THE SUSTAINABLE LANDFILLING CONCEPT

R. COSSU

IMAGE Department, University of Padova; Via Loredan, 20 - 35135 Padova, Italy; e-mail raffaello.cossu@unipd.it

SUMMARY: A useful tool for approaching the sustainable landfill is the mass balance. With this model it is possible to determine the effects of different alternatives for waste and landfill management, on the reductions of the emissions. The sustainable landfill should present at the end pont of the aftercare time (generally 30 years) an environmental acceptable mass accumulation. This should be the reference criteria for evaluating any technology, or combination of technologies, which could be applied for reaching this target. Pre-treatment, in situ treatment, and post-treatment in the aftercare phase should be considered in an integrated way looking for the performance of the system and being precriptive only for the final result: reach of the sustainable targets.

1. INTRODUCTION

In order to comply with the sustainability concept a landfill should reach an acceptable equilibrium with the environment with a generation time (30-40 years). How to put in practice this priciple represents one of the main research issue for the scientific community active on landfilling. Several aspects, both technical and legal need to be clarified.
Main questions are:

- Which technolgies and tools may be applied for reaching sustainabilty?
- How to set targets for for the final residual landfill quality
- Which changes/integration in the existing regulations are necessary in order to implement the sustainable landfill concept?
- Which legal and financial liability should be provided and by which means?

A useful tool for approaching the sustainable landfill concept and for organising the information needed for supporting policy the mass balance model. With this model it is possible to determine the effects of different alternatives for waste and landfill management, on the reductions of the emissions within a given time frame.

2. PRINCIPLE OF MASS BALANCE

The mass balance usually considers the fate of substances entering and leaving a system in various ways.

Proceedings Sardinia 2005, Tenth International Waste Management and Landfill Symposium
S. Margherita di Pula, Cagliari, Italy; 3 - 7 October 2005

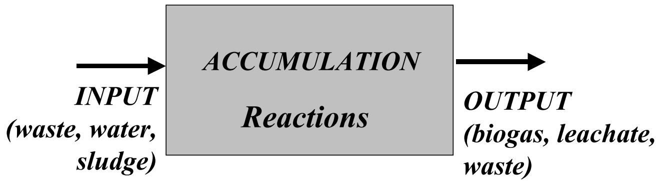

Figure 1 . The landfill mass flow scheme

The modelling approach to the mass balance tries to simplify the system with a Continuous Stirred Tank Reactor CSTR). CSTRs are also useful to describe more complex systems for which the assumption of a single CSTR is not acceptable. Such a system can be described by a distributed parameters model using a network of CSTRs with possible feedback. This is the case of a landfill with some sectors managed in different ways.

The basic assumption is that the concentration of a given substance in the volume V of the landfill is always uniformly distributed in the space. If a change in time of the concentration occurs instantaneously the new concentration is distributed all over the system.

Considering the landfill as a reactor (Figure 1) where reactions and mass accumulation occur the input and output of the component of interest (carbon, nitrogen), associated to the waste and to the emissions (leachate, biogas) the mass balance equation can be summarized as follows:

$$accumulation = input - output \pm reaction \qquad (1)$$

Input in equation (1) represents the mass entering the volume from a variety of sources and different ways. If "*n*" streams of "*i*" waste components are considered with mass Q_i (t/year), each one with a different concentration in the solid phase (x_{Si} in mg/kg waste), the mathematical expression is:

$$\text{Input} = \sum_{i=1}^{n} Q_i \cdot x_{Si}$$

Output in equation (1) is the mass leaving the landfill through biogas (q_G, m^3/y) and leachate (qL, l/y). If the concentrations of the contaminant in the biogas and in the leachate are respectively x_G (mg/l) and x_L (mg/m^3), the expression is:

$$Output = x_L \cdot q_L + x_G \cdot q_G$$

In order to distinguish between the fraction of leachate and biogas that are collected (q_{Lr} and q_{Gr}) and the fraction that migrates in a uncontrolled way through the barrier of the system (q_{LD} and q_{GD}) the following can be written (Figure 2):

