LANDFILL AFTERCARE – SCOPE FOR ACTIONS, DURATION, COSTS AND QUANTITATIVE CRITERIA FOR THE COMPLETION

K-U. HEYER*, K. HUPE* AND R. STEGMANN**

* *IFAS - Consultants for Waste Management, Prof. R. Stegmann and Partners, Nartenstraße 4a, 21079 Hamburg, Germany, www.ifas-hamburg.de*
** *Department of Waste Management, Technical University Hamburg-Harburg, Harburger Schloßstraße 36, 21071 Hamburg, Germany, www.tu-harburg.de/aws*

SUMMARY: With landfills, which are in operation or already closed, there is the question concerning their long-term emission behaviour. The question when and under which criteria a landfill can be released from aftercare is essential. As many sanitary landfills were closed in the last years it has to be discussed what kind of basic target values may be developed. Therefore some proposals are made for leachate and gas emissions. In order to reduce the aftercare period the biological degradation as well as elution processes should be enhanced. This could be achieved by means of in situ aeration and controlled water infiltration.

1. INTRODUCTION

With landfills, which are in operation or already closed, there is the question concerning their long-term emission behaviour. Landfill emissions as leachate and landfill gas (LFG) have to be controlled and treated until their amount and quality has reached a level that is environmentally acceptable. As many landfills were closed in May 2005 there is a great discussion in Germany when and how this will be the case. This question somehow has to be answered since the landfill owner/operator has to provide the sufficient funds to be able to cover the whole landfill closure and aftercare period. The main question is, when and under which conditions the aftercare phase of a landfill ends.

2. COURSE OF EMISSIONS AND AFTERCARE

2.1 Estimation of aftercare periods

The course of emissions in time mainly depends on:
- the potential of substances that can be mobilized due to the waste composition
- the water table in the landfill
- the mobilization behaviour

Proceedings Sardinia 2005, Tenth International Waste Management and Landfill Symposium
S. Margherita di Pula, Cagliari, Italy; 3 - 7 October 2005
© 2005 by CISA, Environmental Sanitary Engineering Centre, Italy

Comprehensive scientific investigations on landfills and in landfill simualtion reactors (LSR) were carried out to predict the long-term emission behaviour (Heyer, 2003). For this reason extrapolation calculations on the basis of the emissions into the leachate phase were done. The course of emissions in time can be described with an exponential function:

$$\mathbf{C_t = C_0 * e^{-k*t}} \qquad (1)$$

with:

C_t = Concentration at time t [mg/l]
C_0 = Concentration at the beginning of the LSR-tests [mg/l]
k = Factor = ln2/$T_{½}$
$T_{½}$ = Half-life, increasing in time [d] resp. [a]
t = Test Period [d]
T_0 = Start of leachate recirculation in LSR-tests [d]

With the idealized conditions in the LSR tests and the setting of a water balance, which is approximately a 50 - 100 times higher than at the landfill, periods T_E can be estimated, until a limiting value C_E is reached (Heyer, 1997). The estimations are based on the following assumptions:

- constant climatic leachate generation of 250 mm per year
  (this means no impermeable surface sealing, only a permeable soil cover)
- a standard height of 20 m
- the dry densities in the LSR-tests are similar to the landfill with approximately 0,75 MgTS/m^3
- uniform percolation through the landfill-body

The periods T_E are compiled in Table 1 together with the concentrations C_0 at the beginning of LSR-tests respectively the present leachate contrentraions on landfills and the values of half-life $T_{½}$. According to German standards for COD in the leachate, the estimation results in an average period of 140 years, until the limiting concentrations of 200 mg/l will be reached. Chloride shows similar periods. All investigations and tests point to nitrogen to be the parameter with the longest release of relevant concentrations into the leachate phase. Up to 220 years on average are possibly necessary until the concentration of 70 mg/l will be reached (Heyer et al., 1997).

