

Municipal Solid Waste: Pre-Treatment Options and Benefits on Landfill Emissions

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Abstract—Municipal solid waste (MSW) comprises of a wide range of heterogeneous materials generated by individual, household or organization and may include food waste, garden wastes, papers, textiles, rubbers, plastics, glass, ceramics, metals, wood wastes, construction wastes but it is not limited to the above mentioned fractions. The most common Municipal Solid Waste pretreatment method in use is thermal pretreatment (incineration) and Mechanical Biological pretreatment. This paper presents an overview of these two pretreatment methods describing their benefits and laboratory scale reactors that simulate landfill conditions were constructed in order to compare emissions in terms of biogas production and leachate contamination between untreated Municipal Solid Waste and Mechanical Biological Pretreated waste. The findings of this study showed that Mechanical Biological pretreatment of waste reduces the emission level of waste and the benefit over the landfilling of untreated waste is significant.

Keywords—emissions, mechanical biological pretreatment, MSW, thermal pretreatment

I. INTRODUCTION

IN South African and in many developed countries, municipal solid waste generated from households, organization and from any other sources are collected and dumped at landfill sites. Landfills are specially designed for the disposal of waste generated on or in the earth's mantle and are the oldest form of municipal solid waste disposal option. When waste are deposited in landfills, series of biological, physical as well as chemical transformation of the organic constituents present in the deposited waste fraction occurs [1]. This biochemical and physical breakdown of the organic constituent present within the waste body results in the production of two forms of emission generated from landfill sites and are the major environmental hazards associated with the disposal of MSW in landfills. These emissions are biogas which are gases (mainly comprising of methane, carbon dioxide, and oxygen) generated as a results of the degradation process taking place within the waste body deposited in the landfills and leachates generated as a results of the percolations of rain water, ground water and surface water as well as degradation process and/or transformation processes taking place within the waste body [2].

According to [3], emissions from landfill site which results in the generation of biogas and leachate from the waste body deposited in the landfill can be characterized as a three stage process namely: Aerobic stage, Acid stage and Methanogenic stage. The composition of the gas generated as well as the characteristic of the leachate produce depends on the landfill emission stage taking place. According to [1], the quality of leachate generated from a typical landfill will depend on the

type and composition of the waste, the stage of degradation reached by the waste, moisture content of the waste body and the operational procedures carried out at the landfill site. Typical composition of leachates generated from landfill site is presented in *Table I*.

During the early stages (Aerobic and Acid stage) of waste degradation in landfills, the characteristics leachate produced is usually high in concentrations of volatile fatty acids, acidic pH, high BOD to COD ratios, and high concentration of ammonical nitrogen and organic nitrogen. According to [1], the degradation of amino acids of proteins and other nitrogenous compounds contained in the waste body results in high levels of ammonical nitrogen in the leachate produced and also the high BOD to COD ratio of the leachate produced indicates that, a high proportion of the organic materials in solution are readily biodegradable. The leachate produced from landfills during the methanogenic stage is usually characterized by a neutral & alkaline pH values reflecting the degradation of organic acids to produce methane and carbon dioxide [3]. Also, during the methanogenic stage of landfill emission, the metal ions in the leachate decreases and become less soluble as the leachate pH increases and ammonical nitrogen concentration contained in the leachate decreases slightly but remains high while the levels of BOD and COD continues to decrease [1].

TABLE I
TYPICAL LANDFILL LEACHATE COMPOSITIONS [4]