$$q_L = q_{Lr} + q_{Ld} \text{ and } q_G = q_{Gr} + q_{Gd}$$

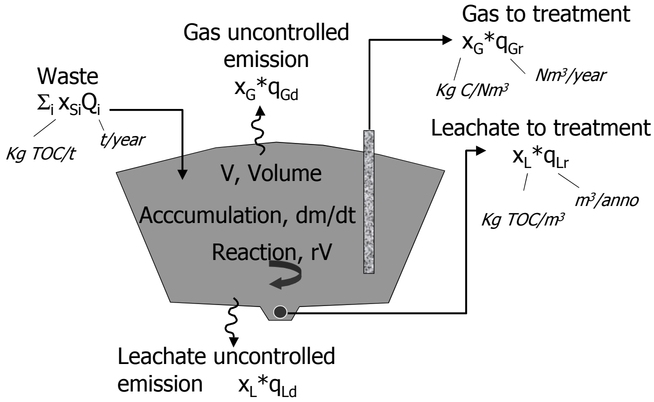

Figure 2. External terms of the landfill mass balance

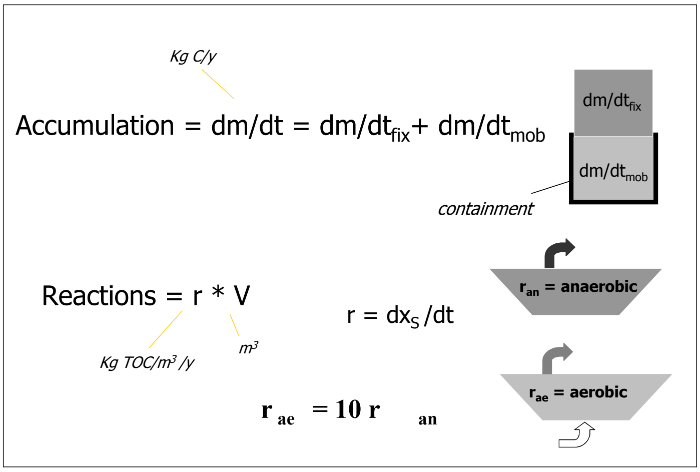

Figure 3. Internal terms of the landfill mass balance

The accumulation term, which represents the increase of mass (*m*) in the landfill system over time (*t*) is expressed as:

$$Accumulation = dm/dt$$

As described graphicallyin Figure 3, the accumulated mass in the landfill can undergo chemical-physical transformations and will either be mobilized and transferred into the liquid phase by means of natural lixiviation (m_{mob}), or transformed into stable non extractable compounds (m_{fix}): The mobile accumulated fraction should be contained in order not to spread in an uncontrolled way into the environment.

Reaction term in equation (1) is a way of leaving the system for the mass by chemical transformation into other substances. The simplest way for this process is a zero or first order kinetic (r in $mg/m^3 \cdot y$):

$$Reaction = r*V$$

Reaction can either occur in an anaerobic environment (with the generation of the typical landfill gas) or under aerobic conditions with air inflow and oxydized gas generation.

The total balance for the system is represented in Figure 4, according to the different external and internal terms as described earlier.

Rearranging the equation in order to bring into the first half of the equation the terms expressing the uncontrolled emissions of leachate and gas it is clear, from the mathematical view point, what an engineer should aim in designing a sustainable landfill and how to achieve it: minimize the uncontrolled emissions ($x_L \cdot q_{Ld}$ and $x_G \cdot q_{Gd}$),, i.e. minimize the positive terms in the second half of the mass balance equation and maximize the negative ones.

This means the following:

- minimization of the amount of mass component introduced in the landfill ($\sum x_{Si} \cdot Q_i$), either controlling the flow (Q_i) either controlling the quality (x_{Si})
- maximization of the amount of the mass component associated to the collected biogas and leachate ($x_L \cdot q_{Lr}$ and $x_G \cdot q_{Gr}$), again either controlling the quality and the quality
- maximization of the containment of the mobile accumulated fraction (dm/dt_{mob}) and of the stabilisation (fixation) processes (dm/dt_{fix})
- maximization the reaction rate of the degradable compounds. This is favoured by aerobic conditions.