Table 1. Estimations of periods T_E for reaching limiting values C_E in the aftercare (Heyer, 2003)

Parameter	C_E Limiting concentrations [mg/l]	C_0 Concentrations at the test beginning [mg/l]	$T_{½}$ Half-life [a]	W/S until C_E [m^3/Mg TS]	T_E Periods until C_E [a]
COD	$C_{E\text{-}51.Anh.}$ = 200 mg/l	500 – 12.700	10 – 40	1,0 – 6,0	80 - 360
	Average	3.000	28	2,4	140
TKN	$C_{E\text{-}51.Anh.}$ = 70 mg/l*	200 – 2.100	15 - 57	2,6 – 7,7	120 - 450
	Average	900	43	4,4	220
Cl	C_E = 100 mg/l	340 - 2.950	15 – 43	1,4 – 4,1	90 - 250
	Average	1.200	33	2,4	140
AOX	$C_{E\text{-}51.Anh.}$ = 500 µg/l	390 - 2.380 µg/l	14 – 42	0,1 – 3,5	30 - 210
	Average	1.600 µg/l	22	1,4	80

* * total amount of nitrogen, sum of ammonia, nitrite and nitrate

W/F Water/Solid ratio

Limiting concentrations according to German 51th Appendix, 1997

Also LFG control may be necessary for several decades after landfill closure, where relatively small amounts of LFG have to be controlled for a long time also in order to protect the atmosphere.

2.2 Technical requirements and options for the landfill closure

The securing of closed landfills can be achieved – and this is the policy reflected by German legislation – by installing a composite liner (mineral liner plus 2.5mm HDPE membrane on top, on which more than 1 meter of suitable soil has to be placed (Anonymous, 1993)). As a result leachate production will be significantly reduced or stopped and the residual LFG has to be collected and treated. This strategy results in a conservation of the landfilled waste and as a consequence the emission potential remains high. This means once the liner may collapse the emissions from the landfill will occur at this latter time.

The authors favour the strategy to reduce the emission potential of a landfill significantly before the landfill cover is put in place. At that point a liner system constructed of natural materials should be installed where soils with a high water storage potential should be used (f.e. capillary barrier and recultivation layer with > 1.5 m of silty sand on top and controlled revegetation) (Hupe et. al, 2001). 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 thought of:

- controlled water infiltration
- in-situ aeration

2.2.1 Water Infiltration

Experience have shown that once landfills have been covered with low permeable soil or liners, gas production may decrease significantly. Also landfills under low rainfall conditions may have a lack of moisture and/or moisture movement. If there is still sufficient biodegradable waste in the landfill and if in addition the landfill has a bottom liner with a leachate collection system, then artificial water addition (f.e. by means of recirculation of treated leachate) into the landfill body may be beneficial for the enhancement of the biological processes.

Research on long-term stabilization of landfills resulted in the conclusion that the solid liquid ratio i.e. the amount of water that has migrated through the total waste mass of a landfill has a significant influence on the emission potential of landfills. (A solid-liquid ratio of 1 means that the same amount of water has migrated trough the same amount of deposited waste). This concept is the base for the so called "flushing bioreactor" where as much water should pass through the waste as technically possible. Research on the emission potential of relatively small closed landfills showed that the solid-liquid ratio of the landfill is an indicator of the existing emission potential (Allgaier and Stegmann, 2002).

As a conclusion leachate infiltration has 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

Dependent upon the amount of water that is infiltrated the enhanced elution becomes more or less significant. Several technologies for infiltration are available, e.g. lances, trenches with drainage systems or infiltration fields (Figure 1).

