Feasibility study pilot project sustainable emission reduction at the existing landfills Kragge and Wieringermeer in the Netherlands

Preliminary design and cost-estimate of the technical measures infiltration and aeration to enhance stabilization at the landfill Kragge

Dutch Sustainable Landfill Foundation

30 March 2009

Final Report

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IFAS

Consultants for Waste Management

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1 INTRODUCTION AND MAIN GOAL

The Dutch Sustainable Landfill Foundation (DSLF) took the initiative to evaluate the possibilities 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 eternal aftercare not a real and sustainable solution for the mitigation of unacceptable emissions due to landfills. In 1999 they initiated a project ‘Sustainable Landfilling’ (lit. 1, generic report) to develop ways to reduce 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.
Main conclusion of this research (lit. 1, generic report) was that, when biochemical and physical processes are allowed to complete, emission potential is reduced significantly. The project ‘Sustainable Landfilling’ however aimed at landfills, yet 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?*
- *Does this also lead to a significant reduction of the potential emissions?*
- *Does this significant emission reduction 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 possibility 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 (annex 1, generic report). Finally two landfills could be selected:

- the landfill “Wieringermeer” in the province of North-Holland (NL) and owned by the landfill operator Afvalzorg;
- the landfill “Kragge” in the province of North-Brabant (NL) and owned by the landfill operator Essent Environment South.

The first step of the initiative is the execution of a feasibility study with respect to the suitability of the two selected landfills. The present site specific report of the landfill Kragge is a part of this feasibility study.

For more information about the technical backgrounds, European and Dutch regulatory framework, overall objectives of the feasibility study and project organization, the reader is referred to the final generic report titled “Processes in the waste body and overview enhancing technical measures” (Royal Haskoning/IFAS, 9T6764, 20 March 2009).

2 BASIC APPROACH OF FEASIBILITY STUDY AND DELIVERABLES

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

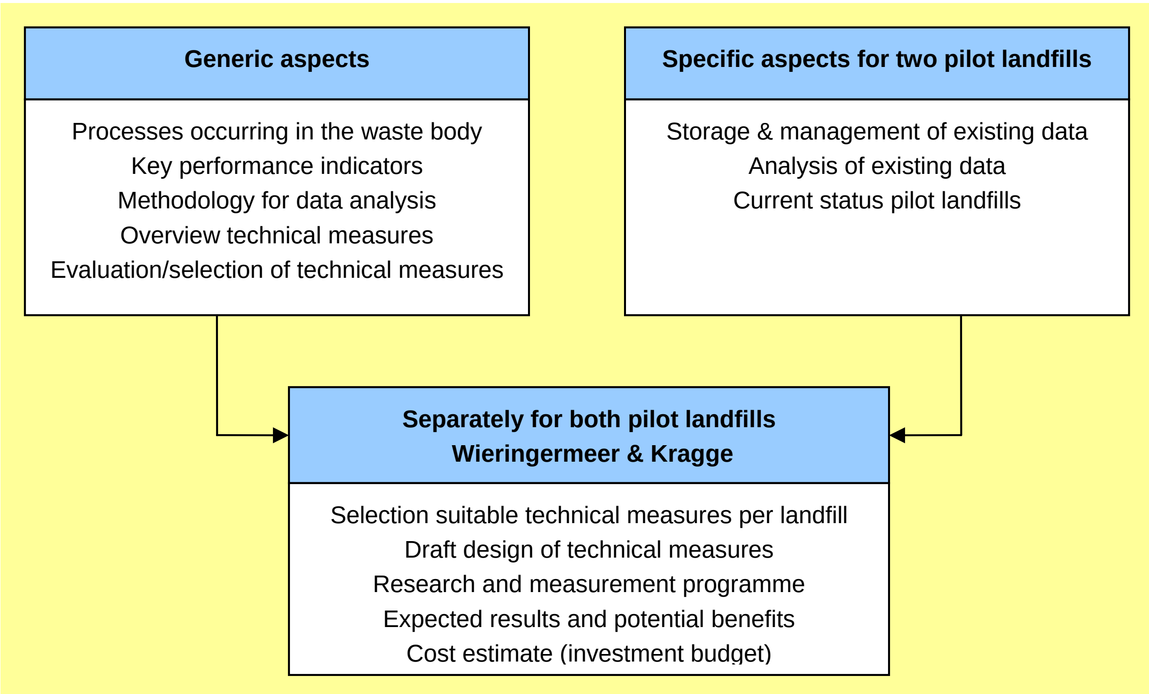

Figure 2.1: Basic approach feasibility study

These three main parts correspond to the required final deliverables, which means the following three section reports:

1. <u>Generic report</u>, comprising a general description of natural processes in the waste body and a general overview of technical measures to be able to enhance these processes.
2. <u>Specific reports</u>, separately for both demonstration landfills, comprising a description of the current status of the landfill with respect to emission potential and stabilization process (reference situation).

3. Specific reports, separately for both demonstration landfills, comprising a preliminary design of enhancing technical measures, and forecast of the achievable level of emission reduction due to autonomic developments, measurement programme and cost estimate.

This document represents the specific report with respect to the design and cost-estimate of the enhancing measures for the landfill Kragge.

3 ACTIVITIES

Based on the above mentioned generic report (lit.1) the preliminary design and cost-estimate for the landfill Kragge is carried out as follows:

- Compilation of the relevant site conditions and evaluation of the emission and landfill behavior as basis for the preliminary design;
- Preliminary design of the selected enhancing technical measures, consisting of infiltration and aeration. One of the main results of the generic report was that the infiltration via infiltration fields with well shafts and the aerobic in situ stabilization by the low pressure aeration have been selected to be the most appropriate methods to improve the landfill behavior of the two landfills to obtain a sustainable respectively long-term storage quality.
- Expected results and potential benefits with respect to the effects of enhanced stabilization on the emission behavior of the landfill.
- Research and measurement program for the in situ stabilization methods, mainly consisting of:
  - solid waste sampling and investigations
  - leach ate monitoring
  - landfill gas monitoring
  - settlements
  - technical equipment
- Preliminary cost-estimate of all costs related to the preparation, installation, maintenance and exploitation of the enhancing technical measures as mentioned above (infiltration and aeration).

4 LANDFILL CHARACTERISTICS

The current status of the landfill Kragge has been described the specific section report "Current status of the landfill Kragge" (lit. 2). From this section report only the relevant information with respect to the preliminary design and cost-estimate is described in the sections below.

4.1 Site conditions

The exploitation of the landfill Kragge landfill (22 ha) started in 1990 and up till now waste is land filled. All 5 waste cells (see figure 4.1) have a bottom liner and a leachate drainage system. However the leach ate drainage system has been divided into 4 compartments O1, O2, O3 and O4 as showed in figure 4.2.

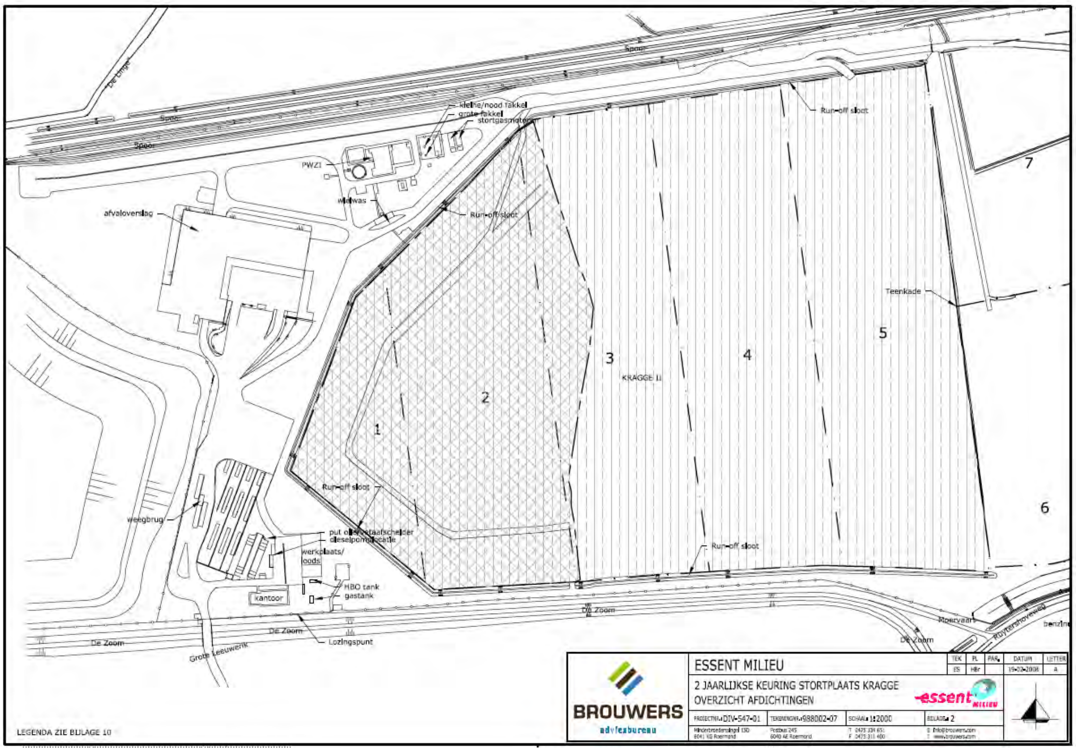

Figure 4.1 Waste cells and situation of top liner (gray shaded part) at the landfill Kragge

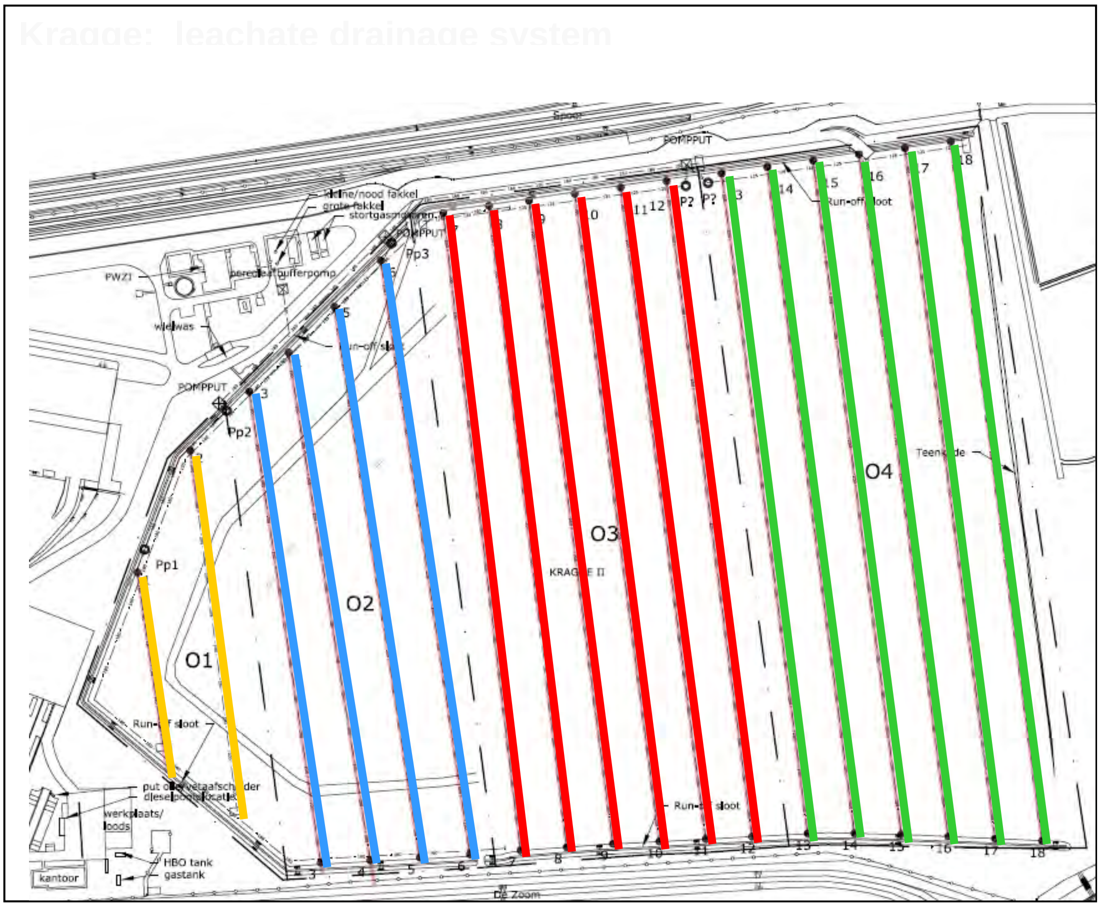

Figure 4.2 Leachate compartments O1, O2, O3 and O4 at the landfill Kragge (Essent Milieu 2008)

The last year waste was processed in the eastern part (cell 5) of Kragge landfill in 2008. An impermeable top-liner has been installed in 2002 on cells 1 and 2 as well as on a very small part of cell 3 (see gray shaded part in figure 4.1).