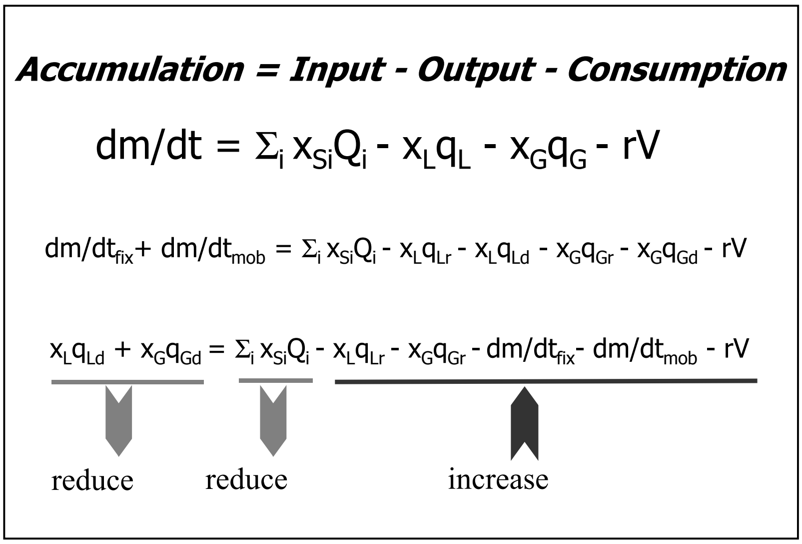

Figure 4. Mass balance equation. In landfill design the uncontrolled emissions terms should be avoided or kept to a minimum.

It is worth to highlight, contrary to the prevailing regulation which aim to minimize the leachate production, the relevance in the mass balance equation of the input of water in the waste mass, either as a reactant for the biodegradation (influence on the reaction rate) either as a mean for favouring the mass transport (flushing).

Minimize the leachate production by prescribing heavy sealing top cover (as in the the Italian Landfill Regulation) can result in a sort of waste mummification which can prolong for a very long time the emission potential of a landfill (centuries, according to Kruempelbeck and Ehrig, 1999), in contrast with any sustainability concept.

3. OPTIONS FOR CONTROLLING THE LANDFILL MASS BALANCE

Many different options are available for reaching the target of the sustainable landfill. In Table 1 the influence of different alternatives for waste and landfill operation on the main parameters in the mass balance is considered. The main options considered are waste minimization and pretreatment, leachate management (recirculation, flushing) and alternative landfill management as the in situ aeration.

There is still much discussion concerning the extension of the pretreatment step which may involve mechanical, biological, thermal and physical-chemical (inertization) processes.

Mechanical pre-treatment such as shredding result in a positive influence on size reduction and on the acceleration of biochemical processes occurring in the landfill body and in the enhancement of the transfer of the biodegradables into the gas and liquid phase.

Biological treatment reduces the amount of readily available organics, enhances the waste degradation processes, moreover it increases the permeability of the waste mass and reduces (by giving rise to a methanogenic leachate) the clogging effect in the granular bed of the drainage system. However, in order to obtain a very well stabilized waste with very low emission potential, the biological pretreatment should last at least four months and this might be costlier than acceptable. A shorter biological treatment step might be coupled to the deposit into an aerated landfill, in order to have the stabilization process completed in situ.

Table 1. Influence of different technologies and operation alternatives on the terms of the landfill mass balance.

Option	X_{Si}	Q_i	x_L	q_{Lr}	x_G	q_{Gr}	dm/dt fix	dm/dt mob	rV
Mechanical pretreatment			+		+		+		+
Biological pretreatment	+								
Thermal pretreatment	++	++							
Waste minimization		+							
Leachate recirculation			+						+
Open landfill/flushing				++					+
In situ aeration						+	++		++
Anaerobic landfill			+		+		+		+

Thermal treatment dramatically reduces the amount of available organics as well as the amount of waste to be deposited; the leaching potential of incineration residues still has to be assessed, especially when deposited in combination with other waste; the real environmental significance of this kind of combined disposal should be further evaluated.

Leachate recirculation has a positive effect on the transfer of the contaminants into the liquid phase, moreover it provides an increase of moisture content and a better diffusion of substrate and nutrients in the whole landfill body and the degradation processes are thus enhanced

Flushing provides an enhancement of the degradation processes for the same reasons; moreover the mass of pollutants extracted with the liquid phase increases dramatically.

Aerobic conditions in the landfill body provide the acceleration of biological degradation processes in comparison to the traditional anaerobic landfill; the formation of non mobile compounds (humic substances) is enhanced as well. The maximization of carbon transfer into the gas phase is obtained by means of forced aeration and collection of exhaust gas.

4. LONG-TERM IMPACTS

As mentioned earlier several studies proved that emissions from traditional contained anaerobic landfilling can last for very long time (centuries), particularly for the ammoniacal nitrogen (i.a. Belevi and Baccini, 1989; Kruempelbeck and Ehrig, 1999).

Therefore for a traditional landfill the mass accumulation vs time of a generic component considered for the mass balance (carbon or nitrogen, for example) follows the trend depicted in Figure 5.

