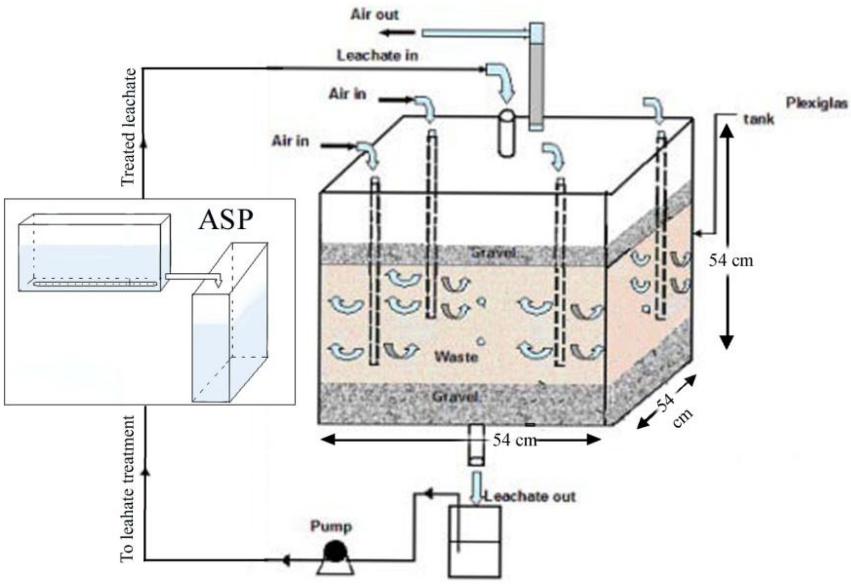

Figure 3.1 Schematic diagram of the aerated bioreactor landfill (Reactor 1)

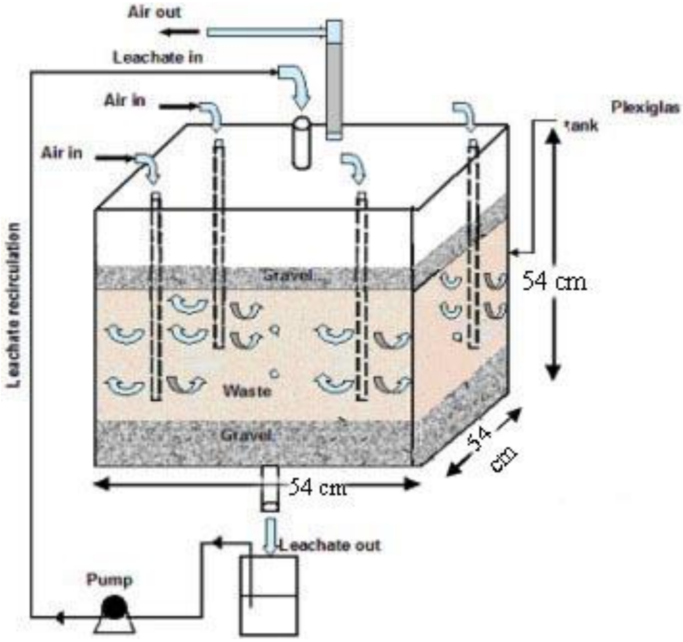

Figure 3.2 Schematic diagram of the aerated bioreactor landfill (Reactor 2)

3.3.1 Loading of the reactor

A thick layer of 10 cm of aggregate was placed in the reactor, which forms the lower layer of the reactor. Aggregates were added to the reactor to prevent clogging of drainage pipes and to provide a uniform distribution of the percolate to the waste. 35 kg of MSW were added to the reactor. Organic waste was collected from Jaypee

University and other wastes were collected from the municipal solid waste landfill in the nearby area. This residue was manually separated and ground before being added to the reactor. Crushed waste provides a large surface for digestion. Waste shredding is performed to homogenize by reducing size and mixing, increasing the specific surface of the waste components for biodegradation and increasing permeability by reducing the impermeable materials and facilitating water distribution (Coelho, 2003). The residue was manually mixed and placed inside the reactor to reach a density of 480.1 kg / m3. This density of the MSW layer is decided by the density range provided by (Coelho, 2003). For the MSW level a specific height of 25 cm has been reached. In a large landfill with medium to high compaction, the density is generally between 400-700 kg / m3 and this was necessary to achieve adequate fluid flow through the laboratory MSW bioreactor [30]. The placing of the municipal solid waste layer is carried in the following manner.

1. An aggregate layer of 10 cm thick is placed on the bottom of the bioreactor to avoid obstruction of the exhaust pipes in the lower part, the metal mesh is fixed at the inlet of the exhaust pipes.

Figure 3.3 First layer of aggregates

2. The waste is crushed to increase the specific surface for digestion. A 25 cm thick MSW layer is placed over the aggregate layer. The thickness of the MSW layer was based on the target density of 480.1 kg / m^3.
3. Finally, after compacting, a 5 cm thick aggregate layer is also placed MSW layer to ensure uniform recirculation of the leachate.

