Braambergen Landfill

Feasibility study on sustainable emission reduction at the existing Braambergen landfill in the Netherlands

Specific report: Preliminary design and cost-estimate of the technical measures to enhance stabilisation with the DEPO⁺ process© at the Braambergen landfill

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1 INTRODUCTION

The Dutch Sustainable Landfill Foundation (DSLF) took the initiative to evaluate the possibilities for and effects of sustainable landfill-methodologies at existing landfills. The main goal of this initiative can be formulated as follows:

The full scale demonstration of sustainable emission reduction at one or more existing landfills in the Netherlands

The DSLF consider isolation and external aftercare not a real and sustainable solution for the mitigation of unacceptable emissions from landfills. In 1999 they initiated a project 'Sustainable Landfilling' [U1] to develop ways of reducing the emission potential of the waste, rather than just isolating the emission potential from the environment.

The goal of sustainable landfilling in terms of the European regulatory framework is to meet the emission thresholds for a landfill for inert waste within about 30 years as well as not to exceed the threshold values for groundwater quality. The main conclusion of this research [U1] was that, when biochemical and physical processes are allowed to run to completion, emission potential is reduced significantly. The project 'Sustainable Landfilling' however aimed at landfills, still to be constructed and concluded with design rules for these future landfills.

The success of the project 'Sustainable Landfilling' led to the follow-up questions:

- Is it possible to retrofit existing landfills in such a way that they become more sustainable?
- Is it possible to stimulate the natural biochemical and geochemical processes at existing landfills?
- Do these actions - if they are feasible - also lead to a significant reduction of the potential emissions?
- Does this significant reduction in emissions also lead to admissible emission levels?

If these questions can be answered positively, less stringent aftercare or discharge from aftercare would be possible. The DSLF is convinced that the EU Landfill Directive provides the opportunity for aftercare that is tailor-made to the real risk of emissions from the waste body.

Within that framework the DSLF requested the Dutch landfill owners to submit landfills, which meet the requirements for a suitable landfill site as described in the Terms of Reference [U1]. Finally one of the selected landfills was the "Braambergen" landfill in the province of Flevoland (NL) and owned by the landfill operator Afvalzorg.

The first step of the initiative is the execution of a feasibility study with respect to the suitability of the selected landfill. The present current status report of the Braambergen landfill is a part of this feasibility study.

For more information on the technical backgrounds, European and Dutch regulatory framework, overall objectives of the feasibility study and project organisation, the reader is referred to the final generic report entitled "Processes in the waste body and overview of enhancing technical measures" [U1].

2 BASIC APPROACH OF THE FEASIBILITY STUDY AND DELIVERABLES

The basic approach is outlined in figure 2.1, which comprises the two main parts of the feasibility study.

Current status report	**Project plan report**
Storage & management of existing data, analysis of existing data, current status of pilot landfill	Selection of suitable technical measures per landfill, draft design of technical measures, research and measurement programme, expected results and potential benefits, cost estimate (investment budget)

Figure 2.1: Basic approach of the feasibility study

These two main parts correspond to the required final deliverables, meaning the following two section reports:

- Specific report, comprising a description of the current status of the landfill with respect to emission potential and stabilisation process (reference situation).
- Specific report comprising a preliminary design of enhancing technical measures, a forecast of the achievable level of emission reduction possible due to autonomic and enhanced developments, and a measurement programme and cost estimate.

This document represents the specific report concerning the preliminary design and cost-estimate of the technical measures to enhance stabilisation at the Braambergen landfill.

3 ACTIVITIES

Based on the above mentioned generic report [U1], the preliminary design and cost-estimate for the Braambergen landfill is carried out as follows:

- Compilation of the relevant site conditions and evaluation of the emission and landfill behaviour as basis for the preliminary design.

- Expected results and potential benefits with respect to the effects of enhanced stabilisation on the emission behaviour of the landfill.

- Concept for the technical measures to be carried out in order to realise in-situ stabilisation in accordance with the DEPO$^+$ process® (modifications to and supplementing of gas wells) followed by the carrying out of a pilot study to determine the existing relationships under optimised conditions and to determine the fundamentals (ranges, flows, qualities) for the detailed planning with the aim of activating the inhibited biological activity (as documented in the status report [U2] and in this way advancing the further stabilisation of the Braambergen landfill with the objective of bringing about an increase over a period of time in the yields of biologically available organic material via the gas and water path.

- Research and measurement programme for the in-situ stabilisation methods, mainly consisting of:

  - solid waste sampling and investigations

  - leachate monitoring

  - landfill gas monitoring

  - settlements

  - technical equipment

- Preliminary cost-estimate of all costs relating to the preparation, installation, maintenance and exploitation of the enhancing technical measures as mentioned above (DEPO$^+$ process®).

4 LANDILL CHARACTERISTICS

The current status of the Braambergen landfill has been described in the specific section report "Current status of the Braambergen landfill" [U2]. From this section report only the relevant information with respect to the preliminary design and cost-estimate is reproduced in the sections below.

4.1 Site conditions

The Braambergen landfill is located near the town of Almere in the north-west of the Netherlands (figure 4.1) and is operated by Afvalzorg. The Braambergen landfill is divided into a south-western and a north-eastern part. The exploitation of the north-eastern part of the landfill started in 1999 and ended in 2008. The height of the north-eastern part of the landfill is approx. 15 meters at the upper plateau.

The surface area of the north-eastern part is 9.7 hectares divided into 4 waste cells 11n, 11z, 12o and 12w.

Figure 4.1 Location and aerial photograph of the Braambergen landfill

Basic data of the north-eastern part are as follows:

- Area of compartments 11 and 12: Approx. 9.7 hectares.
- Volume of compartments 11 and 12: total of 1,216,723 tons, of which 70% has been landfilled in the period 2002 -2006 and 10% in 1998.

- Height of the waste body: 15 m at the upper plateau.
- Soil cover as temporary cover (1-1.5 m).
- Slopes on four sides with an inclination of 1:3
- Bottom liner and leachate drainage system in all compartments (figure 4.2).
- Existing gas wells (figures 4.2):
  - 8 in compartment 11n,
  - 20 in compartment 11z,
  - 4 in compartment 12o and
  - 4 in compartment 12w

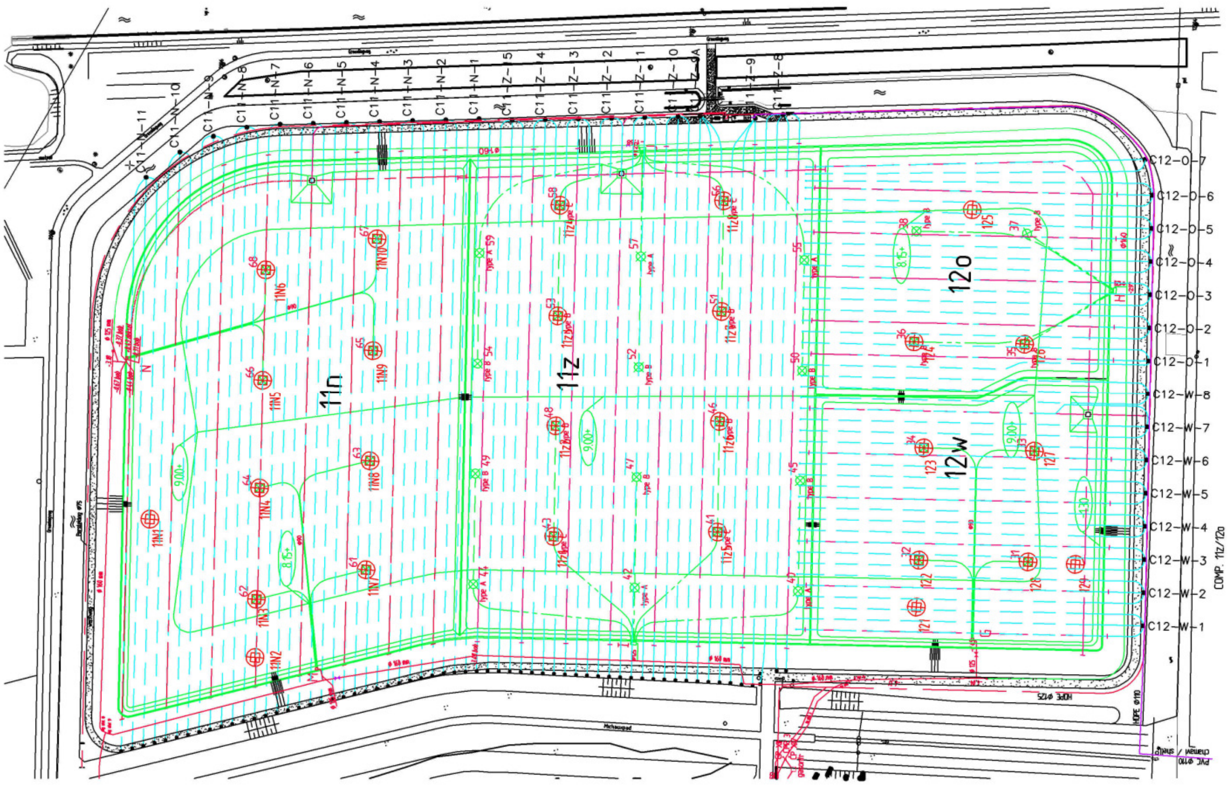

Figure 4.2: Compartments 11n, 11z, 12o and 12w of the Braambergen landfill

4.2 Current Status of the Landfill

As a part of the feasibility study a specific report has been written in respect of the current status of the Braambergen landfill [U2] based on an assessment of available data. The main results are compiled in table 4.2.

Table 4.2 Characteristics in respect of the current status and emission behaviour of compartments 11 and 12

Age of waste	70% from period 2002-2006
Waste composition	29 % organic share, 71 % inert
Waste quantities	Waste: 1,216,723 tons Organic: 351,633 tons
Leachate: macro-parameters	pH = 6.84 to 7.05 —> methanogenic phase
	SO4 = 700 to 1000 mg/l —> methanogenic phase
	COD = 600 to 4000 ml/l —> methanogenic phase (biological conversion restricted)
	DOC = 80 to 250 ml/l —> methanogenic phase (biological conversion restricted)
	PAH (naphthalene) 2 to 4 mg/l —> no relevant KPI for in-situ stabilisation
Leachate: micro-parameters	Mercury 0.003 to 0.01 mg/l —> no relevant KPI for in-situ stabilisation Arsenic 0.1 to 1 mg/l —> no relevant KPI for in-situ stabilisation
Gas collection	Decrease from 83 m3/hr (2003) to 64 m3/hr (2010). The investigations carried out in 2010 show that a considerably greater volume of landfill gas can be achieved by putting the gas collection lines in order. The methanogenic phase has not yet ended.
Gas quality	The investigations carried out in 2010 show mean methane contents of 48 Vol.% . Ratios of CO2 to CH4 of between 1.3 and 1.8 indicate a state of stable anaerobic methane production. The methanogenic phase has not yet ended.
Settlement	Settlement of up to 36 cm with mean settlement of 12.4 cm in 2008 —> methanogenic phase
Overall conclusion	**The landfill is still in the methanogenic phase with anaerobically degradable organic matter remaining.**

5 DESIGN-STRATEGY DEMONSTRATION LANDFILL BRAAMBERGEN

5.1 Stepwise approach

Based upon the results of the current status of the Braambergen landfill as summarised in chapter 4, a design strategy for the demonstration project at the Braambergen landfill has been developed. The biological conversion processes at the Braambergen landfill appear to have slowed down for the following reasons. Targeted investigations of the gas collection system as carried out in 2010 showed indications of damage to the gas wells and the gas collection lines. As a result of the damage to the gas collection system as established, considerable parts of the landfill can no longer be optimally degassed. These peripheral conditions can lead to a slowing down of the decomposition processes.