According to the discussion with the landfill operator Essent Milieu and the expert participants, it was decided to prepare a preliminary design for the three uncovered waste cells 3 to 5 (leachate compartments O3 and O4). Basic data of the three cells 3 to 5 are as follows:

- Area of the waste cells 3 to 5: ca. 11 ha;
- Volume of waste cells 3 to 5: total of 944.327 ton (cell 3: 299.192 ton, cell 4; 329.582 ton, cell 5: 315.553 ton);
- Height of the waste body: 10 - 20 m;
- Soil cover as temporary cover;
- Existing gas wells (figure 4.3):
  - Cell 3: 8 gas wells and gas pipes DN 110;
  - Cell 4: 8 gas wells and gas pipes DN 110;
  - Cell 5: 7 existing and already planned gas wells and gas pipes DN 110;
  - Individual gas wells are clustered into 7 gas collection pits GC1 to GC7.
  - The 7 gas collection pits GC1 to GC7 are extracting gas from the 5 waste cells and the 4 leachate compartments as showed in table 4.1
  - Main pipe for gas collection DN 200;
- Bottom liner and leachate drainage system in cells 3 to 5 (figure 4.2).

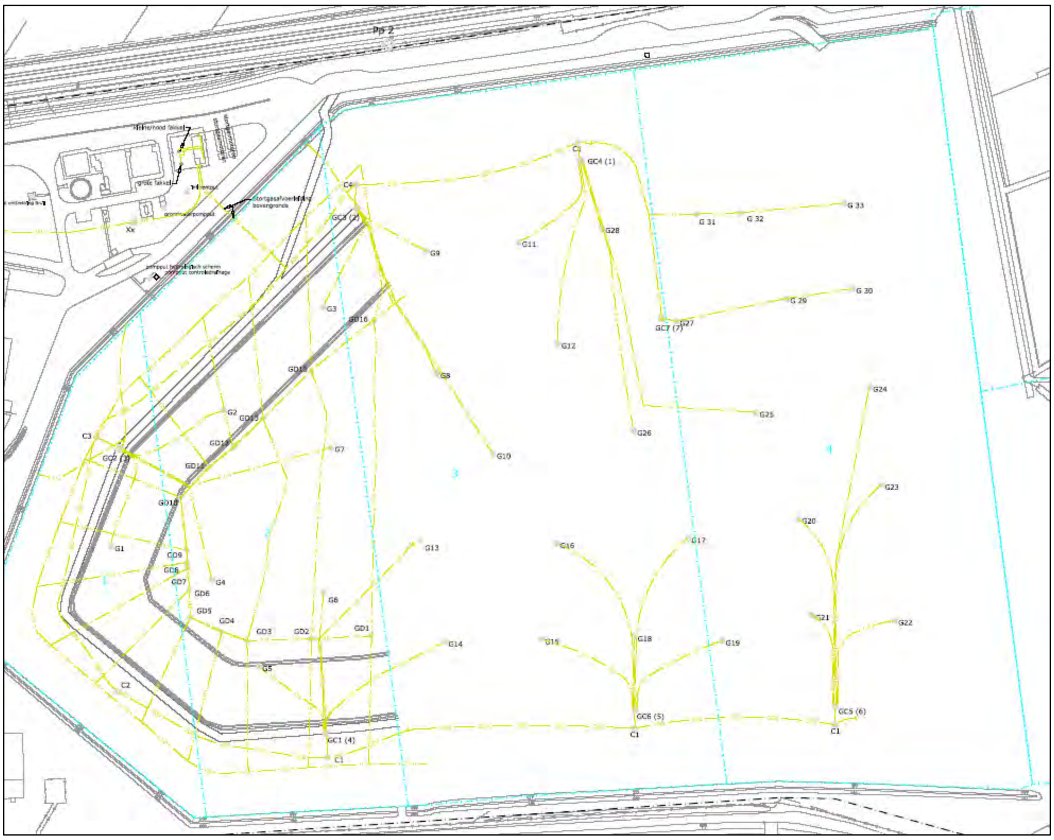

Figure 4.3 existing gas collection system landfill Kragge (Essent Milieu, 2008)

Table 4.1 Distribution of gas collection pits over the waste cells and leachate compartments

Gas collection pit	Gas is extracted from:	
	Waste cells	Leachate compartments
GC1	2 and 3	O2 and O3
GC2	1 and 2	O1 and O2
GC3	2 and 3	O2 and O3
GC4	3 and 4	O3 and O4
GC5	5	O4
GC6	3 and 4	O3 and O4
GC7	5	O4

4.2 Current status of the landfill

As a part of the feasibility study a specific report has been written with respect to the current status of the landfill Kragge (lit. 2), based on an assessment of available data. The main results are compiled in table 4.2.

Table 4.2 Characteristic figures with respect to the current landfill and emission behavior.

Age of waste	Cell 3: 1997 - 2007	
	Cell 4: 2000 - 2007	
	Cell 5: 2000 - 2008	
Waste quantities cells 3 , 4 and 5	Waste: 944.322 ton	Carbon: 93.138 ton
Final covering by top liner	According to the present legislation and permits, the final covering by a top-liner should be installed not later than 2015.	
Leachate: macro parameters (mailnly based on one and only measurement in cell 3 and 4)	pH = 7.5 → metanogenic phase	
	SO4 very high → early stage of methanogenic phase	
	COD and BOD high → early stage of methanogenic phase	
	BOD/COD < 0.1 → in methanogenic phase	
	DOC high → early stage/in height of methanogenic phase	
	COD – BOD high → early stage/in height of methanogenic phase	
Leachate: micro parameters	Still many different micro's at high concentrations, which might indicate that the anaerobic time-period is still too short for neutralizing these micro's due to NA-processes (biodegradation, chemical precipitation, sorption): → early stage/in height of methanogenic phase.	
Gas collection	In 2008 the actual gas collection is 350 to 400 m^3/hr, which is rather high and indicates that a lot of gas can still be produced in the waste body → methanogenic phase can still last for a number of years and a lot of anaerobic organoic matter is left for autonomic gas production / profitable gas utilization.	
Gas quality	Ratio CH_4/CO_2 = 1.5 → in the height of the methanogenic phase.	
Settlement	20 - 40 cm in the last 3 years → anaerobic degradation of organic still in progress → early stage / in height of methanogenic phase.	
Overall conclusion	**Landfill is in the early stage / in the height of the methanogenic phase, a lot of anaerobic degradable organic matter is left.**	

5 DESIGN-STRATEGY DEMONSTRATION PROJECT LANDFILL KRAGGE

5.1 Stepwise approach

Based upon the results of the current status of the landfill Kragge as summarized in chapter 4, a design strategy for the demonstration project at the landfill Kragge has been developed. Because the landfill Kragge appears to be in the starting stage of the methanogenic phase, as yet enhancing the anaerobic processes in the waste body by recirculation of leachate will be an effective measure with a high added value. Once the anaerobic degradation processes are extinguished, the aerobic in situ stabilization measures can be started. The extinction of the anaerobic degradation processes and as a consequence the ineffectiveness of the recirculation of leachate can be assessed by for instance the combination of the following main criteria:

- The rate of gas production (m^3/hr) is lower than the economically profitable gas production rate (for instance < 50m^3/hr).
- The remaining amount of carbon to be converted anaerobically is lower than the limit value of 10 kg per ton of initial waste.

For the design strategy a stepwise approach is proposed as showed in figure 5.1.

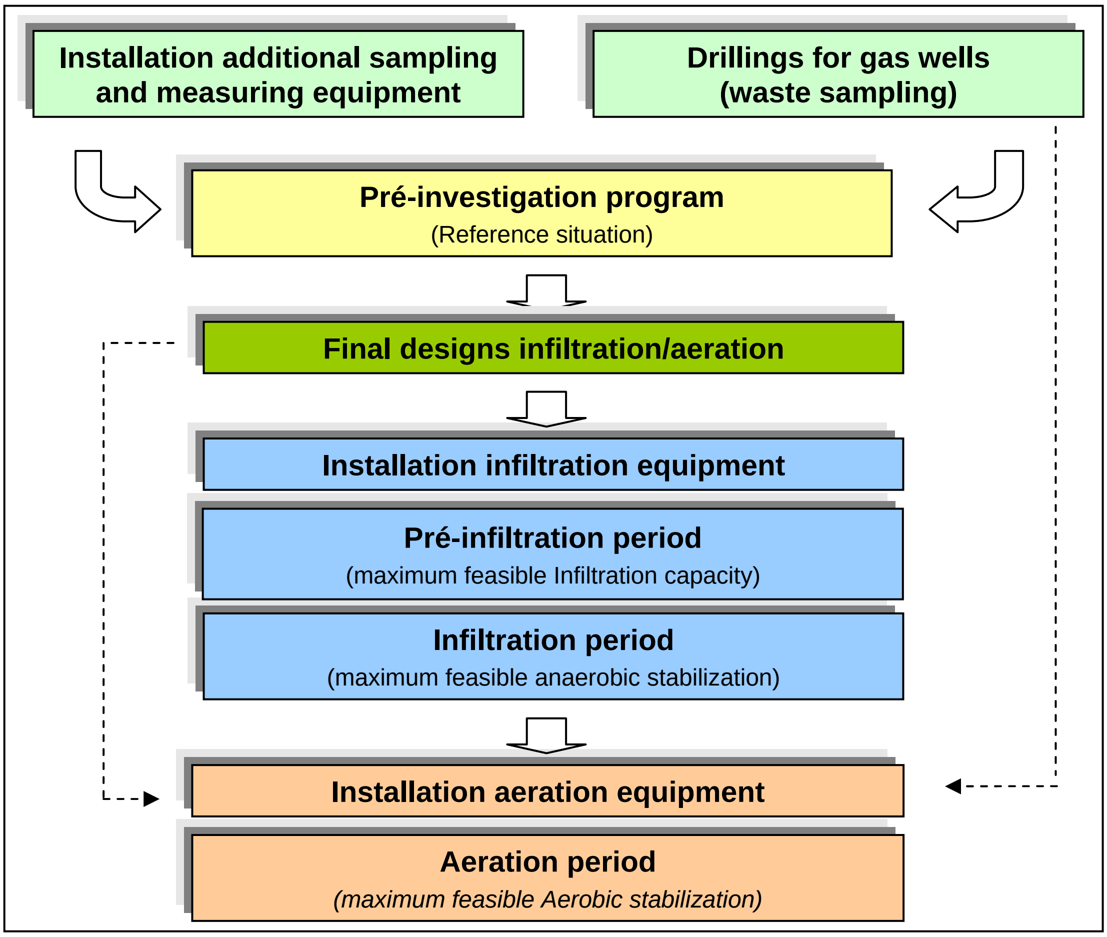

Figure 5.1 Stepwise approach of design strategy demonstration project landfill Kragge

The activities to be carried out in each step are highly specified in the detailed break-down of costs, which can be found in annex 2 (see also chapter 14, titled “cost-estimates”).

The proposed steps have primarily been put into a logic sequence from a technical point of view. The main steps, of which the sequence is fixed, are of course:

1. Installation and operation of infiltration fields with well shafts to maintain or even to improve anaerobic degradation processes in the landfill body of cell 3 to 5 by leachate recirculation in order to optimize the water content, the water distribution and the water transport in the waste body.
2. Installation and operation of gas wells for the aerobic in situ stabilization measures by the low pressure aeration.

From a point of view of capital expenditure, it can be decided to postpone some investments to a later stage (see dotted lines in figure 5.1). This especially concerns the final design of aeration and the installation of the gas wells for the aerobic in situ stabilization, for which two schedules are possible:

a) Installation in parallel to the infiltration fields, as showed in figure 5.1. In this case the additional gas wells can be used for an improved gas collection rate (reduced uncontrolled emissions into the atmosphere, improved climate protection, higher energy production), before the aeration process is started (recommended option).
b) Installation at the moment when the gas production is too low to go on with the gas collection and gas utilization. Then installation of the gas blower station for aeration, gas extraction and gas purification. This is indicated by the dotted line in figure 5.1.

Note:
All design parameters mentioned in chapter 4 and the chapters 8 to 10 with respect to the design of infiltration and aeration are preliminary and need to be updated and revised with the results of the future pre-investigations and the monitoring results.

5.2 Time period

The duration and the operational demand for the infiltration operation and the first period of improved gas production under anaerobic conditions can not be predicted at the moment, as the results from further pre-investigations are necessary to determine the infiltration demand and the gas potential of the deposited waste. It can be a period of 4-10 years, depending on the intensity of anaerobic degradation processes that are accelerated by the infiltration.