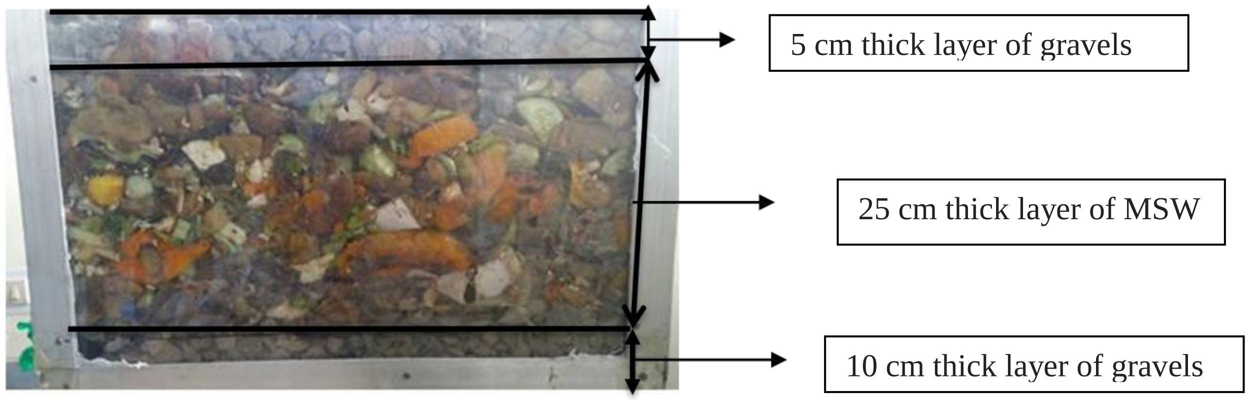

Figure 3.4 Complete filling of reactor

3.4 Preparation of ASP tanks from Perspex Sheet

Figure 3.3 shows the lab-scale setup of ASP used in this study. The lab scale ASP consisted of two tanks of 6 L capacity made of Acrylic. One tank is used for the aeration of leachate called aeration tank (0.30 x 0.10 x 0.20m) and the other tank is used for the settlement of organics present in leachate called the settlement tank (0.10 x 0.20 x 0.30m). The air diffuser and air blower is used to supply continuous air to the waste water (leachate) in the aeration tank. When air or oxygen is forced into leachate to develop a biological floc, it reduces the organic content of the leachate. Settling tank is equipped with two ports; one port is used to collect the treated leachate and the other port is used to return the activated sludge in the aeration tank for further treatment.

3.4.1 ASP operations

Whenever leachate is collected from reactor 1 is then fed into the aeration tank of the ASP. The air is provided to the leachate through air diffusers provided at the bottom of the tank. The hydraulic retention time of the ASP was about 60 minutes. After providing aeration leachate is then transferred to the settling tank for the settlement of solids. The leachate is kept there for about 12 hours and treated water is collected whereas activated sludge is again transferred to the aeration tank for further retreatment. Figure 3.11 shows the operation of lab scale ASP.

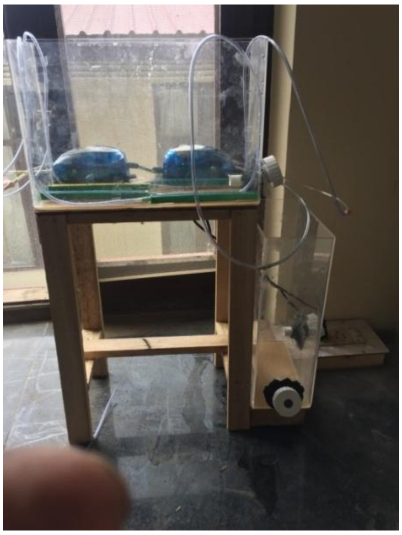

Figure 3.5 Lab scale ASP

Figure 3.6 Operation of lab scale ASP

3.5 Leak test

After fabrication of the reactor, leak test was done. The reactor was filled with water to check the different leakage points as shown in figure 3.4, figure 3.5 and figure 3.6. The reactor was kept like this for 2 hours and after 2 hours water was drained out of it through drainage pipes. Then the epoxy resin was used to fill the leakage points before loading the reactor.

Figure 3.7 Aeration tank filled with water

Figure 3.8 Settling tank filled with water

Figure 3.9 Reactor filled with water

3.6 Instrumentation

The reactors are studied under aerobic conditions to better understand the effect of aeration on the degradation of solid waste. The leachate collected from port 1, 2, 3 in storage bottles is recirculated once a week in both the reactors. The only difference is that the leachate is treated before recirculating in reactor 1. The air inlet at the top of the reactor is connected to an air pump as shown in Figure 3.9 that works at 12 L / min to maintain aerobic conditions. Daily temperature variations were measured with the help of a multiple thermometer as shown in Figure 3.10.

Figure 3.10 Air pump

Figure 3.11 Digital Thermometer

3.7 Testing Procedure

Leachate samples were taken after every 14 days right from the start of the experiment from the ports provided at the bottom of the tank to evaluate leachate quality and the stability of the waste mass. Chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), pH, TDS were determined. All these analyses were performed in accordance with standard methods for the examination of water and wastewater IS: 3025 APHA 22^{nd} edition 2012.

3.7.1 Determination of Biological Oxygen Demand

The biological oxygen demand test is based on a biological test procedure that measures the dissolved oxygen consumed by microorganisms by assimilating and oxidizing the organic matter under aerobic conditions. This test condition includes the incubation of the samples in an airtight bottle in the dark at a specific temperature of 20°C and a specific period of 5 days. In this test sample is diluted by adding distilled water into the BOD bottles. Then the reagents are added to the bottles as shown in Figure 3.11. A bottle is kept in the incubator for 5 days at 20 ° C. The MnSo4 and Azid solution are then added to the remaining bottles, as shown in Figure 3.12. The sample was then titled to calculate the OD of the day as shown in Figure 3.13. The same test is repeated for 5 days DO. The BOD test was also performed using the BOD remote sensor shown in the figure 3.14. This provides BOD values only by injecting the machine into the BOD bottle. The formula used for the calculation of 5 days BOD is detailed below

Day 1 DO = 7.95 mg/L

DO after 5 days = 2.9 mg/L

$$\text{Dilution factor} = \frac{300mL}{0.05mL} \quad (1)$$

$$\text{BOD5} = (7.95 - 2.9)\frac{300\ mL}{0.05\ mL} = 30{,}300\ mg/L \quad (2)$$

3.7.2 Determination of Chemical Oxygen Demand

The COD test is performed using the following reagents:

1) potassium dichromate + dash of sulfonic acid. The sulfonic acid helps eliminate nitrates and nitrites.

2) Mercury sulfate which helps to eliminate the interference of chlorides that form complexes with chloride ions.

3) Ferrous ammonium sulphate has been used as a titrant.