| Constituent | Value, mg/L ³ | | |
|--|-------------------------------------|----------------------|---|
| | New Landfill (less than 2 years) | | Mature landfill (greater than two years) |
| | Range ^b | Typical ^c | Range ^b |
| BOD ₅ (5-day biochemical oxygen demand) | 2,000 – 30,000 | 10,000 | 100 – 200 |
| TOC (total organic carbon) | 1,500 – 20,000 | 6,000 | 80 – 160 |
| COD (chemical oxygen demand) | 3,000 – 60,000 | 18,000 | 100 – 500 |
| Total suspended solids | 200 – 2,000 | 500 | 100 – 400 |
| Organic nitrogen | 10 – 800 | 200 | 80 – 120 |
| Ammonia nitrogen | 10 – 800 | 200 | 20 – 40 |
| Nitrate | 5 – 40 | 25 | 5 – 10 |
| Total phosphorus | 5 – 100 | 30 | 5 – 10 |
| Ortho phosphorus | 4 – 80 | 20 | 4 – 8 |
| Alkalinity as CaCO ₃ | 1,000 – 10,000 | 3,000 | 200 – 1,000 |
| pH | 4.5 – 7.5 | 6.0 | 6.6 – 7.5 |
| Total hardness as CaCO ₃ | 300 – 10,000 | 3,500 | 200 – 500 |
| Calcium | 200 – 3,000 | 1,000 | 100 – 400 |
| Magnesium | 50 – 1,500 | 250 | 50 – 200 |
| Potassium | 200 – 1,000 | 300 | 50 – 400 |
| Sodium | 200 – 2,500 | 500 | 100 – 200 |
| Chloride | 200 – 3,000 | 500 | 100 – 400 |
| Sulfate | 50 – 1,000 | 300 | 20 – 50 |
| Total Iron | 50 – 1,200 | 60 | 20 – 200 |

^a Except pH, which has no units.
^b Representative range of values. Higher maximum values have been reported in the literature for some of the constituents.
^c Typical values for new landfills will vary with the metabolic state of the landfill.

The composition of gas generated from the waste body deposited in landfills also depends on the landfill emission stage reached. Various gases such as carbon dioxide, carbon monoxide, hydrogen, hydrogen sulphide, methane, nitrogen and oxygen are generated from landfills during the different stages of emissions with carbon dioxide and methane been the principal gases produced during the anaerobic bacteria

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decomposition of the organic solid waste components in the landfill [5]. The general characteristics of the gases generated from landfills during the degradation of the organic content present in the waste body deposited in the landfill are presented in *Table II*. Early stages of degradation taking place in landfills are characterized with the production of significant levels of hydrogen and carbon dioxide due to the process of hydrolysis and fermentation of the organic fraction contained in the waste body [1]. The level of hydrogen decreases as the acidic stage sets in and as such promotes the methane generating microorganisms which generate methane and carbon dioxide from the organic acid and their derivatives generated from the earlier stages of degradation [1]. The methanogenic stage is usually the main landfill gas generation stage with typical landfill gas composition of approximately 60% by volume methane and 40% by volume carbon dioxide [1]. The methanogenic stage often last for many years with the highest methane production rate expected to occur at the beginning of the stage which should decrease gradually and be negligible towards the end of the stage as the final degradation stage sets in [2]. According to [1], the quantities of gas generated from the waste body deposited in landfills will depend on the biodegradable fraction of the waste, the presence of microorganisms, suitable aerobic and anaerobic conditions and moisture.

TABLE II
CHARACTERISTICS OF LANDFILL GAS COMPONENTS [6]

| Components | Density(g/l) | Odour | Colour | Flammable | Comments |
|-------------------|--------------|------------|------------|-----------|--|
| Methane | 0.71 | Odourless | Colourless | Yes | Very low solubility in water at STP. Important green house gas. |
| Carbon dioxide | 1.98 | Odourless | Colourless | No | Slightly acidic at high concentration. Very soluble in water, forming corrosive liquids of low pH. |
| Hydrogen sulphide | 1.53 | Rotten egg | Colourless | Yes | High odour which is toxic |
| Hydrogen | 0.09 | Odourless | Colourless | Yes | - |
| Oxygen | 1.42 | Odourless | Colourless | No | - |
| Nitrogen | 1.25 | Odourless | Colourless | No | - |

The pretreatment of MSW before landfilling is generally aimed at reducing the environmental impacts related to the emissions from landfills by accelerating the stabilization of the degradable components of the waste. This paper presents an overview of the most common methods in use for the pretreatment of MSW before landfilling of the waste describing the benefits of waste pretreatment by comparing the characteristics of emission generated from untreated MSW and pretreated waste using laboratory scale reactors that simulate landfill conditions.

