ABSTRACT

To use land as a repository for materials that can be assimilated without adverse impacts on the environment has been the fervour of landfill managers all around the globe. While it is inevitable that a landfill will receive an assorted range of materials from municipal sources pretreatment and processing of the waste dumped has been constantly looked upon as a commendable option. Operating landfills as bioreactors and hence enhancing the stabilization of waste is one such option that has been elaborately investigated and have also already been in practice in a few American and European countries. This paper gives a tangible view of the many benefits of the multifaceted approach evident from the past and ongoing laboratory and field trials and culminates with the need for research on the promising technology in India.

As garnered from literature, research on bioreactor landfills have focused on shifts in bulk parameters of leachate produced, stabilization rates and gas emission rates and the effect of pH control, shredding, compaction, ponding, cover and liner, water, nutrient and sludge addition. Notable merits among these have been reported to be quicker stabilization of waste and amplified gas production. Some auxiliary advantages of this kind of operation include distribution of nutrients and enzymes, pH buffering, dilution of inhibitory compounds, recycling and distribution of methanogens, liquid storage and evaporation opportunities at low additional construction and operating cost.

From lab-scale demonstrations to full fledged landfilling facilities, bioreactor landfills have been given due importance and hence constantly pondered into by environment conscious countries like United States of America, United Kingdom, Germany and Australia. India should also join the line by initiating research on this admirable technology option and concentrate on areas reflecting expected reactions occurring within the landfill by characterization of leachate which will help to provide information on waste degradation phases - an important insight that is yet to be revealed. Other focus areas can include design and operating criteria that suit Indian conditions, with special attention to leachate recirculation, gas entrapment and feasibility of applying the technique for reclamation of tons of garbage heaps in existing dumping grounds of the country.

1 INTRODUCTION

Open dumping of garbage is the method of solid waste disposal in most of the urban and rural areas of our country. The ever-increasing generation of garbage and hence the need for sufficient dumping space is now the point of fret for environmentalists all over our nation. Adverse environmental effects like ground water pollution arising due to unsystematic waste dumping in open unengineered landfills have been constantly addressed by many environmental experts. The continuously changing heterogenous composition of solid waste makes its management even more complex.

To convert open garbage dumps to environmentally secure sanitary landfills and essentially minimise any groundwater pollution from the landfills is one option that is being evaluated. While these facilities ensure that the waste will be preserved for an indefinite period
due primarily to the lack of moisture that is required for biological degradation of the organic fraction of the waste mass, new modified approaches to hasten the biodegradation process was considered as a promising line of thought in countries that already operate secure landfills to manage their garbage. This effort led to the discovery of what is now called Bioreactor Landfills.

Slow degradation of waste means larger volumes of waste awaiting to be contained. Increased volumes mean larger or more landfill space is necessary. A landfill bioreactor offers the possibility of degrading the organic fraction of waste within the landfill. Operating a landfill in a bioreactor mode endorses rapid stabilization of the waste, improved leachate and gas management, and reduces the longterm risks posed by the landfilled wastes. Operating a bioreactor landfill requires additional moisture be added to the landfill. This is achieved by leachate recirculation back to the landfill creating an environment favourable for rapid microbial decomposition of the biodegradable solid waste facilitating the operation of a bioreactor as a reusable landfill. This results in a system that dramatically extends the operating life beyond the conventional landfill.

2 THE BIOREACTOR TECHNOLOGY FOR LANDFILLS

The objective of a Conventional Landfill, which is designed as a Dry Tomb is to control the liquids associated with the landfill, i.e., limit infiltration and collect any leachate. As opposed to this, in a Bioreactor Landfill which is design as a wet cell, the objective is to degrade and stabilize the organic waste constituents as rapidly as possible.

A bioreactor landfill is a sanitary landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years of bioreactor process implementation. This significantly increases the extent of organic waste decomposition, conversion rates and process effectiveness over what would otherwise occur within the landfill. (Figure 1)

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**FIGURE 1. BENEFITS OF A LANDFILL BIOREACTOR**
Stabilization means that the environmental performance measurement parameters (landfill gas composition and generation rate and leachate constituent concentrations) remain at steady levels, and should not increase in the event of any partial containment system failures beyond 5 to 10 years of bioreactor process implementation.

