Bioreactor landfills: New trends in landfill design

Pervez Alam¹, Mehtab Alam²
¹Assistant Professor, Department of civil Engg, School of mathematical sciences and Engg, BGSBU, J&K
²Professor, Department of Civil Engg, F/O Engg and Tech, Jamia Millia Islamia, New Delhi

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Abstract: Environmental concerns of sentry landfills are generally revolve around quantity and quality of leachate production, gas generation mainly methane, and decomposition processes of organic matter occurring therein. Second main concern is to minimizing the time period for maximum organic degradation to minimize the leachate and gas emissions after saturation of landfill. This research paper compares the benefits of bioreactor landfill operation techniques over the conventional landfill techniques with the need for the research for the promising technology in India.

Key words: Landfill, leachate, waste stabilization.

1. Introduction

The solid waste generation has become a very important global issue over the last decade due to the rapid growth in world population and increase in waste production. This increase in solid waste generation poses number of questions concerning the operation of conventional solid waste management systems and their impact on environment. There are number of methods available for the management of solid waste such as land filling, incineration, Recycling etc. In Indian condition we generally preferred to use land filling operation for the treatment of SW. The basic principle of the sanitary landfill design is to store and dispose of the solid waste and minimize the impact of solid waste to humans and the environment. A survey carried out in 1989 on the production and disposal of MSW in 15 industrial countries suggested that 68.8% of their MSW was disposed of by Landfilling operation only (Cossu et al 1989). The degradation of waste in landfills can be accelerated by operating it in the bioreactor mode and in the end; the “stabilized” waste mass with very less methane, odor and leachate.

Due to advance knowledge of landfill operation and decomposition process of MSW, there have been several researches focusing on advancing existing landfill technology from convention landfill to a process-based approach called bioreactor landfill. The concept of “bioreactor landfill” is a scientific approach which permits active management of landfill with the involvement of Physical, chemical and Biological processes with proper leachate management to recover energy in the form of Methane gas and residue as manure. The degradation process of waste aims to put forward an inert method of landfill operation in shorter span of time. A bioreactor landfill accelerates the decomposition of the biodegradable organic waste by controlling moisture content of waste, recycling of nutrients and seeding of micro-organisms by leachate recirculation. This is an emerging technique in developing nations to manage the solid waste rather than making a conventional dumpsite. In comparison to many developed countries, the concept of bioreactor landfill is still relatively very new to India. With a better understanding of landfill decomposition process, behavior and impacts there has been a strong trend in recent years to shift the technique of landfill design from the permanent storage concept towards a bioreactor approach. The
general object of any landfill is to produce a “stable waste” within a reasonable time, ensuring very less impact on environment if lining cracks or destroyed. In opposite to conventional landfill which is simply a dumpsite, a bioreactor landfill is designed to increase the moisture content in the waste in order to minimize leachate migration into subsurface environment and maximize landfill gas generation rates under controlled conditions. The schematic figure of bioreactor landfill is given in figure 1.

![Figure 1: Schematic diagram of Bio- Reactor Landfill](image)

2. Types of bioreactor landfill

On the basis of decomposition method the landfill may be divided into three which are described below:

2.1 Aerobic

In aerobic bioreactor landfill Leachate is removed from the bottom layer, stored to liquid storage tanks, and recirculated into the bioreactor landfill in a controlled manner. Air is injected into the waste mass, using vertical or horizontal wells, to promote aerobic degradation and accelerate waste stabilization. If the injected air is uncontrolled, it can increase waste temperatures to levels where waste combustion may occur. Uncontrolled air addition could also result in creating gas mixtures with explosive characteristics. Proper control of air in the process remains a major issue. It will increase the process cost since it required energy for air circulation. Unlike mechanical blowers used to extract landfill gas, blowers for aerobic landfills will have to handle a volume of gas not involved with the decomposition reaction and will require greater pressures to force air through the waste. The ability of adding air into deep, well-compacted landfills is still unknown. Schematic diagram of an aerobic bioreactor is given above in figure 2.