The aerobic in situ stabilization will probably be carried out over a period of at least 3.5 - 4 years. Then it has to be decided if a prolongation of the stabilization process will be necessary and possible to reach the admissible emission levels as described and visualized in figure 6.15 at page 23 of the generic report (lit. 1).

A further option is to go on with infiltration when the aeration process is started. This might have positive effects on the aerobic conversion of organic compounds in the leachate and the nitrification processes in the landfill body.

For the moment a time-period of 10 years for the execution of the demonstration project is considered to be long enough to reach obvious results. However, it is expected to demonstrate obvious results already in an earlier stage, by which the effectiveness of the enhancing technical measures for anaerobic degradation processes (infiltration/recirculation) can be assessed and a go/no go decision for continuation of the demonstration project can be made.

For the sake of the cost-estimates (see chapter 14 and annex 2), the time period is divided into 5 years of infiltration and 5 (Five) years of aeration. Figure 5.2 shows a preliminary timetable of the demonstration project at the landfill Kragge.

Figure 5.2 Timetable demonstration project landfill Kragge

Activities (steps)	2009				2010	2011	2012	2013	2014				→2019
Additional sampling equipment													
Drilling gas wells[1] and waste sampling											?		
Pré-investigation program													
Final design infiltration & aeration[1]											?		
Installation infiltration equipment													
Pré-infiltration period													
Infiltration period													
Installation aeration measures													
Aeration period													

6 ADDITIONAL EQUIPMENT FOR SAMPLING AND MEASUREMENTS

For the final design as well as for the sake of the pré-investigation program and during the execution of the demonstration project itself, adequate sampling- and measurement equipment need to be present. This means the right equipment at the right place, in tune to the required and desired intensity of measurements with respect to the selected area of the three uncovered waste cells 3 to 5 (leachate compartments O3 and O4). The following site specific additional equipment is recommended (no limited list):

- Additional leachate collection pit and adjustment of the existing leachate drains to the leachate collection pits in order to create three leachate collection pits which are in tune to the three waste cells 3 to 5.
- Flow/volume meters in the leachate collection pits;
- Additional settlement beacons;
- Additional gas wells for differentiated measurements of gas production;
- Piping between the additional and existing gas wells
- Divers in the existing gas wells and new gas wells to be installed;
- Solid waste sampling.

The costs of this additional equipment have been included in the cost-estimate of the project budget (chapter 14).

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[1] From a point of view of capital expenditure, it can be decided to postpone the drilling of gas wells and the final design of the aeration measure to a later stage as indicated by the question mark (?).

7 PRE-INVESTIGATION PROGRAM

In the report on the "Current state of the landfill Kragge" (lit. 2) a table has been presented of available data versus required data, based on relevant key performance indicators (KPI's). This resulted in a number of data on KPI's, which are not available. For the final design of the enhancing measures (infiltration and aeration) as well as for the development of site-specific operation procedures, these lacking data should be collected during the pré-investigation program.

The following pré-investigations are recommended:

- Analyses on solid waste samples;
- Aeration tests at the existing gas wells;
- Chemical analyses on leachate composition;

The costs of the pré-investigations have been included in the cost-estimate of the project budget (chapter 14). The provisional numbers of samples, analyses and tests are specified in the detailed break-down of costs, which can be found in annex 2 (see also chapter 14, titled "cost-estimates").

7.1 Analyses on solid waste samples

It is important to take a representative number of waste samples from the waste cells 3 to 5. These samples can be taken e.g. during drilling of the new gas wells at the depths of for example 5 m and 15 m below surface (e.g. 2 samples from 12 drillings = 24 waste samples).

Analyses of the waste samples are necessary to value the key performance indicators in the current status of the waste body. For the significance and relevance the KPI's (i.e. analyses), the reader is referred to the generic report (lit. 1) in which the significance of the primary and secondary KPI's have been described and explained. For that reason the analyses and tests to be executed are only listed below with a brief explanation if necessary:

<u>Water content, water storage capacity and the biodegradability to estimate:</u>
- The water contents indicate dryer or more humid landfill sections and allow conclusions regarding the actual biological degradation and the landfill gas production. Thus a first assessment of the moistening and recirculation effects to be expected is possible.
- the quantity of leachate/water that can be infiltrated;
- the remaining gas formation potential to estimate the improved gas collection rate;
- the quantity of air that might be added for a complete aerobic degradation;
- the possible impact of infiltration and aeration on the biological degradation processes;
- the biologically available waste portions of the whole landfill body;
- the potential settlements as a result of aeration (or infiltration);

Water holding capacity (field capacity)
The determination of the water holding capacity in connection with the comparison of the actual water content allows an assessment of the water volume to be added in the respective landfill section to achieve an optimal water content and to develop the infiltration program (leachate addition without a significant increase of leachate generation at the bottom of the landfill).

Biological activity by respiration tests and gas formation tests
- The tests allow the determination of the biological activity under aerobic and anaerobic milieu conditions as an improved measurement to characterize the bioavailable organic material that can still be converted.
- Option: Determination of the modifiable waste portion by **elution tests**
- The tests allow the determination of the emission potential under different milieu conditions, e.g. of the heavy metals, VFA, toxic trace components.

Carbon content
Via the determination of the carbon content and in combination with the tests for the biological activity the total quantity of carbon and the portion of the bioavailable organic material that can still be converted into landfill gas can be assessed.

7.2 Aeration tests over one or several of the gas wells

Pre-investigations regarding the aerobic in situ stabilization in the landfill body are possible at the end of the first anaerobic phase. 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 of the cell 3 to 5?
- What effects does the addition of air have on the gas balance of the landfill body of the cells 3 to 5?

The pre-investigations which are carried out in order to settle these questions, lead to the optimized site-related dimensioning and design of the technical equipment, internal requirements and to a more reliable cost estimation.
Aeration tests can be carried out over a few weeks using a mobile aeration system. Additional small pipes for gas control in the surrounding of the aerated gas wells should be installed and the nearby gas wells should be used for monitoring purposes.

7.3 Chemical analyses on leachate composition

The lacking data according to the report on the “Current state of the landfill Kragge” (lit. 2) and which have to be analyzed, are listed below:
- Redox-potential (Eh);
- Biochemical oxygen demand (BOD);
- Alkalinity;
- Volatile fatty acids (VFA);
- Total organic carbon (TOC);
- Dissolved organic carbon (DOC);
- Nitrate (NO_3) and Nitrite (NO_2).

8 GENERAL PRELIMINARY DESIGN INFILTRATION FIELDS AND AERATION

Figure 8.1 shows the general preliminary design for both the infiltration fields and the additional equipment for the aerobic in situ aeration by low-pressure aeration.

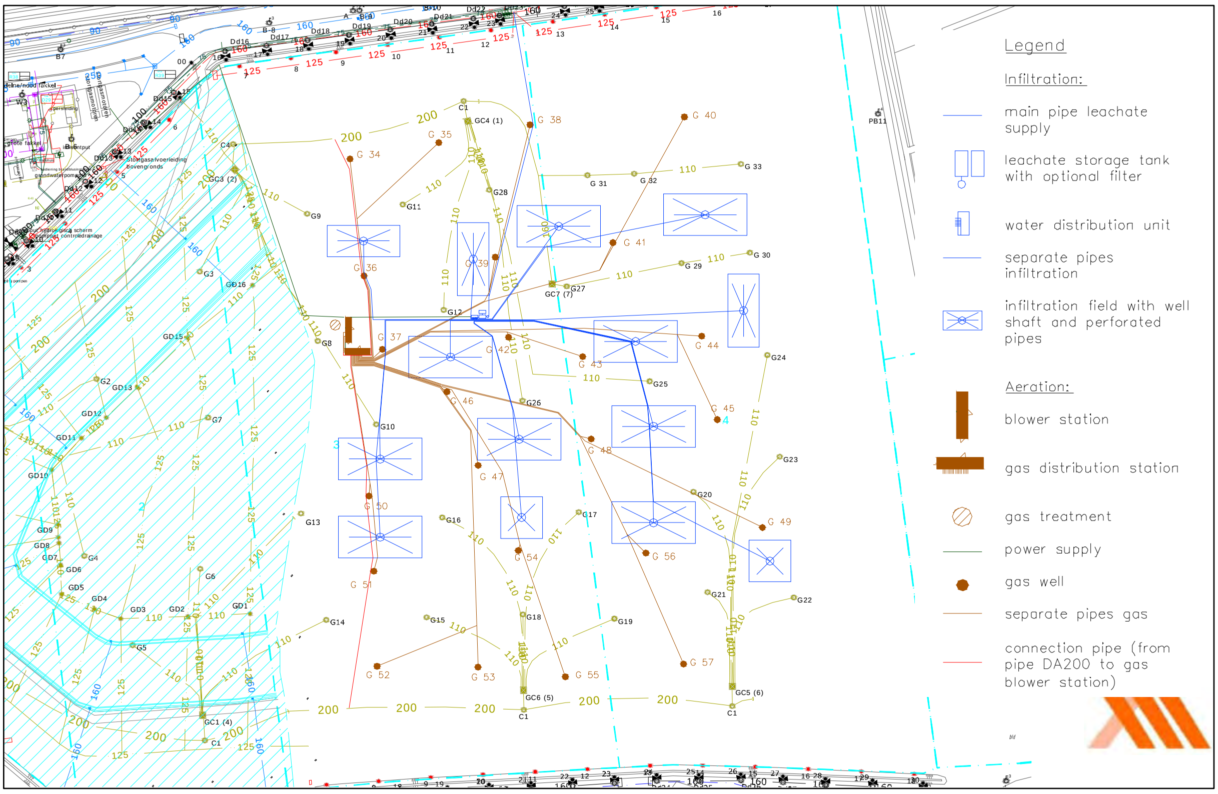


Figure 8.1: General preliminary design for infiltration fields and equipment for the low-pressure aeration at the landfill Kragge, waste cells 3 to 5 (leachate compartments O3 and O4).

8.1 General aspects infiltration fields

The general aspects of the preliminary design with respect to the infiltration fields are listed below:

- About 14 infiltration fields can be positioned in the upper plateau area of waste cells 3 to 5. They will be positioned in a way that the risk of flooding the gas wells is reduced and that the distance to the slopes is high enough in order to avoid stability problems at the slopes because of disadvantageous water movement due to the in homogeneity of the waste body. On the other hand the infiltration fields and their appropriate operation shall reach the highest possible landfill volume in waste cells 3 to 5.

- The infiltration fields can be supplied by a central water distribution station placed at the plateau of waste cell 4. It consists of a storage tank and a water distribution bar that should be operated automatically as the standard operation method and by hand at the beginning or for special purposes. It is possible to start the infiltration operation by hand. As probably necessary and advantageous for the standard operation the technical devices for automation of the infiltration should be implemented.
- Raw leachate or treated leachate can be used. For the supply with raw leachate a pump with a pipe can be installed in the pump pit 3/4 in the north of waste cell 4 (between the leachate compartments O3 and O4). The leachate will be pumped to the storage tank, before it is re-infiltrated via the infiltration fields.
- The infiltration fields are equipped with a well shaft for the addition of high quantities of leachate to ensure a good leachate distribution in the infiltration field. This distribution will be improved by drainage pipes within the drainage layer of the infiltration field. For infiltration tests at the beginning of the operation, it is possible to transport the leachate to the infiltration fields respectively well shafts by a tank truck.
- The infiltration fields can be covered with a geotextile and a soil layer.

8.2 General aspects aerobic in situ stabilization:

The general aspects of the preliminary design with respect to the aeration equipment are listed below:

- As already mentioned in chapter 5.1 the installation of the equipment for aerobic in situ stabilization can be carried out in parallel to the construction of the infiltration fields (improved gas collection rate) or at the moment when the anaerobic gas production becomes too low for economical gas utilization and aeration shall be applied then.
- About 24 additional gas wells can be installed to improve the aeration and gas collection process (optimized oxygen supply for accelerated aerobic degradation processes, reduced uncontrolled emissions via the surface into the atmosphere).
- The gas wells can be connected individually to one or two gas collection stations. They can be operated for gas collection only in the first period in parallel to the existing gas collection system. For aeration in the next period, the new gas collection station(s) is(are) for aeration and gas collection as the standard operation procedure, maybe followed by over-suction or aeration only. To reduce investment costs it is possible to connect two new gas wells via one pipe with the gas collection station (reduced costs for pipes and only one gas collection station instead of two). This option is shown in figure 6.1.
- For aeration a mobile gas blower station can be installed at the plateau of waste cell 3 next to the gas collection station. The blower station will be connected to the new gas distribution station that can be used mainly for aeration. Moreover the existing pipes DN 200 for gas collection from the existing gas collection stations are connected to the new blower station. They are mainly used for gas extraction. The blower station, the existing gas collection pipes and the new gas collection station are equipped with branches and valves in such a way that:
    - Aeration and suction of exhausts can be carried out in parallel (standard process of low pressure aeration, recommended option);
    - All gas wells can be used for an over-suction process (option in a later stage of the aeration process);

- All gas wells can be used for an aeration process only (maybe an option in a later stage of the aeration process, where the soil cover shall act as a biofilter for methane oxidation and odor elimination).