COD Acid (concentrate of H_2SO_4 and $AgSO_4$) 10 ml of leachate sample and 10 ml of blank sample were taken in a reflux flask as shown in figure 3.15. A sample of $HgSO_4$, 5 ml of potassium dichromate solution and 15 ml of COD concentrated acid were added to the samples. Then the samples were placed in the COD digestion unit as shown in Figure 3.16 and then the tubes were covered with capacitors. The samples were heated to reflux for 2 hours at 150° C. After 2 hours. The samples were removed and titrated using FAS as titrant and iron as indicators shown in Figure 3.17. The samples were titled until the color changed to red wine, as shown in Figure 3.18. Thus, the COD of the sample is calculated using the formula.

$$COD = \frac{(V1 - V2) \times N \times 8 \times 1000}{vol\ of\ sample\ taken} \times Dilution\ factor \qquad (3)$$

Where,

V_1= mL Ferrous Ammonium Sulphate [$FeSO_4\,(NH_4)_2SO_4$] used for blank solution

V_{2} = mL Ferrous Ammonium Sulphate [$FeSO_4\,(NH_4)_2SO_4$] used for sample

N= Normality of [$FeSO_4\,(NH_4)_2SO_4$]

V_1 = 3.4 mL

V_2 = 2.2 mL

$$COD = \left[\frac{(3.4 - 2.2) \times 0.11 \times 8 \times 1000}{2.5}\right] \times 50 = 21{,}120\ mg/L \qquad (4)$$

3.7.3 Determination of pH

The pH value is determined by measuring the electromotive force of a cell consisting of an indicator electrode immersed in the test solution and a reference electrode. The contact between the test solution and the reference electrode is generally obtained by means of a liquid junction, which is part of the reference electrode. The electromotive force is measured with a pH meter, which is a high impedance voltmeter calibrated in terms of pH, as shown in Figure 3.12. In this test, the buffer solutions and samples were brought to room temperature. The pH meter has been standardized with a pH solution of 6.2 and 4.1. Then, the electrode was immersed in the sample and the reading was performed.

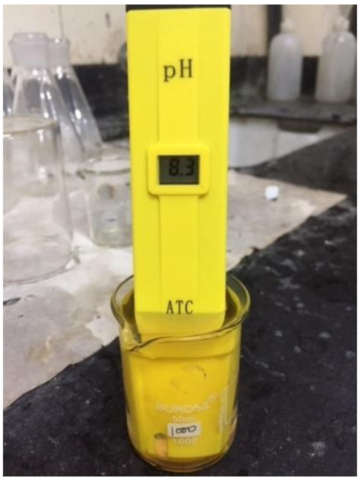

Figure 3.12 pH meter showing the pH value of the sample

3.7.4 Determination of TDS

The total dissolved solid test indicates the amount of solids present in the dissolved sample. In this test, the glass plate with 100 ml of sample is weighed and placed in the oven at a temperature of 103-105 degrees Celsius for 24 hours. After 24 hours, the plate is removed from the oven and weighed again on the scale. The result is calculated using the formula.

$$\text{TDS} = \frac{(A - B) \times 1000}{V} \qquad \text{(v)}$$

where

A = weight of dish + residue in mg

B = weight of dish in mg

V= volume of the sample taken in ml

A =88624.7 mg

B= 87794.2 mg

$$TDS = \frac{(88624.7 - 87794.2) \times 1000}{100} = 8305\ mg/L \quad (6)$$

3.8 Waste Settlement analysis

The prediction of landfill disposal is one of the important parameters that influences the design and maintenance of bioreactor landfills. Due to the large number of variables involved in the settlement mechanism, accurate regulation of landfill regulation is a real challenge.

The recirculation of leachate increases the moisture content inside the reactor which accelerated the process of waste degradation and causing waste settlement to occur. The main component of waste due to which settlement occurred is the presence of organic waste. The organic waste is decomposed by the aerobic bacteria readily under the influence of leachate recirculation. The measurement points were taken every 9 cm in the cell in order to have more representative results. The measurements were taken after every 30 days during the experiment. The parameters are increased with the increase of the concentration of enzymes and with the presence of mud both in the aerobic and anaerobic phase. The increase in the organic content of MSW has led to an improvement in the rate of biodegradation and liquidation. This was reflected in the higher values of the parameters compared to their values in the absence of organic waste [34]. Although it is evident that the aerobic landfill bioreactor can easily fertilize biodegradable waste, the landfill site is still limited due to the multiform composition of the MSW. Plastic, metal, fabric, wood, construction and demolition waste cannot be easily compacted. This is a very important consideration because materials like plastic, metal and glass can be recovered or recycled, so the settlement could reach 70% or more [35].

Chapter 4

Results and Discussions

4.1 General

As per described methodologies the experiments were carried out to study the variation of leachate characteristics over the period of 150 days. Tests were done every 14 days to study the leachate recirculation and its effect on the degradation of the waste. The settlement of MSW with leachate recirculation in bioreactor cell is also discussed in this chapter.

4.2 Moisture content and temperature variations of MSW

Changes in temperature reflect the degree of solid waste degradation. Figure 4.1 shows the temperature inside the bioreactor. It is observed that the reactor temperature was always slightly higher than room temperature. This is a further evidence of higher biological activity inside the reactor and hence a high rate of degradation of MSW layer. It is observed that the temperature of the bioreactor varies with time, at the starting of the experiment the temperature is found to be 28°C which increase to 35°C in 150 days of the experiment. The variation of temperature for the 150 days of the experiment ranged between 16 to 35 °C. Theoretically, the temperature in the reactor could reach to 50 to 68 °C (Green, 1999). As it can be seen from the graph, the temperature after 132 days of the experiment is high as compared to the initial days. This increase in temperature is found to create mesophilic inside the reactor (20°C to 40°C) which is an optimum condition for microbial growth. These microorganisms helps in the degradation of organic waste, hence leads to the waste settlement. The low temperatures inside the bioreactor can be due the leachate recirculation into the waste. The leachate recirculation help to maintain high moisture content inside the bioreactor which leads to a decrease in the inside temperature of the bioreactor.