It is intended first of all in a stepped manner to reactivate the slowed-down biological conversion process by improving the peripheral conditions by means of an anaerobic in-situ stabilisation process (DEPO$^+$ process$^®$) and to continue the anaerobic decomposition process in an accelerated manner. First when the anaerobic decomposition process has been completed to a very large extent will an aerobic in-situ stabilisation process - brought about by targeted over-extraction of the system - ensure final conversion of the organic material in the landfill. Separation/removal of the organic material in a sustainable way within a manageable period of time can also be brought about by a mode of operation combining both anaerobic and aerobic stabilisation of the landfill body. Thus in parts with low levels of gas it can be appropriate to over-extract these aerobically while in the parts of the landfill with higher levels of gas extraction under anaerobic conditions, e.g. by the provision of heat, can best achieve the objective. The decisions on this cannot be made until the results of the pilot study are available or may also be made later in the course of operations.

Here additional feeding back of leachate is not foreseen since the quantities of the stormwater and leachate as determined indicate that the landfill body is moist enough. A final decision on the precise mode of procedure cannot be made until the results of the preliminary investigations are available.

- For the design strategy a stepwise approach is proposed as follows:
- Installation additional sampling and measuring equipment
- Pre-investigation programme: Conversion and supplementing of gas wells followed by the carrying out of a pilot study to determine the existing relationships under optimised conditions and to determine the fundamentals (ranges, flows, qualities) for the detailed planning and the making of forecasts on the development over a period of time of the yields of biologically available organic material via the gas and water path.
- Drillings for gas wells (waste sampling)
- Final design, system engineering
- Installation of system engineering for anaerobic in-situ stabilisation
- Extension of system engineering for aerobic in-situ stabilisation

5.2 Time period

The duration of and operational requirements for the first period of the improved production of gas under anaerobic conditions cannot be forecast precisely at the present time since for this the results of preliminary investigations for the determination of the gas potential or, as the case may be, of the quantities of organic material to be stabilised are needed. However, on the basis of the results available [U1], it is assumed that a period of approx. 4 - 6 years will be needed for the anaerobic in-situ stabilisation process to reach completion. The aerobic in-situ stabilisation process that will then begin will probably take up to a further 4 years. Removal of the organic material in a close-in-time and efficient manner within an overviewable period of time can also be brought about by a mode of operation combining both anaerobic and aerobic stabilisation of the landfill body.

On the basis of the data available it is estimated that carrying out of the model project for a period of some 8 - 10 years will be long enough to permit conclusive results to be achieved. However it is to be expected that it will be possible to evaluate the effectiveness of the technical measures at an earlier point in time so that then decisions can be made on the continuation of the model project.

For the cost estimates (see section 12) the period of time is divided up into 5 years of anaerobic stabilisation and 4 years of aerobic stabilisation. Fig. 5.2 shows a provisional schedule for the model project at the Braambergen landfill.

Figure 5.2 Time schedule, Braambergen landfill model project

Activities (steps)		2011	2012	2013	2017	2018	2021
Additional sampling equipment		X					
Drilling gas wells[1] and waste sampling		X					
Pré-investigation program		X					
Final design system engeneering			X				
Installation, anaerobic stabilization system eng.				X			
Period for anaerobic stabilization				X	X		
Installation, aerobic stabilization system eng						X	
Period for aerobic stabilization						X	X

6 ADDITIONAL EQUIPMENT FOR SAMPLING AND MEASUREMENTS

For the final laying down of the preliminary plan and for the execution of the pre-investigation programme suitable measuring points and measuring equipment must be available. The erection of the following measuring points is recommended. It is possible that the list of measures will have to be extended at a later point of time on the basis of new findings produced in the pre-investigations.

- Drilling of auxiliary level gauges for monitoring the formation of gas in the area of influence of the gas wells including determination of range

- Laying of gas measuring lines to connect the auxiliary gauges to the monitoring unit

- Converting of existing gas wells into deep-filtered gas wells (wells filtered in accordance with the DEPO$^+$ process®) to increase the decomposition of the biologically available organic material

- Preparation of new gas wells to replace defective gas collectors

- Repairing of existing / constructing of new connection lines for the gas wells

- Improving the efficiency of the gas regulating stations

- Taking of samples of the waste material present in the landfill using the material obtained from the drilling of the auxiliary gauge and gas well shafts in order to analyse the solid material and to determine the decomposition rates of this material under different operating conditions for the in-situ stabilisation

The probable costs for these measures are given in the project cost estimate (section 12).

7 PRE-INVESTIGATION PROGRAMME

Presented in the report on the current state of the Braambergen landfill [U2] was a table with the data available on the relevant Key Performance Indicators (KPIs). Certain items of data are still not yet available and need to be determined in the initial phase of the planning of the measures for the in-situ stabilisation within the framework of the pre-investigations.

The following pre-investigations are recommended:

- Analysis of drilled material samples and determination of the decomposition rates of these under different operating conditions.

- Extraction tests on all gas wells including determination of range

- Extraction test on the complete system of landfill compartments 11 and 12

- Supplementary chemical analysis of the leachate

- Further settlement measurements

The probable costs for these measures are given in the project cost estimate (section 12).

7.1 Analyses on solid waste samples

During the production of gas wells and/or gas measurement gauges a representative number of samples are to be taken of the waste recovered from landfill compartments 11 and 12. The analyses of the waste samples are of significance for the determination of the key performance indicators or, as the case may be, for the describing of the current state of conversion of the waste [U1]:

- Water content:
  The water content measurements indicate the areas in the landfill which are moist or, as the case may be, dry. The samples permit statements to be made on whether the moisture present lies within the optimum range for the biological conversion processes

- Biological activity through breathing tests and gas formation tests:
  The tests permit determination of the biological activity under aerobic and anaerobic milieu conditions in order to characterise the biologically available organic material that can still be converted

- Determination by means of eluate analyses of the proportion of the waste that can be mobilised:
  These tests permit determination of the emission potential under different milieu conditions, e.g. of the heavy metals and of toxic trace matter

- Carbon content:
  From the determination of the carbon content and in combination with the results of the tests on biological activity conclusions can be drawn on the total quantity of the biologically available organic material that can still be converted into landfill gas

7.2 Extractions from individual gas wells and gas extraction test

The investigations started in 2010 on the existing gas wells and/or the gas wells to be constructed should be continued within the framework of the pre-investigations. On the basis of the extraction results from individual gas wells it will be possible to prepare characteristics for the optimal extraction of each gas well.

Following execution of gas investigations on the individual gas wells it will be possible to determine the yield capability of the complete gas collection system of landfill compartments 11 and 12 by means of an extraction test carried out. Within the framework of the extraction test it will be possible to set the optimum amount of gas to be extracted from each gas well and to check this for sustainability. Finally the gas extraction test yields a reliable statement on the gas formation potential.

In addition during the gas extraction test a range determination will be carried out for the operating conditions during the anaerobic and aerobic in-situ stabilisation processes.

7.3 Chemical analyses on leachate composition

The items of data listed as missing in the report on the "Current state of the Braambergen landfill" [U1] and which still have to be determined are listed below:

- Redox-potential (Eh);
- Alkalinity;
- NA parameters;
- Volatile fatty acids (VFA);
- Total organic carbon (TOC);
- Dissolved organic carbon (DOC);
- Ammonium (NH4), nitrate (NO3) and nitrite (NO2).

7.4 Settlement measurements

The settlement measurements evaluated within the framework of the status report [U2] stem from the year 2008. New comparative measurements at the measuring points which still exist should enable supplementary statements to be made on the settlement that has taken place in the meantime and thereby on the progress of the biological conversion processes.

8 GENERAL ASPECTS OF THE ANAEROBIC AND AEROBIC IN-SITU STABILISATION PROCESS (DEPO$^+$ PROCESS)

The most decisive factor for the quality of the degasification of a landfill is the gas collection system. The requirements for a successful gas extraction can only be met by using an efficient collection system (deep action, range).

The optimisation of both the degasification system and its operation leads to an increase of the quality and quantity of the landfill gas during the anaerobic in-situ stabilisation. The following aerobic in-situ stabilisation results in a far-reaching material reduction of biologically degradable carbon in the landfill body and therefore meets the criteria for a release from post-closure maintenance obligations.

The DEPO$^+$ process® aims at the optimal material carbon reduction of the landfill body, resulting in an early release of the landfill from post-closure maintenance obligations. The priority of the energetic utilisation of the landfill gas according to the landfill Ordinance (DepV 2009) places the activation of biologically degradable organic material and the discharge of this as high-energy biogas in the anaerobic phase foremost, before aeration of the landfill body is carried out by targeted over-extraction.

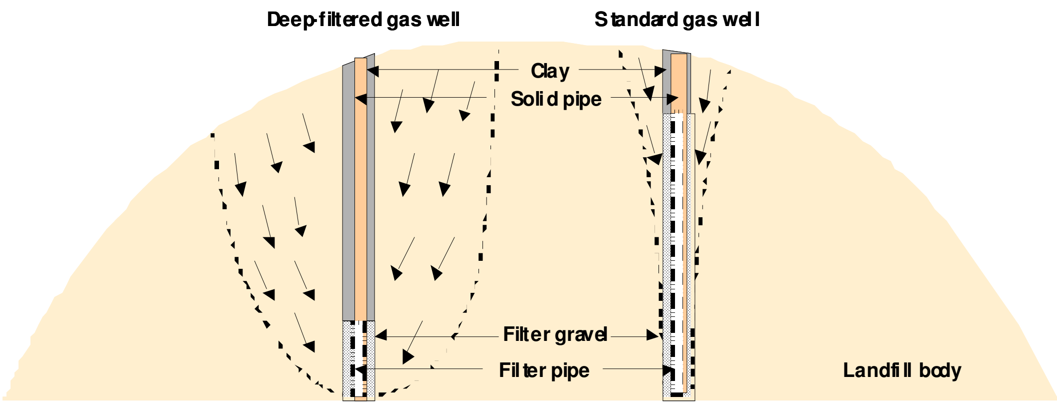

Figure 8.1: Flow behaviour and range – comparison of classical standard gas wells and deep-filtered gas wells of the DEPO$^+$ process®

Figure 8.1 shows the different mechanisms of a single deep-filtered gas well compared with a classical gas well with filters from top to bottom. Experience won during operations at several sites show that if a landfill is deeper than 10 m and the landfill body has many layers, it can be more effective to upgrade deep-filter wells at several different extraction levels. By reason of the expected composition of the waste in the landfill and its maximum thickness of 15 m, single deep-filtered gas wells come in question for the Braambergen landfill.

Figure 8.1 also shows the extraction radiuses at the landfill top in relation to the flow behaviour. The range of deep-filtered gas wells mainly depends on the depth of a landfill and the extraction flow. At several landfill sites the range of the extraction radiuses could be improved from approx. 15 m to more than 40 m.

The gas extraction is operated on the basis of the following principle:

The gas wells extract landfill gas of different qualities and quantities as it occurs. Key parameters, kept under observation during the activation of the decomposition processes in the landfill, are, besides methane and oxygen, the negative pressure as evidence of the effectiveness of the extraction, typical landfill gasses (amongst others CO2, CO, H2S) as well as the temperature as evidence of the effectiveness of the biological decomposition processes.