The maximum of accumulation is reached during the operation phase and then decreases slowly during the aftercare phase. The aftercare phase can be divided in two part: an active and passive ones. During the active aftercare financial provision is provided by the landfill manager, the landfill is controlled and the environmental and legal liability stay with the landfill manager. When the active aftercare phase reaches the end point, according to the Authority evaluation (how and when is still a very controversial and open point) the passive aftercare starts when the control will be absent and the equlibrium between the landfill and the environment will be asymptotically reached.

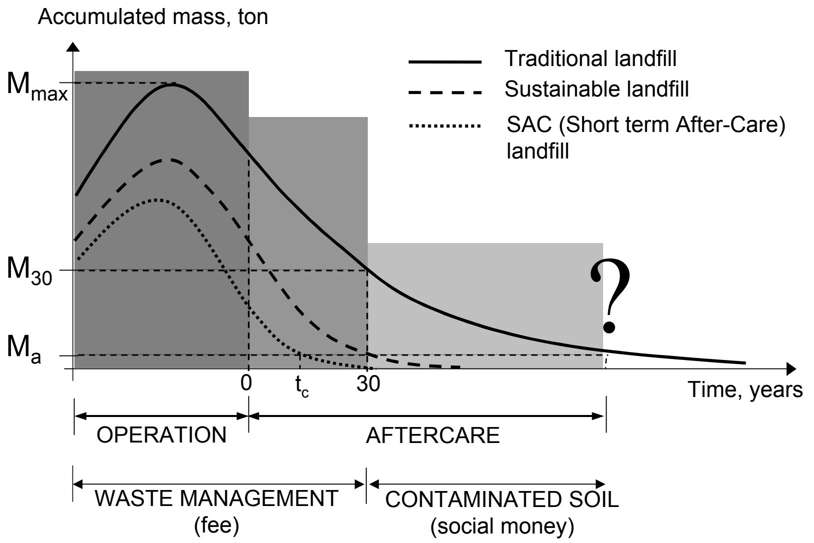

Figure 5. Qualitative trend of the accumulation of the mass of carbon or nitrogen along the landfill lifetime for different kinds of landfill.