![Figure 2: Schematic diagram of aerobic Bio rectore landfill](image)

2.2 Anaerobic
In anaerobic bio reactor landfill Moisture is added to the waste mass in the form of recirculated leachate and other sources to obtain optimal moisture levels. Anaerobic bacteria are responsible for converting organic matter into organic acids and ultimately into methane, carbon dioxide and H2S gas. The moisture condition that is required to optimize anaerobic degradation is about field capacity or (35-40) % moisture. The moisture content in typical landfills is around (10-20) % but in anaerobic bio reactor landfill it should be (35 –40)% for proper degradation. Moisture is typically added in a form of leachate through a variety of delivery systems. Biodegradation occurs in the absence of oxygen (anaerobically) and produces landfill gas most importantly CH4, methane can be captured to minimize greenhouse gas emissions and for energy projects.

2.3 Hybrid (aerobic-anaerobic)

The hybrid bioreactor landfill accelerates degradation of waste by employing a sequential aerobic-anaerobic treatment to rapidly degradation of organics in the upper sections of the landfill and collect gas from lower sections of landfill as the process is anaerobic in lower portion. Operation as a hybrid results in an earlier onset of methanogenesis compared to aerobic landfills. The cycling of aerobic and anaerobic conditions also offers possibilities of treatment of some recalcitrant chemicals and chemical byproducts in the same manner as modern wastewater treatment (e.g. nitrification and denitrification of ammonia).

2.4 Process Involve in Bioreactor Landfill

The various processes involved are briefly described below.

2.4.1 Physical Process

This process involves, shredding of the waste to a uniform size, proper mixing of the waste etc.

2.4.2 Chemical Process

Chemical process for enhancement of microbial growth involves leachate recirculation, pH adjustment, addition of buffers and nutrients etc.

2.4.3 Biological Process

Bioreactor landfill operates under optimum anaerobic environmental conditions for enhancement of bio-degradation process.

3. Waste Stabilization in a Bioreactor Landfill

Study of various phases of the microbial-mediated decomposition in a landfill is necessary in order to provide a basic knowledge for the operation and closure of bioreactor landfills. Soon after disposal of the waste, an anaerobic condition will become predominant since the available oxygen has been utilized by the
microorganism. A condition of anaerobic bacteria will start biodegrading the organic matter mostly converting it into carbon dioxide (CO2) and methane (CH4). The pathway of conversion can be explained by the following equation:

\[
\text{Organic waste} + \text{H}_2\text{O} + \text{Nutrients} \rightarrow \text{CH}_4 + \text{CO}_2 + \text{NH}_2 + \text{Biomass} + \text{Heat} + \text{Resistant organic matter}
\]

Biodegradation in landfill follow a sequence until it reaches the end product. Each step of anaerobic biodegradation is subdivided into 5 continuous phases by its predominant products in both leachate and landfill gas.

3.1 Phases of Municipal solid waste degradation

![Figure 3: Phases of MSW degradation in a typical Bioreactor landfill](image)

3.2 Phase I-Initial adjustment phase (lag phase)

When solid waste is dumped into the landfill, it takes moisture and air (oxygen) continuously with it. Thus, dominant gases are still N2 and O2. Biological decomposition occurs under aerobic condition because of availability of oxygen that results in elevation of CO2 concentration.

3.3 Phase II – Transition phase

The transition phase means the initial lag phase is going to shift towards anaerobic phase or anaerobic environment. Oxygen is consumed by the microorganism respiration (utilization). Anaerobic conditions result to end product such as volatile fatty acids and CO2. The pH of leachate is decreasing due to the presence of volatile fatty acid and CO2 solution. The low pH is responsible for the mobilization of heavy metal from the waste into the leachate.

