The concept of sustainable landfills

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1. Sustainable landfill

1.1 Introduction

Emissions caused by landfills even after their closure are considerable over decades. Therefore, the operation of closed landfills has to continue in order to seize remaining emissions and reduce them to an acceptable minimum. This so-called aftercare phase will last for a few decades. Therefore, the landfill will be observed from its beginning up to an undetermined time in the future.

When municipal solid waste (MSW) is landfilled without pretreatment, emissions occur during and after the landfill operation in the form of approximately 150 m³ biogas/tn MSW and 5 m³/ha*d polluted leachate, depending on composition and climatic conditions. Additionally, due to biological degradation processes significant settlings take place, between 20 – 25% of the height of the landfill, which may damage the barriers of the landfill. The leachate obtained has to be collected and treated and the biogas produced is extracted and flared with great expenditures.

Engineering measures for landfills, such as bottom liners, top covers or treatment plants, have a service lifetime of only three decades maximum.

<table>
<thead>
<tr>
<th>Duration (years)</th>
<th>10-20</th>
<th>20-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological barrier</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Geomebrane</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Clay liners</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Leachate treatment plant</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Biogas treatment plant</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Top cover</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1: Landfill’s barriers duration

Decomposition processes in landfills are fairly long term. Landfill gas and long term leachate emissions cannot be prevented in case of traditional landfills.

Finance for the operation phase will be provided by reserves from the solid waste producers. As far as the aftercare phase is concerned, the finance should be provided by reserves made during landfill’s active use. However the most common practice is the shift of the finance to the next generations.

Founded on the above, it is obvious that the landfill must be handled in a different way, towards sustainability. The basic principles of the sustainable landfill are:
- The environmental and financial cost of the landfill operation and management must be paid by the users and not be transferred to the future generations.

- The solid waste degradation has to be accomplished within the service lifetime of the landfill’s barriers.

- By the end of the aftercare phase the landfill must not consist risk for the environment and the public health.

The key factor for landfill sustainability is the mass balance, as sustainability requires:

- Solid waste volume reduction
- Stabilization of waste
- Less biogas
- Rapid biogas production
- Reduction of leachate organic load

\[
\text{Accumulation} = \text{Inlet} - \text{Outlet} - \text{Degradation}
\]

**Figure 1: Mass balance of a landfill**

Consequently, operation of a landfill must not be dealt just as earthworks, which demand management of the emissions, but rather as an active bioreactor that should be properly engineered. In order to achieve the sustainability of a landfill, control and acceleration of the processes that take place in the landfill must be of the first consideration. Therefore, treatment of the solid waste is necessary. By waste treatment, processes taking place in the landfill over long periods (decades) will be shortened to a few years with beneficial influence to the environment as well as the landfill’s finance. The aftercare phase will be kept as short as possible and the landfill will then remain self-regulatory and only very few measures of control will be necessary.
It is worth to mention that according to EU legislation (Directive 99/31) all the amounts of solid waste must be subjected to treatment prior to landfilling, in order to reduce the organic load and consequently the environmental impacts from the landfill operation.

The above must constitute the guide for the formation and implementation of an integrated solid waste management system.

1.2 Towards sustainability

Solid waste can be treated prior to landfilling and / or after disposal to landfill, in-situ, at the operation phase. Solid waste treatment after disposal in the landfill is cheaper but also less sustainable than treatment prior to landfilling.
In the above Figure, the basic theses for an overall concept for sustainable landfill are described.

As mentioned before, the main step is to reduce (not to maintain) the emission potential of landfills. The following procedure is recommended:

- Future landfills will only receive treated waste, either thermally or mechanically.
- Landfills that receive untreated waste should be operated as mostly controlled bioreactors with a high biological component turnover ratio. In this case:
  - The produced leachate should be collected and treated in a treatment plant.
  - The produced biogas should be collected and flared or used as an energy source
  - Recirculation of treated leachate is recommended in order to increase the moisture content and to enhance the biological degradation
- It has to be ensured that the groundwater will not be contaminated. So attention must be drawn to the protection of landfill barriers from damage.
• In order to reduce the emission potential of closed landfills, an in-situ aeration if need in connection with moisture regulation after landfill closure is recommended.