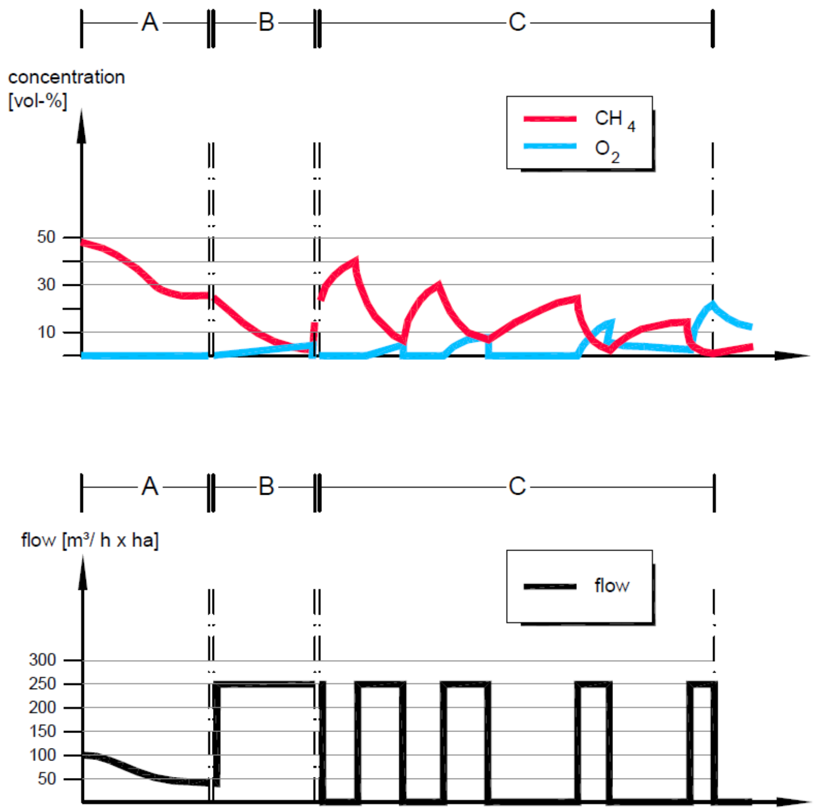

Figure 8.2: Schematic course of gas flow and gas concentration during anaerobic in-situ stabilisation (phase A), followed by presentation of the course during the aerobic in-situ stabilisation (phase B) and during the intermittent operation at the end of the landfill extraction (phase C)

Figure 2 illustrates the different phases A (extraction during the utilisation of energetically usable landfill gas), B (extraction during the aerobic in-situ- stabilisation) and C (intermittent extraction at the end of the landfill degasification), the extraction rates and the forecasted gas concentrations.

The separate phases are defined as follows: (figures 3 and 5 illustrate the organic decomposition in phases A (anaerobic) and B (aerobic)).

Phase A:

Depending on the degree of decomposition of the biogenically available organic material, the extraction of the landfill targets the generation of energetically usable landfill gas. Setting the extraction flow to a suitable level in this phase (Figure 8.3) guarantees an efficient emission control of the landfill. The inverse direction of the flow ensures that the state of the landfill body remains anaerobic to enable an optimised energetic utilisation of the landfill gas.

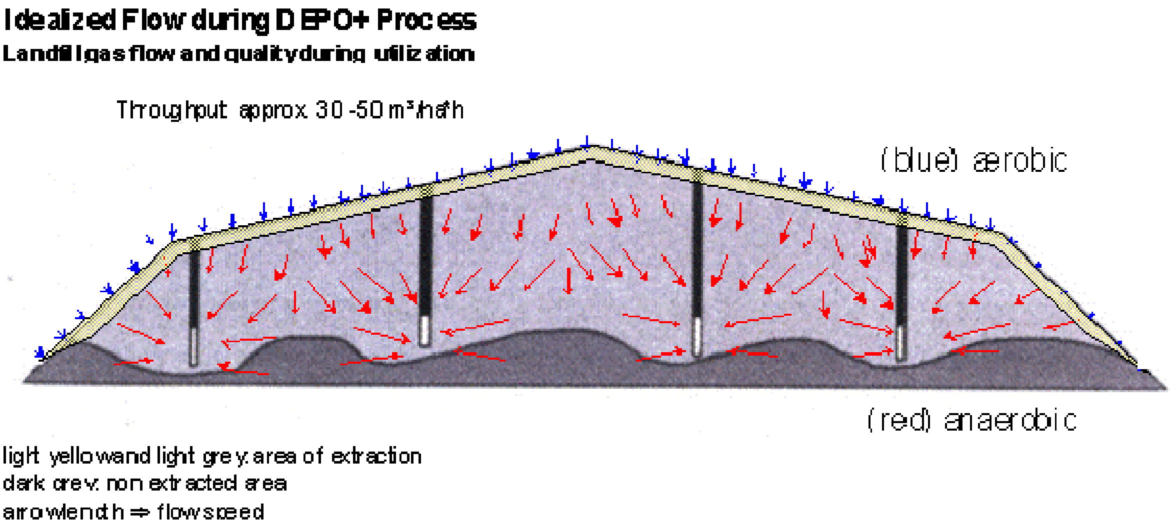

Figure 8.3: DEPO^{+} process®, organic decomposition during the anaerobic in-situ stabilisation

This extraction process is maintained until a continuous operation is neither ecologically useful nor economically sensible.

Figure 8.4 shows the main benefits of the supply of landfill gas for an economical utilisation in the first phase of decreasing landfill gas quantities and qualities, if the DEPO^{+} process® is applied.

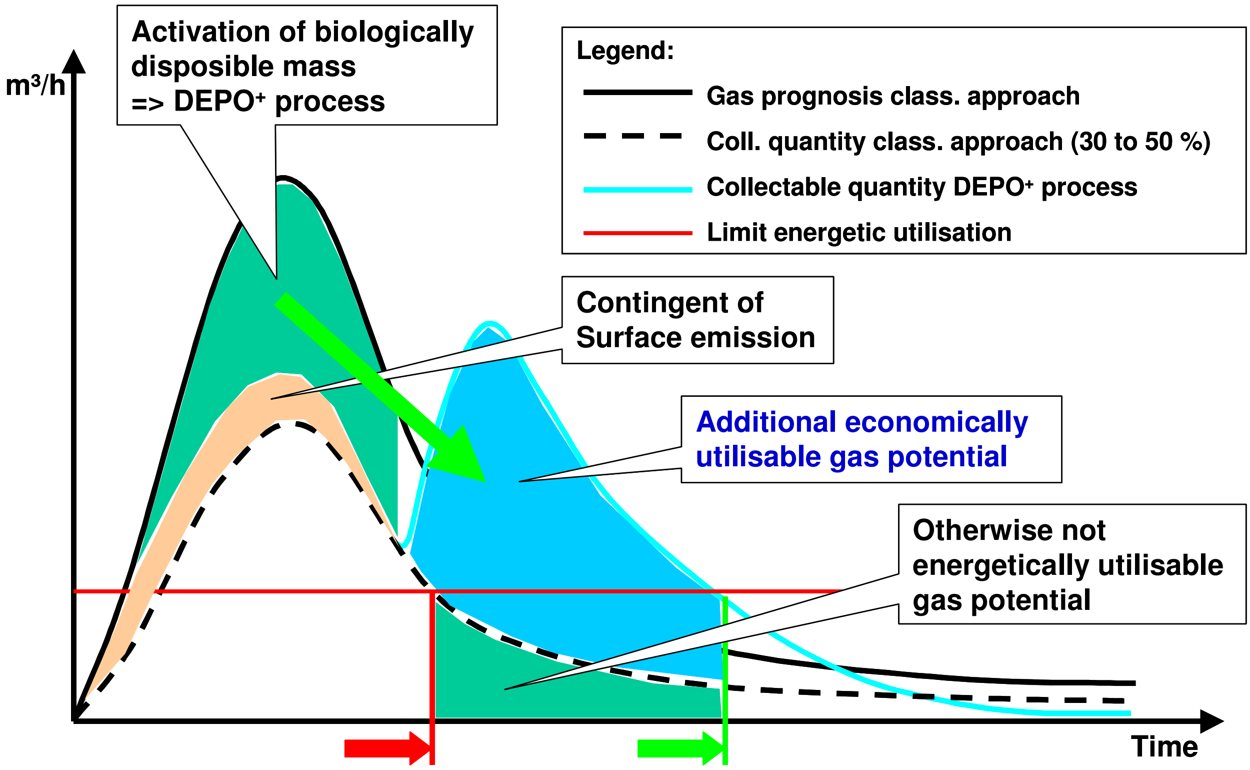

Figure 8.4: Effects of the application of the DEPO+ process® during the anaerobic in-situ stabilisation

Phase B:

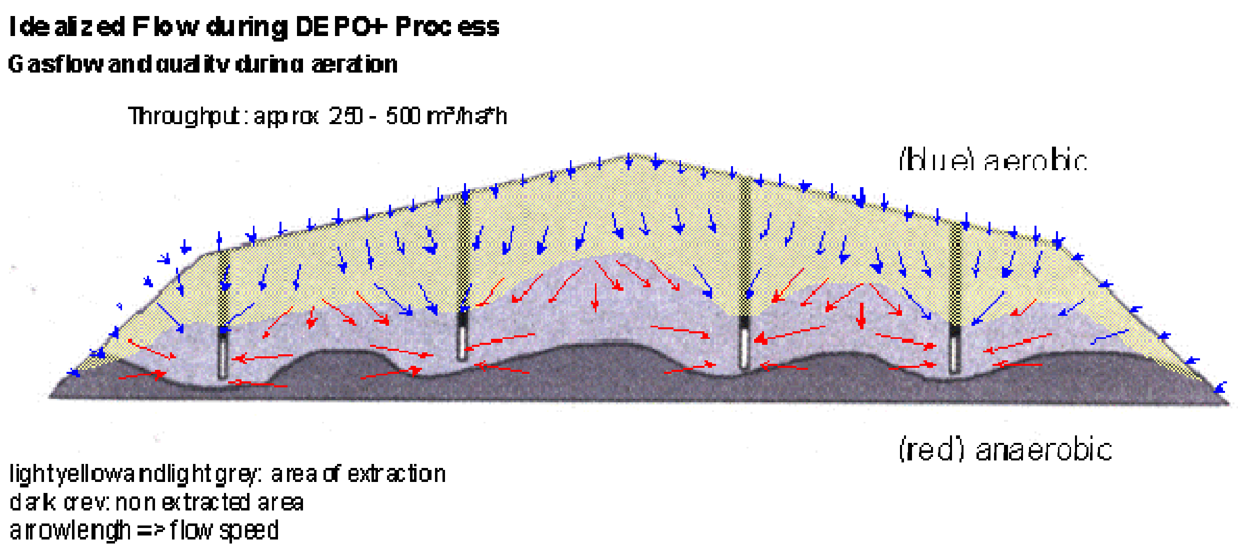

Figure 8.5: DEPO+ process®, organic decomposition in the aerobic in-situ stabilisation phase

The technical operational concept must provide for a permanent maximum organic discharge, if possible for the utilisation. As soon as these requirements can no longer be met, phase B starts with the aerobic in-situ stabilisation. The required extraction rate depends on the reaction of the landfill and is adjusted step-by-step under permanent monitoring.

The increased extraction and the resulting decomposition of biogenic mass leads to a reduction of the methane concentration while the oxygen concentration increases. The aerobic front seeps through the landfill step-by-step from the outside to the inside (Fig. 8.5).

Generally, one has to observe that, due to oxidation with the atmospheric oxygen during the aeration process, landfill fires are possible. The DEPO$^+$ process® takes this danger into account (c.f. Figure 8.6) in phase B by:

- introducing oxygen via the landfill top and therefore over the largest area possible,
- keeping the introduction velocity very slow, thus guaranteeing a high capacity,
- raising the temperature only slightly (37 °C) and therefore reducing the risk of dehydration.