3.4 Phase III – Acid phase

Continuous hydrolysis of solid waste, followed by the microbial degradation of biodegradable organic matter, result in the production of volatile fatty acid and CO2 at high concentrations. The pH value can be observed at the lowest value from the other phase.
3.5 Phase IV – Methane fermentation phase

The conversion of volatile fatty acid and H2 gas to CH4 and CO2 is a predominant event due to strict anaerobic bacteria. The utilization of organic is also responsible for the elevation of pH value. Organic contents in leachate transform to CH4 and CO2 gas, which make COD decrease significantly. Occurrence of heavy metals in the leachate tends to decrease because of a high pH value that causes complexion, precipitation and transition to solid phase. Production of CH4 in bioreactor landfill is more than the traditional landfill as shown in figure 4.

![Figure 4: Comparison of CH4 gas production in tradition and Bioreactor landfill](image)

3.6 Phase V – Maturation phase

In this phase, most of the biodegradable wastes have been decomposed by anaerobic bacteria. The remaining biodegradable waste is of such nature that is difficult to degrade in anaerobic condition. Thus, gas production drops and leachate strength stays at a constant level. The atmospheric pressure outside the landfill will permeate through the solid waste, results increase in the amount of N2 and O2 gases.

3.7 Advantages of Bioreactor Landfill

The bioreactor technology is popularly increasing in developed countries like America and Europe, and has been demonstrated at various landfills but it is still new to developing countries like India. The following are their advantage, which shows why bioreactor landfills are better than sanitary landfill.

1. Bioreactor landfill degrades organic matter quickly within a relatively short time. Thus, it increases landfill space, capacity, reuse and consequently the amount of waste that can be placed into it.

2. Operation with leachate recirculation reduces cost of leachate management by improvement of its quality and reduction of its quantity through evaporation and gas extraction.

3. Enhance the land fill gas generation rates, CH4 and reduction the impact on environmental impacts.

4. Methane oxidation is possible in the early years of the landfill life as long as methane generation is
abundant and this will minimize the greenhouse gas effect.
5. Bioreactor landfill saturate in very less time in comparison to the sanitary landfill.
6. Enhanced degradation will result in fewer long-term environmental risks. In the long term, it will be cost saving; and During the dry season, liquid wastes such as sewage sludge or food processing waste can be buried together with waste material in the bioreactor landfill to increase the moisture content and to accelerate biodegradation. This reduces the cost for liquid (lechate) waste treatment.
7. Reduction in post-closure and maintenance.

4. Limitations of Bioreactor Landfill

1. Aside from its benefits, the bioreactor landfill has certain limitations, which require further improvement in its process and operation as follows:
2. When there is scarcity of leachate than it’s difficult to maintain the optimum moisture content in bioreactor landfill.
3. Its increases the odor, surface seeps, landfill fires and physical instability of the waste due to increased moisture content and density are also some limitations of concern.
4. The earlier regulations for the design of a conventional engineered landfill mention that a strict selection of cover soil materials that give impermeable performance is required to reduce the seepage of water and outlet of gas in landfill that has been mentioned (Koerner and Daniel, 1997). Such a practice is opposed to the bioreactor landfill concept.
5. It is uneconomical since its required lot of energy to regulate moisture and air content in bioreactor landfill. Thus, investment costs will be higher due to the instrumentation, installation and monitoring costs.

5. Conclusion

The application of bioreactor landfill technology is a logical extension of the liquid treatment process and gives rapid saturation of solid waste. In the near future, this approach to waste management may become the norm and the sustainable landfill a reality. Bioreactor landfill also gives CH4 gas in early phase of life this can be use for generation of electricity which reduces the running cost. Landfill is an essential part of an integrated waste management strategy, without which effective waste management will not be possible. The development of a truly sustainable landfill will be important to the safe and effective management and control of waste in the future. As a solution to mismanaged open dumps in the country. The planning should take into account the various benefits of operating dumpsites as bioreactors and must be conceptualized accordingly while making proposals.

6. References

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