II. MUNICIPAL SOLID WASTE PRETREATMENT OPTIONS

Thermal pretreatment (incineration) of MSW and Mechanical Biological pretreatment of waste are the most common methods in use for the pretreatment of municipal solid waste. Thermal pretreatment of waste involves the

controlled burning of waste, with or without energy recovery. This method of waste pretreatment has increasingly been in use over the past few years mainly to reduce the amount of waste and to decrease their biological activity [7]. However, this method of waste pretreatment entails a much higher cost; longer pay back periods due to high capital investment and although, modern incinerators do comply with existing emission regulations, the public are still concerned with the adverse effects associated with the emissions from incinerators on health [1].

Mechanical Biological pretreatment of municipal solid waste on the otherhand involves two treatment processes; Mechanical preparation of waste and Biological degradation of waste. The mechanical treatment process involves shredding/homogenization, sorting and regulation of certain physical and chemical properties of the waste in order to optimize the biological degradation of the waste during the biological treatment processes [8]. These properties are moisture content of the waste, particle size and carbon /nitrogen ratio. The biological process involves the degradation of the remaining organic materials such as kitchen and green waste, paper etc to the greatest possible extent by the application of anaerobic or aerobic processing technologies [9]. Various studies have been conducted to investigate the effect of waste pretreatment on landfill emissions ([10]; [11]; [12]; [13]) and all these studies have indicated that, MSW pretreatment reduces the polluting potential of the emissions generated to a large extent. It has been found that generally the acid phase during which highly loaded leachate is produced in the landfill body is omitted and organic content (COD) and total nitrogen in the leachate are about 90% lower than that of the untreated waste after the pretreatment MSW [10]. In addition to this reduction the degradation processes that generally takes many years or even decades as shown to be shortened to a few years.

III. COMPARISON OF EMISSIONS PRODUCED FROM UNTREATED AND MBP WASTE

Untreated waste collected from a landfill site in Durban as well as waste collected after performing mechanical biological pretreatment of the waste were placed in laboratory scale bioreactor that simulate landfill conditions. *Figure 1* presents the set up for the laboratory scale used to simulate landfill conditions. Two of this laboratory scale bioreactor was constructed, one containing the untreated waste collected directly from the landfill site and the other containing the MBP waste. This was done in order to be able to compare the emission generated from the untreated waste and the pretreated waste in terms of the leachate characteristics as well as the biogas characteristics. On a weekly basis, the biogas quality was determined thereafter the bioreactors are completely drained off and the leachate generated are analyzed for pH, conductivity, Chemical oxygen demand, volatile solids, ammoniacal nitrogen using the standard method [14].

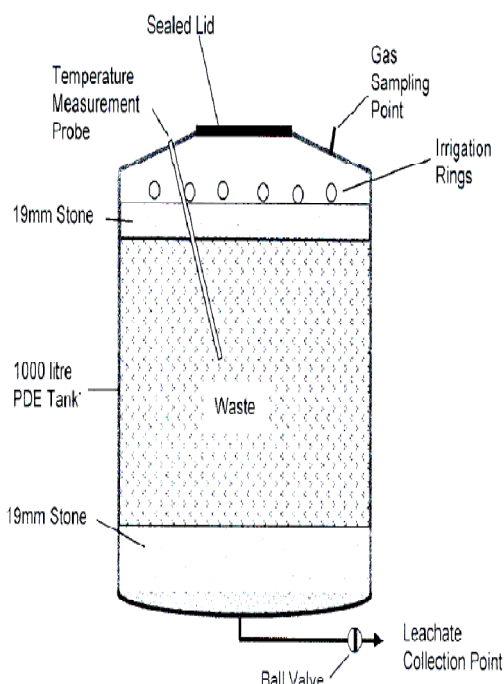


Fig. 1 Set up for the laboratory scale bioreactor

The plot of the result obtained from the weekly analysis of leachate collected as well as the weekly biogas (methane) test for both the untreated and MBP waste is presented in *Figure 2* for comparison purpose. The results of each analysis performed are discussed as follows;