• For the reduction of leachate mainly low maintenance surface liner systems, with capillary barriers, should be installed. The recultivation layer should optimise the system reservoir with high evapotranspiration.

• The deformation and mechanical stability of the landfill body has to be surveyed and analysed, if necessary repairs have to be made.

To the table below several treatment methods are presented as well as their influence to the landfill, especially to the environmental impacts mainly caused by the organic load.
### Table 2: How we can affect mass balance

<table>
<thead>
<tr>
<th>Treatment prior to landfilling</th>
<th>Decomposition duration</th>
<th>Landfill volume</th>
<th>Income Organic load</th>
<th>Leachate organic load</th>
<th>Biogas organic load</th>
<th>Disposed Solid waste quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical/Biological Treatment (MBT)</td>
<td>-</td>
<td>-</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Thermal Treatment</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Waste minimisation</td>
<td>--</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>Non acceptable</td>
<td></td>
</tr>
<tr>
<td>Bailing</td>
<td>+</td>
<td>-</td>
<td>--</td>
<td>--</td>
<td>Non acceptable</td>
<td></td>
</tr>
<tr>
<td>In-situ treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate recirculation</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In situ aeration</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Acceptable</td>
<td></td>
</tr>
<tr>
<td>Anaerobic degradation</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>Non acceptable</td>
<td></td>
</tr>
</tbody>
</table>

Cross (+): parameter increase  
Dash (-): parameter decrease
From the table above it can be concluded that an acceptable quality of the disposed solid waste, that will not consist a threat for the environment at the end of the aftercare phase, can be achieved only by solid waste treatment prior to landfilling.

Figure 4: Long term landfill impact

Also, the application of either Mechanical Biological Treatment or Thermal Treatment is necessary in order to achieve a product that could be disposed of at the landfill with no required additional actions for the protection of the environment.

In the table below, the main parameters of a traditional landfill and of a sustainable landfill are presented.
Table 3: Parameters of traditional and sustainable landfill

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Traditional landfill</th>
<th>Sustainable landfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅ (mg/l)</td>
<td>5.000</td>
<td>11</td>
</tr>
<tr>
<td>COD (mg/l)</td>
<td>10.000</td>
<td>1.442</td>
</tr>
<tr>
<td>BOD₅ / COD</td>
<td>0.4</td>
<td>0.008</td>
</tr>
<tr>
<td>TVA (mg C/l)</td>
<td>4.000</td>
<td>106</td>
</tr>
<tr>
<td>TKN (mg N/l)</td>
<td>3.000</td>
<td>46</td>
</tr>
<tr>
<td>NH₃ (mg N/l)</td>
<td>2.500</td>
<td>6.3</td>
</tr>
<tr>
<td>NOx (mg N/l)</td>
<td>0</td>
<td>270 x (15)</td>
</tr>
<tr>
<td>Chloride (mg Cl/l)</td>
<td>2.000</td>
<td>1.500</td>
</tr>
<tr>
<td>Copper (mg Cu/l)</td>
<td>1.5</td>
<td>0.67</td>
</tr>
<tr>
<td>Lead (mg Pb/l)</td>
<td>0.5</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Concluding, sustainable landfill is basic condition for the implementation of an integrated solid waste management system with respect to the environment. Therefore, solid waste treatment prior to landfilling is demanded as a precondition.
2. Strategy of Landfill Operation

2.1 Introduction

As it mentioned in the previous chapter, even if landfill operation and monitoring is properly carried out, the most possible incident is that the environmental and economical problem of landfill’s emission management will be transferred from our generation to the next one. Such a situation cannot be acceptable and this is the reason for introducing the term of “sustainable landfill”.