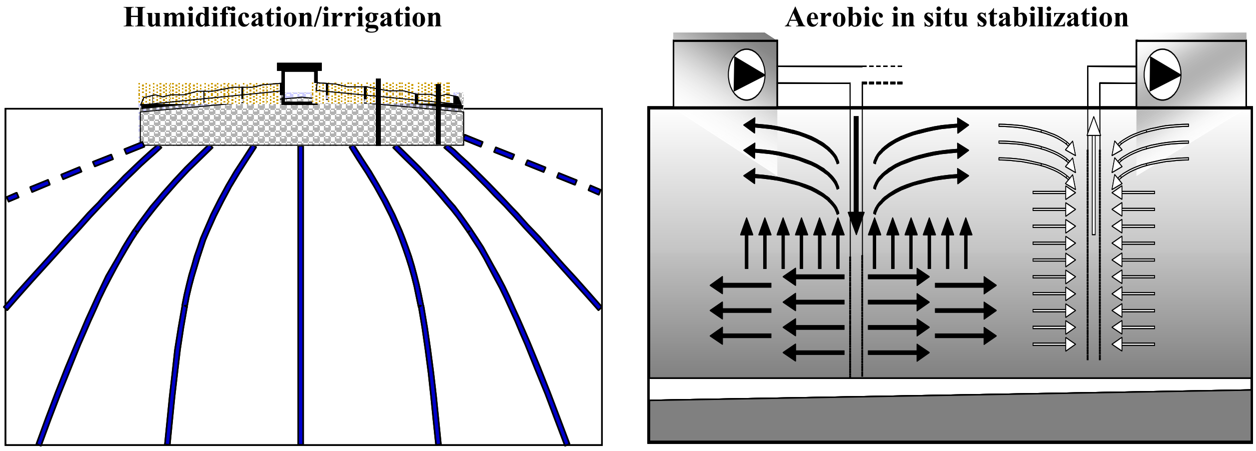

Figure 1. Methods regarding the in situ stabilization for the reduction of the aftercare

2.2.2 In situ Aeration

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

The basic principle of aeration and waste gas collection is shown in Figure 1. Ambient air is pressed under low positive pressure into the landfill body via aeration wells by means of a blower. Air resp. atmospheric oxygen is distributed by convection and diffusion processes in the landfill body. Depending on the rate and the duration of aeration, an aerobisation of the almost 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 it is 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, 2002). In this directive existing German regulations have been included.

The different landfill phases can be described as follows:

- Operation phase and closure where the landfill closure is part of the operation phase. Beyond others 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 process have come to an end, the closure phase may last over a period of several years.
- The aftercare phase starts when the authorities have formally agreed on the end of the landfill closure resp. operation 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 means that almost no activities are required and that there will be no necessity for future remediation.

Regarding the emission behaviour resp. the emission potential of the landfill body at the end of the aftercare phase no detailed information are given by the authorities. In § 13, Abs. 5 of the German Landfill Directive (DepV, 2002) criteria are presented that are the basis for the release out of 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 functionable and in a stable condition so that present and future landfill utilisation is not influenced. It has to be ascertained that this is also true when the kind of landfill utilisation changes.
5. Surface water from precipitation is transported via the surface in a controlled way.
6. The landfill is sustainable mechanical stable.
7. The maintenance of constructive and technical installation is no more necessary, a landfill mining has eventually been realised.
8. Any eventually produced leachate is in correspondence with the water regulation for the discharge in natural waters.
9. No groundwater pollution is affected by the landfill which would make an observation or remediation necessary.

Respecting 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 what kind of general and site specific criteria determine the exact time when a landfill can be released from aftercare is not answered. In the German Technical Regulations Municipal Solid Waste (TASi, 1993) it is only described 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 as long as the responsible administration releases the landfill out of the aftercare”.

4. DISCUSSION OF POSSIBLE CRITERIA AND TARGET VALUES FOR THE COMPLETION OF THE AFTERCARE PHASE OF A LANDFILL

In this context the difference between a landfill build as a mound or in a pit becomes relevant. One of the main reasons for operating landfills as a mound is that the leachate can migrate on the basis out of the landfill by gravity while leachate from a landfill pit has to be pumped (unless there is no leachate). The question is whether drain systems have to be observed and cleaned also when the aftercare phase has ended.

4.1 General Approach

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

- By means of which criteria resp. parameters the environmental acceptable emissions resp. emission potential may be described?
- In how far is it possible to deduct from those parameters general applicable and /or site specific target values?

For the development of criteria the following “systems” for analysis resp. test methods are available:

- Landfill body:
  - Monitoring of the water budget including leachate production and quality
  - Monitoring of the landfill gas (LFG) production and quality
  - Monitoring of the development of the settling, temperature regime, etc.
- Waste Samples from the investigated landfill
  - Landfill inventory and solid waste sample quality as there are f.e.: water content., carbon- and nitrogen content, volatile solids
  - Elution test analysing the eluate for pH, conductivity, nitrogen parameters, COD, TOC, BOD, heavy metal toxicity, SO_4, Cl, buffer capacity etc.
  - Biotests for the determination of the biological activity resp. its potential using respiration tests (AT_4) and gas production potential (GB_{21}) (AbfAblV, 2001)
  - Some of these samples can be further investigated in landfill lysimeter tests
- Landfill simulation reactor (LSR) (Ehrig et al., 1997)
  - Monitoring of the water budget including leachate concentration
  - Monitoring of gasproduction and –quality
  - Monitoring waste samples from the investigated landfill before and after the test
  - Operating the LSR with significant higher water application in order to gain long term development results in a short time (enhancement factor ~100)