Biogas Quality

An infrared gas analyzer (GA 2000) was used to determine the biogas quality liberated from the gas vent connected to the head space of both bioreactors. The biogas liberated from the head space of these bioreactors comprises mainly methane, carbon dioxide and traces of oxygen. For the purpose of this paper the amount of methane generated seems to be the appropriate constituent that can be used to make comparison between the behaviour of untreated MSW and pretreated MSW in laboratory scale bioreactor that simulate landfill conditions. This is because it as been widely documented in literatures that methane is only liberated from waste deposited in landfills which have reached the methanogenic stage of landfill emissions. The assessment of the amount of methane liberated as presented in *Figure 2a*, indicated that the average value of methane produce from the pretreated waste through the entire duration of the experimental set up was significant higher (about 98 %) than amount generated from the untreated waste. This was expected because, one of the major benefits of pretreatment of MSW is that the acidic inhibition stage which is normally observed when untreated MSW is landfilled is eliminated as a results of the pretreatment of the waste. The liberation of methane from the untreated waste should not be observed however, this amount was very negligible ($< 0.1\%$).

pH and Conductivity

The pH value of the leachate generated from the waste body in the laboratory scale bioreactor was determined using an

electronic pH meter (Orion LABTECH 410A) calibrated before each use while the conductivity was also determined using an electronic meter (Corning Checkmate II sensor). The plot of the pH and conductivity results obtained from the bioreactors throughout the entire period of analysis is presented in *Figure 2b*. The leachates pH is an indication of the state of biological activity taking place in the bioreactors. The average pH obtained from the leachate generated from the untreated waste and the MBP waste over the entire period of the analysis was approximately 5.5 and 8 respectively. The pH obtained for the untreated waste indicates that the untreated waste deposited in the reactor is still in the acidic stage of waste degradation as reported in other researches whereas the MBP waste as reached the methanogenic stage and as such conforms to the fact that the acidic stage of waste degradation in landfills as been eliminated due to the pretreatment of the waste. The average value of the pH obtained is consistent with other studies of pretreated waste. The average conductivity obtained from the bioreactor in which the untreated waste was deposited was significantly higher than the average conductivity obtained for the pretreated waste. The conductivity of the leachates sample is an indication of the quantities of the soluble salts present in the leachate. Leachate with high conductivity indicates the presence of high quantity of soluble salts in the waste material.

Chemical Oxygen Demand

Chemical Oxygen Demand is a measure of the oxidizable organic matter present in samples. The chemical oxygen demand is an indication of the polluting potential of the collected leachate samples. As presented in *Figure 2c*, the average COD value obtained from the bioreactor which contains the untreated MSW is significantly higher (about 90%) than that which contained the pretreated waste. This tells us that when MSW are pretreated before landfilling the polluting potential can be significantly reduced.

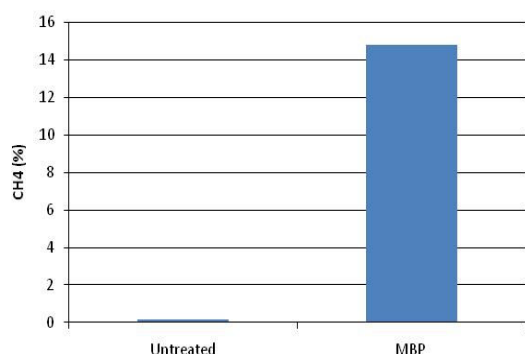
Volatile Solid

The volatile solid generated from the waste body place in each bioreactor is an indication of the amount of organic compounds present within the solid fraction of the collected leachate samples. As shown in *Figure 2d*, the leachate sample collected from the bioreactor containing the untreated MSW as the highest average volatile solid value when compared to the pretreated waste. This is an indication that the untreated waste contains higher organic fraction (about 52%) and that the pretreatment of the waste as significantly reduce the amount of the organic fraction presents within the untreated MSW.

