Final Storage Quality

Lechner P. (Hrsg.): Waste matters. Integrating views. 2nd BOKU Waste Conference 2007, 16. - 19. April 2007, Wien. Proceedings; Facultas Verlags- und Buchhandels AG, ISBN 978-3-7089-0060-5

Landfill Aftercare – Duration, Strategies and Closure Criteria

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Abstract
Subsequent to completion of the closing measures, specific aftercare techniques should be applied to landfills. Leachate and landfill gas continue to be produced, requiring collection and treatment. The overall landfill behavior, including both technical equipment as well as emissions, must be monitored. The issue of long-term emission behavior should be addressed for landfills still in operation or which have already been closed. The question of when and according to which criteria a landfill can be released from aftercare is crucial. In addition to waste quality in the landfill, the load for the direct discharge can be calculated by means of the produced (measured) leachate using a water budget module in cases where the landfill is not lined. Thus, proposals for the management of leachate and gas emissions are put forward. In order to reduce the aftercare period both biological degradation and elution processes should be enhanced; this could be achieved by means of in situ aeration and controlled water infiltration.

1 Introduction
With regard to landfills which are still in operation or have already been closed, the fundamental issue of their long-term emission behavior should be addressed. Landfill emissions such as leachate and landfill gas (LFG) should be monitored and treated until their amount and quality have reached an environmentally acceptable level. As due to legal requirements many landfills in Germany were closed in May 2005, leading to considerable great discussion in Germany as to when and under which conditions closure is envisaged. This question requires an answer since the landfill owner/operator has to provide sufficient funds to cover the whole landfill closure and aftercare period. The main question is when and under which conditions does the aftercare phase of a landfill end?

The basic thesis of the authors for the achievement of an aftercare-free landfill is: "At the end of the aftercare measures, the deposited waste shall be in such a state that biological processes and other conversion or reaction processes have been completed in a sustainable manner and it should be basically ensured that such processes will not be reactivated in the future as a result of unfavorable

circumstances. Any emissions still occurring in the long term should be so insignificant as to prove environmentally acceptable; in particular, groundwater protection should not be put at risk. As far as conventional municipal waste landfills are concerned, it should be highlighted that the deposited waste may not only be preserved (e.g. through desiccation subsequent to sealing of the surface) but that during closure and aftercare phase, further to low emissions a condition of low emission potential of the waste will be achieved.

2 Technical measures and requirements during closing and aftercare

2.1 Technical measures

The following additional closing measures may be of relevance:

- Continuation of leachate collection and treatment
- Continuation of landfill gas collection and treatment
- Installation of a temporary surface cover (§ 14 DepV (German Landfill Ordinance, Anonymous, 2002))
- Infiltration measures for the optimization of biological degradation processes in the landfill body (§ 14 DepV)
- Aerobic in situ stabilization (aeration) for an accelerated reduction of biodegradable organic waste components to improve long-term behavior
- Installation of (final) surface sealing (§ 12 DepV)
- Monitoring measures to control landfill behavior
- Groundwater remediation measures
- Landfill mining

In particular, aftercare measures, including long-term protective measures and control of landfill behavior, should be performed and documented.

2.2 Technical requirements and options for landfill closure

The securing of closed landfills can be achieved – by installing a liner. As a result leachate production will be significantly reduced or inhibited, thus implying the need for residual LFG to be collected and treated. This strategy results in conservation of the landfilled waste with emission potential remaining high as a consequence. Accordingly, once the liner has collapsed emissions from the landfill will subsequently be reinstated.

The authors favor the strategy of reducing the emission potential of a landfill significantly before the landfill cover is put in place. Subsequently, a liner system constructed preferably of natural materials should be installed (e.g. capillary barrier and recultivation layer with > 1.5 m of silty sand on top and controlled revegetation) (Hupe et. al, 2001) in landfills constructed on soils with a high water storage capacity. A low emission potential of the landfill is also a prerequisite for the end of the aftercare phase.

