# AEROBIC IN SITU STABILISATION OF LANDFILLS IN THE CLOSURE AND AFTERCARE PERIOD

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SUMMARY: In Germany, many landfills were closed in May 2005 to meet the requirements of German legislation. For the planning and implementation of the closure and aftercare period, aerobic in situ stabilisation will be included to improve the medium and long-term emission behaviour. Besides surface sealing and water infiltration for humidification purposes, this stabilisation method is a promising step to reach several objectives, such as the significant reduction of costs and of the duration of the aftercare period. Therefore, many landfills offer the possibility to implement this method. Since 1999, aerobic in situ stabilisation using low pressure aeration was implemented in three German landfills and old disposal sites. Furthermore, additional investigations were carried out in large landfills from 2002 to 2004. This type of disposal site represents a huge number of German landfills which were closed during the years leading up to until May 2005.

## 1. AEROBIC IN SITU STABILISATION DURING THE CLOSURE AND AFTERCARE PERIOD OF LANDFILLS

As a result of several regulations (Technical Instructions on Municipal Solid Waste, TASi, 1993 and Landfill Ordinance, DepV, 2002), many German landfills were closed by May 31$^{st}$ 2005. In these landfills, the closure and aftercare period is now starting, involving a whole string of structural and technical measures. As regards the selection of suitable technical measures for the closure of a landfill, local conditions, the situation of the protective goods, aftercare targets and the after-use need to be taken into account besides legal requirements.

By technical measures, such as the

- installation of temporary coverings
- collection and treatment of leachate
- collection and treatment of landfill gas
- infiltration of water
- aerobic in situ stabilisation
- installation of the final surface sealing,

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a lasting improvement of the emission situation will be achieved. Compared with the initial situation, emission reductions are to be achieved and ensured in the long term, in order to be able to release the landfill from aftercare measures. In situ stabilisation measures aim to achieve:

- accelerated reduction of the emission and settlement potential
- reduction of the technical and financial expenditure during the aftercare phase and a
- reduction of the aftercare period.

Extensive scientific investigations have shown that a sustained improvement of the emission and settlement behaviour of landfills through aerobic in situ stabilisation measures can be achieved when the process technology is adapted to the conditions of the landfill body and operated in a qualified manner (Ritzkowski et al., 2005, Heyer, 2003). To achieve this objective, the low pressure aeration was developed, which has been applied for several years now on landfills and old deposits. Its application in larger municipal waste landfills which, amongst other things, show an significant deposition thickness and are equipped with a bottom sealing, is imminent. Over-suction methods for aeration may also be used, provided that the landfill body meets certain boundary conditions (Hupe et al, 2003).

## 2. LANDFILL AERATION: DEVELOPMENT STATE AND FIELDS OF APPLICATION

### 2.1 Low pressure aeration

Low pressure aeration according to the AEROflott® method has been investigated and developed further for 10 years now. The technical basic concept comprises a system of gas wells, through which (via active aeration) atmospheric oxygen is introduced into the landfill body to such an extent that an accelerated aerobic stabilisation of the deposited waste is achieved. Simultaneously, the low-contaminated waste air is collected and treated in a controlled manner via further gas wells. Aeration is implemented using low pressures and is continuously adjusted to the oxygen demand, so that the stabilisation operation is constantly optimised (Heyer et al., 2003).

As regards the stabilisation operation using low pressure aeration, experience could already be gained at several municipal waste landfills and old deposits:

- Old Kuhstedt landfill, district of Rotenburg (Wuemme) – Lower Saxony, Germany, BMBF project (Ministry of Education and Research) (with test fields for the examination of alternative surface sealings) since 2000
- Old Amberg-Neumühle landfill – Bavaria since 2001
- Old Milmersdorf landfill, district of Uckermark – Brandenburg since 2002

In addition, preliminary aeration tests were carried out in larger TASi II landfills and old deposits, in order to dimension a site-specific low pressure aeration and adjust operation to the local conditions:

- Doerentrup landfill, ABG Lippe, district of Lemgo, Northrhine-Westphalia
- Leppe landfill, “Bergisches Land”, Northrhine-Westphalia
- Old deposit: Schwalbach-Griesborn, Saarland
- Old deposit Römerstraße, city of Memmingen, Bavaria

### 2.2 Over-suction methods

As far as the over-suction methods are concerned, the effect of aerobisation is to be achieved via suction operation including drawing-in of the atmospheric oxygen over the surface of the landfill and/or via passive aeration wells. In general, this is implementable only at sites with emission-relevant deposition thicknesses of < 10 m as, otherwise, the oxygen supply and thus aerobisation may not be guaranteed (Hupe et al., 2003).