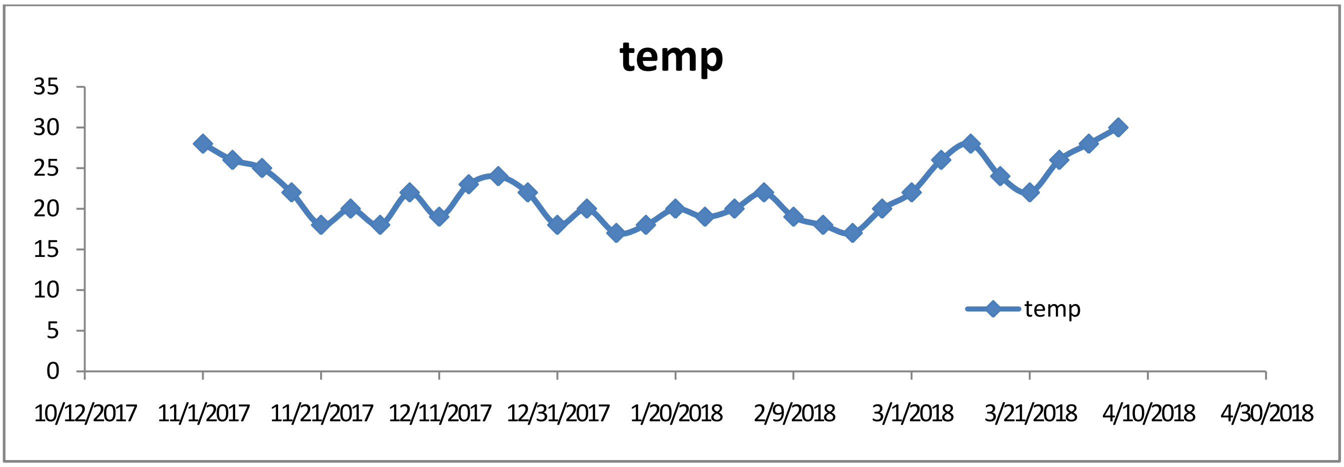

Figure 4.1 Variation of temperature with time

4.3 Leachate characteristics

4.3.1 pH

The change in the pH is given in figure 4.2. It is observed that in the starting of the experiment, the pH value of both the reactors was around 4.6 which signify that the reactor started off in acidic conditions. The acidic condition of the leachate during initial phase indicates that recirculation of leachate was not sufficient in removing organic acids. It is observed from figure 4 that the pH values were in the range of 4.6 to 6.5 in the initial 30 days of the experiment.

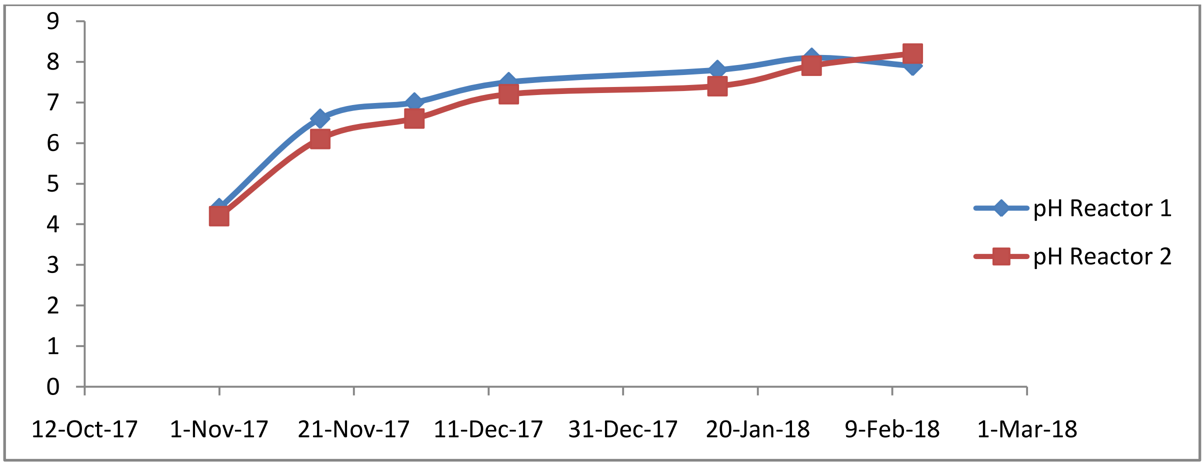

Figure 4.2 Variation of pH with time

This shows that the leachate is young because the value of pH for young leachate should always be less than 6.5 [31]. After 30 days of the experiment, it was observed that the pH of leachate began to increase and reached to 8 after 90 days of the experiment. After that, no considerable change was observed in pH. At the end of the experiment, pH of the leachate produced from reactor 1 and reactor 2 was 7.9 and 8.2 respectively.The range of the pH of the aerobic reactor has been reported as 6.5 to 9.0 [32]. Analysis of pH values is an indicator of the degree of aeration of the system [32]. As reported, CO_2 is stripped from air in an aerobic system results in a reduction of carbonic acid (H_2CO_3) and bicarbonate ion (HCO_{3-}) concentration (Bilgili et al., 2006; Erses et al., 2007), which is found to provide constant high pH values for aerobic degradation throughout the experiment.

4.3.2 Chemical Oxygen Demand

The variations of the COD concentrations are shown in figure 4.3. In the initial stage of the experiment the value of COD in reactor 1 and reactor 2 was found to be 32,865 mg/L and 33,764 mg/L respectively. COD concentration increased to have a maximum value of 37,442 mg/L and 38,452 mg/L after 15 days of the experiment. This indicates that the leachate recirculation rate, which is provided to the system, is insufficient in removing the non biodegradable organic matter and organic load in the initial stage of the experiment.