The investigation of some or all of the above described media will produce results that describe the status of the landfill in a sufficient resp. comprehensive way. The question is how the results should be evaluated and validated in regard to future emissions and this acceptability for a specific landfill situation. In this context the question has to be answered, what kind and amount of environmental loading by means of leachate and gas emissions are acceptable in a specific environment without causing any adverse effects.
This discussion can be made on the basis of different philosophies:

- The emissions should meet set target values independent upon the specific situation (f.e. discharge values for treated sewage, air emission standards)
- The acceptable emissions are dependent upon the specific situation respecting beyond others the geological, hydrogeological soil and surface water situation. In this context also the kind of future utilisation of the landfill may be respected.
- A combination of both models where minimum set target values have to be met and in addition there is a further precision of the site specific target values respecting the specific landfill and its environment as well as the kind of future utilisation.

The authors so far favour the last approach where an acceptable emission behaviour of each landfill is guaranteed by the minimum standards and their adaptation to the specific landfill and its environmental is respected.

4.2 Potential requirements for the landfill gas production resp. emissions

As already stated LFG is produced – although at a low amount - also decades after closure of the landfill. This means that also LFG is a long term problem. Potential effects of LFG-emissions are known as there are global warming, explosions, displacement of air, oxygen reduction in the recultivation layer due to CH_4-oxidation and/or air displacement, controlled migration into adjacent soils etc. The question is how much gas production resp. emission is acceptable. One approach may be to use the CH_4 oxidation potential of the top cover as a measure for maximum gas production in the landfill. Different investigations show that methane oxidation rates dependent on soil quality, temperature, moisture content etc. are in the range of 0,34 – 5,6 CH_4/m^2h (Figueroa, 1998).

If f.e. a gas production in the landfill is equivalent to a surface load of 1 lCH_4/m^2h, methane oxidation in the surface cap should be in most times of the year possible. Using this value would mean that landfills with a larger surface to the atmosphere (as mounds) may absolutely produce more LFG than landfills in pits. Since the emission of 1 lCH_4/m^2h amounts to 20 m^3LFG/ha*h, a high landfill may produce per m^3 of waste volume less LFG than a shallow one.

On the other hand large landfills may produce absolutely more gas than small ones (f.e. 1 ha landfill produces 20m^3LFG/h compared to a 10 ha landfill with 200m^3/h). The latter production is at a level when LFG utilisation is still valid.

The actual gas production/extraction rates may either be determined by means of extraction tests (if a LFG extraction system exists) or by using a standardised LFG prediction model. Of course regarding these reflections it should be kept in mind that the LFG production and LFG extraction rates do not correspond.

Based on this discussion the authors propose that the size of the landfill has to be respected as well. As a consequence two target values have to be respected as there are absolute gas production of the landfill and the maximum target values for the specific gas migration through the top cover (in lCH_4/m^2h).

Which values should be chosen? In order to start the discussion the following proposal is made:

- Total LFG-production resp. extraction rate
  - The total amount of LFG that is extracted from the landfill independent of its size should not exceed 50-70 m^3/h. This amount is the minimum volume that can be treated in a high quality standard flare.
  - The LFG surface emission should not exceed 0,5 – 1,0 l CH_4/m^2h.

These values would mean that up to a landfill size of around 1 – 2 ha surface area the target value 0,5 – 1,0 l CH_4/m^2h. is valid. At larger landfills the LFG emissions could be limited due the production resp. extraction rate which should not exceed around 50 – 70 m^3/h. All these reflections are based on a LFG composition of 50% CH_4 and 50% CO_2 , that means nearly undiluted LFG.

4.3 Potential requirements for leachate emissions

The landfill can only be released from aftercare when either the collected leachate at lined landfills as well as the leachate from unlined landfills that migrate through the unsaturated soil into the groundwater meet the target values of a lined landfill. This refers to the leachate concentrations and the loads resp. quantity. In addition the kind of the bottom liner system installed as well as its functionality has to be respected. It can be expected that those systems may only be effective over a certain period of time.