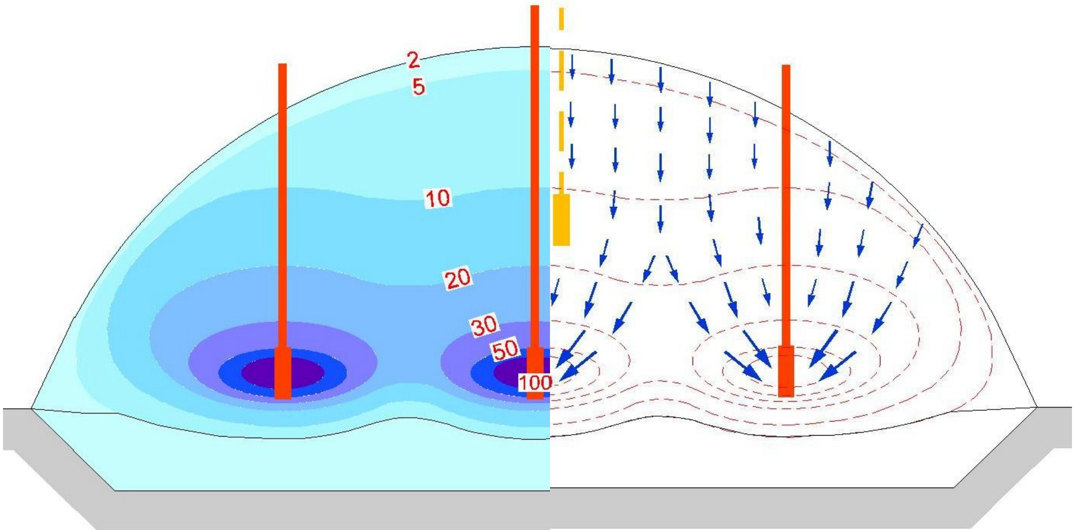

Figure 8.6: DEPO$^+$ process®, organic decomposition during the aerobic in-situ stabilisation, arrows length/size = flow speed; 2, 5 … 100 = percentage of under pressure indicated in the filter pipe

The process is monitored to observe the safety conditions and provide evidence of the success of the in-situ stabilisation. For example, it will record carbon monoxide (CO), a key parameter for the detection of the existence of a landfill smouldering fire. This is especially important at the start of the aeration measure. Apart from this, other parameters like methane, CO2, O2 and flow will be permanently recorded to measure the results and avoid a mock stabilisation.

Phase C:

Phase B cannot be defined as the end of the aeration process, as the expected heterogeneity of the landfill causes there to be regions of low reaction parallel to regions of intensive reaction. The gas permeability plays an important role. Those regions, which are rich in organic material, flooded well by oxygen and have a high reaction and intensive CO2 emission, will be stabilised first and therefore, the "demand for oxygen" will decrease earlier. This means that the access and transport of oxygen only takes place via diffusion processes and is therefore much slower, leading to a deceleration of the decomposition of the residual organic material in the pore voids. A result is a decrease in the oxygen concentration with a concurrent increase of the carbon dioxide concentration. The speed at which the available oxygen can be catabolised depends on the location of the regions and their reaction to extraction.

When stationary conditions with the above mentioned concentrations in the exhaust gas have been reached, the system will be operated intermittently. The aim is to identify the time at which only minor methane quantities are produced. The intermittent operation usually starts with a rest phase, followed by an up-time, followed once again by a rest phase and so on. The criteria for stopping the intermittent operation or, as the case may be, the end of the whole project, is defined by the time, at which the methane concentration does not exceed a certain maximum value after a predefined rest phase (c.f. figure 8.6).

9 PRELIMINARY DESIGN FOR THE IN-SITU STABILISATION

9.1 Basic elements

The provisional arrangement of all control and gas collection elements on landfill compartments 11 and 12 for the carrying out of in-situ stabilisation will follow during the final design. It is a matter here of the elements listed below:

- Gas wells to be enhanced
- New gas wells
- Auxiliary measurement gauges
- Compressor station in modular construction design
- Lean gas flare
- Bio filter

In the following sections the individual components of the planned study for the in-situ stabilisation of the Braambergen landfill are described and presented in more detail.

9.2 DEPO$^+$ Gas well

The general mode of functioning of DEPO+ gas wells has already been described in section 8. For the in-situ stabilization of the Braambergen landfill it is a matter of the following gas well types:

- **Conversion of existing gas wells into deep-filtered gas wells (gas wells filtered in accordance with the DEPO+ process**
  With this process existing, conventional gas wells are modified by the insertion of an inliner and compacting by means of pressure all the cavities above the desired filter section (including those in the gravel filter) in such a way that the filter section used for the collection of gas is displaced deep into the lower part of the gas well.

- **Construction of new deep-filtered gas wells (DEPO+ process)**
  New gas wells constructed in accordance with the DEPO+ process are prepared in vertical drilled holes in the landfill body. Construction is carried out in such a way that the perforated suction-extraction pipes and the related jacket of gravel are placed in the lower part of the gas well. The upper section of the drilled hole is prepared with solid pipes and a jacketing of sealing material in order to prevent external air flowing in and thereby diluting the landfill gas.

- **Alternative mode of utilization of the afore-mentioned DEPO+ gas wells, namely using them as auxiliary gauges**
  Alternative mode of utilization of the DEPO+ gas wells described above, i.e. as auxiliary gauges for checking the effects of actively extracted DEPO+ gas wells in the periphery of these. Checking of the composition of the gas and of the negative pressure. In addition checking of the leachate levels. Should this be required, these gauges can also be used as well as gas wells.

9.3 Gas compressor station in modular form of construction

Illustrated schematically in the following figure (Fig. 9.1) is the construction of the modular gas extraction station (shown here by way of example for 3 gas wells to be extracted and 3 auxiliary measurement gauges) in respect of the control and measurement lines.

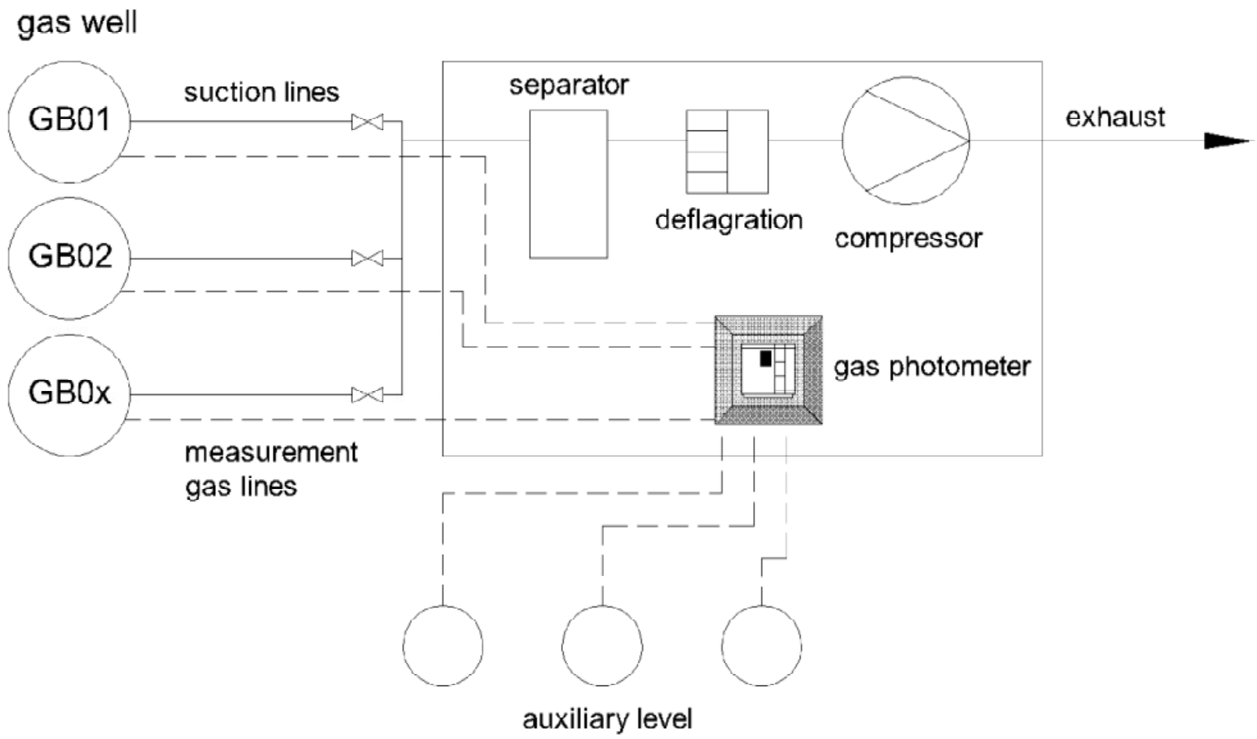

Fig. 9.1: Overview schematic – modular-construction unit for extraction

Subject to the results of the pre-investigations, the compressor is configured to have an extraction capacity of between 25 and 250 m^3/h with infinitely variable control. The extraction system is to be provided with separate intakes, each able to be regulated in respect of flow. In this way a number of lines can be extracted at the same time in a pro-rata manner. The modular form of construction makes it possible for the extraction capacity to be increased on the completion of the anaerobic in-situ stabilisation process for the aerobic in-situ stabilisation that follows.

The compositions of the gas from each well as well as from each neighbouring auxiliary measurement gauge are recorded automatically several times a day via a central measuring station and from there this data is available for data transmission. Error messages are transmitted immediately so that correction measures can be taken directly.

The landfill gas extracted is either disposed of via a lean gas flare or fed into the existing gas collection system and the existing gas utilization system. Malfunctions in the extraction system will lead to the extraction being switched off.

The condensate arising through the extraction is led off via the existing collection system.

9.4 Lean gas flare

A lean gas flare system is necessary if extraction is carried out although the landfill gas extracted is not being used energetically (e.g. when maintenance work is being carried out on the boiler or if there are malfunctions in the system engineering) as well as also all the time once the methane content of the landfill gas falls below 35 Vol.% at the end of the anaerobic phase.

Modern lean gas flares function without any problem at methane levels in the landfill gas of down to approx. 15 Vol.% and accordingly are suitable for a part of the aerobic in-situ stabilization phase as one element of the treatment of the exhaust air.

9.5 Exhaust air treatment (only with aerobic stabilisation)

When the system engineering is being operated for aerobic in-situ stabilisation it is necessary that treatment of the landfill gas collected is continued even after its methane content has fallen below 15 % Vol. For this operational phase the use of a bio-filter is envisaged. Here the landfill gas as collected is fed via distributor elements covering as much as possible of the base of the bio-filter and from these elements into a substrate (e.g. bark mulch). The gas introduced is forced to flow past the pieces of bark mulch with their large surface area. Here biological treatment of the exhaust gas is carried out by the aerobic bacteria colonised on the surface of the substrate.

Different treatments are possible depending on the amount landfill gas and the methane concentration thereof. For example the incineration of landfill gas with a methane content below 15 Vol.-% is technically viable after the addition of gas with a high methane content.

9.6 Optional aeration infiltration ditches

By reason of the large quantities of sludge and sludgelike soil that have been dumped in the landfill, it may be necessary for the phase of the aerobic in-situ stabilisation to support the flow of external air into the landfill body by constructing so-called infiltration ditches. With these - constructed as narrow, deep ditches which are subsequently filled with gravel - the possible inhibiting effect of layers of sludge or earth bringing about horizontal sealing can be combated and the flow of external air into deeper parts of the landfill optimised.

10 MEASUREMENT AND MONITORING STRATEGY

10.1 Introduction

Application of the technical measures as described above will serve to promote the stabilisation processes in the landfill body (decomposition of the organic substances) and will lead - when successfully realised - to minimisation of the emission potential. As a result this can mean that the intensity of the post-closure maintenance measures can be reduced and release from the post-closure maintenance obligation achieved at an earlier stage.

The principal challenge of this pilot project is to prove that the technology employed leads to effective stabilisation of the complete landfill. The question is not whether one is able to activate the decomposition processes but instead how thoroughly and comprehensively one is able to treat the landfill body in such a way that the greater part of the organic substances that can be decomposed can be removed from the landfill body. The residual emission potential corresponds approximately to the quantity of the unconverted waste in the landfill body. For consideration of the emission potential quantification of this quantity is a central question. Knowledge of the spatial distribution of the conversion processes to be expected within the landfill body is of special significance for the operating of the stabilisation equipment so that then the greatest possible decomposition of the biologically available organic material can be brought about in the shortest possible time.

10.2 Operational Monitoring Programme

Within the framework of the measurement strategy explained here the primary key performance indicators (KPIs) serve to monitor the base parameters of the in-situ stabilisation process. The fundamental elements of the monitoring programme are the measurement of the quantity and quality (chemical composition) of the leachate and in particular of the landfill gas removed. This data is augmented by measurement of the settlement and of the state of the leachate in the landfill body. The fundamental monitoring programme is summarised in table 10.1.