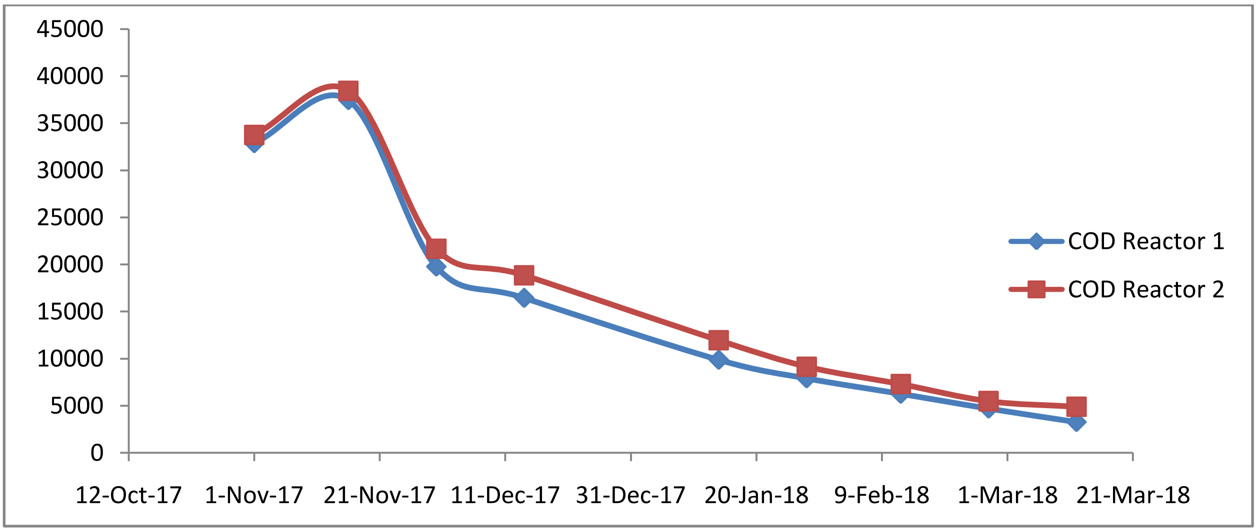

Figure 4.3 Variation in COD with time

After reaching to a maximum value of COD, the concentration is found to decrease and reach a value of 4,692 mg/L after 150 days of the experiment. The removal efficiency of COD is 90 % for reactor 1 and 85.5 % for reactor 2 in 150 days of the experiment. This clearly shows that, aeration and leachate recirculation enhances the degradation of organic waste present in bioreactor.

4.3.3 Biological oxygen demand

The variations of the BOD concentrations with are shown in figure 4.4. It was observed that in the initial stage of the experiment the value of the BOD for reactor 1 and reactor 2 was found to be 30,680 mg/L and 31,200 mg/L respectively. It is observed that after 15 days of the experiment BOD concentration is increased to maximum value of 31,974 mg/L for reactor 1 and 33,890 mg/L for reactor 2. This indicates that the leachate recirculation rate, which is provided for the system is insufficient in removing the organic load in the initial stage of the experiment. After reaching to a maximum value BOD the concentration began to decrease rapidly and the concentration after 44 days was found as 986 mg/L and 1264 mg/L. The concentration on the last day of the experiment (150 days) was found as 498 mg/L and 845 mg/L. The removal efficiency of BOD is 98.37 % for reactor 1 and 97.2 % for reactor 2 in 150 days of the experiment. This clearly shows that, aeration and leachate recirculation enhances the degradation rate of organic matter in the bioreactor.

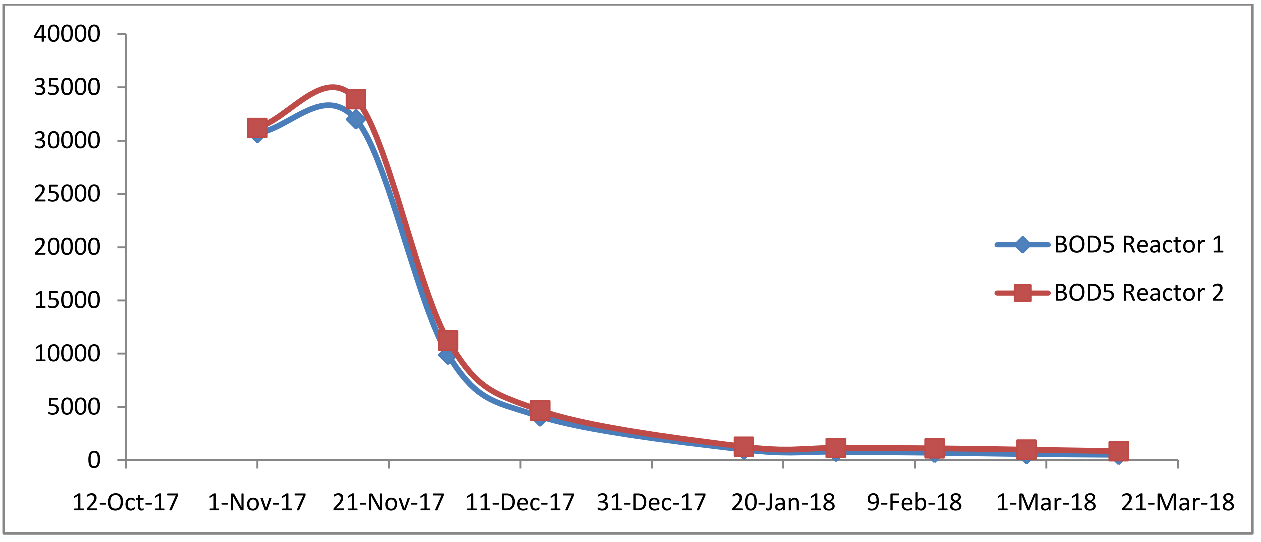

Figure 4.4 Variation in BOD with time

COD and BOD_5 are generally used to determine the degree of degradation of the MSW. The BOD_5/COD ratio is used to assess the biodegradability of the organic matter in the leachate, and hence to understand the degree of stabilization. A low BOD_5/COD ratio suggests that leachate is low in biodegradable organic compounds such as humic compounds.

In this work, initial BOD_5/COD ratio is high i.e. 0.90, which shows that the waste is highly degradable. After 15 days of the experiment, a sudden decrease in the ratio of BOD_5/COD was observed and it was found to reach a value of 0.24 after 45 days of experiment this signifies that the degradability of waste is decreased. This ratio is then found to be 0.15 after 150 days of the experiment. Biodegradation constantly changes the physical structure of a waste matrix. This occurs as a result of changes to particle size of waste due to biodegradation as well as waste settlement. The higher rate of degradation in the initial stage of the experiment has resulted in faster decrease in the BOD_5/COD ratio. The BOD_5/COD ratio can also be found to classify the waste according to its age. In the present study the initially BOD_5/COD is greater than 0.3, which state that the waste is young, but after 30 days of the experiment the ratio is less than 0.3 which depicts that the waste is old [22] . The Variation in BOD_5/COD ratio with time is shown in figure 4.5.