In order to reduce the emission potential of existing landfills two main activities can be envisaged:

- controlled water infiltration
- in-situ aeration

2.2.1 Water Infiltration and In-situ Aeration

Previous experiences have shown that once landfills have been covered with low permeable soil or liners, gas production may decrease significantly. Likewise, landfills affected by low rainfall conditions may have a lack of moisture and/or moisture movement. If sufficient biodegradable waste remains in the landfill and the latter has a bottom liner with a leachate collection system, addition of water (e.g. by means of recirculation of treated leachate) into the landfill body may be beneficial for enhancement of the biological processes.

In conclusion leachate infiltration produces two effects:

- enhancement of biological processes due to an increase in water content and water flux
- enhanced elution of substances out of the landfill body

Aerobic in-situ stabilization accelerates biological degradation processes in the landfill body leading to significantly reduced emissions – compared to anaerobic conditions - after a treatment time of approx. 3-6 years. This is due to the reduction of organic components that are more easily degradable under aerobic than anaerobic conditions. This is also relevant for many hazardous waste components introduced into the landfill with the MSW and/or commercial waste (Ritzkowski, 2005).

Ambient air is pressed under low positive pressure into the landfill body via aeration wells by means of a blower. According to the rate and duration of aeration, aerobisation of almost the entire landfill body and an accelerated degradation of the organic waste components is achieved. The equivalence of the infiltrated air is extracted as waste gas out of the landfill via gas wells and treated thermally or biologically and/or physically before being released into the environment (Heyer et al., 2001).

3 Legal aspects for landfill closure and aftercare in Germany

The EU-Landfill Directive has been transformed into German Legislation in the Landfill Directive (Deponieverordnung, DepV, Anonymous, 2002). Existing German regulations have been included in this directive.

The different landfill phases can be described as follows:

- Operation phase and closure where the landfill closure is part of the operation phase. The construction of a top cover liner is the main task in this phase. Since this liner should be installed when the main biological degradation processes have come to an end, the closure phase may last over a period of several years.
- The aftercare phase starts once the authorities have formally agreed on the

end of the landfill closure phase. During the aftercare phase it has to be assured by the former landfill owner/operator that there will be no adverse effects on the environment resulting from the closed landfill.

- The end of the aftercare phase implies that almost no activities are required and no future remediation will be required.

To date, no detailed information has been provided by the authorities with regard to emission behavior or emission potential of the landfill body at the end of the aftercare phase. In § 13, Abs. 5 of the German Landfill Directive (DepV, 2002) the criteria presented form the basis for release outside the aftercare period:

1. Biological degradation processes as well as additional conversion and reaction processes in the landfill body are insignificant.
2. Gas production has decreased to an extent that no-active gas extraction is necessary and adverse effects due to gas migration into the vicinity can be excluded.
3. Settling of the landfill body has decreased to an extent that settling related damages of the surface lining systems can be excluded.
4. The surface lining system and the recultivation layer are functioning and in a stable condition, thus not affecting present and future landfill utilization. It should be ascertained that this is also true should the mode of landfill utilization change.
5. Surface water from precipitation is transported via the surface in a controlled manner.
6. The landfill is sustainable and mechanically stable.
7. The maintenance of constructions and technical installations is no longer necessary.
8. Any eventually produced leachate conforms to water regulations for discharge in naturally occurring waters.
9. No groundwater pollution is produced by the landfill, thus rendering necessary remediation techniques.

In line with the proportionate principle a landfill should be released from aftercare when the results from control and supervision measures indicate that no adverse effects can be expected, i.e. that the landfill shows no adverse environmental effect.

The question as to what kind of general and site specific criteria can determine the exact time of release of a landfill from aftercare still remains unanswered. In the German Technical Regulations Municipal Solid Waste (TASi, 1993) the issue is only addressed in a general way: "The control and action measures described in No. 10.6.6. as well as appendix G of the TASI have to be practiced until such a time as the responsible administration releases the landfill from aftercare".