The bioreactor landfill requires certain specific management activities and operational modifications to enhance microbial decomposition processes. The single most important and cost-effective method is liquid addition and management. Other strategies, including waste shredding, pH adjustment, nutrient addition, waste pre-disposal and post-disposal conditioning, and temperature management, may also serve to optimize the bioreactor process. Successful implementation also requires the development and implementation of focused operational and development plans.

The bioreactor process requires significant liquid addition to attain and maintain optimal conditions. Leachate alone is usually not available in sufficient quantity to sustain the bioreactor process. Water or other non-toxic or non-hazardous liquids and semi-liquids are suitable amendments to supplement leachate (depending on climatic conditions and regulatory approval). Other process amendment strategies may also be included, subject to regulatory approval. Shortly following closure of a bioreactor landfill, the landfill gas generation rate will usually be at its highest. It will then quickly decline over the next 5 to 10 years to a stable and relatively low and declining rate. Similarly, shortly after landfill closure, many leachate contaminant concentrations will change from levels regarded as highly polluted to much lower levels normally characteristic of extended stabilization. The leachate quantity at closure will be a finite amount, amenable to on-site treatment with limited need for off-site transfer, treatment and disposal. In the event of post-closure partial containment system failure, the quality of the leachate generated from infiltration into a bioreactor landfill will be much better than other drier landfills.

2.1 LEACHATE RECIRCULATION – THE KEY ACTIVITY

Among all the enhancement techniques, leachate recirculation is by far the most investigated process based management option. Its main drive is being generated from the arguments that the recirculated leachate helps:
1. to promote an active microbial degradation by providing an optimum moisture;
2. to induce a water flux to provide a mechanism for the effective transfer of microbes, substrates, and nutrient throughout the refuse mass, and;
3. to dilute local high concentration of inhibitors.

There are also potential operational benefits claimed, including:
   a. temporary storage of leachate and the partial in-situ treatment of leachate;
   b. improvement of landfill gas production rate and total yield;
   c. accelerated waste compression or settlement to create additional space for disposal and to allow earlier use of the site, and;
   d. reduction in time and cost of post-closure monitoring.

To successfully apply the technique, a comprehensive knowledge of the whole stimulation process is required. During the start-up period, leachate will be recirculated at slow flow rates to maintain a number of methanogenic bacteria. High flow rates will deplete buffering capacity and remove methanogenic bacteria. When gas production is well
established, leachate can be recirculated more frequently and at greater flow rates. Leachate recirculation is controlled by the field capacity of the waste, which can be maintained by adjusting the liquid addition according to the waste input as depicted in Fig. 2. The biggest problem with early recirculation attempts are short-circuiting, ponding, side-seeps, and interference with gas collection. Ideally, minimal compaction should be practiced for the bioreactor landfill to optimize early leachate recirculation. This time, conductivity will decline. However, at that point the landfill cell will be closed, consequently minimal leachate will be produced and lower recirculation rate will be acceptable (Reinhart and Townsend, 1998).

![FIGURE 2 LIQUID ADDITION REQUIREMENTS TO MEET FIELD CAPACITY (QIAN ET AL., 2002)](image)

2.1.1 METHODS OF LEACHATE RECIRCULATION

Leachate recirculation methods employed on a full-scale include prewetting, vertical injection wells, horizontal infiltration systems, surface ponds and spraying.

**Prewetting**
This method is simple, efficient and ensures uniformity but at the same time is labor-intensive, incompatible with closure and causes leachate blowing and compaction.

**Vertical Injection Wells**
This technique (as illustrated in Fig. 3) facilitates recirculation of relatively large volumes of leachate using low cost materials and is compatible with closure. Yet, subsidence problems, limited recharge area and interference with waste placement operation are a few demerits.

**Horizontal trenches**
This has all the advantages of vertical injection wells and is unobtrusive to landfill operation but potential biofouling limiting the volume and subsidence affecting the trench integrity are feared.

**Surface Ponds**
It leads to very effective wetting directly beneath the pond and provides for leachate storage while may be unfavourable in that it may collect storm, cause foating of waste and odour problems and is incompatible with closure.
Spray irrigation
It promotes evaporation and is flexible while it may cause leachate blowing and misting, decreased permeability and is incompatible with closure. The hydraulic application rates of a few full-scale recirculation systems are shown in Table 1.