This procedure, enabling stabilisation and gas-related decontamination, is applied in, amongst others, the following old waste disposal sites:

- Old Schenefeld landfill, district of Pinneberg - Schleswig-Holstein, Germany
- Old Kiel-Drachensee landfill, city of Kiel – Schleswig-Holstein, Germany

The situation of these sites was characterised by following boundary conditions:

- Endangering of the development by migrating landfill gas, both of the residential and of the commercial development.
- Missing technical barriers, where subsequent securing measures (surface sealing, vertical slurry walls, landfill mining etc.) would be too costly or technically unfeasible.
- The essential precondition for the application of passive aeration via over-suction was a relatively insignificant thickness of the deposits, so that a sufficient amount of oxygen could be supplied over the depth of the landfill body (Hupe et al., 2004).

## 3. PROCEDURE REGARDING THE APPLICATION OF AEROBIC IN SITU STABILISATION

Aerobic in situ stabilisation is one of the links of a chain of measures which need to be undertaken when a landfill is closed. Therefore, the site-related development of an overall plan regarding the closure of a landfill is useful.

### 3.1 The conceptual integration of in situ stabilisation into the closure of a landfill

As regards the conceptual integration of in situ stabilisation into the closure period, the following aspects should be treated:

- Acquisition of the actual state
  Deposition surface, deposition volume, cubature, thickness of the deposition in peaks and slope areas
- Sealing systems
  Bottom sealing, existing temporary coverings or final sealings, development and utilisation situation, where required
- Leachate collection
- Landfill gas collection
- Consistency of the deposited waste substances
  Deposition age, waste composition, recent results (if any results are available) regarding the waste composition (for example on the basis of test diggings or waste solid samplings)
- Current landfill behaviour and forecast regarding the future emission behaviour depending on the closure measures
  - Future water balance, emission behaviour via the water path including the future development of the leachate quantity and consistency
  - Settlements and settlement forecast
  - Landfill gas balance and landfill gas forecast

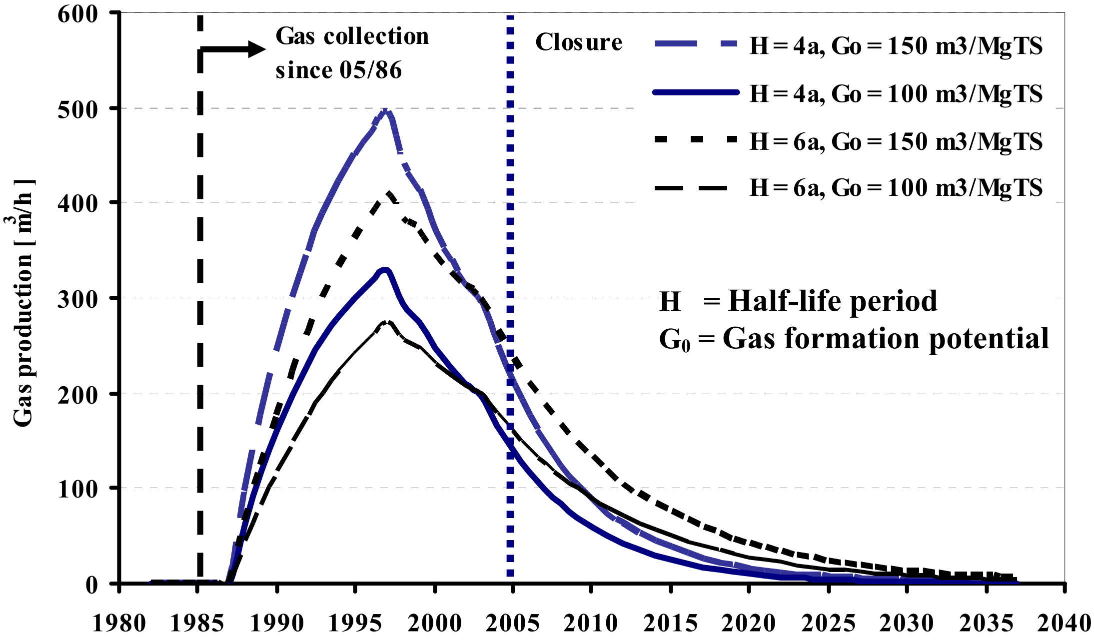


Figure 1: Range of the potential landfill gas production of a landfill section of a TASi II landfill which was filled up until 1996, including variation of the half-life period and of the carbon content