4 Discussion of possible criteria and target values for the completion of the aftercare phase of a landfill

4.1 General Approach

In this context the difference between a landfill built as a mound or in a pit gains increasing relevance. One of the main reasons for operating landfills as a mound is that the leachate is able to migrate out of the landfill by the force of gravity while leachate from a landfill pit has to be pumped (unless leachate is absent). It remains to be determined whether drain systems have to be controlled and cleaned also once the aftercare phase has ended.

The main questions regarding the release of landfills outside the aftercare phase are:

- Which criteria and parameters are suitable to determine the environmental acceptability of emissions and emission potential?
- To what extent is it possible to deduct from those parameters general applicable and /or site specific target values?

This discussion can be based on various philosophies:

- Emissions should meet set target values independent upon the specific situation (e.g. discharge values for treated sewage, air emission standards)
- Acceptable emissions are dependent upon the specific situation respecting the geological, hydrogeological soil and surface water situation. In this context also the future means of utilization of the landfill may be safeguarded.
- A combination of both models where minimum set target values have to be met, further establishing site specific target values respecting the specific landfill and its environment as well as the kind of future utilization.

To date the authors have favored the combination model where an acceptable emission behavior of each landfill is guaranteed by the minimum standards and their adaptation to the specific landfill and its environment is complied with.

4.2 Proposals for quantitative criteria for the release of a Landfill from aftercare

4.2.1 Criteria for leachate, surface waters and groundwater

Proposals for aftercare criteria for use in establishing the termination of landfill aftercare will be developed for:

- emission behavior
- technical barriers and underground strata conditions
- acceptable or permissible emissions

In addition to pollutant concentration, the mass flow (load) as a product of concentration and annual leachate production per hectare landfill area may be applied as the main criterion indicating leachate contamination.

For the parameters COD, $N_{tot.}$, Cl and AOX, the following leachate discharge scenarios with regard to termination of aftercare should be met:

- direct discharge into surface waters

- indirect discharge
- percolation into the underground strata

Table 2 presents a summary of the quantitative criteria proposed for the water path regarding leachate and groundwater contamination.

Tab. 2: Proposal for quantitative criteria to determine release from aftercare on the basis of leachate and groundwater contaminations, and direct and indirect discharge

Parameters	Direct discharge of leachate		Percolation into the subsoil and groundwater	
	Concentration [mg/l]	Load [kg/ha*a]	Concentrations (difference value)[1] [mg/l]	Load [kg/ha*a]
COD	200	50 – 200	12	50 – 200
$N_{tot.}$	70	25 - 100	NH_4 0.3 – 5	25 – 100
Cl	100	100 - 200	30	100 – 200
AOX	0.5	0.1 – 0.5	0.02	0.1 – 0.5

[1] difference values in the groundwater flow direction between entrance and exit of the landfill area

In order to limit emissions, such a combination of concentration and load values represents a suitable solution in view of the concerns posed by water conservation and landfill aftercare. Existing stringent concentration values established by official regulations were used as a basis (e.g. AbwV (Wastewater Ordinance, Anonymous, 1997). However, the concentration values applied should be flexible to such an extent that they enable release from aftercare only once negligible effects on the environment can be expected. Therefore, in specific cases the authorities should be able to abstain from compliance with the indicated concentration limit value when the loads are within the indicated ranges and when a further-reaching emission reduction seems to be inappropriate in relation to the efforts incidental thereto.

4.2.2 Criteria for landfill gas

The effects of methane emissions on the anthropogenic greenhouse effect constitute an essential criterion for the assessment of gas balance. In order to determine release from aftercare, the methane volume flow should be limited to such an extent that the emitted methane is biologically oxidized in the surface layer of the landfill.