- For the standard process of controlled aeration and extraction of the exhausts a purification unit for the treatment of exhaust will be necessary. In the first period a high temperature auto thermal oxidation process is an appropriate option that can be followed by biofilters.

In the following chapters the preliminary design of infiltration and aeration equipment and the site specific adaptation will be described in more detail.

9 DETAILS PRELIMINARY DESIGN INFILTRATION FIELDS

9.1 Basic principles

The principle of infiltration with infiltration fields is shown in Figure 9.1. The whole infiltration system consists of the following equipment and devices:

- Main leachate supply pipe from a pump pit or comparable existing leachate storage tank of the leachate treatment plant, installation of a pump in the pump pit
- Optional, if necessary: filter before the storage tank (to reduce particles in the leachate, that can cause clogging, incrustations)
- Leachate storage tank
- Water distribution unit: pump with a system control and a distribution bar
- Leachate pipes to the infiltration fields
- 16 infiltration fields with well shafts

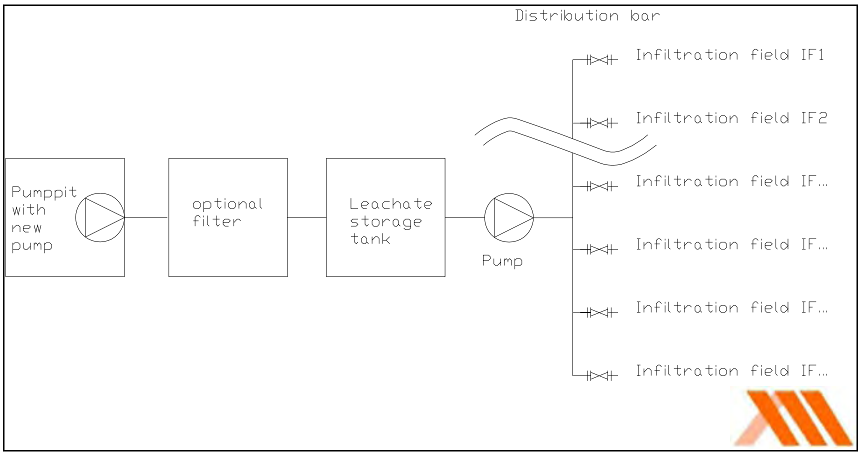


Figure 9.1 Principle of infiltration with infiltration fields

9.2 Infiltration / recirculation quantities

For the preliminary design and the basis for calculations of infiltration/recirculation quantities, different approaches and assumptions are possible:

- Climatic leachate generation to raise the water content;
- Leachate recirculation to improve substrate mobilization.

9.2.1 Climatic leachate generation to raise the water content

One option is the addition of water to raise the water content without a significant increase of leachate generation in the leachate collection system at the bottom of the landfill. This approach leads to rather low water addition quantities that can be estimated according to the following assumptions:

The infiltration volume should correspond to 50% of the annual precipitation (≈ maximum climatic leachate generation) to maintain and optimize biological degradation processes. With an annual precipitation of 800 mm, this is 400 mm or 4,000 m^3 per hectare per year. For the waste cells 3 to 5 this equals to ca. 40,000 m^3 per year or to an average daily pumping rate of 110 m^3/d.

9.2.2 Leachate recirculation to improve substrate mobilization

This option is to increase the water movement significantly within the landfill body to enhance the mobilization and biological degradation of the organic fraction and the mobilization of some inorganic components. In this case the leachate generation at the bottom of the landfill is significantly increased and this additional leachate quantity can be recirculated by the infiltration system.

With this strategy the internal recirculation rate can be much higher than the maximum climatic leachate generation as describer above, maybe with the factor of 3 to 4. With an annual precipitation of 800 mm and the factor 4 of the maximum climatic leachate generation, this corresponds to 1,600 mm/year or 16,000 m^3 per hectare per year. For the cells 3 to 5 this equals to ca. 160,000 m^3 per year or to an average daily pumping rate refers of maximum 440 m^3/d. The infiltration rates should be adapted continuously to the results of the monitoring program for infiltration (see chapter 12).

9.2.3 Recapitulation

Figure 9.2 shows the different options to affect the water content and water transport in the waste body:

- the climatic leachate generation (mainly depending on precipitation, evaporation, quality/permeability of the (temporary) surface cover), 0 to 50% of precipitation;
- the artificial water addition to raise the water content (lower quantities) by infiltration of raw or treated leachate, surface or process water etc.;
- the leachate recirculation of raw leachate (higher quantities), maybe combined with the addition of leachate from other landfill compartments, surface water or process water etc.

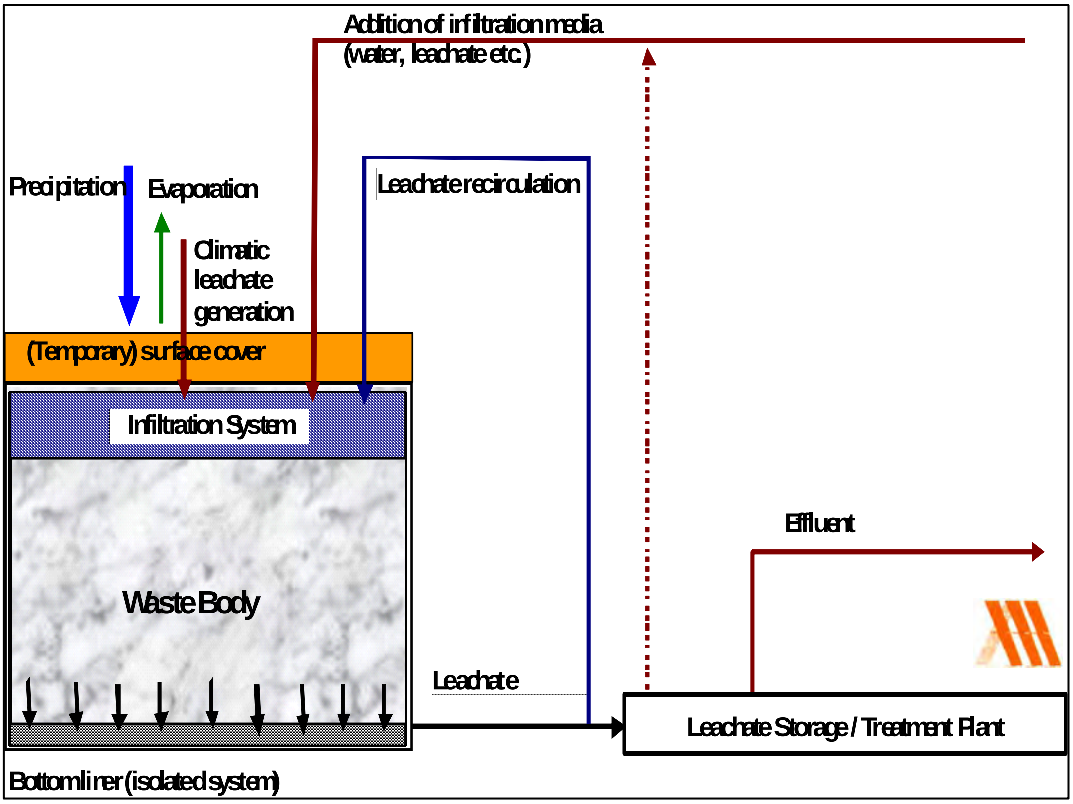


Figure 9.2 Main options to affect the water content and water transport [2] of a landfill body by technical measures

With increasing recirculation quantities the following possible effects have to be especially monitored:

- flooding of gas wells;
- water level in the landfill body and mechanical stability of the slopes;
- the higher hydraulic charge/load on the drainage layer and the leachate collection system may cause increasing incrustation processes.

Leachate supply, pumps and pipes
The infiltration medium, probably raw leachate will be pumped from an existing pump pit like pump pit 3 or 4 in the north of the leachate compartments O3 and O4 to the water distribution unit. The pump will be installed directly in the pump pit and connected to a power supply and an operation unit. The PEHD pipe (ca. DN 100, PN 10[3]) can be emplaced in a sand bed in the soil cover. The operation of the pump depends on the leachate quantity respectively the leachate level in the pump pit, the infiltration procedure of the fields and the capacity of the storage tank.

As mentioned in chapter 9.2 the infiltration volume for the waste cells 3 to 5 equals to ca. 40,000 up to 160,000 m^3 per year. The average daily pumping rate refers to 110 - 440 m^3/d.

[2] Water balance of a landfill body influenced by:
- Climatic leachate generation (mainly precipitation – evaporation)
- Infiltration by addition of leachate, water etc.
- Leachate recirculation (increased quantities).

[3] DN: nner diameter [mm]; PN: pressure resistance [bar]

For variations within the year the pump can have a capacity of ca. 500 m^3/d or 50 m^3/h (or two pumps with 25 m^3/h each, average period of operation 10 h per day) at a pressure height of 25 m. This may require a maximum pumping pressure of ca. 5 bars.[4]

9.3 Optional filter before the storage tank

As an option a processing of the raw leachate might become necessary to reduce the particles and suspended matter. This reduces the risks of incrustations, clogging and improves the durability of pumps, valves, the infiltration capacity etc. For this purpose an encapsulated sand filter that is designed for the high pressures in the infiltration system can be installed before the storage tank. Other systems like separators in the storage tank are possible, too.

9.4 Leachate storage tank

For the leachate storage at the plateau of the landfill Kragge, two steel tanks with a capacity of 60 - 120 m^3 each can be used. This means the average water volume for half a day to one day can be stored, so an intensified water addition to the infiltration fields is possible. As mentioned the water level in the tanks must be measured continuously to operate the pump in the pump pit and the pump in the water distribution unit properly.

9.5 Water distribution unit: pump, distribution bar, electronic devices

In the water distribution unit (a container or garage building) a pump and a water distribution bar are installed. Moreover the electronic devices for the pumps the automated valves etc. for an automated operation are integrated. With the distribution bar (PEHD pipe ca. DN 150) each infiltration field can be supplied with leachate individually. The valves should be served automatically, for special purposes or at the beginning manually (figure 9.3).

The pump(s) should have a capacity that allows an average speed in the pipes to the infiltration fields of 1 - 2 m/s. With a DN 100 pipe this refers to a pump capacity of 30 - 60 m^3/h at a pressure of about 2 bars.

[4] All design parameters are preliminary and can still be modified in the further planning stages.

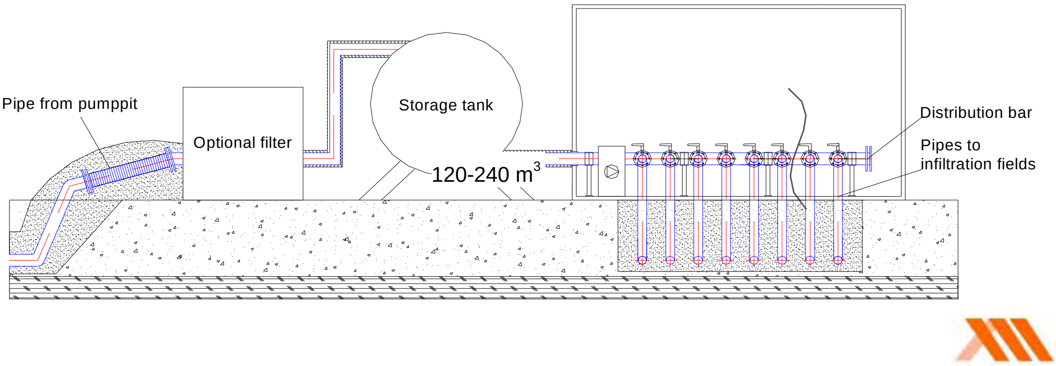


Figure 9.3: Preliminary design of the optional filter, the storage tank and the water distribution unit on the plateau of the landfill Kragge

9.6 Leachate pipes to the infiltration fields

Each infiltration field will be supplied by a separate pipe (ca. DN 100, PN10) from the water distribution bar. Before the well shaft of the infiltration field a low point will be constructed to avoid access of landfill gas into the pipe or air with oxygen that might cause incrustations.

The pipes trenches can be laid in a sand bed in trenches within the soil cover. This is an additional protection against heat, frost or mechanical stress.