As an example, Figure 1 shows the results of a gas prognosis for an older landfill section of a TASi II landfill, which may be stabilised aerobically during the next few years. In this respect, half-life period and total gas potentials were varied in order to take into account the uncertainty regarding the consistency of the deposited waste and the milieu conditions. According to the gas forecast, gas production is already decreasing continuously at this site and currently lies between 150 and 250 $m^3$/h. In only a few years, the gas production may drop to below 100 $m^3$/h. In addition, the methane concentration will deteriorate. Therefore, on-site monitoring measurements at regular intervals and additional preliminary investigations are designed to show the landfill sector's behaviour, the period during which gas utilisation will still be possible and, finally, when and how aerobic in situ stabilisation is to be implemented.

## 3.2 Preliminary investigations regarding the solid's consistency

Through drillings in the landfill body, solid samplings and laboratory tests, information about the consistency of the solid material and the biological activity under aerobic milieu conditions can be obtained. The targets:

- Determination of the biologically available waste portions and estimation of the required aeration rates
- Assessment of the potential settlements as a result of aeration
  Experience gained up to now at landfill sites which are stabilised aerobically, shows (taking into account the results of the solid examinations) that the settlements occurring during aerobic in situ stabilisation may still account for up to 10% of the initial height within a few years, as a result of the accelerated mass degradation. Figure 2 (qualitatively) shows the different settlement courses for a landfill section which is to be stabilised aerobically in the future. The future settlement course is forecasted including aeration from 2005 onwards.