![Figure 3: Landfill Bioreactor](http://www.wastemanagement.com/Bioreactor.ppt)

**TABLE 1 HYDRAULIC APPLICATION RATES IN FULL-SCALE RECIRCULATION PRACTICES**

<table>
<thead>
<tr>
<th>RECIRCULATION METHOD</th>
<th>APPLICATION RATES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical injection wells</td>
<td>0.23 to 0.57 m³/hr per 6.4 cm diameter well</td>
<td>Noncontinuous injection rate industrial landfill, hydraulic conductivity $10^{-2}$ cm/sec</td>
</tr>
<tr>
<td></td>
<td>4.6 to 46 m³/hr per 1.2 m diameter well 0.005 to 0.09 m³/m² landfill area/day</td>
<td>Noncontinuous injection rate municipal landfill, estimated hydraulic conductivity $10^{-4}$ cm/sec</td>
</tr>
<tr>
<td>Horizontal trenches</td>
<td>0.31 to 0.62 m³/m of trench length/day at 14 to 23 m³/hr</td>
<td>Early in application period</td>
</tr>
<tr>
<td>Surface ponds</td>
<td>0.0053 to 0.0077 m³/m²-day</td>
<td></td>
</tr>
<tr>
<td>Spray irrigation</td>
<td>0.73 m³/m² of landfill area/day</td>
<td>Intermittent application</td>
</tr>
</tbody>
</table>

Source: Reinhart and Townsend (1998)
3 A SHORT REVIEW ON BIOREACTOR LANDFILL STUDIES

As early as the 1970s, researchers started exploring the potential of applying leachate recirculation in landfills to enhance the stabilisation of waste and production of landfill gas. This resulted in a significant amount of research conducted at laboratory and lysimeter-scale followed by full-scale trials over the past two decades (Yuen, 2001).

3.1 Laboratory and lysimeter demonstrations

Early experiments had the objective of evaluating chemical characteristics of leachate and biogas from landfill to study landfill behavior (Qasim et al., 1970; Rover and Farguhar, 1973). These studies measured the leachate production or water balance for assessing the volume of leachate sent to treatment units. Thus, sizes of bioreactors were quite large until 1975, when Pohland (1975) conducted one of the first experiments on leachate recirculation. The experiment, supported by EPA, showed the importance of leachate recirculation and pH control. After this, the sizes of bioreactor have been smaller, involved no complicated operation, and tested no other factor except the effects of leachate recirculation. For example, the smaller bioreactor with 400 L capacity, was used to study the temperature effect to find optimum temperature to accelerate waste biodegradation. Figures 4 depicts a typical reactor used for bioreactor. Since 1985, the experiment has changed its focus from energy recovery to co-disposal. Pohland (1985) found that apart from accelerated stabilization of solid waste in laboratory scale by leachate recirculation, it was possible to work with hazardous waste co-disposed with industrial waste sludge. The test results found that leachate recirculation could enhance complexation and precipitation of heavy metals while solid waste stabilization occurred. Recently, many researches were aimed at sequential operation with leachate recirculation in laboratory scale. The experiments used leachate recirculation from one unit that had already been stabilized to the other young units, as the results showed quick stabilization in young units (Onay and Pohland, 1998).

The small-scale studies have provided sufficient evidences to suggest that the concept of bioreactor landfills is technically viable. However, these small-scale experiments have their own limitations. While they can allow the flexibility to study a large number of operational variables under controlled conditions, it is obvious that they cannot accurately simulate the natural degradation processes in full-scale landfills due to scale effects (Yuen, 2001). For example, almost all of the small-scale studies worked with shredded waste but very rarely the same treatment was given to the MSW in full-scale landfills. It also appears that the natural pH buffering capacity in a real landfill environment generally performs far better than that in a bench-scale simulator, possibly as a result of the presence of soil covers and a more diversified source of waste material. In addition, the kind of recirculation rate and uniformity of moisture distribution that can be achieved in a laboratory test cannot be obtained easily in a full-scale landfill cell. Other important conclusions of lab scale and pilot scale investigations of the late ’80s and ’90s include that saturation of waste is not beneficial; Recirculation promoted attenuation of inorganic and organic pollutants (Pohland et al., 1992). There are concerns on the production and escape of gas before landfill completion, leachate ponding, leachate toxicity due to high ammonium content (Lechner, 1993).
As a result of the positive effects of laboratory scale experiments using leachate recirculation in 1975, pilot scale models were constructed with provisions allowing reintroduction of leachate through it. To simulate landfill behaviour, large pilot-scale models that resembled the normal landfill, were constructed and located outside for exposure to natural conditions such as rainfall, sunshine, wind blow, etc. Leckie et al. (1979) started the leachate recirculation operation in 1979 to find the effect of moisture on the rate of waste stabilization. The results were similar to laboratory scale experimental results, but the settlement rate increased significantly. Later in leachate recirculation testing, the other effects were used to find the impact on solid waste stabilization. Hence, sewage sludge seeding was added with shredded solid waste in 1987 that resulted in increased gas yield, gas quality and gas production (Kinman et al., 1987). An example of a pilot-scale bioreactor is shown in Figure 5.