9.7 Infiltration fields with well shafts

The infiltration fields are designed as follows:

- Well shafts are installed at the landfill surface for a controlled water addition. They may have a height of 1 - 2 m and a diameter of 1 - 2 m. The bottom of the shaft is perforated figure 9.4). Ducts in the shaft are connected to the perforated pipes (4 - 8 per infiltration field, ca. DN 100) to ensure the even water distribution. Moreover even water addition shall be ensured by addition of higher water/leachate volumes per infiltration cycle to reach a short-time pile-up in the infiltration field.
- Below the well shafts, infiltration fields (gravel or coarse recycling material, water permeability ≥ 10^{-3} m/s) are laid out in order to distribute the infiltration medium over the area (figure 9.4). The height of the gravel layer is between 0.5 - 0.8 m. The size of each infiltration field is adapted to the specific situation of each cell and the position of the surrounding gas wells. They are probably between 20 x 20 m, 15 x 35 m and 20 x 40 m (figure 9.5). The distance between the borders of the infiltration fields should not exceed 50 m.

- In order to avoid a mixture with the soil cover and the drainage layer of the infiltration field, the area of the infiltration field may be equipped with a geotextile or, if necessary to avoid uncontrolled gas migration, a gastight covering/sealing. The well shaft is watertight and rather gastight. For even moisture penetration throughout the waste body, a terminable accumulation of leachate within the infiltration field is useful in order to achieve a distribution of the infiltration medium over the entirety of the infiltration field. The possibility of leachate accumulation must be taken into consideration during the detailed planning phase and may be realized in a process-related and structural manner.
- The charging of the well shafts / infiltration fields may be implemented using tank trucks at the beginning followed by a largely automated water distribution system, consisting of distribution stations and piping. For long-term infiltration measures, the elaborated piping and distribution system with an automated operation should be employed (figure 9.3).
- In order to control the function of an infiltration field in respect to even water distribution over the infiltration area, measurement devices to control the filling level during and after the leachate addition can be installed. They show how fast the infiltration from the field to the landfill body occurs and if there are changes over the operation time, e.g. by clogging. The measurement device can consist of a vertical pipe that is emplaced at the edge of an infiltration field and equipped with a float and a measurement scale of height of the water level.
- As mentioned above the infiltration volume for the cells 3 to 5 may be equal to ca. 40,000 to 160,000 m^3 per year. The average daily infiltration rate with 14 fields refers to 7.5 - 30 m^3/d per field. These quantities show that an automated infiltration system might become necessary when an infiltration process with increasing infiltration rates shall be carried out. The capacity of an infiltration field of 20x20 m, a height of 0.5 m and a pore volume of the gravel material of at least 30%, has a minimum value of 60 m^3 (short-time storage capacity) and thereby meets the requirements.

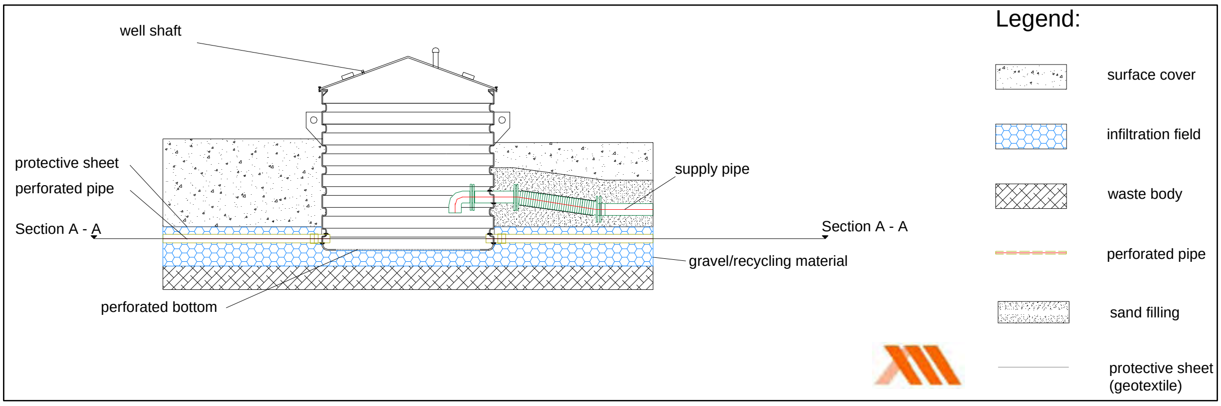
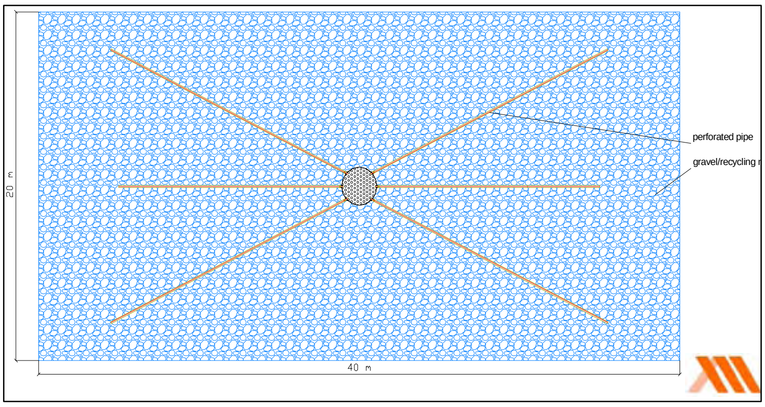


Figure 9.4 **Infiltration field integrated in the soil cover with a well shaft for charging**

The final fixing of the dimensions for the well shafts and infiltration fields (diameter and height), as well as the distance between the individual well shaft / infiltration field units must be realized while taking into consideration the local conditions of cell 3 to 5.
At the moment it is difficult to asses the final situation of the northern part of cell 5 after the completion of waste deposition at the end of the year 2008.



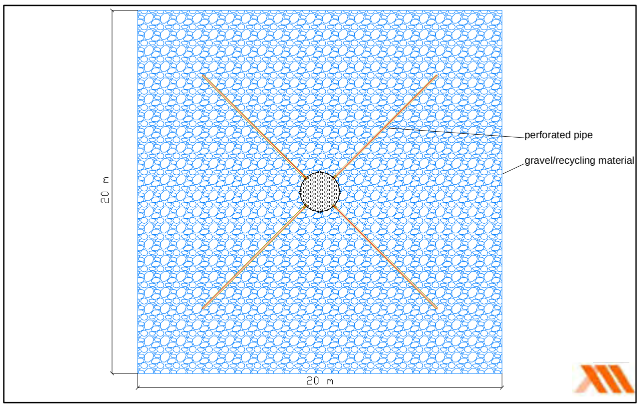


Figure 9.5 Infiltration fields with well shafts and additional perforated distribution pipes

The following calculation shows that the infiltration fields have a sufficient capacity for the higher addition quantities by leachate recirculation:

The 14 infiltration fields cover ca. 9,500 m^2 and have a total volume of ca. 6,000 m^3. The total pore volume of the drainage layer for water infiltration of all infiltration fields is about 2,000 m^3 (minimum pore volume of the drainage/gravel layer in the fields 30%).

Even if the water addition is carried out:

- in an infiltration field only one time a day,
- in only 50% of the above mentioned pore volume capacity of at least 2,000 $m^{3,}$
- 300 days per year by an automated operation,

A total water volume of 1 x 1,000 m^3/d x 300 d/a = 300,000 m^3/a can be infiltrated. This is higher than the maximum quantity according to the assumptions explained in chapter 9.2 and therefore offers a high flexibility for the different options of the future operation.

10 DETAILS PRLEIMINARY DESIGN AEROBIC IN SITU STABILIZATION

10.1 Basic principles

The principle of low pressure aeration with aeration and gas collection in parallel for cell 3 to 5 is shown in figure 10.1. It consists of the following equipment and devices with respect to aeration, gas extraction and gas treatment:

- 24 new gas wells with a drilling depth of ca. 10 - 20 m and a drilling diameter of ca. 400 mm mainly for aeration and partly for collection of exhausts;
- Construction of two new connection pipes between the existing main gas collection pipes (DN 200) and the gas collection station in waste cell 3, thereby integration of the existing gas collection system: utilization mainly for gas/exhausts collection over the existing gas wells and the existing gas collection stations;
- Excavation of trenches in the soil cover for the PEHD pipes between the new gas wells and the gas distribution station and/or lay of pipes on the soil cover; supply of two gas wells by one pipe (to reduce the necessary amount of PEHD pipe material)

- Optional: condensate traps to avoid condensate accumulation in the lowest points of the pipe system
- Preparation of the operation area for containers at the plateau (for infiltration container and tank, too)
- Installation of the gas distribution station for the individual adjustment of each gas well (mainly for aeration, optional suction), volumes, pressures, monitoring devices etc.
- Installation of a mobile gas blower station with aggregates/blowers for aeration, suction, gas analysis, system control for automated operation, safety devices etc. Installation at the moment when gas collection and gas utilization is no longer feasible for technical or economical reasons.
- Installation of a mobile gas purification unit like high temperature auto thermal oxidation reactor, maybe followed by biofilters. Installation in parallel to the gas blower station
- Infrastructure: power supply and telephone for remote control

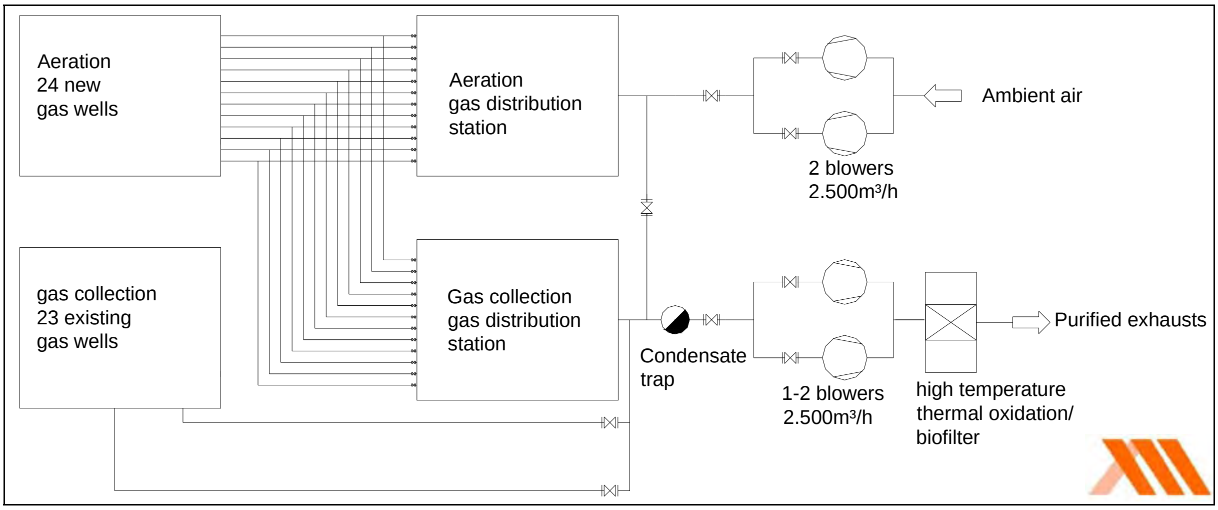


Figure 10.1 Principle of aerobic in situ stabilization by low pressure aeration

10.2 Aeration and gas extraction volumes

For the final design and the basis for calculations for aeration and suction volumes, diameters of pipes, capacities of blowers, demand of power for operation etc. further pre-investigations will be necessary (see chapter 7). For the preliminary design the following assumptions are used:

10.2.1 Waste characteristics:

The oxygen demand for the aerobic in situ stabilization depends mainly on the biodegradable organic fraction. The biodegradability can be assessed by the oxygen consumption in biotests like the standard respiration tests over 4 days (or over a longer period).

According to the German experience and the German standard respiration test, the oxygen demand over 4 days:

- for fresh waste ca. 50 mg O_2/g dry substance DS (range: 40 - 80 mg O_2/g DS);
- for old landfilled waste before the start of aeration ca. 5 mg O_2/g dry substance (as an average value, range: 3 - 10 mg O_2/g DS; IFAS results, figure 10.2)

So ca. 90% of the easy and medium degradable organic compounds are already converted under anaerobic conditions when the anaerobic LFG production becomes too low for further economical utilization and the aeration is started.