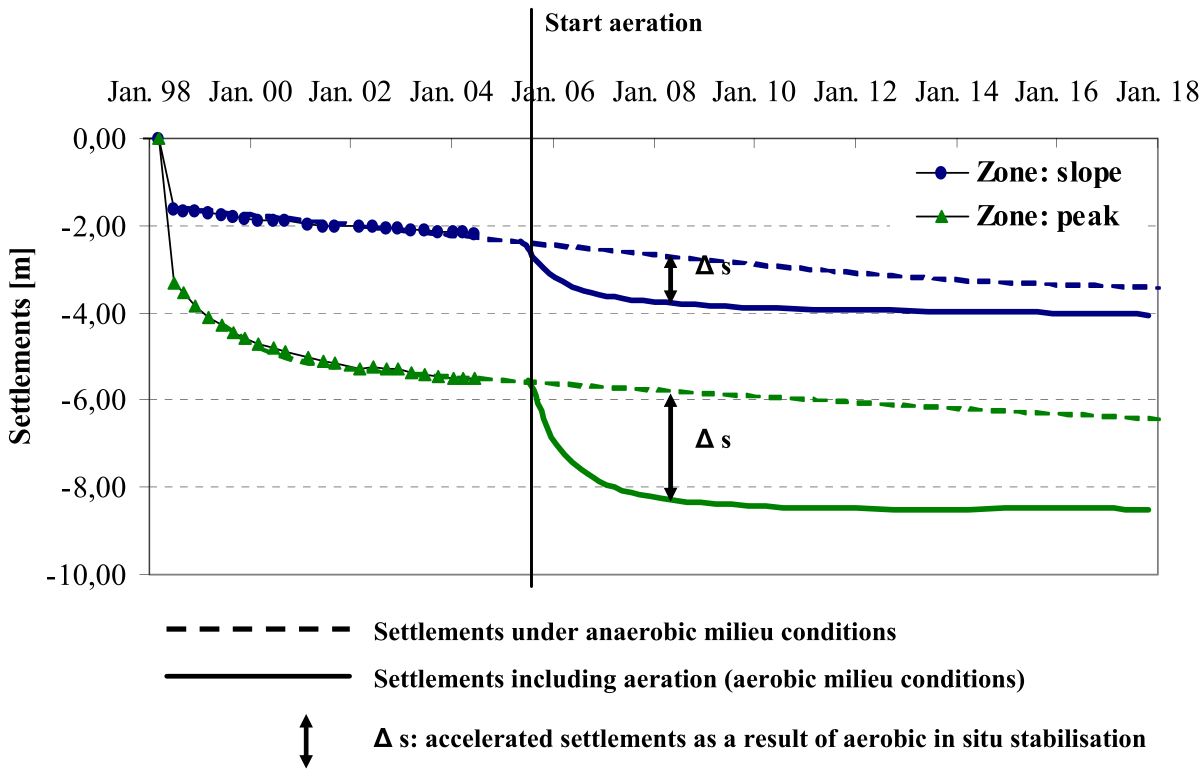


Figure 2: Course of the settlements in the proximity of two gas wells in the peak and slope area under anaerobic and aerobic milieu conditions

## 3.3 Preliminary investigations regarding the aerobic in situ stabilisation in the landfill body

As a rule, preliminary investigations are carried out in the landfill sections to be stabilised. The investigations should address the following points:

- Is it possible, from the technical point of view, to introduce sufficient amounts of fresh air into the landfill body?
- How is the introduced air diffused in the landfill body?
- What effects does the addition of air have on the gas balance of the landfill body?

The preliminary investigations which were carried out in order to settle these questions, lead to the site-related planning and dimensioning of the technical equipment, internal requirements and to a cost estimation.

The aeration tests are carried out over a few weeks using a mobile aeration system. However, in many cases, existing gas wells may be used for the introduction of air.

Investigations in several TASi II landfills have shown that low pressure aeration via conventional gas wells or already existing gas wells is suitable. According to the results obtained during the preliminary investigations, the catchment radius of the aeration wells often lies between 15 and 25 m.

Practical experience regarding landfills with a deposition thickness of > 10 m shows that it is also imperative to introduce a sufficient amount of atmospheric oxygen into the deeper landfill areas. This may not be achieved using the over-suction method. Therefore, an active, depth-differentiated air supply will be most effective in this case.

## 4. DATA REGARDING THE TECHNICAL IMPLEMENTATION OF THE IN SITU STABILISATION IN LARGER LANDFILLS

### 4.1 Technical equipment

The essential technical equipment comprises:

- Gas wells for aeration purposes and for the collection of waste air
- Gas mains system for aeration purposes and for the collection of waste air
- Gas distribution system for the adjustment of the aeration rates and of the overpressure, or of waste air collection rates and of the negative pressure per gas well
- Aeration aggregates in the gas booster station
- Waste air treatment stages: autothermic methods (RTO) or biofilters

The arrangement of the technical equipment for an older landfill section of a large municipal solid waste disposal site is portrayed by way of an example in Figure 3.