The research findings provide some useful indications on the general reaction patterns and outcomes that one may expect from leachate recirculation combined with other supplementary operations (Yuen, 2001). Some of these findings include the following (Reinhart et al, 2002):

Leachate Recirculation alone accelerates early hydrolysis and acid production, and results in a high volatile acids concentration in the leachate. If the natural buffering capacity of the system is insufficient, the acidic environment will inhibit the growth of methanogens and delay methane production (Kinman et al., 1987). Leachate Recirculation with pH Neutralization by buffer addition helps to mediate the acidic environment caused by any vigorous acid production, and enables early onset of methanogenesis (e.g. Pohland, 1975; Tittlebaum, 1982; Leuschner, 1989).

Recirculation with methanogenic leachate offers several benefits in the recycling of old methanogenic leachate in young landfills. Benefits include rapid reduction in leachate strength and early methane production, which are attributed to the high alkalinity and the seeding of methanogens from the methanogenic leachate. Leachate Recirculation with Sludge Addition or co-disposal with anaerobically digested sewage sludge, serves the purpose of moisture enhancement, nutrient addition and microbial seeding. (e.g. Leuschner, 1989; Knox 1997). However, there has to be some cautiousness regarding the characteristics of the sludge as it has been demonstrated that, for instance, septic tank sludge exhibits a detrimental effect due to its low pH nature (Leuschner, 1989). Leachate Recirculation with waste shredding gives no conclusive findings to suggest that this would provide a better enhancement effect than without shredding (e.g. Tittlebaum, 1982). Leachate Recirculation with Nutrient Addition does not seem to provide any further enhancement as nutrient deficit is generally not a limiting factor (e.g. Tittlebaum, 1982). Leachate Recirculation with temperature control suggests that the optimum temperature range for anaerobic degradation lies between 34 and 38 °C, with or without leachate recirculation (Mata-Alvarez et al., 1986). Leachate Recirculation with waste pretreatment gives positive effects on leachate strength reduction (e.g. Nilsson et al., 1995a and b). Leachate Recirculation at different rates suggests that higher rate of recirculation provides a better anaerobic degradation (Ham and Booker, 1982). However, any secondary effects (e.g. drop in waste temperature), as a result of a high recirculation rate, should also be considered. Aeration of leachate prior to recirculation may be used to pre-treat the leachate to reduce its high organic load prior to recycling. This is particularly beneficial if the leachate is to be recycled by direct spray irrigation onto landfill surfaces with vegetation cover. The pretreated leachate would sustain vegetation growth by providing nutrient.
A few important observations include short-circuiting that occurs during leachate recirculation, preventing achievement of field capacity for most of the landfill. Continuous pumping of leachate at two to three times the generation rate is necessary to avoid head build-up on the liner. A more permeable intermediate cover may be more efficient in rapidly reaching field capacity than leachate recirculation. Low permeability, intermediate cover, and heterogeneity of the waste leads to side seeps. Accelerated gas production may lead to odors if not accommodated by aggressive LFG collection. Leachate infiltration and collection piping are vulnerable to irregular settling and clogging. If waste is less permeable than anticipated, increased condensate production leads to short circuiting of moisture into landfill gas collection pipes. Storage must be provided to manage leachate during wet weather periods. Conversely, leachate may not be sufficient in volume to completely wet waste, particularly for aerobic bioreactors. Increased internal pore pressure due to high moisture content may lead to reduced factor of safety against slope stability and must be considered during the design process; and channeling leads to immediate leachate production, however long term recirculation increases uniform wetting and declining leachate generation as the waste moisture content approaches field capacity.

**FIGURE 4  LABORATORY SCALE LANDFILL BIOREACTOR DEMONSTRATION**
3.2 Full-fledged bioreactor landfill facilities

Following the positive results demonstrated by small-scale and pilot-scale studies, there has been an increase in the number of cases reported in recent years on the practice of leachate recirculation in full-scale operating landfills in countries such as the U.K., Germany and U.S. However, the research and development devoted to full-scale investigations are still relatively limited, due mainly to a poor regulatory awareness and negative perception. Landfill regulations in many countries still do not encourage the practice of leachate recirculation because of the concern that feeding back the highly polluted leachate into a landfill may concentrate the pollutants and overload the containment system.