At a total landfill gas production rate of ≤ 25 m^3 CH_4/h i.e. no gas utilization is possible and even flaring is difficult and ≤ 5 m^3 CH_4/(h * ha) the following measures may be introduced:

Tab. 3: Allocation values of mechanically-biologically treated waste in accordance with Appendix 2 of the AbfAblV and target values or quantitative criteria for solid waste samples from landfills for the termination of aftercare measures

Parameters	**Proposed Target values at the end of the aftercare measures**	**Allocation criteria Appendix 2 AbfAblV**
Eluate Criteria		
pH value	6.0 – 9.0	5.5 – 13.0
Conductivity	≤ 2500 µS/cm	≤ 50000 µS/cm
TOC	≤ 150 mg/l	≤ 250 mg/l
Phenols	≤ 0.5 mg/l	≤ 50 mg/l
Arsenic	≤ 0.1 mg/l	≤ 0.5 mg/l
Lead	≤ 0.4 mg/l	≤ 1 mg/l
Cadmium	≤ 0.05 mg/l	≤ 0.1 mg/l
Chromium-VI	(≤ 0.1 mg/l)	≤ 0.1 mg/l
Copper	≤ 1 mg/l	≤ 5 mg/l
Nickel	≤ 0.2 mg/l	≤ 1 mg/l
Mercury	≤ 0.005 mg/l	≤ 0.02 mg/l
Zinc	≤ 2 mg/l	≤ 5 mg/l
Fluoride	(≤ 25 mg/l)	≤ 25 mg/l
Ammonium nitrogen	≤ 50 mg/l	≤ 200 mg/l
Cyanides, easily releasable	≤ 0.1 mg/l	≤ 0.5 mg/l
AOX	≤ 0.5 mg/l	≤ 1.5 mg/l
Ignition loss	-	-
TOC	-	-
Biodegradability of the waste sample		
Determined as respiration activity (AT_4)	≤ 2.5 mgO_2/gDS	≤ 5 mgO_2/gDS
Determined as gas formation rate in the fermentation test (GB_{21})	≤ 10 l/kgDS	≤ 20 l/kgDS

DS: Dry Substance

- Biological methane oxidation in the recultivation layer, once it has been established that less than 0.5 l CH_4 / (m^2 * h) enters into the recultivation layer and the maximum surface gas emission via the recultivation layer does not exceed 25 ppm of hydrocarbon compounds (mainly methane).
- In the event that this criterion is met over a 10 year period, release from aftercare can be achieved with regard to gas production.

4.2.3 Criteria for the solid waste quality in the landfill body

In view of the fact that no concentration limits have been proposed for leachate migrating from the landfill into the subsoil – due to the difficulty of measurement involved – in addition to the load proposed in Table 2 the landfill itself should have a low emission potential.

Numerous extensive solid waste sampling investigations have been carried out on landfills. Target values to be met by the waste prior to release from aftercare, are deduced from the comparison of the solid waste quality and eluate values together with resulting emission behavior. For classification purposes, these target values are, amongst others, compared with the required values reported for mechanical biological pretreated municipal solid waste (Appendix 2 of the AbfAblV, Anonymous, 2001, Table 3)

6 Conclusion

The release of landfills from aftercare is a particularly relevant subject to be faced by all landfill owners and operators. The aftercare phase may be terminated when the emission potential is sufficiently low to imply that the actual emissions will not harm the environment. Accordingly, leachate treatment will no longer have to be carried out and the landfill gas is naturally oxidized in the top cover of the landfill. The emission potential of landfills can be described by means of waste samples taken from the specific landfill areas for analysis of biological activity (respiration test), elution potential (elution test) as well as present and future landfilling behavior (landfill lysimeter test). The present paper discusses the scale of target values applied in the different tests as well as the issue of emissions. In addition a potential procedure for the enhancement of the biological stabilization and physical elution of waste components is presented, providing for in-situ aeration as well as enhanced water infiltration using leachate, in which the leachate is treated prior to infiltration. The role of a landfill capping liner system is also discussed.

Release of a landfill from aftercare implies that the landfill is now able to be left unattended, inoperative and free from supervision due to the presence of environmentally acceptable emission potential and emissions. To this regard, debate should determine whether such a practice is realistic, in view of the possibility that minor activities may continue even after the aftercare phase, e.g. leachate pumping from pit landfills, cleaning of drainage pipes, care of the vegetation, natural post treatment of leachate on the landfill site, control of sewage pipes, manholes as well as groundwater monitoring. In-depth discussions of this crucial issue should be commenced between the scientific community and the decision makers with the aim of reaching a mutually-feasible outcome.

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