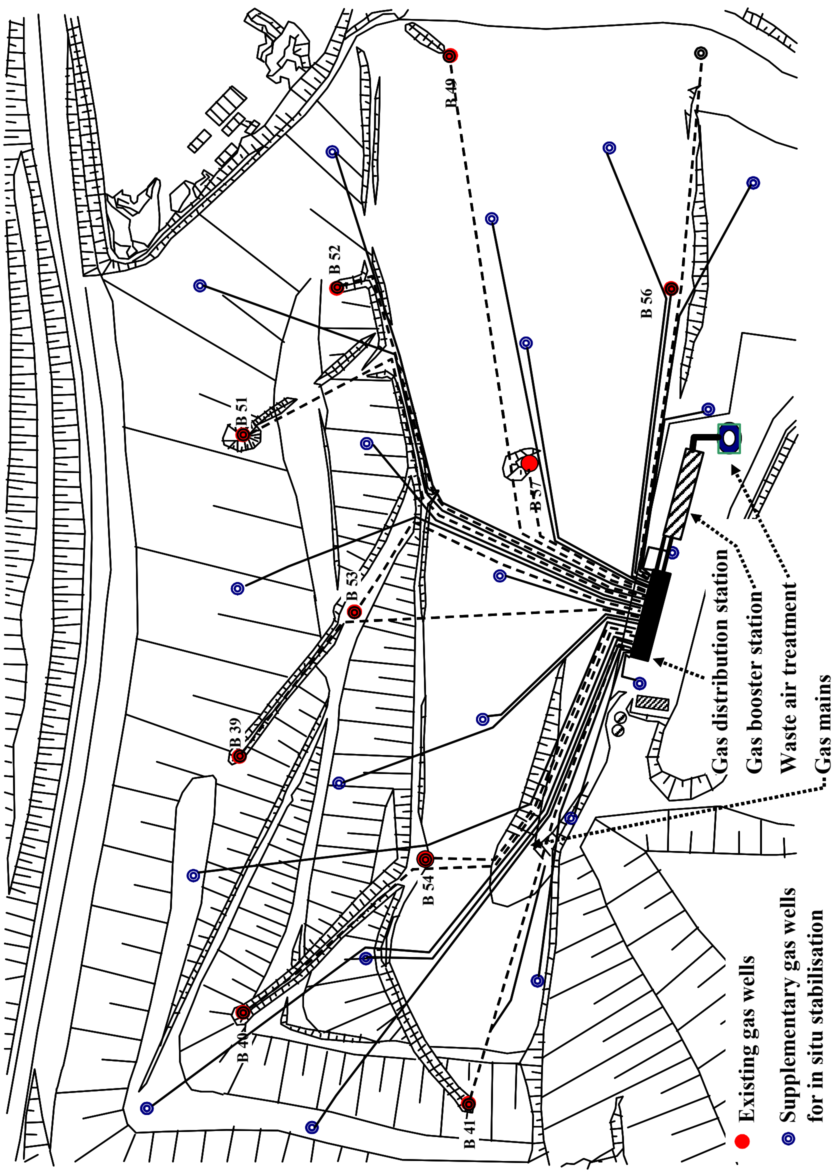


Figure 3: Arrangement of the gas distribution station, the gas booster station and the waste air treatment system in a landfill section of a municipal solid waste disposal site

### 4.2 Stabilisation operation, monitoring, technical engineering-related supervision

For the successful implementation of in situ stabilisation, qualified aeration operation and technical engineering-related supervision is imperative. Among other things, the latter comprises:

- Registration of the operating values, implementation of the monitoring program in order to record the stabilisation course and to control the success of the measures
- Control and optimisation of the stabilisation process, for example via remote data transmission
- Reporting (amongst others for the licensing and surveillance authorities)
- Aftercare concept (amongst others application-related) at the end of in situ stabilisation

Standard activities with regard to operation and monitoring measures at regular intervals may be carried out by the personnel working at the disposal site.

### 4.3 Processes and effects occurring during aerobic in situ stabilisation

Under average landfill conditions, in situ aeration operation is intended for a period of 3 to 6 years. Basically, aeration includes the following processes in the landfill:

- A changeover from anaerobic to aerobic milieu conditions takes place, which results in an accelerated and, in parts, further-reaching degradation of the bioavailable waste components.
- At the end of stabilisation, organic compounds consist of only persistent or non-degradable organic compounds with a very low gas formation potential.
- As a result of the accelerated biodegradation processes, the main settlements are also anticipated.

Effects on the water path:

- Along with the aerobic degradation of organic compounds and release into the gas phase (as carbon dioxide), an accelerated decrease of the parameters COD and, above all of nitrogen (TKN or $NH_4$-N) can be observed in the leachate path as a result of aeration.
- Compared with strictly anaerobic conditions, the aftercare periods for the leachate emission path are reduced by at least several decades when applying in situ aeration.

Effects on the gas path:

- The accelerated carbon degradation and discharge leads mainly to an increased carbon dioxide formation rate.
- Prevention or reduction of the methane content in waste air (reduced gas production at old disposal sites at the end of the stable methane phase) and therefore, for example, a lower explosion risk and fewer costs with regard to long-term waste air treatment.

The carbon conversion and discharge via the gas path may serve as the measure of intensity and of the acceleration of the biodegradation processes and can be determined as a load via the introduced and withdrawn gas volumes in connection with the waste air consistency.

- To draw a comparison and to classify the effects of aerobic in situ stabilisation at the Milmersdorf landfill, the carbon discharge which would arise under average anaerobic milieu conditions is estimated. For this purpose, the results of the gas forecast calculations (on the basis of the waste solid analyses) are taken into account (according to Figure 1). The actual carbon discharge ("actual C discharge") presented in Figure 4 lies at approx. 2900 Mg $C_{bio}$ at the end of June 2005 (bioavailable carbon in the waste solid material) due to aerobic in situ stabilisation.