A few examples of full-fledged landfill activities initiated so far are listed below (Pacey et al, 1999; Yuen, 2001; Reinhart and Townsend, 1998).

**United States**

For three years, Yolo County has been operating a bioreactor demonstration cell that contains 9,000 tons of refuse in California. The Delaware Solid Waste Authority has operated the major landfill (largest in the state) at Sandtown as a bioreactor for more than 10 years. A demonstration bioreactor landfill has been established at more than 3.2 million dollars and is ongoing Florida. At Georgia two aerobic bioreactor landfill projects are operational; one at the Live Oak Landfill in Atlanta, the other at the Baker Road Landfill in Columbia County. At Iowa, the Bluestem Solid Waste Authority has commenced waste placement in December 1998. An anaerobic bioreactor operation is being carried out at the Mill Seat Landfill; a pretreatment aerobic bioreactor activity is operational at Elmira, both at New York. The State Research and, Development and Demonstration Program is sponsoring an aerobic activity at the Aiken County Landfill, South Carolina. Washington Administrative Code specifically permits bioreactor landfills. The pertinent section on operating criteria on liquid restrictions states, “Bulk or non-containerized liquid waste may not be placed in MSWLF units unless the waste is leachate or gas condensate derived from the MSWLF unit, or water added in a..."
controlled fashion and necessary for enhancing decomposition of solid waste, as approved during the permitting process.”

**United Kingdom**

Spray irrigation is already in practice in the Seamer Carr Landfill, Yorkshire and Brogborough Landfill, Bedfordshire, U.K; while infiltration has been employed in the Lower Spen Valley Landfill, West Yorkshire.

**Germany**

At the Lingen Sanitary Landfill, 2 cells each of 1 ha. are being operated as bioreactors, while in Bornhausen & Bornum Landfills, cells of 0.5 to 1.25 ha. are being spray irrigated.

**Sweden**

Infiltration of leachate is carried out at the Spillepeng Landfill, Malmo.

**Australia**

Injection wells are used at Lyndhurst Landfill, Victoria, Australia. (Yuen et al. 2001)

An example of the positive effect in reduction of leachate strength at Sea Carr Landfill demonstrated that leachate recirculation technique in full-scale is highly effective. However, this technique should be further studied since it allows dispersion of highly concentrated pollutant to the environment. Further treatment of leachate at some stage may be required. Nevertheless, full-scale practices since 1978 showed the environmental impacts from leachate recirculation technique, particularly, leachate seepage and leachate break out. Thus, operations were modified to diminish this effect by using alternative daily cover instead of clay soil to increase leachate infiltration rate. Lower Mount Washington Valley Secure Landfill uses this operation. When the landfill is permitted to have a water inlet, the liner system will be the same but needs superior protection such as a double composite liner.

### 4 NOTABLE MERITS

Several merits have been emphasized and these are listed hereunder.

#### 4.1 Rapid organic waste conversion/stabilization

Due to rapid settlement, the waste volume is reduced and stabilized within 5 to 10 years of bioreactor process implementation. This leads to increased gas unit yield, total yield and flow rate and almost all of the rapid and moderately decomposable organic constituents will be degraded within 5 to 10 years of closure. Leachate quality is improved and stabilizes within 3 to 10 years after closure. Early land use is possible following closure.

#### 4.2 Maximizing of landfill gas capture for energy recovery projects

Significant increase in total gas available for energy use is achieved, which provides entrepreneurial opportunities. A potential increase in total landfill gas extraction efficiency is enabled over a shorter generation period. Lessened emissions leads to increased greenhouse gas reduction. There is also an increase in fossil fuel offsets due to increased gas energy sales. Hence, there is a significant economy of scale advantage due to high generation rate over relatively short time.
4.3 Increased landfill space capacity reuse due to rapid settlement during operational time period

Amount of waste that can be placed into the permitted landfill airspace is increased leading to effective density increase. This extends landfill life through additional waste placement. Deferred capital and financing costs is only needed to locate, permit and construct replacement landfill resulting in capital and interest savings. Thus there is a significant increase in realized waste disposal revenues.