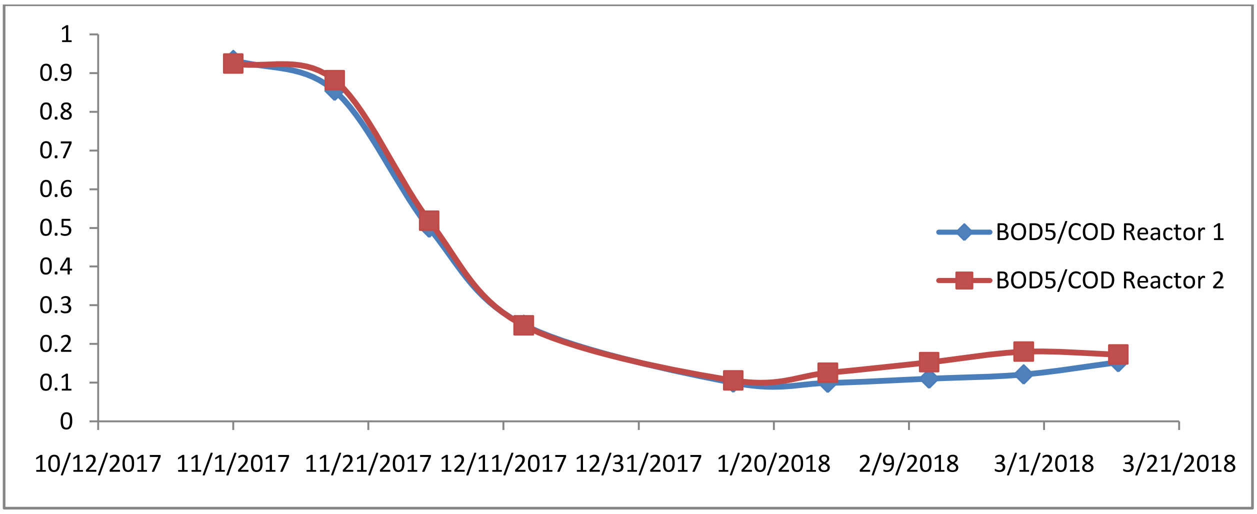

Figure 4.5 Variation in BOD_5/COD ratio with time

4.3.4 Total Dissolved Solids

The variation in the TDS concentration is shown in figure 4.6. A very high initial value of TDS was found in both reactors equal to 8685 mg/L for reactor 1 and 8780 for reactor 2 was observed at the start of the experiment. This high value shows the high concentration of dissolved solids in the leachate. The TDS is found to rapidly decrease to a value of 3928 mg/L within 30 days of the experiment. Beyond 30 days only small variation in TDS is observed to occur till 150 days. However, it was seen that the concentration of TDS was found to reach a value of 1956 mg/L and 2145 mg/L. This increase in the total dissolved solids can be account to the fact that the aeration provided to the reactor is now insufficient for the degradation of the inorganic ion present in the reactor [33].

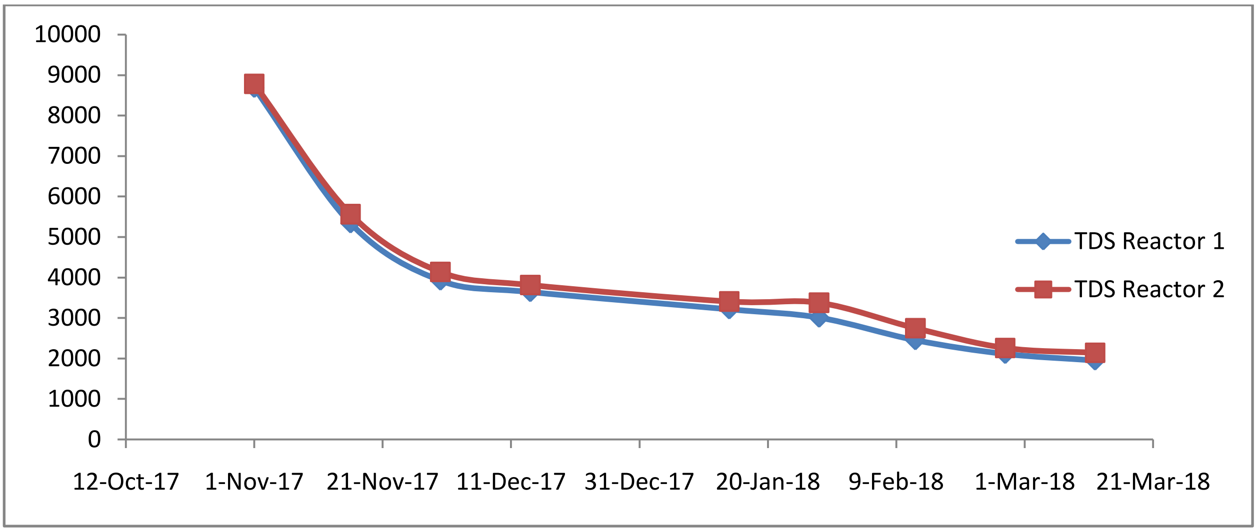

Figure 4.6 Variation in TDS with time

4.4 Settlement

The rate and the magnitude of landfill settlement depend primarily on the waste composition, operational practices and factors affecting biodegradation of landfill waste [34]. Figure 4.7 and Figure 4.8 shows the changes of MSW settlement in both the reactors during the experiment.