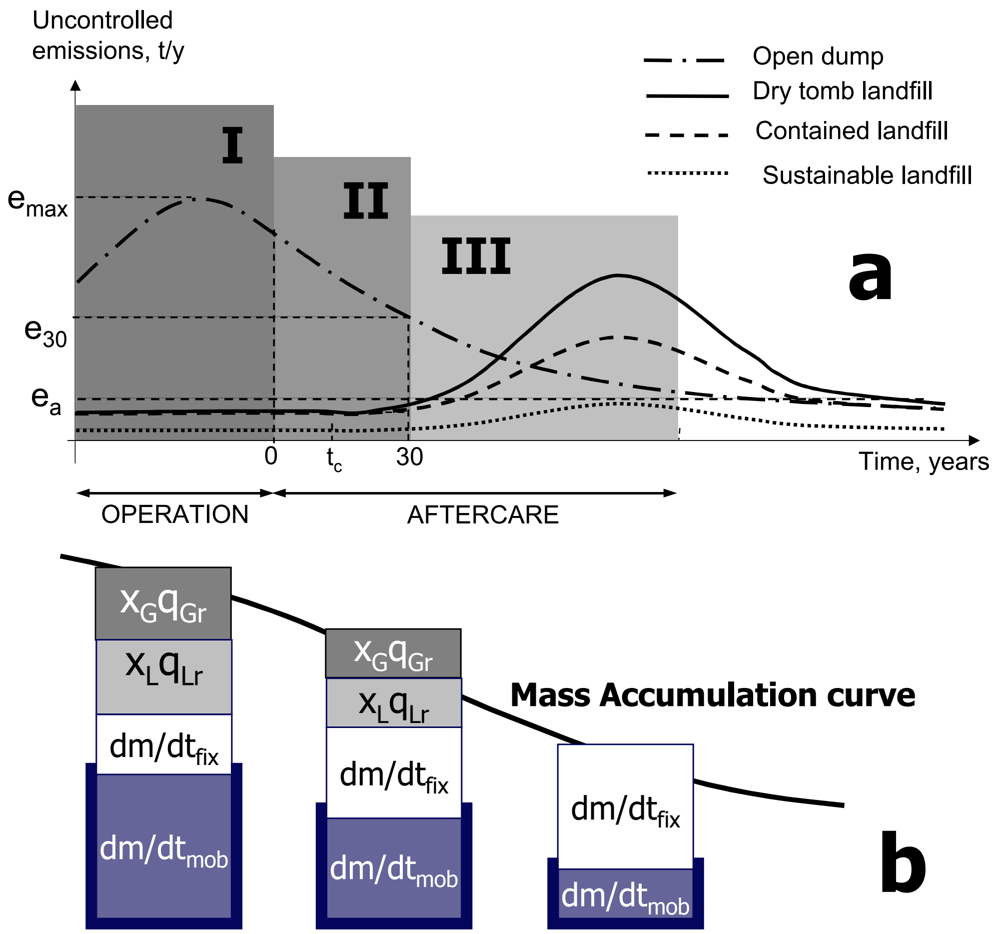

Figure 6. Uncontrolled emissions of leachate and gas as they can occur from different kinds of landfill according to the quality and duration of the adopted barriers (a). Relative weight of the the various mass balance terms along the decrease in the mass accumultion curve (b).

Nowdays with the traditional landfill technology after the financial provision time (30 years for the European landfill Directive) the accumulated mass of Carbon and Nitrogen (M_{30}) is well above the environmental acceptable mass accumulation (M_a).

This means that after the financial provision time the landfill should be regarded as a contaminated site.

On the contrary by the time covered with the financial provision, the sustainable landfill should present a mass accumulation below the environmental acceptable one (Ma) as defined with appropriate tools (Table values, risk assessment or other) to be planned when designing the landill system. If the provision time is 30 years this means that the landfill manager is committed to reach the targeted environmental equilibrium within 30 years. Some economical incentive may promote design and operation of landfill even with shorter aftercare time.

These aspects look even more critical when considering the uncontrolled emissions patterns for different kind of landfills (Figure 6a). The uncontrolled emissions patterns of the contained landfills, infact, differently from the the old landfills are such to postpone the environmental hazards in a way thet the aftercare impacts may be very severe.When the physical barriers fail due to the normal aging (the lifetime of geomembranes and traditional mineral liner do not exceed the generation time; Cossu, 2005) the emissions release should be below the environmental acceptable (e_a)level in order to avoid problems. This means that the accumulation trend should be be influenced by influencing the individual terms of the mass balanced, described earlier, as described in Figure 6b.

This should be the reference criteria for evaluating any technology, or combination of technologies, which could be applied for reaching this target (Figure 7).

Pre-treatment, in situ treatment, and post-treatment in the aftercare phase should be considered in an integrated way , looking for the performance of the system and being precriptive only for the final result: reach of the sustainable targets.

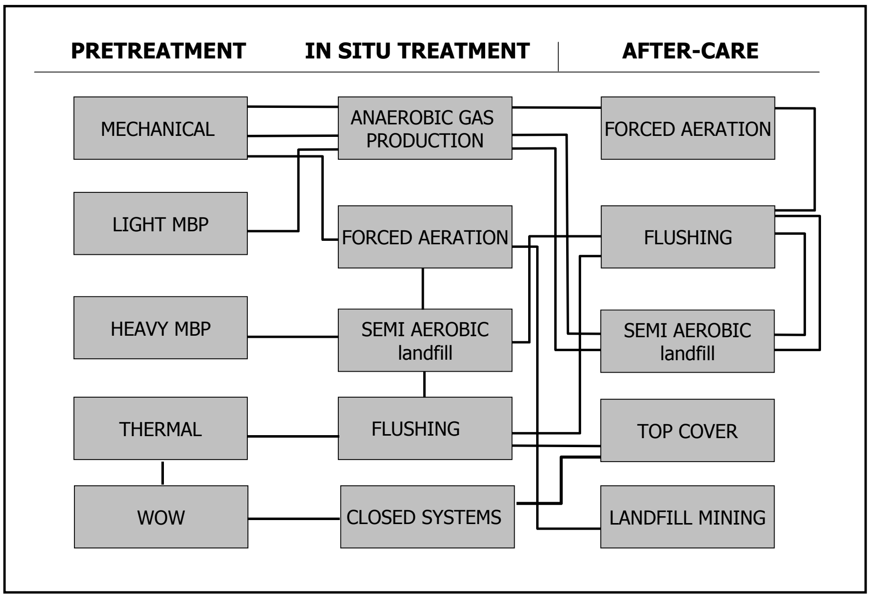

Figure 7. Different possible combination of operational altrnatives for influencing the landfill mass balance in different lifetime phasses in order to achieve sustainability.

REFERENCES

Kruempelbeck I.& Ehrig H.-J (1999). Long term behaviour of municipal solid waste landfills in Germany. Proceedings Sardinia 99, Seventh International Waste Management and Landfill Symposium, eds. T.H. Christensen, R. Cossu, R. Stegmann, CISA Publisher,Italy, vol. I, 27-36