4.4 Improved leachate treatment and storage

Low cost partial or complete treatment is achieved. There is significant biological and chemical transformation of both organic and inorganic constituents, although mostly relevant to the organic constituents. Reintroduction of all leachate over most of the operational and post-closure care period significantly reduces leachate disposal costs. Absorption of leachate within landfill is available up to field capacity.

4.5 Reduction in post-closure care, maintenance and risk

Rapid waste stabilization (within 5 to 10 years) minimizes environmental risk and liability due to settlement, leachate and gas. Landfill operation and maintenance activities are considerably reduced. Landfill monitoring activities can also be reduced. There is a considerable reduction of financial package requirement. In the event of partial liner failure, there should be no risk of increased gas generation, worsening leachate quality, increased settlement rate or magnitude.

Another major benefit of bioreactors may come from greenhouse gas abatement. Bioreactors can generally rapidly complete methane generation while attaining maximum yield. This can be combined with nearly complete capture of generated gas using the bioreactor landfill in combination with a landfill gas energy project. With this approach, the high generation level and gas capture efficiency maximizes landfill greenhouse gas offset potential.

Additional goals and benefits may also accrue, including: 1) transformation of certain resistant organics (dehalogenation, etc.) and sequestration of certain inorganics (precipitation, etc.); and 2) pollutant removal processes of filtration, capture, sorption, etc. that are promoted by leachate recirculation (Pohland, 1992). and 3) increased environmental stewardship and economics.

5 NECESSITY FOR AN INDIAN STUDY

As compared to many developed countries, the concept of bioreactor landfills is still relatively very new to India. As a solution to mismanaged open dumps in the country, a systematic rehabilitation strategy must be planned and executed. This planning should take into account the many benefits of operating dumpsites as bioreactors and must be conceptualized accordingly while making proposals. Initiation of pilot scale and lab scale bioreactor studies must be executed at the outset to experiment the feasibility of the technology for Indian refuse.

5.1 RESEARCH AREAS TO FOCUS AND TECHNICAL & NON-TECHNICAL ISSUES TO ADDRESS

For India to actualize this technology to its municipal solid waste a systematic approach is needed. This includes a comprehensive, up to date, compilation, analysis and results of all the bioreactor facilities and research performed or operating currently worldwide. Proposals focusing on full-scale field tests and well-instrumented and monitoring facilities to provide the field performance data that will show the merits and shortcomings of the bioreactor
should be encouraged. While proposing it must be noted that designs for the facilities should be performed based on function, i.e., what is the function of the particular unit of the facility, e.g., leachate collection system, and design must be made for the purpose intended. The experience obtained from the full-scale studies generally suggests that future studies of bioreactor landfills should be focused on the following areas:

- The improvement of leachate recirculation systems to distribute moisture uniformly throughout the waste mass;
- Investigation on the extent of channelling and dead zones of recirculation due to heterogeneity;
- The long-term performance of recirculation devices taking into account the potential reduction in efficiency caused by bio-fouling and siltation;
- Supplementary enhancement methods such as waste shredding, waste pre-wetting, and use of permeable alternative daily cover;
- Alternative numerical moisture transport models such as the recently proposed two domain approach for moisture distribution prediction; and
- The implementation of more full-scale bioreactor experiments to determine other biodegradation influencing factors such as waste composition, climate, and hydrological conditions, which can vary substantially from region to region.

5.2 PROBLEMS ANTICIPATED

It is predictable that the regulatory bodies will express a hesitancy to the change. There may be public perception that bioreactor may increase odors and air emissions. Significant capital investment will be required for bioreactor landfills. Operational challenges include leachate recirculation system maintenance, uniform wetting of waste mass, settlement of the system, clogging of leachate collection system.

6 CONCLUSION

Given the design goals remain the same, there is little reason to change the design, regulations, or our approach to solid waste disposal; however, the design goals are changing! Partially by better engineering for long-term solutions, partially by public pressure and partially by economics, the goals of our solid waste disposal philosophy are evolving and will continue to evolve. As our goals change, we must engineer solutions to meet the changes.

It would take a long time to get the research data, performance data and know-how for bioreactor landfill systems. But the effort will be amazingly fruitful as there will be conservation of landfill space and this would provide longer term, even permanent solutions, for our solid wastes. Bioreactors, in regard to the organic constituents, may provide the next generation of solid waste disposal. Requirements for research, development and field performance monitoring of prototype systems should not preclude the concept but rather, should be employed judiciously and critically to arrive at the best practicable solution for our local conditions.
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