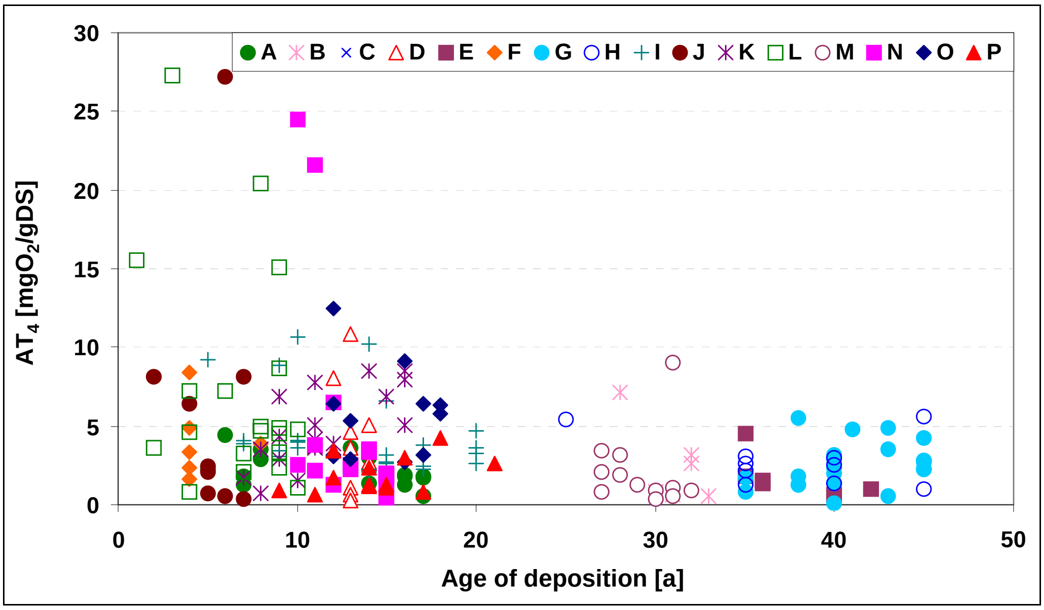


Figure 10.2: Oxygen consumption (respiration index after 4 days) of solid waste samples from 16 landfills (A – P) over the age of deposition (IFAS, 2008, internal data)

By extrapolation the total oxygen consumption can be determined by the cumulative curve of the oxygen consumption over time. Results show that the total oxygen consumption is on average often 8 times higher than the consumption over 4 days. This means that the total oxygen consumption of old waste before the start of aeration can be estimated to 40 mg O_2/g DS. If at least 80% of the biodegradable fraction shall be converted during the aerobic in situ stabilization process, about 32 mg O_2/g DS have to be supplied.

1 mol of oxygen (O_2) has a weight of 32 g and a volume of ca. 22.4 l. Air has an oxygen concentration of 20.9%, so 100 l of air contain ca. 32 g oxygen.

Based on the solid waste investigation results and this calculation, the oxygen demand for a complete aerobic degradation of 1 Mg DS might correspond to the supply with ca. 100 m^3 of air (according to the large-scale / long-term operation experience of IFAS, see also example below).

Remark

If the oxygen demand of solid waste samples is significant higher than 100 m3 of air (for example 300 – 500 m^3 of air per ton of dry waste), then the gas production of the investigated landfill compartment (intensity of anaerobic degradation processes) is still so high that it is more economical and ecological to go on with the LFG extraction and utilization. To verify the explained approach, site specific investigations at the landfill Kragge are recommended for the final design (see chapter 7).

Example Kuhstedt Landill

As an example the results of the reduction of the gas formation potential during the aerobic in situ stabilization of the landfill Kuhstedt is shown in figure 10.3. At the Kuhstedt landfill an average oxygen/air consumption of ca. 125 m^3 of air per ton of dry waste (20,000,000 m^3 of air for 160,000 tons of dry waste mass) was calculated before the aeration. After the supply of this oxygen/air volume after 6 years, very good results for the biological activity were achieved what is visible by the reduced gas formation potential of the stabilized waste (Moreover the corresponding respiration index AT_4 at the beginning and at the end is presented to express the correlation between the respiration index, the required air volumes and the reduction of the gas formation potentia**l.**

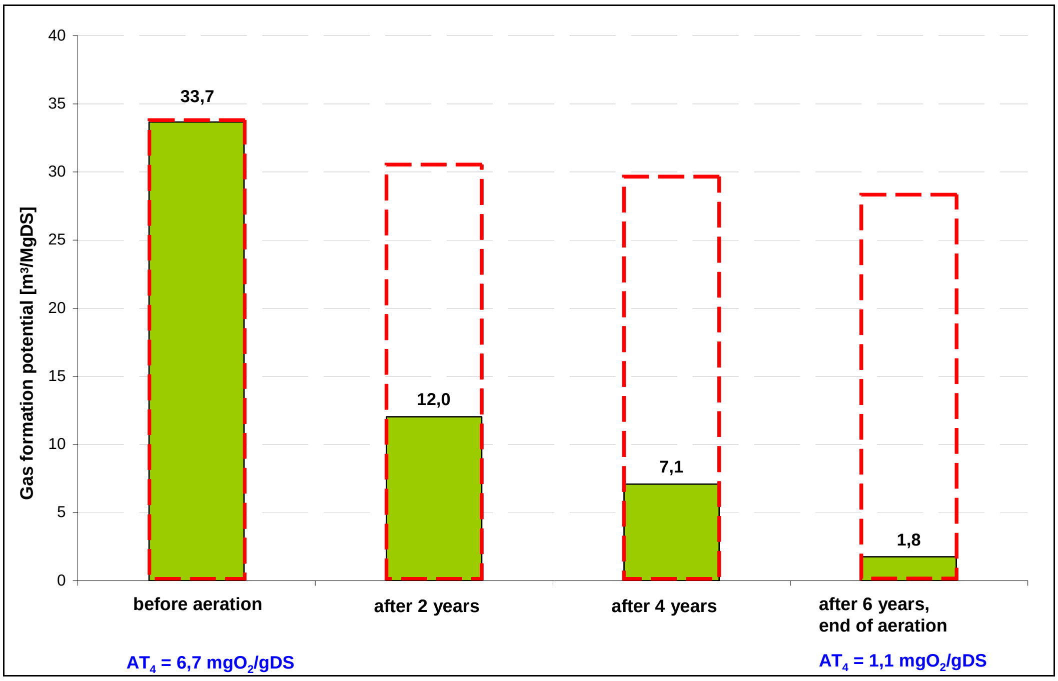


Figure 10.3 Reduction of the gas formation potential after 2, 4 and 6 years of aerobic in situ stabilization, landfill Kuhstedt, Germany (derived from Ritzkowski et al, 2008, Hamburg University of Technology)

Legend:

- Green bars: results of reduced gas formation potential after 2, 4 and 6 years of aeration.

- Red dotted bars: probable gas formation potential that would have occurred under anaerobic conditions without aeration).

10.2.2 Landfill site characteristics

The dry waste mass of the waste cells 3 to 5 may consist of ca. 750,000 Mg DS. This requires 75,000,000 m^3 of “fresh air” to stabilize the waste body of the waste cells 3 to 5. For an operation time of 30,000 hours (3.5 to 4 years of operation), this corresponds to an aeration and gas extraction rate of 2,500 m^3/h.

Another important aspect for the design of the aeration system and the required blower capacities is the efficiency of the oxygen distribution and consumption of the added air respectively oxygen in the landfill body.

Remark
If the required air quantities are in the future higher than the first estimations for the preliminary design or compared to the results of the pre-investigations, the low pressure aeration can be operated very flexible to meet the oxygen demand:

- the operation period can be extended;
- the pressures and volumes over the existing gas wells can be increased;
- additional gas wells can still be installed after for example one or two years of operation, if it turns out that in some landfill sections the oxygen distribution/supply is not sufficient (e.g. because of low gas permeability in some parts of the landfill body).

10.3 Gas wells for aeration and exhaust air collection

An advantage of low pressure aeration is that existing respectively ordinary state of the art gas wells can be integrated into the aeration operation. Preliminary investigations through low pressure ventilation over a pilot gas well should examine how many gas wells are necessary. Among others, the collection radius of the gas wells is determined, in order to keep the capital outlays low and to design the stabilization operation in an optimal manner.

As already described for the waste cells 3 to 5 a design of 24 new gas wells is proposed. Figure 10.4 shows the possible design of a gas well. The drilling diameter of 400 mm and an inner pipe diameter of about 100 mm will probably be sufficient for a maximum aeration rate of 100 – 200 m^3/h by one gas well. In addition, the technical design of the gas wells should take into account that the deeper sections of the landfill can also be sufficiently supplied with oxygen.

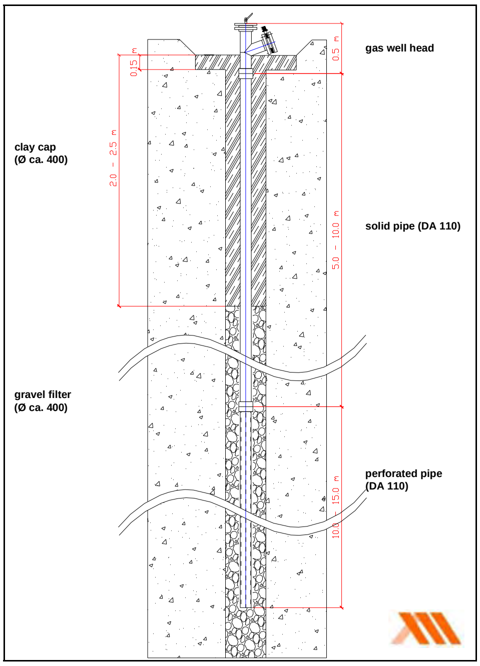
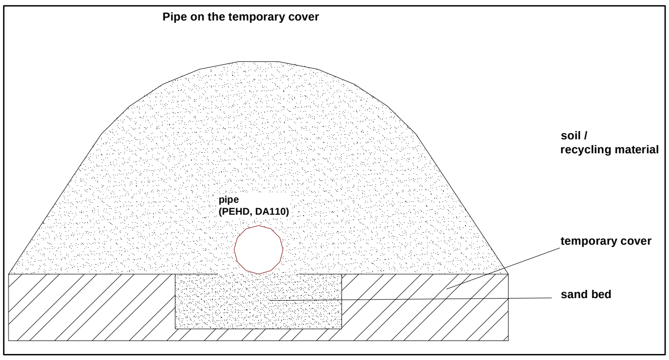


Figure 10.4 Design of a new gas well

Through this site specific dimensioning with the future results of pre-investigations, the gas wells can probably be designed smaller and thus more economically like in figure 10.4 than standard gas wells. For uniform ventilation, great borehole and extension diameters of the gas wells are not crucial, but their number and positioning is. The possible position of the existing and new gas wells with spheres of influence of 20-25 m is given in figure 8.1.

10.4 Pipe system for aeration and exhaust air collection

The PEHD pipes (ca. DN 100, PN 6) between the new gas wells and the gas distribution station can be laid in trenches in or on the soil cover (figure 10.5). To reduce the stress by heating, frost and mechanical damages and because of safety reasons they should be covered with soil or appropriate recycling material. The installation should be carried out in parallel or after the installation of the infiltration fields. It is important to establish a constant slope to control the condensate flow in the pipes. For this reason condensate traps might be necessary for some pipes to avoid high water levels by condensate accumulation in the lowest points of the pipe system.



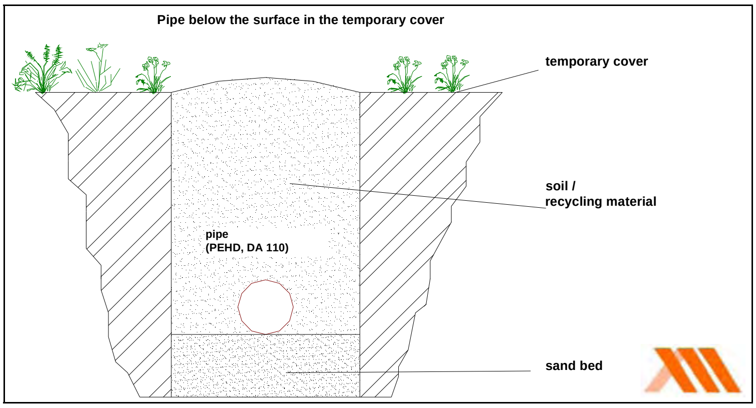


Figure 10.5 Lay of pipes within or on the temporary soil cover

10.5 Gas distribution station

For the landfill Kragge the aeration and gas collection system will be implemented in a way that a good compromise between the task to reduce investment costs by integrating the existing system on the one hand and the option of a high flexibility on the other hand is realized. That means, that all new gas wells can be used for aeration as well as for exhaust air collection (respectively two gas wells via one pipe).
This can be achieved by means of a dual circuit principle in the pipe system of the new gas distribution station. The necessary condensate separation from the exhaust side can also be integrated here. Figure 10.6 is an example of how the gas distribution station is organized.

The two main pipes from the distribution bars of the gas distribution station are connected with the two new main pipes from the existing gas collection pipe (DN 200). With this connection the new gas wells and the new gas distribution station can be used for improved gas extraction that should be advantageous during the first years of water infiltration when the anaerobic degradation processes with an increased gas production shall be enforced. During this period the gas blower station for aeration is not yet necessary. It will be installed and connected with the described pipe system later when the aeration process will be started.