In addition to the fundamental monitoring programme, the following measurements and tests may also be used as additional indicators:

- Further special investigations such as tracer tests or geophysical tests to investigate the flowing of stormwater through the landfill body (water balances)
- Further special investigations such as gas emission tests above the surface (e.g. FID investigations) or temperature measurements in the landfill body during the in-situ stabilisation process

- Regular checking of all the technical equipment, e.g. checking of all the gas lines for deformation leading to water pockets (e.g. as a result of settlement) and tightness.

Table 10.1 Monitoring parameters and possible analysis frequencies

Item	Monitoring parameter	Analysis frequencies
Leachate	Flow/Volume	Continuous in the leachate shaft (pump pits) of compartment 11 and 12 on a daily to weekly basis
	Composition 1)	6 times in the first year, then 4/year
Landfill gas	Flow/Volume	Continuous via gas collection stations for compartments 11 and 12 at each gas well once a week to once a month
	Composition 2)	Continuous via gas utilization unit (CHP), at each gas well once a day
	Gas temperature	Continuous via gas utilization unit (CHP), at each gas well once a week to once a month
	Gas negative pressure	Continuous via pressure gauge , at each gas well once a week
Waste body	Leachate Level	4 times a year via auxiliary gauges and gas wells
	Settlement	4 times a year at existing beacons
Solid waste sampling in the waste body	Water content	Before start-up 3)
	Water storage capacity	Before start-up 3)
	Biodegradability, TOC	Before start-up 3)
Meteorological data	Temperature, atmospheric pressure, precipitation, atmospheric humidity, wind speed, etc.	Continuous on a daily basis

1) pH, Conductivity, COD, TOC, BOD, TKN, NH4, NO3, NO2, Cl, metallic compounds, phenols, phosphate, sulphides, AOX and relevant NA-parameters (leachate and infiltration medium might be identical).
2) CH4, CO2, O2, H2S.
3) Solid waste sampling before and after (and if necessary during) the controlled infiltration and aeration

The further tests and measurements can be carried out in accordance with requirements in the project phase.

11 EXPECTED RESULTS AND POTENTIAL BENEFITS

In order to assess the expected results and potential benefits the effects of stabilisation on the emission behaviour of the Braambergen landfill will be estimated and described. Therefore the following documents and results of the feasibility study are integrated:

- basic effects of moisturisation and aerobic in-situ stabilisation of landfills as compiled in the generic report [U1]
- compilation and assessment of available specific data of the Braambergen landfill [U1]

* preliminary design for anaerobic and aerobic in-situ stabilisation as described in the previous sections in this report.

A forecast of autonomic emissions without enhancing technical measures is carried out in order to compare and assess the reduction of emissions by infiltration of stormwater and by anaerobic in-situ stabilisation followed by aerobic in-situ stabilisation:

* gas emissions
* conversion of biodegradable carbon
* leachate emissions COD and NH4-N as key performance indicators (KPIs)
* settlements

The following estimations and results of calculations should mainly show the qualitative course of emissions and settlements for the Braambergen landfill whereas the quantitative results are all provisional.

All calculations and estimations of future landfill behaviour explained in the next chapters are provisional and need to be updated and revised with the results of the future pre-investigations and the future monitoring results.

11.1 Future gas emissions

11.1.1 Starting points and conditions

To forecast the range of current and future landfill gas production of the relevant waste compartments 11 and 12 of the Braambergen landfill, the following assumptions were used:

Compartments 11 and 12 of the Braambergen landfill are divided up into 6 subsections with areas of approx. 9.7 hectares and were filled with 1,216,723 tons of municipal solid waste from 1999 to 2008. Of the total quantity dumped in this compartment, some 29 % had organic content, this corresponding to approx. 351,633 tons. The other material disposed of was primarily inert or, as the case may be, mineral waste.

To estimate the range within which the gas produced by the Braambergen landfill lies, the following assumptions have been made:

* Waste deposition from 1999 to 2008
* 1,216,723 tons of municipal solid waste

- 29 % of the municipal waste has organic content; this corresponds to approx. 351,633 tons.

- The biologically convertible carbon content is set with an average total gas potential of G_0 = 130 m³/mg dry substance.

- The average half lives of the gas production during the life cycle of a municipal waste landfill are considered between 5 and 10 years.

- The time between the commencement of landfilling and the commencement of the relevant anaerobic decomposition processes is not taken into account, i.e. it is assumed that the landfill goes into the anaerobic phase right from the start.

- It is assumed in the calculations that there were/are no significant restrictions or constraints on the biological decomposition processes as a result of shortage of water, waterlogging, biological inhibitors and too high or, as the case may be, too low temperatures in the landfill body.

- The average half lives of the gas production during the anaerobic in-situ stabilisation are considered up to 4 years.

As stated in chapter 4, the Braambergen landfill is still in the methanogenic phase. This means that the anaerobic degradation processes are still progress, but will be extinguished in the near future and that the added value from and the effectiveness of enhancing the anaerobic processes in the waste body by means of an in-situ stabilisation should be questioned. Thus serious consideration should be given to starting directly with the anaerobic in-situ stabilisation measures by means of an anaerobic in-situ stabilisation followed by aeration. The final decision on this should be substantiated by and based on the results of the proposed pre-investigation.

Accordingly the forecast of gas production in the waste body is primarily based on the situation that a start is made with the anaerobic in-situ stabilisation measures directly in 2011.

In the landfill compartments 11 and 12 under consideration the Braambergen landfill does not possess at present a temporary or a final landfill seal. In the medium term too it is not to be assumed that the landfill compartments under consideration will be affected by covering/sealing measures. In view of this background situation it is assumed that the amount of stormwater able to reach the landfill body will be sufficient to maintain the biological conversion processes. Accordingly additional re-infiltration measures (e.g. circulating of the leachate or similar) are not considered necessary.

11.1.2 Forecast gas emissions on the basis of the actual state of the landfill

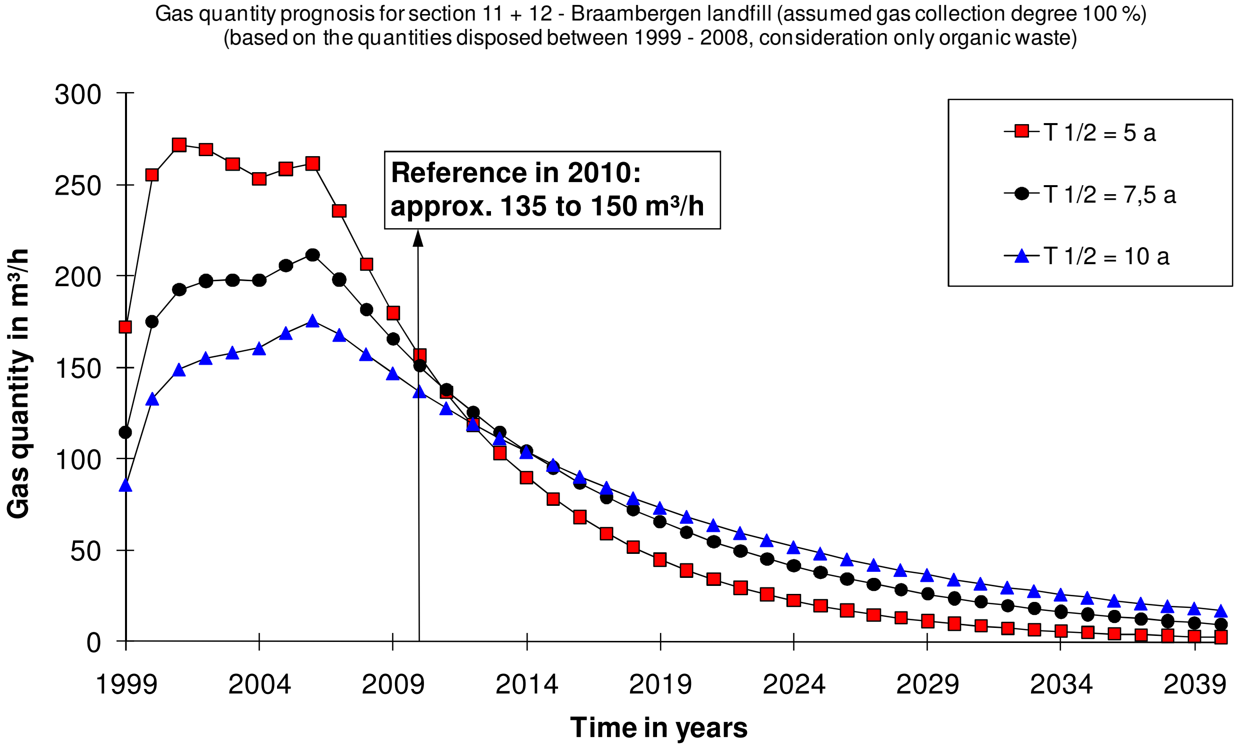

Fig. 11.1: Gas quantity prognosis for the Braambergen landfill – section 11 and 12

In this section a prognosis will be formulated on the basis of the existing degassing system and on knowledge of the defects of the wells as established, of the waterlogged material and of the thereby related reduced gas production and gas collection potential. Fundamentally the results of the gas prognosis calculations contain uncertainties since the parameters entered in the models are not able to be quantified to an adequate degree. Against this background it is recommended that the actual gas production potential is proved in-situ with the aid of a reliable gas extraction test.

On the basis of the quantities of waste disposed as documented in the previous chapter, a gas prognosis was prepared in accordance with the well-known mathematical models (EHRIG, TABASARAN/ RETTENBERGER). The calculations were based only on the quantities of domestic refuse and commercial and industrial refuse similar to domestic refuse as disposed and the quantity of gas to be expected was calculated on the basis of half lives of 5, 7.5 and 10 years.

Considered in relation to the prognosis values, the estimated degree of extraction (c.f. historical values) lay between 40 and 50 % in the years from 2003 to 2010 (Fig. 12.2).

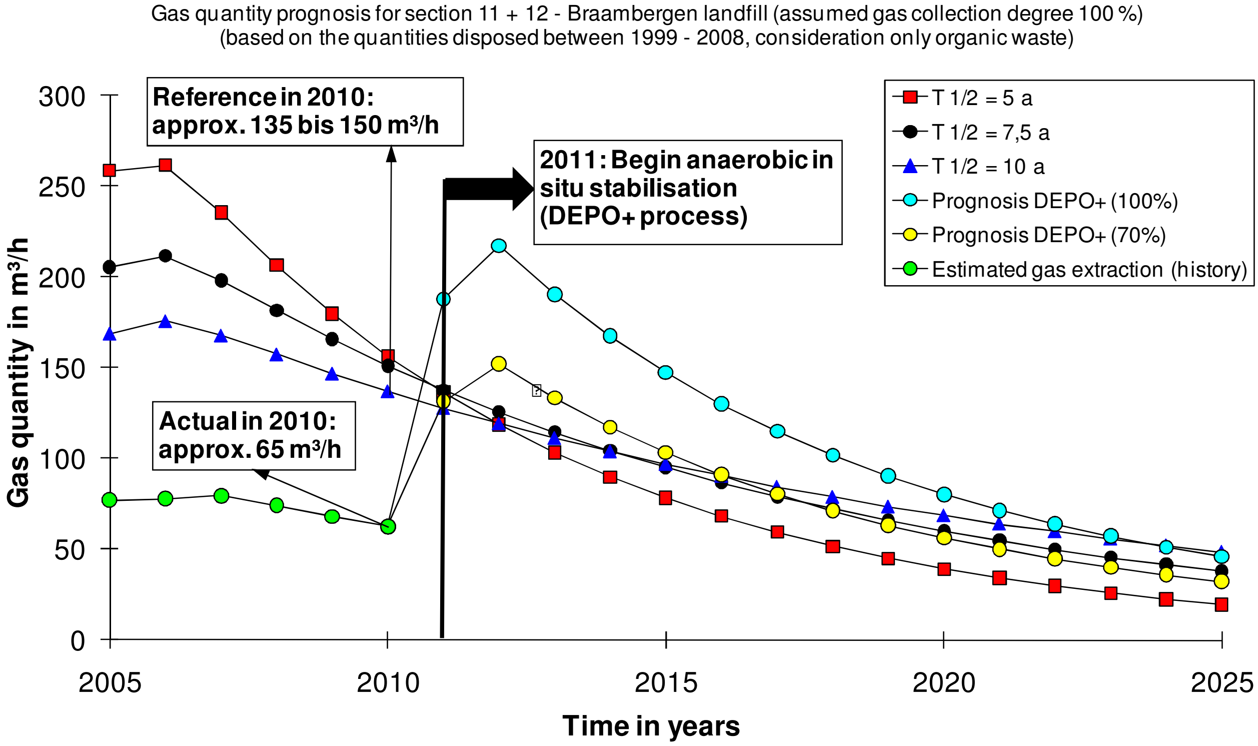

Fig. 11.2: Landfill gas prognosis taking into account the influence of deep-filtered gas wells (DEPO⁺ process®) – cells 11 and 12

Building on the experience gained at a very wide range of different landfills and old landfills and subject to the results of further investigations within the framework of a gas extraction test on selected gas wells that have been converted, it is to be stated that an increase of the methane and thereby of the energy yield relative to the yields given by the classical gas quantity prognosis is to be reckoned on (Fig. 11.2). It is expected here that - relative to the current landfill gas yield of some 65 m³/h (actual state, 2010) - an increase of up to approx. 150 m³/h (prognosis value for the year 2011 for a „DEPO⁺ 70% degree of collection “) might result.