For the collected leachate that migrates (or is pumped) into the surface waster the discharge values of the German 51th Appendix have to be respected. It should be discussed whether a natural treatment/polishing of the leachate also after the aftercare period may be allowed (f.e. constructed wetland, lagoons, sandfilter) in order to reduce the aftercare period. Otherwise this period may exceed 100 years until the leachate meets the above mentioned target values.

The leachate that migrates into the ground water should not cause a significant change of the groundwater quality. It could be discussed whether a large groundwater volume may accept higher leachate loading rates than smaller ones. In addition it can be discussed whether the improvement of the leachate quality in the unsaturated zone by means of sorption as well as biological degradation and chemical oxidation/reduction processes should be respected. These possible processes are summarized under the term “natural attention”. The results from investigations on natural attenuation should be evaluated and may be a basis for the detailed determination of target values.

Ehrig et al. 2002 propose for the leachate quality, leaving the unlined landfill at the bottom COD and anorganic N max. concentrations of ≤ 100 mg COD/l respectively 50 mg anorganic N/l. The loading rates are proposed not to exceed 100 kg COD/ha*a and 50 kg anorganic N/ha*a which results in average concentrations (based on a climatic leachate production of 250 mm/a) of 40 mg COD/l respectively 20 mg anorganic N/l.

For these or other potential target values the authors propose to calculate the leachate volumes that enter the subsoil of the landfill by means of a standardised water budget model (f.e. HELP model, Schroeder, 1994) where beyond others the annual precipitation rate as well as the kind of top cover/liner system is respected. The expected leachate concentrations have to be estimated on the basis of standardised analysis of the waste samples taken from the landfill body.

4.4 Utilisation of analytical results from landfill samples for the determination of the landfill emission potential

In order to receive a clear picture of the emission potential of a landfill samples from the landfill body should be taken and analysed. This is necessary since also an old landfill that has been closed before many years or even decades, the emission potential may be still very high. This may be a result of an immediate lining of parts or the entire landfill surface after the landfill operation had come to an end. If the landfill had been completely open for decades, the amount of precipitation that has entered the landfill is resulting in a high reduction of the emission potential by means of elution and optimized biological degradation.

In order to describe the emission potential of a landfill and to estimate roughly gas production rates and leachate concentrations, the following investigations may be target oriented:

- Taking f.e. mixed waste samples over the entire landfill (f.e. grit of 50 – 100 m f.e.1-4 samples/ha) from 2-3 different depths (the amount of samples taken has somehow to be related to the landfill size). Although representative sampling of waste in a landfill is due to the heterogenity not possible, experiences show that using the above described procedure meaningful results are gained (Heyer et al, 1997). These samples may f.e. be analysed by using the following procedures:
- Elution tests (f.e. DEV S4)
- The amount of biologically degradable substances can be indirectly measured by means of a respiration test. Respiration values similar to those in the natural soils may be a guide for setting a target value for the release from aftercare which are in the range of 2-4 mg O_2/gTS*96h.
- Landfill lysimeters are an additional test system by which the actual and future emissions resp. the emission potential of landfill samples can be described. These tests are somewhat time consuming and costly but they deliver very relevant practice oriented values that are a sound basis for a decision regarding the release from aftercare.

5. COSTS FOR CLOSURE AND AFTERCARE

To determine the costs for the closure and aftercare of landfills the following expenses have to be considered:

- Temporary surface cover
- Final surface sealing
- If necessary enhancement of the base sealing system

- Collection and treatment of leachate
- Collection and treatment of LFG (benefits for utilisation, costs for weak gas treatment)
- Enhancement measurements for the emission potential: water infiltration and aerobic in situ stabilisation (additional costs for investments and operation, cost-savings in the aftercare)
- Dismantling of dispensable equipment and buildings
- Monitoring for supervision: settlements, leachate and groundwater, LFG, weather and climate conditions, technical equipment, sealings, collection systems, documentation and reports
- Insurances etc.

Both investment and operation costs have to be calculated. As time scales 30 years according to the EU Landfill Directive can be regarded on the one hand and up to 100 years on the other hand. The expenditure and duration of aftercare measurements behind this time that may depend on the remaining emission behaviour is hard to predict at present.

In the following several calculations for German sanitary landfills that were filled with unpretreated MSW are compiled. Table 2 shows the correlation between the area volume, average height of deposition respectively volume and the costs for closure and aftercare. Larger and higher landfills often show a lower financial demand referred to one m^3.