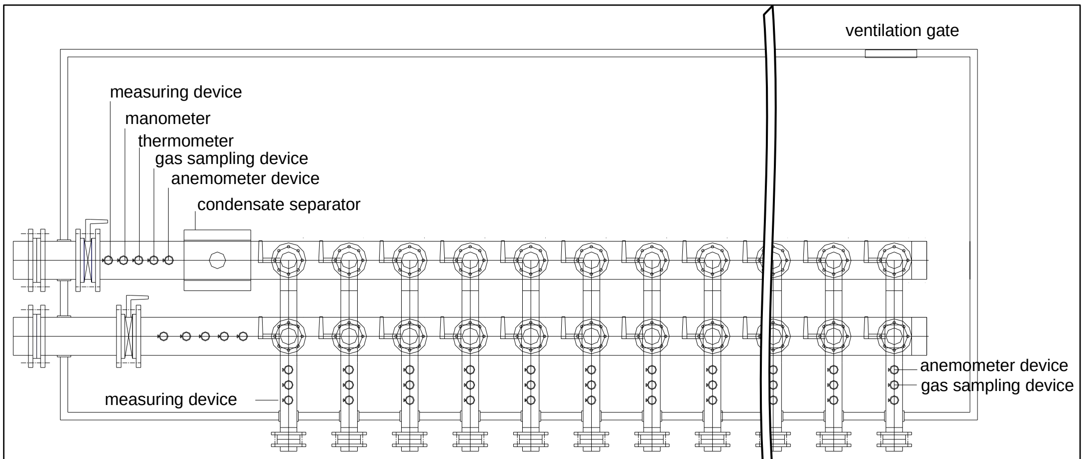


Figure 10.6 Layout of the aeration and gas collection system in the gas distribution station

10.6 Aeration equipment and gas booster station

The equipment for the air supply is generally similar to those for exhaust air suction. Among others, side channel compressors and rotary piston compressors can be used. In addition, measuring, control and feedback control systems on the aeration processes and the exhaust air collection should be installed. The aeration rate should be adjusted in a way so that an optimal oxygen uptake rate is obtained and no anaerobic zones establish.

The whole equipment is installed in a container to have the necessary flexibility and mobility. The container should be delivered fully mounted and ready to connection like the container with the gas distribution devices.

As already mentioned the performance of the equipment should be specified for the aeration and exhaust air collection by means of preliminary investigations in order to achieve the optimal economical investment of the plant. At the landfill Kragge the results of the first gas extraction period and the corresponding monitoring program might give enough information, so only reduced pre-investigations might become necessary. In figure 10.7 the organization of the gas blower station is represented.

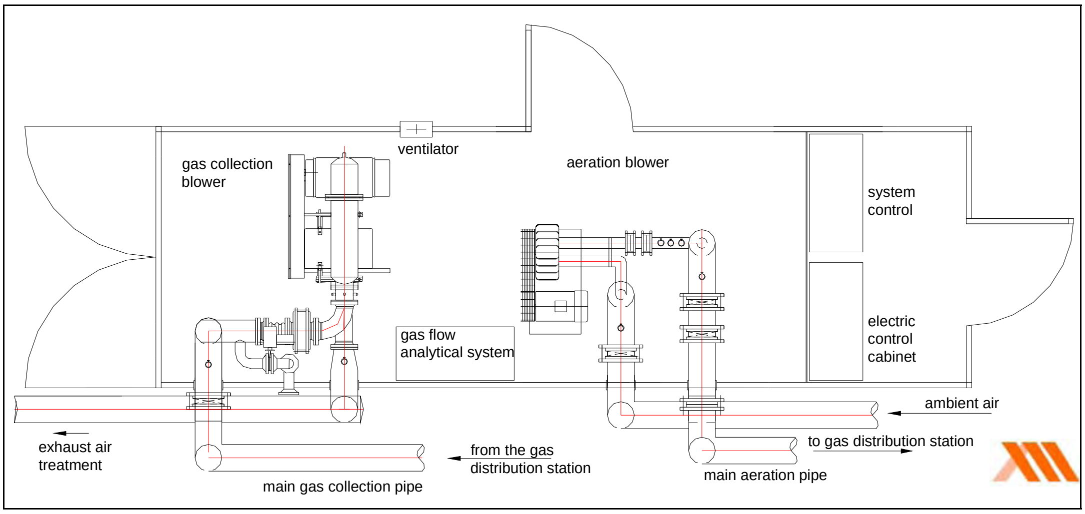


Figure10.7 Possible preliminary layout of the compressor unit for aeration and collection of exhaust gas in the gas blower station

10.7 Exhaust air treatment

In principle, the exhaust air can be treated by bioscrubbers and biofilters or through auto thermal processes. Due to initially higher methane contents in the first phase of in situ stabilization, a special flare for weak landfill gas with methane concentrations or a high temperature auto thermal oxidation plant can be used. This auto thermal oxidation plant can be replaced by less complex treatment methods when the methane content is lower. Whether such an approach for exhaust air treatment or e.g. the immediate employment of a biofilter is selected depends on the results of the preliminary investigations and planning based around it, the guidelines of permission, and the licensing and supervising authority for exhaust air treatment.

11 MEASUREMENT AND MONITORING STRATEGY

11.1 Introduction

Application of the enhancing technical measures is stimulating the stabilization processes in the waste body (degradation of organic matter) and leads to a minimum remaining emission potential, which might be equal to admissible emission levels. As a result a much lower intensity in after-care will be required and even discharge from aftercare might become possible.

Challenges for the demonstration pilot lie in <u>proving</u> that the applied technology results in an effective stabilization <u>throughout</u> the landfill. The question is not so much if we will be able to stimulate degradation, but how thorough we are able to treat the landfill body in order to remove most of the degradable organic matter. The emission potential is related to the amount of non-reacted waste within the landfill body. For closure of a landfill, quantification of this amount is the key issue. For operation of the landfill stabilization, knowing the spatial distribution of the required intensity in order to reach emission risk levels that are protective of the surrounding environment will allow for running the landfill stabilization technology in as short a time as possible.

11.2 Goals

The main goal of the demonstration project at the landfill Kragge is the demonstration of sustainable emission reduction at existing landfills by means of the application of infiltration and/or aeration as the enhancing technical measures for landfill stabilization.

Within this framework the measurement and monitoring strategy should fulfill two goals:

1. <u>*Quantifying the **effects** of the landfill stabilization*</u>. The effects are related to the direct prove of sustainable emission reduction and can be measured by means of the <u>primary</u> key performance indicators (KPI's) as identified and described in the generic report (lit. 1).
2. <u>*Following the **process** during landfill stabilization*</u>. This process is related to the performance of the necessary and required conditions for a successful degradation process and can be measured by means of the <u>secondary</u> KPI's (lit. 1). It can also be used as circumstantial evidence of the degradation processes.

11.2.1 Effect monitoring

For effect monitoring a thorough measurement of the stabilization status in the landfill before, during and after the demonstration is proposed. This requires a statistical sound approach of taking waste samples from spots in the landfill and assessing the amount of stabilization before and after operation. In addition to the general chemical composition of the samples it is essential to characterize the properties of the organic material present in the samples. Due to the expected heterogeneity in the landfill body (both in horizontal and vertical sense) it is essential to take a relatively large number of samples. In order to optimize the taking of samples, geophysical imaging of the landfill before sampling may assist in locating the most relevant points for sampling (e.g. where are the spots with different properties).

Mass balances are another means of assessing effects. Notably the mass balance of carbon, by monitoring the gas flux (both CH4 and CO2).

Landfill stabilization should have a profound effect on the leachate quality, especially the concentration levels of the dissolved metals. Monitoring of changes in time and space is important. Interpretation however will be very difficult due to heterogeneity in the landfill. If stabilization is achieving its goal (increasing stabilization by reducing effects of heterogeneity), variations in the data set should damp out with time.

11.2.2 Process monitoring

Process monitoring will be used to assess the effectiveness of the applied measures. One of the important goals of the measures is to reduce the heterogeneity in water content and water transport. The direct means for obtaining information is carrying out flux measurements in different sections of the drains present (both gas and water). Comparison of the values obtained from the different sections will provide information about the spatial effect of the applied measures. Time lapse imaging with geophysical methods is probably the only efficient means for large scale measurement of processes.

A similar approach is also valid for leachate quality; spatial information may be obtained from quality measurements in different parts of the landfill.

Short term experiments should be carried out during the implementation of the stabilization technology. Examples are adding tracers to the infiltrated leachate, followed by a detailed (temporarily intensification of the monitoring program), temporarily stopping the measures to see how the landfill recovers, temporarily increasing/decreasing rate of infiltration. Each of these experiments should be closely monitored. Preferably with in-situ sensing instrumentation.

11.3 Scale, samples, experiments and analysis

Scale and heterogeneity are the most difficult challenges to overcome. Detailed experiments in the laboratory will tell us a lot about how processes occur and what endpoints are possible, but direct extrapolation to the field results is hardly possible.

Another complication is that relatively large samples can be taken (50 kg or perhaps even 1 m^3) but the laboratory analyses carried out will be done on minute sub samples (in the range of 100 mg to 10 g). Quantitative analyses are generally done on very small samples (a volume of landfill gas of a couple ml is analyzed; a couple of ml of leachate is injected in a chromatograph). The means for up scaling analyses is to carry out experiments on samples of a larger scale and interpret the results from samples taken during the experiment in the context of the larger sample. Possible large scale analyses are:

- water content by geo-electrical measurements;
- measurement of compressibility;
- column leaching tests;
- fermentation tests;
- tracer tests
- The experiment carried out on the landfill scale is the demonstration project it self.

Samples extracted from the landfill will represent different scales of landfill volume. In other words, which landfill volume is influencing the properties of the sample.
For example, sampling the landfill gas in the gas-extraction system close to the gas treatment plant will have a support which is related to the effective sampling volume of the complete gas-extraction system (hundreds of m^3). However sampling a single monitoring well will have a support that is limited to the direct neighborhood of the filter screen (in the range of tens of dm^3). The key to quantifying the consequences of scale and heterogeneity is to obtain samples over all scales possible and compare these data with each other.

Playing with the dynamics in the demonstration project will provide a large amount of information that can be used for understanding what is occurring within the landfill. An example is the variation in leachate quality in the drains. Initially this variation will be very high, as the stabilization proceeds, the variation in leachate quality should decrease due increased landfill stabilization. How often samples need to be taken and analyzed should be defined in a measurement protocol.

Another type of experiment is a tracer test. Monitoring the breakthrough a tracer in the leachate during the infiltration allows us to estimate how large the mobile volume of leachate is, how much leachate is used for increasing the water content and how preferential flow will change in time. Carrying out experiments with different infiltration rates will allow for quantification of exchange of water and volumes of mobile and immobile leachate. Try to close the internal water balance by knowing what goes in and what comes out as a function of time.

11.4 Data interpretation

Measured data will be very complicated to interpret because the results will be a manifestation of a wide range of different processes occurring simultaneously at different places. Data interpretation should be strengthened with the application of numerical (conceptual) process models in order to estimate the rates of occurring processes. Most important challenges are heterogeneity and the related uncertainty in the outcomes. This can be overcome by increasing the number of spatial and temporal measurement points (statistics) but also by carrying out simulations. Combination of all approaches is the only viable approach to minimize uncertainty and get the best understanding of the consequences of heterogeneity at an acceptable cost.

Essential are the integrated conceptual model of processes in the waste body and the conceptual process design as described in the chapter 6.5 of the generic report (lit. 1). These will allow us to extrapolate in time, using the monitoring data.

12 OPERATIONAL MONITORING PROGRAMME

In the generic report (lit. 1, annex 4) a number of key performance indicators (KPI's) has been identified and explained. Within the framework of the measurement strategy, these KPI's serve for the basis of the parameters to be monitored.

One basic step of the monitoring program are the measurements for quantity (incoming and out coming flows/volumes) as well as for quality (chemical composition) of leachate, landfill gas, infiltrated/recirculated/discharged leachate and extracted exhausts during aeration. The basic monitoring program is compiled in table 12.1.

Next to the basic monitoring program also the following measurements and tests are possible/necessary to be carried out:

- Additional special investigations like tracer tests or geophysical tests to investigate the water movement in the landfill body (before, during and after infiltration).
- Additional special investigations like gas emission tests over the surface cover (e.g. in gas boxes) or temperature measurements in the landfill body during aerobic in situ stabilization.
- If possible the quantity and quality of the surface run-off should for the water balance.
- The check of all technical equipment should be carried out continuously. It is important to check possible incrustations in the pipes and the infiltration fields.