However this prognosis is based on the assumption that the current inhibiting conditions - as present - are combated in a long-term manner by successful optimisation measures on the landfill. As a result it is expected that the following effects should come about. Initially extraction by suction at depth should lead to a higher degree of collection which then in turn will combat the inhibiting conditions in the landfill body and promote activation of the biological decomposition processes.

The calculations for the modified landfill gas prognosis are based on a half-life of 6 years for the region near the surface of the landfill (less active phase or, as the case may be, less activated region), for the deeper region of the landfill a half-life of 10 years (region with little or no active collection) and for the deeper lying region of the landfill activated by the DEPO+ process® (region activated by extraction via deep-filtered gas wells) a half-life of 4 years.

If a surface sealing system is fitted, a fall in the production of landfill gas and a decrease in the amount of settlement is to be expected. The reasons for this are that a sealing measure in the form of a convection barrier will prevent water entering the body of the landfill and in the medium and long-term will have an effect on the water balance of the landfill. The inhibiting of biological decomposition processes in this way can have an unfavourable effect on the duration of the post-closure maintenance periods. Post-closure maintenance periods are characterised by leaching-out processes of the landfill body that go on for a long time - according to the prognoses between approx. 130 and 200 years until the limit values listed in Appendix 51 of the German Wastewater Order for the "problem parameter" ammonium is reached (see Krümpelbeck [U3]).

Fundamentally it is recommended that biochemical decomposition processes - and here in particular those for the biologically available organic material - are brought to the point at which they abate before the surface sealing system is realised (decaying of the main incidences of settlement, avoidance of the mummifying of the landfill body and avoidance of the situation of the reactive processes being displaced into the future and taking place if the barrier system should fail in the future).

Experience has shown that the amount of leachate arising decreases significantly within 5 years following the placing of a surface sealing system and as a consequence thereof the formation of landfill gas also decreases. The collectable quantity of landfill gas increases initially through the fitting of the surface sealing system but then falls again rapidly after a relatively short time. The extent to which the placing of the surface sealing system soon after dumping has been stopped (and thereby too early) might have a negative effect on the production of landfill gas at the Braambergen landfill depends on a number of factors (amongst others: moisture content of the gas-producing layer beneath the mineral layer, water retention capacity of the landfill body).

11.2 Settlement to be expected

As a result of biological conversion processes acting on the biologically available organic material, a corresponding discharge of carbon in the form of landfill gas (primarily methane and carbon dioxide) takes place. Going hand in hand with this discharge is a corresponding loss in the mass of the dumped material, whereby this loss arises at the points where the decomposition processes take place. Hollow spaces arise in the dumped material as a result of the mass loss. This leads to settlement whereby one has to differentiate between two types of settlement. On the one hand the supporting framework that has established itself in the dumped material breaks down over the course of time, this leading to sudden settling. On the other hand deformation of the landfill body takes place, this being conditioned by the superimposed burden (settlement). The two can be added together.

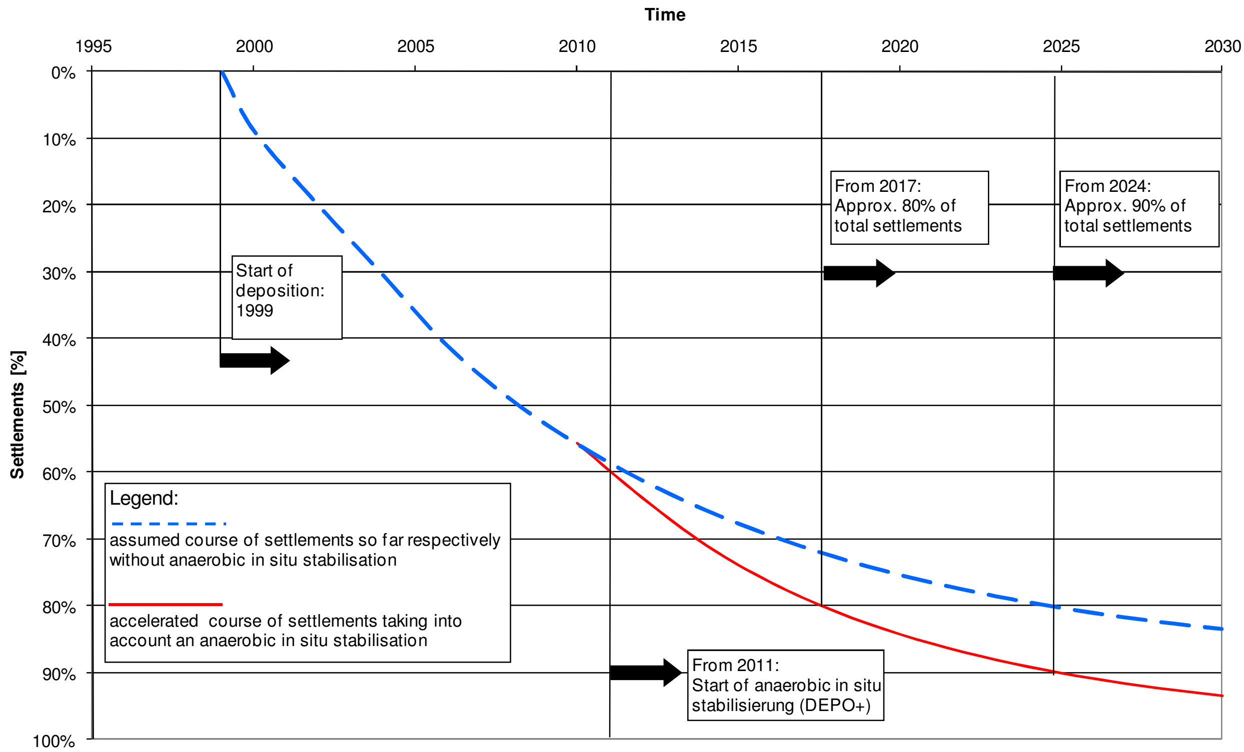

Fig. 11.3: Course of settlement to be expected with or, as the case may be, without optimisation measures on the gas collection system during the anaerobic in-situ stabilisation

A landfill body represents in general a comparatively heterogeneous formation in which the various biochemical processes take place not in a homogeneous manner but distributed to a greater or lesser extent.

The course of settlement coming about as a result of biological conversion processes has been estimated in accordance with the landfill gas prognosis given in section 11.1 for the landfill compartments 11 and 12. According to this and assuming non-inhibiting milieu conditions it is probable that at the present time some 55 to 60 % of the biologically available organic material should have been decomposed so that one could reckon with residual settlement of an order of magnitude of 40 to 45 % of the total settlements. Since however it is likely that inhibiting conditions are present in parts of compartments 11 and 12 as a result of the dumping situation and the presence of waterlogged material (here sludges) and since this will probably have led in the past to much less organic material being converted than would otherwise have been expected, it is to be surmised that a considerably higher amount of settlement can be expected in the future. The amount of this cannot be reliably estimated on the basis of the data currently available. In view of this situation it is advised that the gas extraction test as recommended is carried out on selected test wells in order to obtain sufficient information to permit a reliable gas production and settlement prognosis to be formulated.

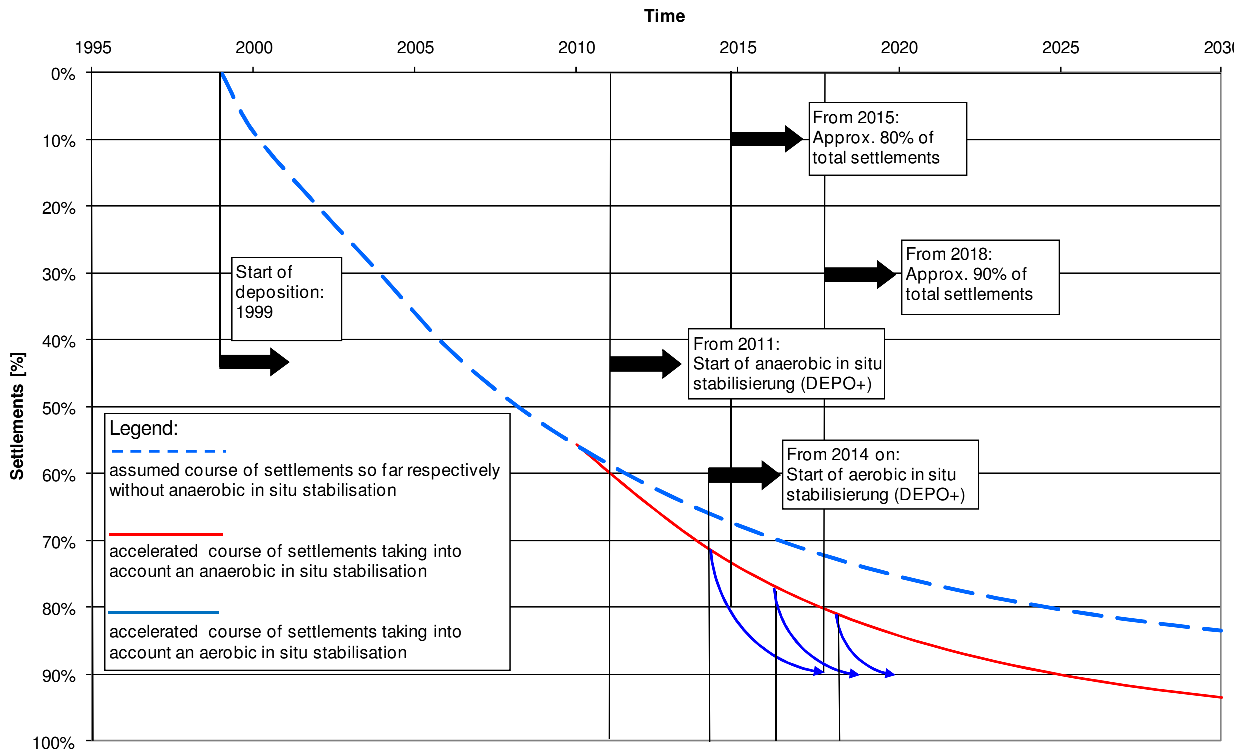

Fig. 11.4: Course of settlement to be expected with or, as the case may be, without optimisation measures on the gas collection system during the aerobic in-situ stabilisation

The Braambergen landfill shows that the increase in utilisable gas during the anaerobic in-situ stabilisation is directly related to the accelerated reduction of biologically available organics. This in turn accelerates the settlement of the landfill. A prognosis states that - under the implementation of the DEPO$^+$ process® during the anaerobic in-situ stabilisation phase - 80% of the total settlement takes place 7 to 8 years earlier and 90% of the total settlement more than 15 years earlier than can be expected when using classic methods.