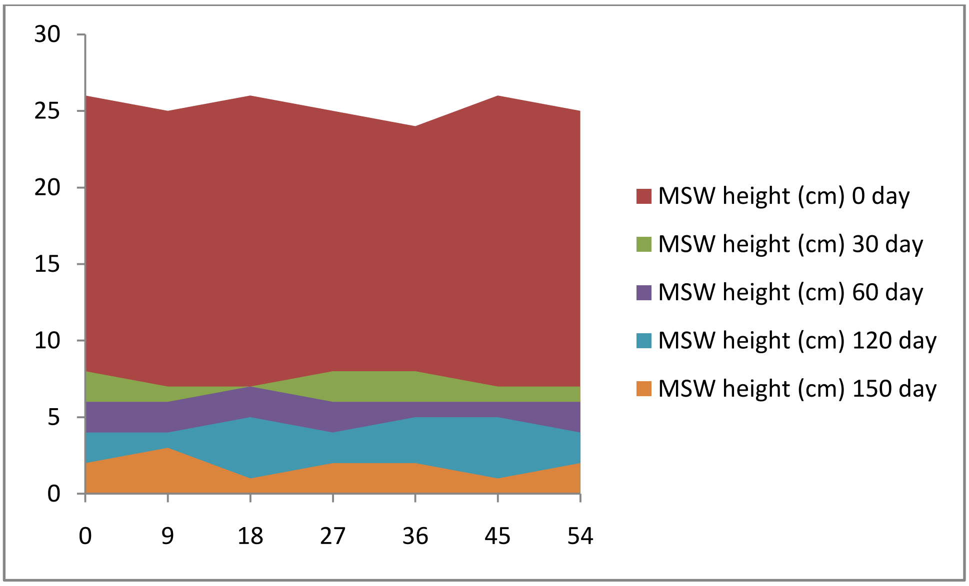

Figure 4.7 MSW settlement during the experiment in reactor 1

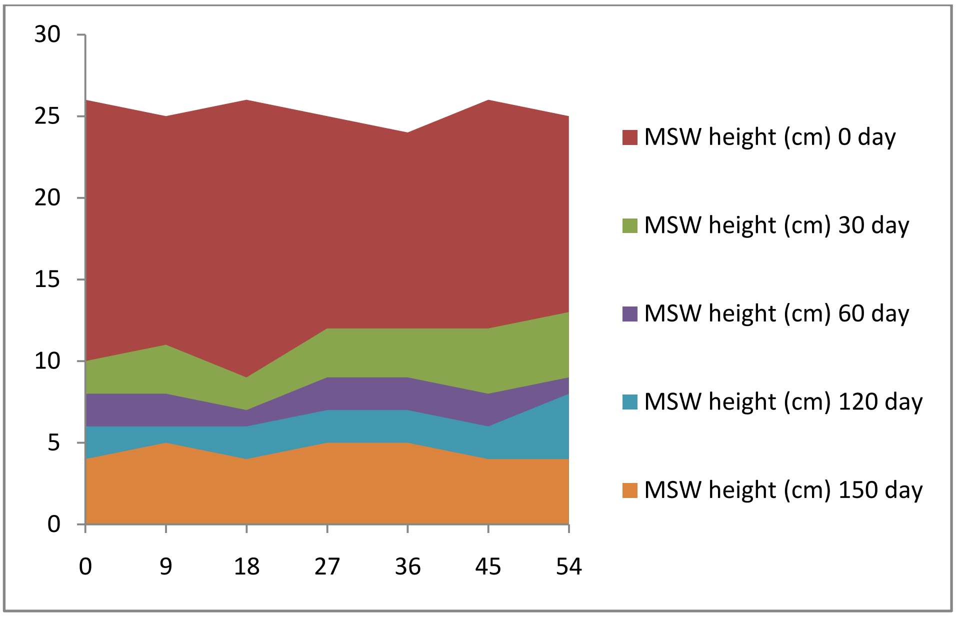

Figure 4.8 MSW settlement during the experiment in reactor 2

The measurement points were taken every 9 cm in the cell in order to have more representative results. The first measurements were taken after 30 days. At this day, the BOD5/COD rate for reactor 1 and reactor 2 was 0.50 and 0.51 and the MSW settled about 68% and 56% respectively. The next sets of measurements were taken after 60 days when 76% in reactor 1 and 68 % settlement of MSW in reactor 2 had occurred. By the end of the experiment the MSW settlement had reached 92% and 84% for reactor 1 and reactor 2. Results show that the maximum settlement occurred in the initial stage of decomposition when the composition of organic biodegradable matter was high. Although it is apparent from results that the aerobic reactor has the tendency to decompose waster faster but the settlement in the landfill remains constant due to the presence of other materials and the multi proportional composition of the MSW. Plastic, metal, textile, wood, construction and demolition wastes cannot be compacted easily. This consideration is very necessary as these materials can be collected and recycled, so settlement could reached 70% or more [35]. So in this case we have attained a higher settlement due to the presence of organic matter in larger proportion.

Chapter 5

Conclusions

5.1 General

Two aerobic bioreactors simulated for landfills was built to study the effect of leachate recirculation in waste disposal. Several parameters of the leachate were tested to study the effect of the leachate recirculation and the variation of its characteristics. Measurement of settlement was done after every 30 days. From the experimentation, it is observed that the recirculation of the leachate and the aerobic condition help to accelerate the stabilization of the waste. Moreover it was concluded that treatment of organics present in the leachate prior to its recirculation can increase the rate of stabilization inside the reactor.

5.2 Conclusions

The important conclusions that can be drawn from the present study are as follows:

- In this study, MSW was treated by two simulated aerobic landfill bioreactors. In general, aerobic reactor has shown that aerobic decomposition of the MSW could be achieved successfully. The operation of the aerobic bioreactor has proven to be useful in reducing the organic load in a very short period. After 60 days of treatment, there was a reduction of COD and BOD_5 of 69.9% and 96% respectively in the first reactor, whereas at the end of the experiment it had reached 90% and 98.3% respectively.
- In the second reactor, after 60 days of experiments, there was a reduction of COD and BOD_5 of 64.6% and 95.9% respectively, while at the end of the experiment it had reached 85.5% and 97.2%.
- The results suggest that the initial BOD_5 / COD ratio is greater than 0.3, indicating that the MSW used for the experiment is young. It is observed

that a BOD_5/ COD higher than 0.3 indicates high biodegradability [22]. Therefore, it can be concluded that the municipal solid used in the bioreactor is young in age and highly biodegradable at the beginning of the experiment. But after 30 days of experiments, it is found that its value is less than 0.3, which classifies it as old MSW and, therefore, less biodegradable.

- It is concluded that the settlement of MSW reached 92% and 84% for reactor 1 and reactor 2 at the end of the experiment due to the biodegradation of organic matter in the MSW. Since the settlement in reactor 1 is slightly larger than reactor 2, therefore, it can be concluded that if we treat the leachate before recirculating it, a higher settlement could be achieved. In this work, ASP was adopted to treat the leachate before being recycled. However, other effective methods of treatment of leachate can also be adopted.