The percentage distribution of the total costs for the different measurements for closure and aftercare can be performed as follows:

- Temporary and final surface sealing: 40 – 50%
- Collection and treatment of leachate and surface water: 25 – 30%
- LFG: 6 – 12%
- Long-term monitoring, dismantling etc.: 15 – 22%
- In situ stabilisation like water infiltration and aeration: 2 – 10%
  (partly covered by the general costs for collection and treatment of leachate and LFG)

Table 2. Calculated funds for several German landfills referred to the landfill volume (Gallenkemper et al., 2003, IFAS Hamburg, 2005)

Landfill	Area [ha]	Volume [Mio. m^3]	Average height of deposition [m]	Specific costs for aftercare [€/m^3]
A	20	3.5	17.5	7.5
B	6.5	0.8	12.3	7.5
C	10.5	1.0	9.5	9.0
D	19.7	4.0	20.3	7.5
E	4.0	0.3	8.0	24.0
F	30.9	7.1	23	9.8
G	10	1.5	15	10
H	3.2	0.22	7	18
I	30	8.0	27	11
J	30	7.0	23	25*
Average	16.5	3.4	16.3	13

* Assumption for the aftercare period >> 30 years

The specific costs for the closure and aftercare measurements differ depending on the local boundary conditions of the landfills and the existing technical systems and equipment:

- Temporary surface covers: 5 – 25 €/m^2 landfill surface, depending on the required life-span and design (e.g. option for final integration in the final surface sealing)
- Final surface sealing: 35 – 87 €/m^2 landfill surface for material and application,
- Collection and treatment of leachate: 15 – 50 €/m^3 leachate at landfills with a base sealing system
- In situ stabilisation like infiltration or aeration: 0,5 - 3 €/m^3 of landfill volume

6. CONCLUSIONS

The release of landfills from aftercare is a very relevant subject for all landfill owners resp. operators. The aftercare phase may end, when the emission potential is that low, that the actual emissions do not harm the environment. This means, that leachate treatment should not be practiced anymore and that the landfill gas is naturally oxidised 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 which may be analysed regarding their biological activity (respiration test), elution potential (elution test) as well as their actual and future landfilling behaviour (landfill lysimeter test). The scale of target values for the different tests as well as emissions is discussed in this paper. In addition a potential procedure for the enhancement of the biological stabilisation and physical elution of waste components is presented as there are in-situ aeration as well as enhanced water infiltration f.e. by using leachate, where the leachate is treated prior to infiltration. Also the role of a landfill cap resp. liner system is discussed.

Release of a landfill out of the aftercare period should mean that the landfill can be left without any operation and/or supervision due to an environmental acceptable emission potential and actual emissions. In this context it should be discussed if this is realistic, since there may be some minor activities also after the aftercare phase as there are f.e. 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.

It is time that an intensive discussion starts on this subject where the scientific community and the decision makers work closely together.

REFERENCES

Allgaier G., Stegmann R. (2002) Evaluierung von Altdeponien im standardisierten Verfahren, Ergebnisse aus dem EU-Projekt, EVAPASSOLD. Aus: *Hamburger Berichte*, Band 18, Deponietechnik 2002, Hrsg.: Stegmann, Rettenberger, Bidlingmaier, Ehrig, Verlag Abfall aktuell, Stuttgart

Anonymous (1993) Dritte Allgemeine Verwaltungsvorschrift zum Abfallgesetz (TA Siedlungsabfall) vom 14. Mai 1993, Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen, Bundesanzeiger Nr. 99a, 1993.

Anonymous (1997). AbwV - Abwasserverordnung (1997):Verordnung über Anforderungen an das Einleiten von Abwasser in Gewässer vom 21. März 1997

Anonymuous (2001) Verordnungen über die umweltverträgliche Ablagerung von Siedlungsabfällen und über biologische Abfallbehandlungsanlagen, AbfAblV. In: http:/www.bmu.de/

Anonymuous (2002) Verordnung über Deponien und Langzeitlager (DepV - Deponieverordnung) vom 24. Juli 2002 BGBl I 2002, 2807