From a definite point in time it is appropriate for ecological and economic reasons to changeover from anaerobic to aerobic in-situ stabilisation. The point in time at which approx. 90 % of the biologically available organic material has been removed from the landfill body depends on the time at which a start is made on aerobic in-situ stabilisation (c.f. Fig. 11.4). Regardless thereof, there will be an additional degree of settlement with aerobic in-situ stabilisation compared to that with anaerobic in-situ stabilisation since a definite proportion of the organic material permits itself to be converted only aerobically.

For the plateau of the Braambergen landfill with a height of approx. up to 15 m, total settlements of about 1,35 m can still occur (this means approx. 45 % of 3 m of total settlements). It is possible that the settlements in some parts of the landfill will be even higher in the aerobic in-situ stabilisation phase. At the end of the stabilisation processes a very low potential for future settlements will be left, so constructions at the landfill surface within the framework of redevelopment and re-use of the landfill can be applied without the risk that it will be damaged by future processes in the landfill and corresponding settlements.

11.3 Forecast of the conversion of biodegradable carbon

The aim of measures for the acceleration of biological decomposition processes is to minimise the emissions within a reasonable period of time, if possible within one generation. The gas path should be focussed upon, because more than 90% of the biologically degradable organics can be discharged from the landfill along this way. The key factor for the quality of the material reduction is the dischargeable amount of carbon per unit of time. This carbon load derives from the volume flow and the concentration of carbonaceous gas. The higher the volume flow and/or the concentration of carbonaceous gas, the faster the targeted discharge will be achieved. Therefore, the organic decomposition is focussed on in the anaerobic phase followed by the aeration. Measurements show that landfill gas usually contains +/- 90 % carbonaceous gas (mainly methane and carbon dioxide), whereas exhaust gas from the aeration has a content of approx. 30 % (CO_2) of carbonaceous gas. The material balance indicates that in terms of figures more than three times as much organic material can be discharged via the gas path under anaerobic conditions as under aerobic conditions, with the same volume flow. However, due to the considerably higher growth rate of the aerobic micro-organisms, which are responsible for decomposition, aerobic biological reactions are much quicker than anaerobic reactions, so that the results of the processes are similar.

Corresponding to the biological degradation processes the biodegradable carbon will mainly be converted and released as landfill gas and during aeration as exhaust gas. In figure 11.5 the biodegradable carbon content in the landfill body and its release over the gas path is estimated according to the assumptions explained in chapter 11.2.

The decomposition of the biodegradable carbon (or biologically available organic material) takes - as a function of the type of in-situ stabilisation employed - different paths (c.f. Fig. 11.5). The decomposition paths described in Fig. 11.5 for anaerobic in-situ stabilisation correspond with the assumptions for the gas forecasts made in section 11.1. If the changeover to aeration is carried out, an accelerated decomposition of the biologically available organic material is to be expected. The removal path for biologically available organic material is illustrated in Fig. 11.5 for different in-situ stabilisation scenarios (commencement of aeration in 2014, 2016, and 2018). Examination of Fig. 11.5 shows that - in terms of stabilising the landfill at the earliest possible point in time - it is appropriate to stabilise the landfill body aerobically from a definite point in time.

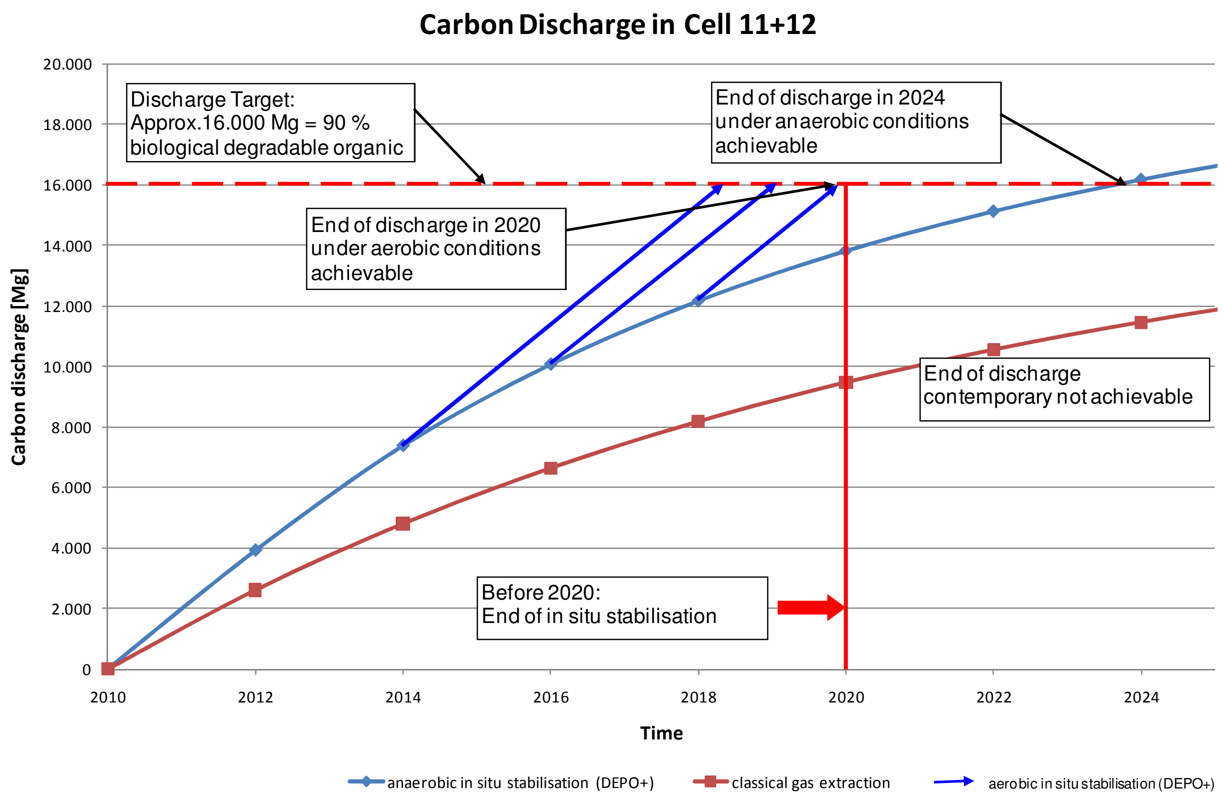

Fig. 11.5: Yield of biologically available organic material with or, as the case may be, without optimisation measures on the gas collection system

11.4 Preliminary conclusions

Based upon the calculations and estimations as described in the previous sections, the following preliminary conclusions can be formulated:

- Provided that the Braambergen landfill is not provided with a surface sealing system during the in-situ stabilisation phase, it is to be assumed at the present time that there will be enough water available for the biological conversion processes in the landfill body

- With the anaerobic and aerobic in-situ stabilisation the carbon potential might be reduced to less than 10% of the biodegradable carbon content by the year 2020.

These preliminary results once again show the potential for a sustainable landfill by site-specific closure and post-closure maintenance measures.

11.5 Future leachate emissions

Starting from the few available analyses of the leachate, it has to be established first that the quality of the leachate is characterised by high levels of organic material as well as by metals and heavy metals, as well as also at lower levels by chloro-organic compounds.

If one compares the KPI concentrations with those for different landfill types, then it can be seen that the Braambergen landfill values cannot be assigned to one particular landfill type. In a status report [U4] the Environmental Office for the Land of North Rhine-Westphalia has stated the typical constituents of leachate from different landfill types, amongst others for domestic refuse landfills, for landfills with low amounts of domestic refuse, for landfills for sewage sludge and for landfills for inorganic wastes (primarily industrial wastes). In Appendix 2 the leachate values for the Braambergen landfill are compared with the results for the afore-mentioned landfill types. The comparison permits it to be established that the Braambergen landfill corresponds primarily with the "Inorganic wastes" landfill type. Further parameters correspond in respect of the relevant concentrations with the "Landfills with low amounts of domestic refuse" landfill type. Only the parameters for COD and nitrogen are to be assigned rather to the "Domestic refuse" landfill type.

The post-closure maintenance periods for landfills with relatively high levels of organic material have been estimated as follows in accordance with KRÜMPELBECK [U3]:

Table 11.1

Parameter	Post-closure maintenance (years)
CSB (<200 mg/l)	65-320
AOX (<0,5 mg/l)	90
N total (<70 mg/l)	100-500
Cl (<100 mg/l)	25-60
Heavy metals (<0,1-2 mg/l)	<10

The limits stated hold good for the introduction of leachate into sewage systems (Appendix 51 of the Rahmenabwasserverwaltungsverordnung (Framework Wastewater Administration Order) and are regarded in Germany as the relevant scale for the releasing of a landfill from post-closure maintenance obligations.

These post-closure maintenance periods hold good for a landfill at which no further measures are taken. If in-situ stabilisation measures are taken, a different situation results.

If organic compounds of biological origin are decomposed under anaerobic or aerobic conditions, elements integrated in the organic matrix are released.

These elements, e.g. Cl^-, $S2^-$ or nitrogen as $NH4^+$, $NO3^+$ or $NO2^+$, are then transported away via the leachate, where there is no activation constant or decreasing concentrations of the elements come about at the end of the methane phase.

It has been shown that in many cases the decomposition processes abate and falsely indicate that the methane phase has ended although in fact a significant part of the organic material still remains.

If such a landfill is activated in accordance with the DEPO+ process®, the decomposition processes are activated again.

It has been possible to show at certain landfills studied as examples that the effect of the activation is also reflected in the composition of the leachate as early as shortly after the start of deep extraction.

Chloride has shown itself to be the parameter that changes most rapidly. At one landfill the level of chloride in the leachate more than doubled within a period of 8 weeks. The salt content is possibly not desired but it indicates the decomposition of cells and the release of the cooking salt present in them.

The level of sulphur depends very much on the material being decomposed. However in many cases the H2S level increased since organic material of biological origin was being decomposed. Depending on the degree of aeration taking place in the activation phase, sulphur is oxidised and is either converted into elementary sulphur. Alternatively an increase in the concentration of sulphate in the leachate may be detected if the oxidation proceeds further.

In spite of strongly accelerated decomposition as can be demonstrated, the ammonium concentrations generally do not increase. Organically bound nitrogen is decomposed under anaerobic conditions to either ammonium or ammonia depending on the pH and is transported away via the leachate. At increased rates of decomposition more nitrogen is also released as ammonium. With the DEPO+ process® an aerobic zone forms in the peripheral areas of the deposited material as a result of the - in part - clear over-extraction. Here ammonium is converted direct to nitrate which however is then converted directly to nitrogen with the dissolved organic material (DOC). However this process defies detection by regular analyses.

Slight acidification takes place again through the activation of the conversion processes with the pH of the leachate falling by 0.5 to 1 pH steps depending on the degree of conversion.

The reduction of the pH can lead to a change in the solubility behaviour of heavy metals. However it has been shown with stabilisation processes carried out to date that heavy metals are not significantly mobilised. In spite of activation the concentrations do not as a rule change by reason of the fact that a part of the heavy metals are fixed in humic matter. However a different mode of behaviour can set itself up if particular chemical conditions prevail.

Mineral oils are decomposed under both anaerobic and aerobic conditions. In general the conditions for the decomposition of mineral oil hydrocarbons are significantly improved by activation. The concentrations in the leachate should decrease.

The decomposition of PAHs is not significantly accelerated under the conditions that establish themselves.