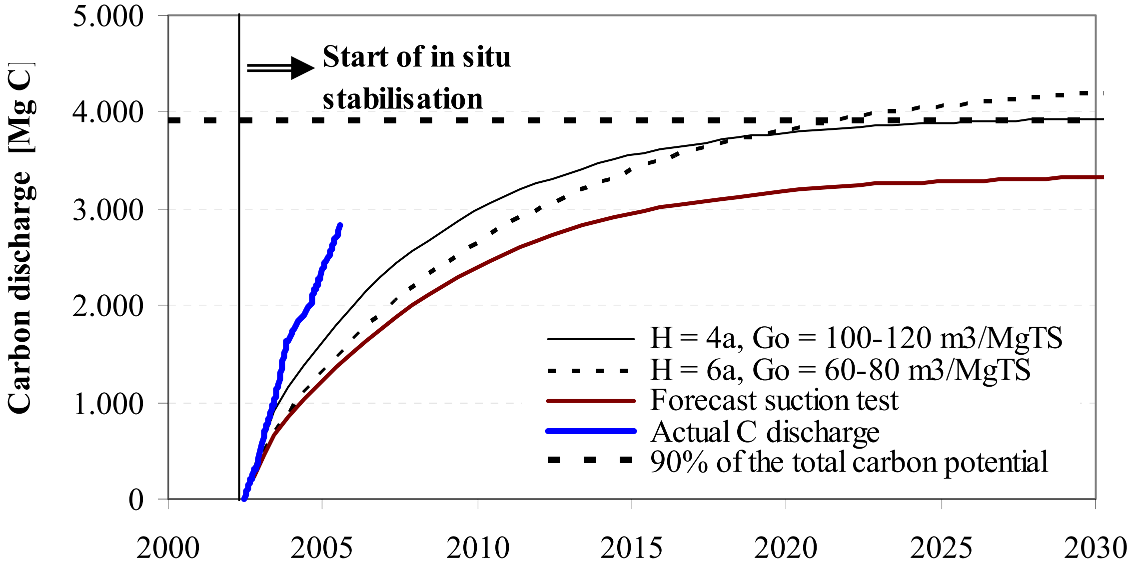


Figure 4: Range of the biologically convertible carbon, dischargeable via the gas path, under anaerobic milieu conditions from 2002 onwards. Comparison with the actual carbon discharge as a result of aerobic in situ stabilisation

The curve traces in Figure 4 show that:

- an accelerated conversion of bioavailable residual organic substances takes place in the landfill body
- since April 2002, significant parts of the total carbon which were still available were mobilised in a controlled manner and discharged. The carbon load mobilised within a short period of time amounts to approx. 60 – 80% of the total bioavailable carbon potential in the landfill body of 3500 to max. 4200 Mg $C_{bio.}$.

compared with anaerobic milieu conditions, the acceleration factor, expressed as carbon discharge per unit of time, lies at least between 3 and 4.

### 4.4 Costs of the aerobic in situ stabilisation and cost-saving potentials

#### *4.4.1 Costs*

Under favourable to average general site conditions, and with an optimised stabilisation operation, cost assessments result in a basic cost in the range of approx. 0.5 - 1 €/m$^3$ landfill volume. Only under unfavourable general conditions (such as very small, old disposal sites without any existing infrastructure) may the costs increase to 2 - 3 €/m$^3$ landfill volume. Thus, the investment costs (for example for supplementary gas wells and gas mains systems) the rental fees (for example for the gas booster station and for waste air treatment) and the operating costs for approx. 3 years are covered.