According to the principles of sustainable landfilling, the operation of a landfill does not refer only to earthworks and emissions management. In order to achieve sustainability through the operation of the landfill, the major concern of the operator is related to the processes that take place in it as well as the systematic control of emissions and their completion at the end of aftercare period.

During the last years, a number of intervention techniques during the aftercare period of the landfill have been developed in order:

- to achieve rapid completion of biodegradation processes
- to eliminate the aftercare period of the landfill,

Such techniques are the in-situ aeration, the landfill mining, or the flushing techniques that cause sudden increase of water level in the waste volume.

It is very important that the costs of the techniques that will be applied in a landfill have to be less or equal to the aftercare costs. In such cases, the incorporation of these techniques during the operation and aftercare period is economically efficient solution and ensures insignificant environmental risk and releases land for further new use much earlier than the traditional way of landfill operation.

In the following parts of this session, different operation strategies are presented, that the landfill operator must consider in order to select the strategy that he will follow in order to achieve the expected outcomes.

2.2 Parameters that affect the landfill performance
The landfill performance is the outcome of the interaction of many factors. The main of these factors are:

1. The climate and the environmental status of the landfill location, i.e. the sensitivity of the area to the environmental impacts of the landfill, the moisture balance of the area which is merely related to the biodegradation level of waste and the leachate management procedures and the distance from residential areas and from the aquifer which points out the level of biogas and leachate management needed, respectively.

2. The design and the construction of the landfill.
   - There is direct relationship between the way that the landfill is designed and constructed, and the operation cost and the viability of the landfill.
   - The high quality of design and construction, does not guarantee high quality of operation, but it is a precondition for accurate operation.
   - Proper operation is an important design criterion for a landfill. The landfill operation aims to the “construction” of an environmentally acceptable waste volume.

3. The characteristics of incoming waste (amount, composition)
   - Every landfill is designed to accept specific types of solid waste, not all the types.
   - The reception of all the kind of solid wastes, without control and sampling, is illegal and very dangerous for the staff of the landfill.
   - The reception of non-accepted waste in the landfill cannot be a solution. It is a problem that passes form the waste producer to the landfill operator.

4. Human resources that participate in the administration and the operation of the landfill
   - The proper landfill operation cannot be reached if there is no organisation and well-trained staff.
   - Health and safety are the least conditions for the proper operation of the landfill. If the people that work in the landfill do not care for their health and safety, they will not care about the environment either.
5. The overall waste management strategy for the served area
   o If landfilling is the only solid waste management technique for the area, then there is no waste management strategy
   o The waste management strategy must contain recycling, and/or treatment, and/or prevention and minimization plans. The served area must choose the right mix according to its characteristics and needs
   o Waste management strategy + technical assistance + management = successful management system

It is obvious that the last factors 3, 4 and 5 are the only factors that can be affected by the landfill operation team. But at the same time, these 3 factors are the more important and significant for the environmental performance of the landfill.

2.3 Expected Outcomes

There are a number of possible expected outcomes from the operation of a landfill. In real life, the landfill operator usually desires more than one outcome. The landfill operator must know exactly what he wants to receive as outcome from the landfill in order to take the adequate measures. Some of the expected outcomes of landfill operation are the following:

Outcome No.1: Maximisation of biodegradation rates.

1. Waste treatment is necessary. If the disposed material is treated, complete biodegradation becomes earlier
2. Compaction of disposed material is required for maximization of the biodegradation rate. It is better to avoid bailing.
3. For the untreated wastes:
   a. The moisture level must be kept around 50%
   b. A recirculation network must be incorporated in the landfill. This network will be supplied by large tanks of treated leachate. In any case the recirculation procedure must be monitored.
c. The capping method must be designed and implemented according the level of moisture in the completed waste volume.