Beaven, R.P., Walker, A.N., Powrie, W., 1997, Overcoming in the development of a high rate flushing bioreactor. In: *Landfill processes and waste pre-treatment*, Sardinia ´97, vol. 1 (T.H. Christensen, R. Cossu, R. Stegmann eds.), CISA, Cagliari, Italy, 397-408

Ehrig H.-J. (Wissenschaftlicher Leiter) (1997) SAV 1: Probenahme von Feststoffen aus Altdeponien und Altablagerungen. SAV 3: Beprobung von Abfallstoffen in Deponiesimulationsreaktoren (DSR). In: *Verbundvorhaben Deponiekörper*, Tagungsband zum 2. Statusseminar am 4. und 5. Februar 1997 in Wuppertal, Herausgeber Umweltbundesamt, Projektträger Abfallwirtschaft und Altlastensanierung (PTAWAS), pp. 323 - 328., pp. 345 - 358.

Ehrig H.-J., Stegmann R. (2002): Beurteilungskriterien für die Entlassung von Deponien aus der Nachsorge. In: Stegmann, Rettenberger, Bidlingmaier, Ehrig (Hrsg.): *Deponietechnik 2002*, Hamburger Berichte 18, Verlag Abfall aktuell, S. 297 - 318

Figueroa R. A. (1998): Gasemissionsverhalten abgedichteter Deponien. Untersuchungen zum Gastransport durch Oberflächenabdichtungen sowie zum mikrobiellen Abbau von Methan und FCKWs in Rekultivierungsschichten, Hamburger Berichte, Bd. 13, (Hrsg.: R. Stegmann), ISBN 3-87081-048-3, Economica Verlag, Bonn

Gallenkemper, B., Eitner, R., Kotzur, T. (2003): Kosten und Finanzierung der Deponienachsorge. In: Tagungsband „Verkürzung der Deponienachsorge“, Workshop des BWK am 19.11.2003 bei der EDG Dortmund

Heyer K.-U. (2003) Emissionsreduzierung in der Deponienachsorge. Hamburger Berichte, Band 21, Stegmann (Ed), Verlag Abfall aktuell, Stuttgart.

Heyer K.-U., Stegmann R. (1997) Langfristiges Gefährdungspotential und Deponieverhalten von Ablagerungen; Bericht zum Teilvorhaben TV 4 im BMBF-Verbundvorhaben „Deponiekörper“, Arbeitsbereich Abfallwirtschaft der TU Hamburg-Harburg, Projektträger PTAWAS (Umweltbundesamt Berlin)

Hupe K., Unger A., Heyer K.-U., Stegmann R., (2001) Alternative Oberflächenabdichtungssysteme für in-situ stabilisierte Deponiekörper – Versuchsfelder auf der Altdeponie Kuhstedt In: *Belüftung von Altdeponien zur in-situ Stabilisierung*, Tagung am 31.05.2001 in Kuhstedt, Landkreis Rotenburg (Wümme), Band 3 der Schriftenreihe Abfall aktuell, Hrsg. R. Stegmann, Verlag Abfall aktuell, Stuttgart

IFAS Hamburg (2005): Landfill closure and aftercare, survey and information see also www.ifas-hamburg.de

Ritzkowski M., Heyer K.-U., Stegmann R., (2001) Aerobe in-situ Stabilisierung der Altdeponie Kuhstedt – Hintergründe, Potenziale, Möglichkeiten – In*: Belüftung von Altdeponien zur in-situ Stabilisierung*. Band 3 der Schriftenreiche Abfall aktuell, Hrsg. R. Stegmann, Verlag Abfall aktuell, Stuttgart

Ritzkowski M. (2005) Beschleunigte aerobe in situ Stabilisierung von Altdeponien am Beispiel der Altdeponie Kuhstedt. Hamburger Berichte 26 (Hrsg.: R. Stegmann), Verlag Abfall aktuell, Stuttgart

Heyer K.-U., Hupe K., Ritzkowski M., Stegmann R. (2001) Technical Implementation and Operation of the Low Pressure Aeration of Landfills, In: *Sardinia 01, Eighth International Waste Management and Landfill Symposium*, Conference Proceedings

Schroeder P.R., Aziz N.M., Lloyd C.M., Zappi P.A. (1994) The Hydrologic Evaluation of Landfill Performance (HELP) Model: User`s Guide for Version 3, EPA/600/R-94/168a, US EPA, Cincinnatti, Ohio