#### *4.4.2 Cost saving potentials*

The costs arising with regard to aerobic in situ stabilisation including low pressure aeration must be considered with a view to the significant cost-saving possibilities, as far as the landfill closure and aftercare are concerned:

- Lower operating costs for the treatment of leachate at sanitary landfills which are equipped with a bottom sealing, earlier completion of the leachate treatment

- Prevention of long-term diffuse gas emissions which may require poor gas treatment and, possibly, involve explosion risks and affect the atmosphere. For example the significant greenhouse gas emissions which still emerge from landfills should be mentioned. Where required, options for a trade in emissions may be developed, so that, via certificates for the prevention of greenhouse gas-relevant emissions, a further source of revenue may be created on the basis of the stabilisation method
- Reduction of the aftercare phase by several decades
- Replacement of a cost-intensive surface sealing with a lasting surface sealing which is adjusted to the landfill body poor in emissions, lower investment and maintenance costs
- As far as old disposal sites are concerned: fewer costs with regard to groundwater remediation and technical securing measures
- Faster recultivation and after-use, which is of increasing importance in metropolitan areas in particular.

Therefore, the costs of the aeration measures need to be compared with significant cost-saving potentials, so that, in the medium and long term, cost reductions may be taken into account.

#### *4.4.3 Financial requirements – comparison of scenarios*

In the following, two scenarios will be compared on the basis of the financial requirements of the closure and aftercare period of a landfill. As a “time schedule” for the aftercare cost calculation, a minimum duration of 30 years and an “emission-relevant” aftercare period of 100 years were chosen. When examining the scenarios, the following phases which are of importance for the calculation of the aftercare costs are taken into account:

- Closure phase
- Intensive aftercare phase
- Extensive aftercare phase, reduced costs

*Example comparison of costs:*

- Scenario A: temporary covering from 2006 onwards, installation of the final surface sealing (standard sealing, composite sealing) from 2015 onwards without in situ stabilisation of the landfill body
- Scenario B: temporary covering from 2006 onwards, in situ stabilisation of the landfill body from 2006 onwards and installation of the final, site-adjusted surface sealing from 2020 onwards

*Boundary conditions:*

- Landfill with a bottom sealing
- Landfill surface: 40 ha; landfill deposition volume: 8 million $m^3$
- 31.05.2005: start of the closure phase and installation of the temporary surface sealing / covering including profiling from 2006 onwards
- Mean amount of precipitate: 800 mm/a
- Via energetic landfill gas utilisation, a surplus may be achieved as far as the gas collection and treatment is concerned (with a time limit and depending on the gas production rate, and on the water balance).
- The investment costs with regard to profiling, installation of the temporary surface covering and of the final surface sealing are both taken into account (in equal portions) over a period of 2 years. Extra construction costs and costs for infrastructure measures are taken into account with 30% of the investment costs for the respective sealing measure.
- Depending on the degree of preservation or stabilisation of the landfill body, the operating costs will be adjusted (decreasing tendencies).