12 PRELIMINARY COST-ESTIMATES

Table 12.1 Preliminary average cost-estimate demonstration project Braambergen landfill (price level 2011)

Cost items	Investment costs [€]	Yearly costs [€]
Pre-investigations (time and depth-zoned measurements, inspection of gas extraction system, gas extraction test, engineering service), 2011	60.000	
Final design, final cost-estimates, tendering, 2011 and 2012	75.000	
In situ stabilisation (installation gas wells and monitoring wells, measurement equipment, compressor section, lean gas flare and biofilter maintenance and monitoring), 2012/2013	520.000	
In situ stabilisation maintenance and monitoring), 2013 – 2021 (9 years)		150.000
Communication & PR		20.000
Post pilot waste sampling (in 2021)	50.000	
Totals	**705.000**	**1.530.000**
10 % for uncertainties	70.500	153.000
Totals including uncertainties	**775.500**	**1.683.000**

For the Braambergen landfill a preliminary cost-estimate has been established consisting of the investment costs for the installation of the enhancing technical measures, namely in-situ stabilisation, as well as the yearly costs of maintenance and exploitation of the measures. The cost-estimates are based on the technical specifications of the preliminary design of the technical measures as described in the chapters 9 to 10. In addition to the costs of the technical measures themselves, the cost-estimate also includes the costs of preparation, pre-investigations, final design and tendering procedure, measurements and monitoring, supervision and communication. All costs are related to the price-level of 2011. The cost of materials and manpower are based on unit prices conformable to the Dutch market. In order to be realistic 10 % for uncertainties have been taken into account. An overview of the average costs has been compiled in table 12.1.

13 LITERATURE

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[U2] Feasibility study on sustainable emission reduction at the Braambergen landfill in the Netherlands, Specific report: Current status of the Braambergen landfill, CDM 79575/2, 2011.06.07

[U3] Krümpelbeck, Untersuchungen zum langfristigen Verhalten von Siedlungsabfalldeponien, Bergische Universität Gesamthochschule Wuppertal, Dissertation, Wuppertal, 1999

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CDM Consult GmbH
Bochum, 2011-06-20

ppa.	i. A.
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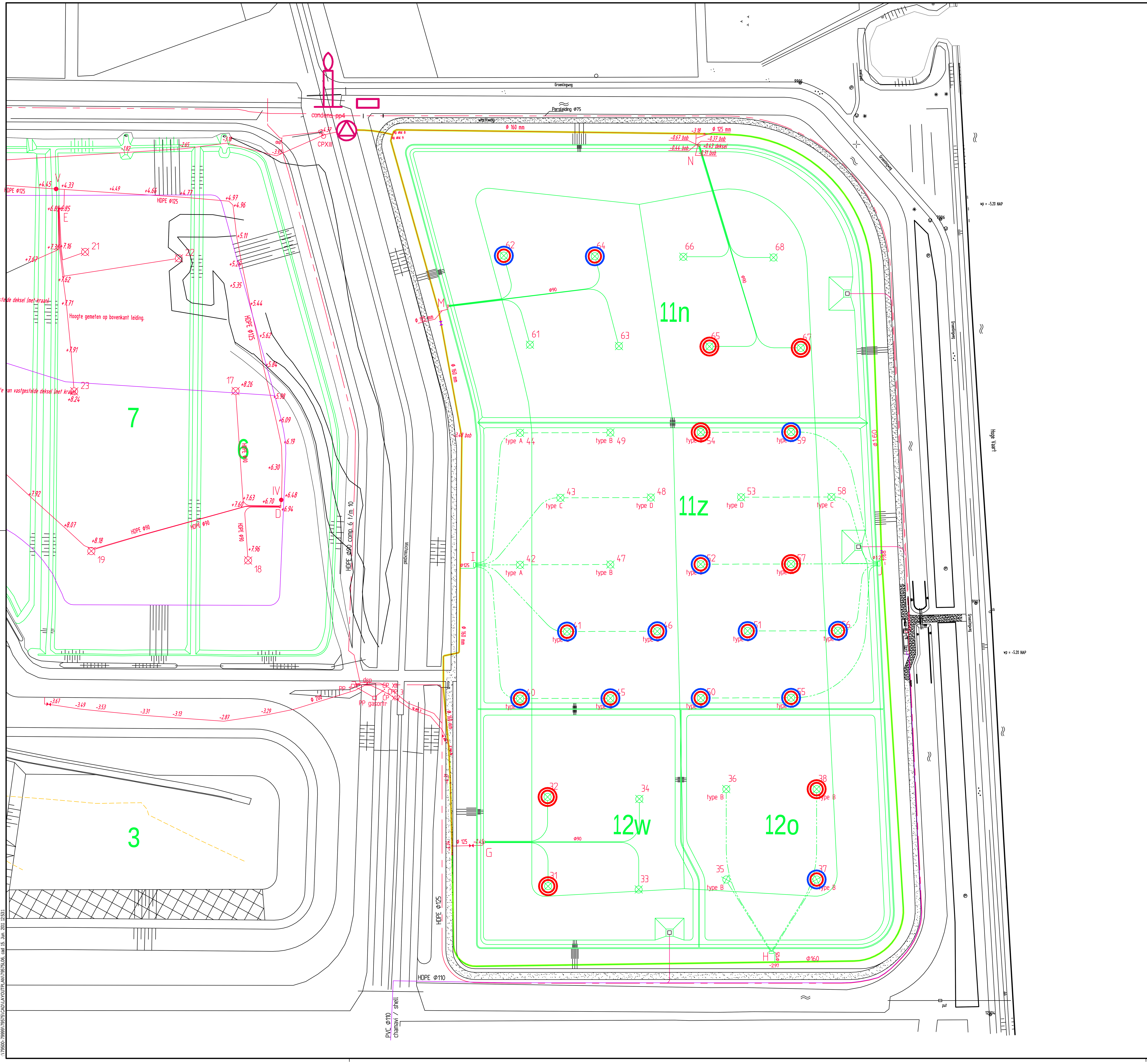
ppa.	i. V.
Dipl.-Ing. Ulrich Klos	Dipl.-Chem. Jürgen Kanitz



legend:

58	not yet measured gas well
56	gas well to be upgraded (DEPO+) alternative used as auxiliary measurement gauge
57	new gas well (DEPO+) alternative used as auxiliary measurement gauge
	gas closed circular pipeline
	compressor station
	lean gas flare
	bio filter

1:1.000

0 10 20 30 40 50 60 70 80 90 100 m

owner / client

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project

Braambergen Landfill

subject

Layout plan with investigation points entered

	drawn by	checked by	phase	project-no.	scale	attachment
date	03/2011	03/2011		79575	1:1.000	1
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Braambergen landfill			C0 LFD Inert	HG	11N	11Z	12	RAbwVwV	mun. waste landfill NRW			multi-disp. landfill NRW			sew. sludge landf. NRW			anorg. waste landf. NRW		
Annex 2								Annex 51	No landfills		55	No landfills		10	No landfills		5	No landfills		8
Number of samples				1	1	1	1		each: from - to		2200 - 5800	each: from - to		187 - 423	each: from - to		121 - 222	each: from - to		136 - 394
									Median	75%-Quantil	Maximum	Median	75%-Quantil	Maximum	Median	75%-Quantil	Maximum	Median	75%-Quantil	Maximum
pH-Wert		[-]		7,0-7,6	6,8-7,3	6,8-7,6	6,2-7,2		7,3-8,0			7,3 - 7,8			6,8 - 7,5			7,2 - 9,1		
el. LF		[mS/m]							1.091	3.845	42.500	582	2.313	4.844	256	1.022	4.980	825	2.740	17.600
Arsen	As	[mg/l]	0,1	0,1	0,2	1	0,2		0,02	0,111	18	0,01	0,147	2,58	0,005	0,028	0,109	0,017	1,739	16
Aluminium	Al	[mg/l]	-	-	0,03	1	-													
Barium	Ba	[mg/l]	-	-	0,1	0,2	0,1													
Calcium	Ca	[mg/l]	-	-	500	600	1.000		127	271	5.490	230	399	3.300	165	364	786	417	774	2.990
Cadmium	Cd	[mg/l]	0,02	0,001	0,001	0,015	0,001	0,1	0,0015	0,03	1	0,001	0,024	0,35	0,0001	0,002	0,011	0,001	0,048	0,2
Cobalt	Co	[mg/l]	-	-	0,01	0,03	-													
Chrome	Cr	[mg/l]	0,1	0,06	0,1	0,06	0,2	0,5	0,08	0,322	4,12	0,011	0,038	0,39	0,01	0,025	0,15	0,03	0,243	2,1
Copper	Cu	[mg/l]	0,8	0,9	0,03	0,3	0,02	0,5	0,04	0,224	4,1	0,013	0,368	4,61	0,012	0,495	7,6	0,02	0,133	1,6
	DIC	[mg/l]	-	-	950	800	900													
Fluor	F	[mg/l]	3	-	0,6	1,1	0,2													
Iron	Fe	[mg/l]	-	-	8	600	15													
Mercury	Hg	[mg/l]	0,002	0,01	0,008	0,008	0,003		0,0005	0,0019	0,04	0,0002	0,0031	0,05	0,0001	0,0002	0,001	0,0002	0,0053	0,05
Potassium	K	[mg/l]	-	-	400	300	300		518	840	4900	380	1627	2470	23	57	300	150	599	2400
Magnesium	Mg	[mg/l]	-	-	200	200	200		92	155	1.121	79	124	11.190	30	86	250	83	6.508	33.200
Manganese	Mn	[mg/l]	-	-	0,9	4	1													
Molybdenum	Mo	[mg/l]	0,3	-	0,007	0,002	0,012													
Sodium	Na	[mg/l]	-	-	700	700	700		912	1.509	10.100	552	1.687	5.440	67	171	650	625	3.692	35.000
Nickel	Ni	[mg/l]	0,2	0,08	0,3	0,3	0,09	1,0	0,116	0,283	3,56	0,036	0,234	1,83	0,016	0,586	4,7	0,06	0,999	4,98
Phosphor	P	[mg/l]	-	500	8	3	6													
Lead	Pb	[mg/l]	0,3	0,01	0,05	0,18	0,02	0,5	0,013	0,246	5,24	0,01	0,089	0,75	0,01	0,032	0,2	0,01	0,084	0,66
Sulfur	S	[mg/l]	-	-	-	-	-													
Antimony	Sb	[mg/l]	0,1	0,06	-	0,06	0,06													
Selenium	Se	[mg/l]	0,05	-	0,006	0,006	0,006													
Silicium	Si	[mg/l]	-	-	-	-	-													
Sulfate	SO4	[mg/l]	2.000	700	800	950	850		77	431	11.000	280	1.260	22.172	210	569	2.200	2.000	24.928	145.200
Zinc	Zn	[mg/l]	2	0,7	0,7	3	0,8	2,0	0,11	0,996	23,3	0,051	0,583	4,17	0,02	0,162	1,3	0,109	8,212	49,5
COD		[mg/l]	-	-	5.000	5.000	900	200	1.300	3.809	49.250	239	384	1.099	96	831	1.850	77	206	883
DOC		[mg/l]	250	-	250	80	120													
Chloride	Cl	[mg/l]							1.153	1.998	10.668	820	3.757	5.300	190	479	1.900	639	2.162	8.216
TOC		[mg/l]							512	1.305	16.320	84	172	423	24	152	1.000	25	110	1.300
Nges, bonded		[mg/l]						70	730	1.355	19.000	122	293	716	11	107	395	46	542	1.780
Ammonium	NH4	[mg/l]							615	1.149	8.160	140	331	750	10	153	820	6	81	820
AOX		[mg/l]						0,5	0,68	1,461	22,9	0,19	0,557	3,3	0,05	0	0,53	0,082	0	0,76

No. of Parameters similar to landfill types in NRW

1	**munic. waste landf. NRW**
5	**multi-disp. landfill NRW**
-	**sewage sludge landf. NRW**
8	**anorganic waste landf. NRW**

Krümpelbeck	years
aftercare period for CSB (<200 mg/l)	65-320
aftercare period for AOX (<0,5 mg/l)	90
aftercare period for Nges (<70 mg/l)	100-500
aftercare period for Cl (<100 mg/l)	25-60
aftercare period for heavy metals (<0,1-2 mg/l)	<10

= barticular parameter for duration of aftercare period

LANUV NRW, quality of sewage water of landfills in NRW
LANUV- technical report No. 24, 2010

Krümpelbeck: Analysis of long-term bevaviour of municipal waste landfills, BU GH Wuppertal, 1999