Outcome No.2: Maximisation of the lifespan of the landfill
1. Waste pretreatment is necessary. The lifespan of the landfill increases when the volume of the disposed material is decreasing
2. Compaction is required
3. Minimisation of daily cover to an acceptable rate. The use of alternative daily covers is proposed only if it is economically effective
4. Reception only of the waste that are acceptable and described in the landfill permit
5. The big dykes (permanent or provisional) reduce effective lifespan of the landfill
6. If it is possible, the increase of waste volume slopes is indicated for the maximisation of the effective capacity of the basin

Outcome No.3: Use of the biogas for energy generation
1. The decrease of the level of organic waste in the waste volume, decreases the energy generation potential of the landfill
2. Biological pretreatment reduces the time needed for the biogas production
3. The landfill volume must be developed at height. This is the best way to create anaerobic conditions.
4. Monitoring of the moisture level and the recirculation in order to achieve the best conditions for biogas production
5. Biogas should be extracted actively through vertical drilled wells on the completed waste volume. During the operation of the landfill, the biogas must be extracted through horizontal trenches.
6. Many of the non acceptable wastes can cause delay to the biodegradation and the biogas generation
**Outcome No.4: Elimination of the aftercare period**

1. For the selection of the most appropriate process for the maximisation of biodegradation rates, a cost–benefit analysis is required
2. Use landfill mining procedure for the recover of metals and for the production of secondary fuel, if there is potential user
3. Landfill mining is not indicated if the landfill is close to residential areas because there will be huge problem with the odours
4. If landfill mining is not possible, the flushing process is an option.
5. If the conditions in the waste volume are not anaerobic, flushing process ensures the protection from fire generation

**Outcome No.5: Cap-As-You-Go**

1. Working in small and discrete cells, with separate leachate and biogas collection systems, helps to the rapid completion of the cell and consequently the earlier capping of this part of the basin
2. Proper compaction (preferably from top to bottom) of the waste is crucial.
3. For better compaction, the daily cell must consisted of smaller layers of 50-60 cm thick

**2.4 Impact of Pre-treatment on landfill operation**

Generally speaking pre-treatment can cause positive impacts to the waste handling in a landfill, as well as creates better conditions for the biodegradation process.

**Impacts of Shredding**

Shredding of the wastes multiplies the active surface of the waste and at the same time decreases their size. So:

1. The biogas and leachate generation begins earlier
2. The biodegradation processes complete earlier
3. Proper compaction of the waste is easier

**Impacts of Bailing**

Bailing increases the density of the waste and increases the lifespan of the landfill. However, the biodegradation process for the bailed waste is delaying significantly and the moisture infiltration through the waste becomes very difficult. Due to the very high compaction levels of the waste, moisture retention cannot be realised. In days of high precipitation the channels created between disposed bails of waste lead to immediate appearance of large quantities of leachate. In this case the level of pollutants in the leachate is very low.

**Impacts of Biological Treatment**

Biological treatment:

- Reduces the amount of immediate biodegradable substances and facilitates the degradation of waste
- Increases the permeability if the waste volume and reduces the possibility for clogging of the leachate collection pipes and the drainage layer

Biological treatment’s disadvantage is that in order to achieve the acceptable final quality, the waste must be treated at least 14-16 days at the treatment facilities. As a consequence of this disadvantage is the increasing cost of this treatment, which affects the viability of such an investment. Reduction of the biological treatment period can be achieved if the maturity process is combined with the application of forced ventilation of the waste.

**Impacts of Thermal Treatment**

Thermal treatment:

- Reduces significantly the amount of waste to be disposed
- Removes the amount of organic waste and therefore the biogas production and the organic load of the leachate
- Ensures the compaction of the residuals in very high levels
REFERENCES – SUGGESTED READINGS

1. EPEM SA, “Guide for internal control of operational and safety issues in Landfills”, 2006