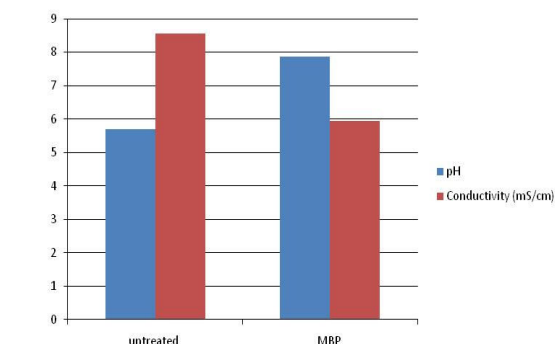
Ammoniacal Nitrogen

The standard method [14] was used to determine the amount of ammoniacal nitrogen present in the leachate samples collected from both bioreactors containing the untreated and pretreated MSW. This analysis is an indication of the amount of nitrogen in the form of ammonia in the leachate sample. It was also observed as shown in *Figure 2e*, the average value of ammoniacal nitrogen obtained from the analysis carried out leachate sample collected from the bioreactor containing the untreated waste was significantly

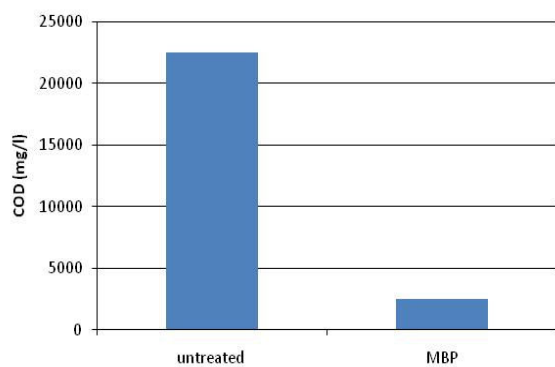
higher than that of the bioreactor containing the pretreated waste. This is a typical characteristics of the leachate produced during the acidic stage of landfill emissions.



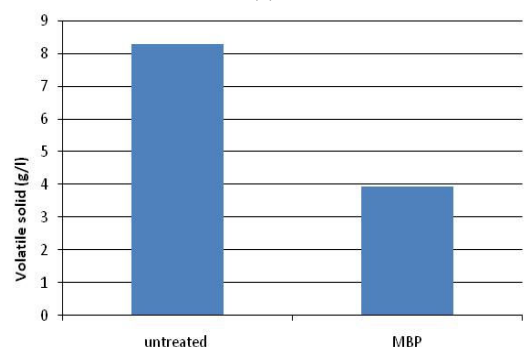
(a)



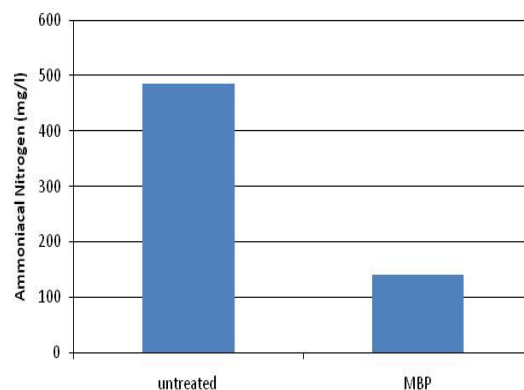
(b)



(c)



(d)



(e)

Fig. 2 Plot of the various leachate contaminants determined from the laboratory scale bioreactor containing untreated and mechanical biological pretreated MSW

IV. CONCLUSION

This paper has presented a brief summary, stating the benefits of these two most commonly used pretreatment methods and also present a small scale laboratory investigation of the effect of waste pretreatment on landfill emissions. The benefits of waste pretreatment on municipal solid waste were observed with significant reductions in all parameters determined when comparing untreated MSW and MBP waste. Thus, the pretreatment of MSW before landfilling the waste as the ability to significantly reduce the emission level of waste and the benefit over the landfilling of untreated waste is significant.

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