5.3 Scope for Future Work

Regarding studies carried out all over the world, there is no pre treatment of leachate prior its recirculation. During the bioreactor operation, gas emissions are observed. The study of these gases helps to better understand the decomposition of waste through different phases that occur over time. It is also noted that the gas generation from a bioreactor also depends on factors including the composition of the waste, the age of the waste, the pH, the temperature, the moisture content and the size of the waste particles. Therefore, this could be an area of study for future researchers. The recirculation of the leachate increases the moisture content inside the reactor. Increasing the moisture content can reduce the structural stability of the landfill by increasing the interstitial water pressure inside the waste. Thus, it is possible to study the effects of moisture content on bioreactor performance. Furthermore, leachate treatment with activated sludge process is found to have a positive impact on biodegradation of waste, thus there is a lot of scope and this type of laboratory as well as field studies can be done in a large scale to better understand the effect of leachate treatment prior its recirculation.

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APPENDIX

APPENDIX A

Data of Leachate Characteristics

A1) Determination of pH

Variation of pH with time

For Reactor 1

Date	pH	Date	pH
1-11-2017	4.4	28-01-2018	8.1
16-11-2017	6.6	12-02-2018	7.9
30-11-2017	7	26-02-2018	7.9
14-12-2017	7.5	12-03-2018	7.9
14-01-2018	7.8		

For Reactor 2

Date	pH	Date	pH
1-11-2017	4.2	28-01-2018	7.9
16-11-2017	6.1	12-02-2018	8.2
30-11-2017	6.6	26-02-2018	8.0
14-12-2017	7.2	12-03-2018	7.9
14-01-2018	7.4		

A2) Determination of COD

$$COD = \frac{(V1 - V2) \times N \times 8 \times 1000}{vol\ of\ sample\ taken} \times Dilution\ factor$$

Where,

V_1= mL Ferrous Ammonium Sulphate [$FeSO_4\,(NH_4)_2SO_4$] used for blank solution

V_2 = mL Ferrous Ammonium Sulphate [$FeSO_4\,(NH_4)_2SO_4$] used for sample

N= Normality of [$FeSO_4\,(NH_4)_2SO_4$]

V_1 = 3.4 mL

V_2 = 2.2 mL

$$COD = \left[\frac{(3.4 - 2.2) \times 0.11 \times 8 \times 1000}{2.5}\right] \times 50 = 21{,}120\ mg/L$$

For Reactor 1

DATE	COD (mg/L)
1-11-2017	32865
16-11-2017	37442
30-11-2017	19762
14-12-2017	16441
14-01-2018	9865
28-01-2018	7898
12-02-2018	6256
26-02-2018	4690
12-03-2018	3260

For Reactor 2

DATE	COD (mg/L)
1-11-2017	34764
16-11-2017	39452
30-11-2017	21668
14-12-2017	18848
14-01-2018	11946
28-01-2018	9148
12-02-2018	7296
26-02-2018	5480
12-03-2018	4895

A3) Biological oxygen demand at 20°C

Day 1 DO = 7.95 mg/L

DO after 5 days = 2.9 mg/L

$$\text{Dilution factor} = \frac{300mL}{0.05mL}$$

$$\text{BOD5} = (7.95 - 2.9)\frac{300\ mL}{0.05\ mL} = 30{,}300\ mg/L$$

For reactor 1

DATE	BOD_5 (mg/L)
1-11-2017	30680
16-11-2017	31974
30-11-2017	9885
14-12-2017	4098
14-01-2018	986

28-01-2018	785
12-02-2018	690
26-02-2018	568
12-03-2018	498

For Reactor 2

DATE	**BOD_5 (mg/L)**
1-11-2017	31200
16-11-2017	33890
30-11-2017	11224
14-12-2017	4668
14-01-2018	1264
28-01-2018	1148
12-02-2018	1113
26-02-2018	946
12-03-2018	845

A4) Determination of TDS

$$\text{TDS} = \frac{(A - B) \times 1000}{V}$$

where

A = weight of dish + residue in mg

B = weight of dish in mg

V= volume of the sample taken in ml

A =88624.7 mg

B= 87794.2 mg

$$TDS = \frac{(88624.7 - 87794.2) \times 1000}{100} = 8305\ mg/L$$

For Reactor 1

DATE	TDS (mg/L)
1-11-2017	8685
16-11-2017	5340
30-11-2017	3928
14-12-2017	3644
14-01-2018	3218
28-01-2018	3013
12-02-2018	2456
26-02-2018	2117
12-03-2018	1956

For Reactor 2

DATE	TDS (mg/L)
1-11-2017	8780
16-11-2017	5566
30-11-2017	4140
14-12-2017	3816
14-01-2018	3410
28-01-2018	3380
12-02-2018	2753
26-02-2018	2264
12-03-2018	2145

APPENDIX B

B1) Variation in settlement of waste with time

For Reactor 1

Measurement points (cm)	MSW height (cm)				
	0 day	30 day	60 day	120 day	150 day
0	26	8	6	4	2
9	25	7	6	4	3
18	26	7	7	5	1
27	25	8	6	4	2
36	24	8	6	5	2
45	26	7	6	5	1
54	25	7	6	4	2

For Reactor 2

Measurement points (cm)	MSW height (cm)				
	0 day	30 day	60 day	120 day	150 day
0	26	10	8	6	4
9	25	11	8	6	5
18	26	9	7	6	4
27	25	12	9	7	5
36	24	12	9	7	5
45	26	12	8	6	4
54	25	13	9	8	4

B2) Variation in Temperature (°C) with time

Date	Temp
11/1/2017	28
11/6/2017	26
11/11/2017	25
11/16/2017	22
11/21/2017	18
11/26/2017	20
12/1/2017	18
12/6/2017	22
12/11/2017	19
12/16/2017	23
12/21/2017	24
12/26/2017	22
31/12/2017	18
1/5/2018	20
1/10/2018	17
1/15/2018	18
1/20/2018	20
1/25/2018	19
1/30/2018	20
2/4/2018	22
2/9/2018	19
2/14/2018	18
2/19/2018	17
2/24/2018	20
3/1/2018	22
3/6/2018	26
3/11/2018	28
3/16/2018	24
3/21/2018	22
3/26/2018	26
3/31/2018	28