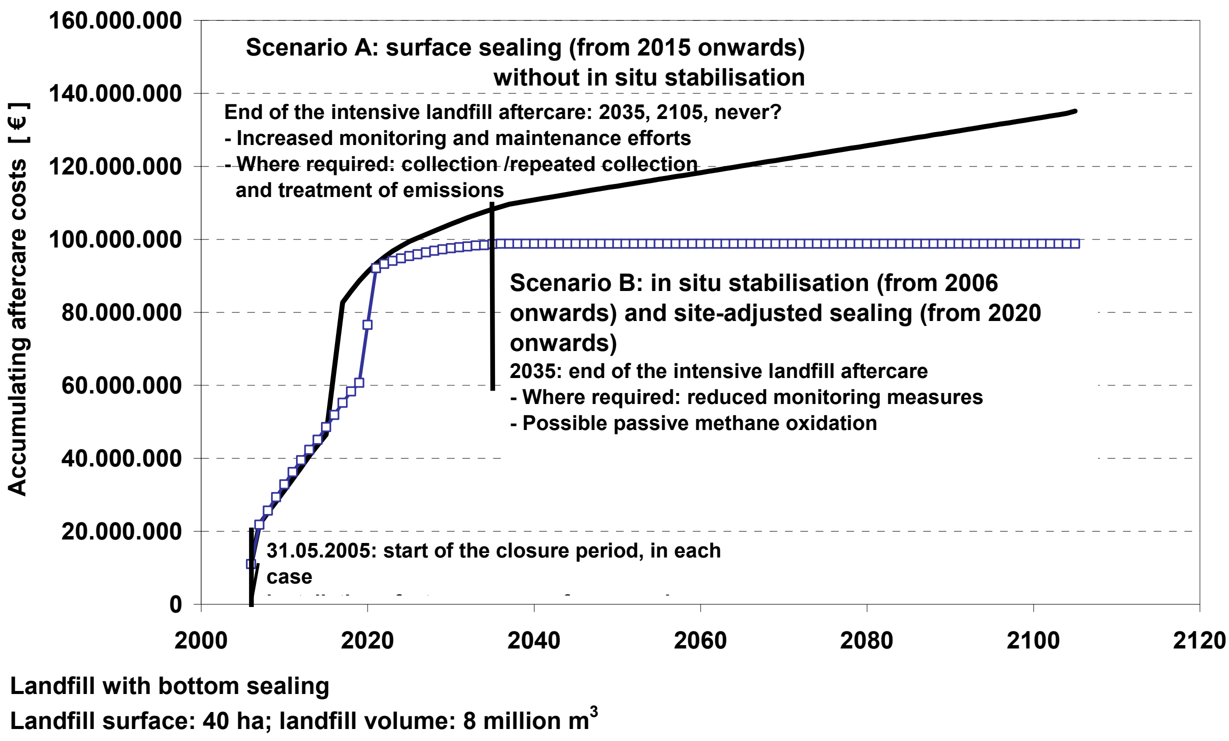


Figure 5: Cost comparison regarding the closing and aftercare of larger municipal solid waste disposal sites: Procedure excluding (scenario A) and including aerobic in situ stabilisation (scenario B)

Figure 5 shows the course of the accumulating aftercare costs for both scenarios over a period of up to 100 years subsequent to the start of the closing phase in 2005.
As a result of the remaining emission and settlement potential, the following can be stated for scenario A (surface sealing from 2015 onwards <u>without</u> in situ stabilisation):

- The point of completion of the intensive landfill aftercare is unclear: 30 years or 100 years after the closure was started or even much later.
- Even 30 years after the closure was started, increased monitoring and maintenance efforts will still be required (compared with scenario B).
- In the event of malfunction of the sealing system, (technical structure), renewed collection and treatment of emissions or additional cleanup measures may be required.

As a result of the stabilised landfill body which is thus poor in emissions and settlements, it can be stated for scenario B (surface sealing from 2020 onwards, subsequent to the completion of in situ stabilisation) that

- the installation of a site-adjusted sealing system is possible
- an end to the intensive landfill aftercare 30 years after the closure was started is much more likely,
- where required, an extensive landfill aftercare is possible at an earlier moment, involving only little monitoring effort or including possible measures for passive methane oxidation.

## 5. CONCLUSIONS AND OUTLOOK

Aerobic in situ stabilisation including low pressure aeration has been implemented from 2000 onwards at three landfills and old disposal sites. This procedure which, in the meantime has been fully developed, is now to be applied at larger, bottom-sealed TASi II landfills which were closed during the last few years or which stopped deposition operation by June 1st 2005. Aerobic in situ stabilisation represents an essential measure in the entire closure and aftercare concept. Therefore, qualified acquisition of the actual state with the actual emission behaviour and a forecast of the future long-term emission behaviour dependent on the respective closure measures is to be implemented. In many cases, preliminary investigations for the determination of the current consistency of the landfill body and the resulting biological residual activity are useful. Preliminary aeration investigations often follow in order to adjust aeration technology and aeration operation to the site-specific conditions and, in this manner, achieve an optimised and economic stabilisation operation.

In flat landfills or old disposal sites with deposition thicknesses of < 10 m, over-suction methods, in many cases in combination with passive aeration, may also be applied to achieve aerobic in situ stabilisation of the waste body. In this respect, it is vital to ensure a sufficient supply of oxygen to the deeper regions as well. For all process variations, qualified waste air treatment is required, amongst other things in order to prevent odour emissions and guarantee climatic protection.

For larger TASi landfills, a basic cost of 0.5-1 € per $m^3$ regarding aerobic stabilisation is to be expected. Considerations of the total costs show that, as a result of stabilisation, cost reductions with regard to closing and aftercare of at least 5% or, in some cases, of 10 to 15% are achievable, as operation, maintenance and aftercare period may be significantly reduced.

Conclusion: Aerobic in situ stabilisation and, in particular, low pressure aeration are methods which, in the future, will be applied in many landfills as a result of economic considerations and for reasons of an accelerated and controlled reduction of emissions.

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