Table 12.1 Monitoring parameters and possible analysis frequencies

Item	Monitoring parameter	Analysis frequencies
Leachate	Flow/Volume	Continuous in the leachate shaft (pump pits) of cells 3 – 5, on a daily to weekly basis
	Composition[1)]	6 times in the first year, then 4/year
Infiltration medium	Composition[1)]	6 times in the first year, then 4/year
Infiltration system	Flow/Volume/Intervals for each infiltration field	Continuous as part of system control, on a daily basis
	Leachate level in system	E.g. via vertical measurement wells in infiltration fields
Landfill gas (before and during infiltration)	Flow/Volume	Continuous via gas collection stations for cell 3 - 5, 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 week to once a month
	Gas temperature	Continuous via gas utilization unit (CHP), at each gas well once a week to once a month
Aeration / air supply (during aerobic in situ stabilization)	Flow, volume, pressure and temperature	Continuous as part of system control, at each gas well once a week
Extracted exhausts (during aerobic in situ stabilization)	Flow, volume, pressure and temperature	Continuous via gas blower station as part of system control, at each gas well once a week
	Composition[2)]	Continuous via gas blower station as part of system control, at each gas well once a week
Waste body	Leachate Level[3)]	Continuous to monthly, e.g. via additional monitoring wells, optional in gas wells
	Settlement/mechanical stability	4/year, 50 m grid (settlement beacons, integration of existing beacons)
Solid waste sampling in the waste body	Water content	Before start-up[4)]
	Water storage capacity	Before start-up[4)]
	Biodegradability, TOC	Before start-up[4)]
Meteorological data	Temperature, atmospheric pressure, precipitation, atmospheric humidity, wind speed, etc.	Continuous on a daily basis

1) pH, Conductivity, COD, TOC, BOD, TKN, NH_4, NO_3, NO_2, Cl, metallic compounds, phenols, phosphate, sulphides, AOX and relevant NA-parameters (leachate and infiltration medium might be identical).
2) CH_4, CO_2, O_2, H_2S.
3) leachate level: especially examination of the free slopes when infiltration takes place within the area close to the slope.
4) Solid waste sampling before and after (and if necessary during) the controlled infiltration and aeration.

13 EXPECTED RESULTS AND POTENTIAL BENEFITS

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

- basic effects of infiltration and aeration as compiled in the generic report (lit.1);
- compilation and assessment of available specific data of the landfill Kragge (lit. 2);
- preliminary design for infiltration and aerobic in situ stabilization as described in the previous chapters in this present 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 and aeration for:

- gas emissions;
- conversion of biodegradable carbon;
- leachate emissions (COD and NH_4-N as "key performance indicators" KPI);
- settlements.

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

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

13.1 Future gas emissions

13.1.1 Starting points and conditions

To forecast the range of current and future landfill gas production of the relevant waste cells 3 to 5 (leachate compartments O3 and O4) of the landfill Kragge, the following assumptions were used:

- Waste deposition started 1997 and ended 2008.
- 980,000 m^3 of waste volume (wet mass) with a density of 1 ton/m^3, a water content of ca. 25% and 750,000 tons of dry waste (dry substance (DS)) with relevant biodegradable components.
- Biologically degradable carbon content of 100 kg $C_{bio.}$/ton of waste (DS) and a total gas potential of 130 m^3/ton DS. The "Biodegradable Carbon Content $C_{bio.}$"is lower than the "Total Organic Carbon Content TOC" that contains for example plastics and other non degradable materials.
- Average half-life value of biological degradation processes and gas production during the deposition period between 4 and 6 years.

- Average half-life value of biological degradation processes and gas production during the <u>closure and aftercare period without stabilization measures</u> between 6 and 10 years.
- Average half-life value of biological degradation processes and gas production during the <u>infiltration / recirculation</u> period between 2.5 and 4 years.
- No significant anaerobic gas production during aerobic in situ stabilization.
- No significant limitations of the biological degradation processes due to inhibition effects.

13.1.2 Forecast gas emissions

The gas production is calculated by the addition of the deposited waste mass per year and their specific gas production rate P_t at the time t with a first order decay model:

$$P_t = G_0 \cdot k \cdot e^{-k\,t}$$

with:

P_t	specific gas production [m^3 Gas/ton DS a]
G_0	total gas potential [m^3/ton DS waste]
k	reaction coefficient (k = ln2/H) [1/a]
t	age of deposition (reaction time) [a]
H	half-life value = period in which 50% of the gas potential is produced

The range of the gas production in the waste cells 3 to 5 is compiled in figure 13.1. The red line and black line are based on the assumptions as indicated in table 13.1.

Table 13.1 Variable average half-life values of biological degradation

	Half-life values of biological degradation processes		
	Deposition period	Closure & aftercare period	Infiltration period
Black line	**4 years**	**6 years**	**2,5 years**
Red line	**6 years**	**10 years**	**4 years**

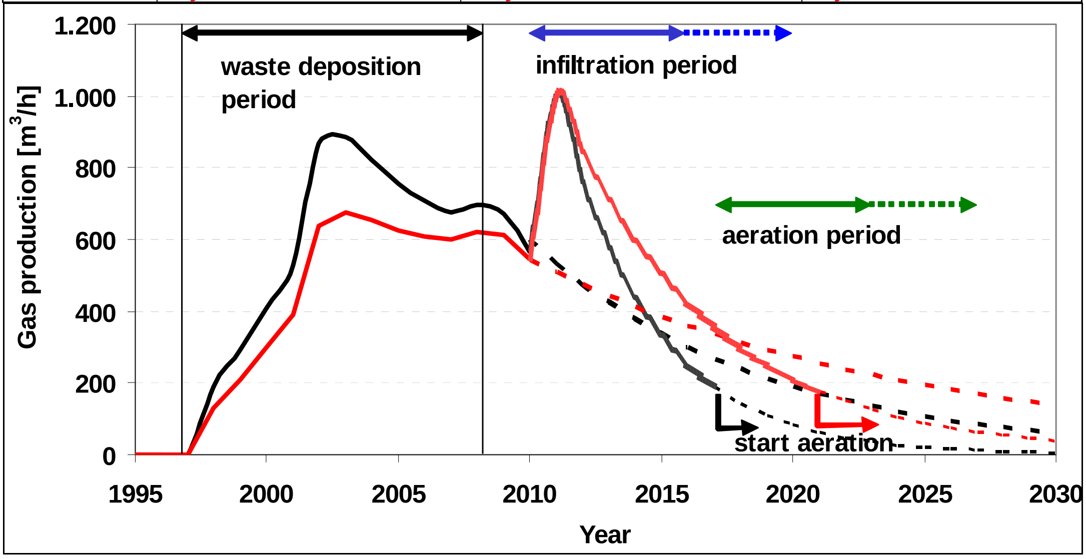


Figure 13.1 Gas production in the waste cells 3 to 5 of the landfill Kragge; variation of the half-life value and possible impact of infiltration / recirculation

According to the (theoretical) gas prognoses the present gas production might be in a range of 600 – 700 m^3/h. The present extractable gas collection rate is lower and is in the range of 350 – 400 m^3/h (see table 4.2). These figures are in line with the prognoses carried out with the TNO-model (Oonk et al, 1994) by Hans Oonk. The results of this TNO-prognosis are attached in annex 1.

Because of the infiltration and intensified leachate recirculation (maybe starting 2010) an increase of the anaerobic degradation can be expected. By a reduction of the half-life to 2.5 to 4 years, the gas production might increase to ca. 800 to 1,000 m^3/h. If the additional 24 gas wells are installed before the infiltration (see chapter 8) the gas collection rate and therefore the economical gas utilization can be improved[5].

According to this calculation the additional gas production during the infiltration period can be in the range of 8 to 13 Mio. m^3 LFG that would otherwise occur in the long-term probably in a poor gas quality.

After approximately 5 to 8 years of infiltration when the greatest portion of the degradable organic fraction is converted into LFG and an economical gas collection and utilization is no longer feasible the aerobic in situ stabilization can be started.

13.1.3 Forecast conversion of biodegradable carbon

Corresponding to the biological degradation processes the biodegradable carbon ($C_{bio.}$) will mainly be converted and released as landfill gas LFG (methane and carbon dioxide) and during aeration as exhaust gas (mainly carbon dioxide). In figure 13.2 the biodegradable carbon content in the landfill body and its release over the gas path is estimated according to the assumptions explained in chapter 13.1. The red line and black line are based on the assumptions as indicated in table 13.2.

5 For the active gas extraction and utilisation it has to be obeyed that the gas collection rate is always lower than 100%. It can range between 40 and 80% depending on the surface cover of the landfill and the system of gas wells and the general operation.

Table 13.2 Variable average half-life values of biological degradation

	Half-life values of biological degradation processes		
	Deposition period	Closure & aftercare period	Infiltration period
Black line	**4 years**	**6 years**	**2,5 years**
Red line	**6 years**	**10 years**	**4 years**

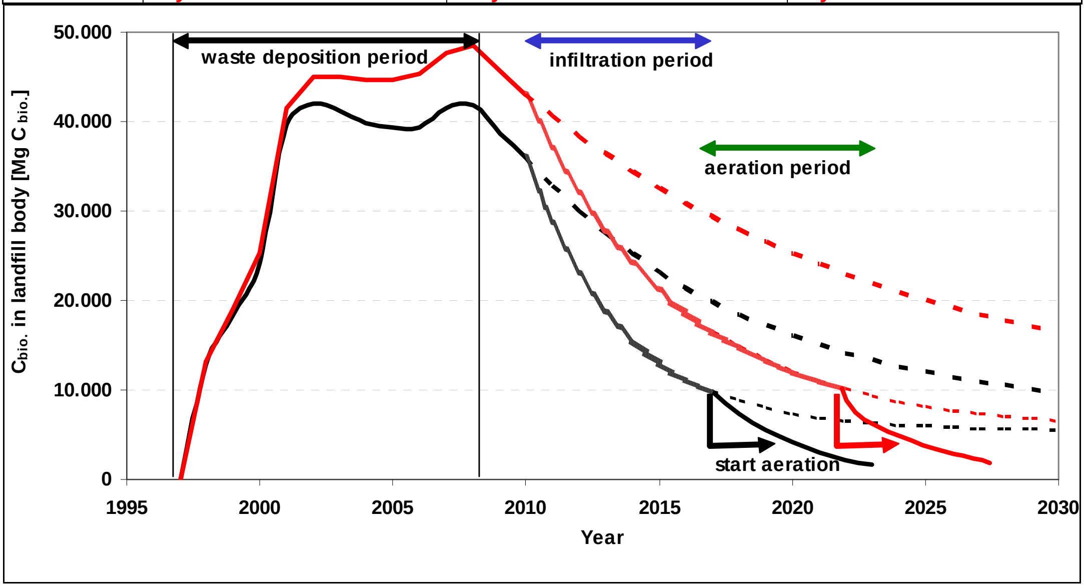


Figure 13.2: Range of carbon conversion in the waste cells 3 to 5 of the landfill Kragge; variation of the half-life value and possible impact of infiltration / recirculation

In the waste deposition period the content of biodegradable carbon in the three waste cells is the difference between the deposited carbon minus the carbon release under anaerobic conditions. In the year 2009 it can be in the range of 40,000 to 50,000 tons $C_{bio.}$.

In the closure period the biological activity can be optimized by the infiltration. When the gas production under anaerobic conditions is too low, the remaining carbon potential might be about 10.000 tons $C_{bio.}$. At that time (maybe after 5 to 8 years of infiltration) the aerobic in situ stabilization can be started in order to finally reduce the biodegradable carbon in an accelerated manner. That means that organic compounds that are not degradable under anaerobic conditions (or only in a very long period) are now degraded within 3 – 5 years of aeration. Maybe the aeration time can still be prolonged in order to improve the leachate emissions. Moreover it has to be decided if a reduced infiltration operation goes on when the aeration is started.

13.1.4 Preliminary conclusions

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

- A further reduction of the biodegradable carbon content without active stabilization measures is possible as long as enough water from the climatic leachate generation enters the landfill and an undesired dry conservation of the organic fraction (by a surface sealing) is prevented. On the other hand this will require a long aftercare period.

- For the waste cells 3 to 5 of the landfill Kragge the infiltration has probably a significant positive effect on the landfill gas production and the remaining emission potential.
- With the aerobic in situ stabilization following or in parallel to the infiltration the carbon potential might be reduced to 90 – 96% compared to the initial carbon content in the year 2009.

These preliminary results show again the potential to come to a sustainable landfill by site specific closure and aftercare measures.

13.2 Future leachate emissions

The forecast of the future leachate emissions will be carried out for the organic compounds (COD as “key performance indicator”) and the nitrogen concentrations (NH_4-N as “key performance indicator”). Compared to the landfill gas production and the carbon conversion the leachate emissions are more difficult to predict as they depend on many factors like the water balance, the height of the waste body, drying effects, chemical-physical reactions, preferential flow, etc.

In figure 13.3 the course of COD and NH_4-N in the leachate for all compartments of the landfill Kragge between 2000 and 2008 is presented. Up to now there is no reliable trend to decreasing concentrations visible.

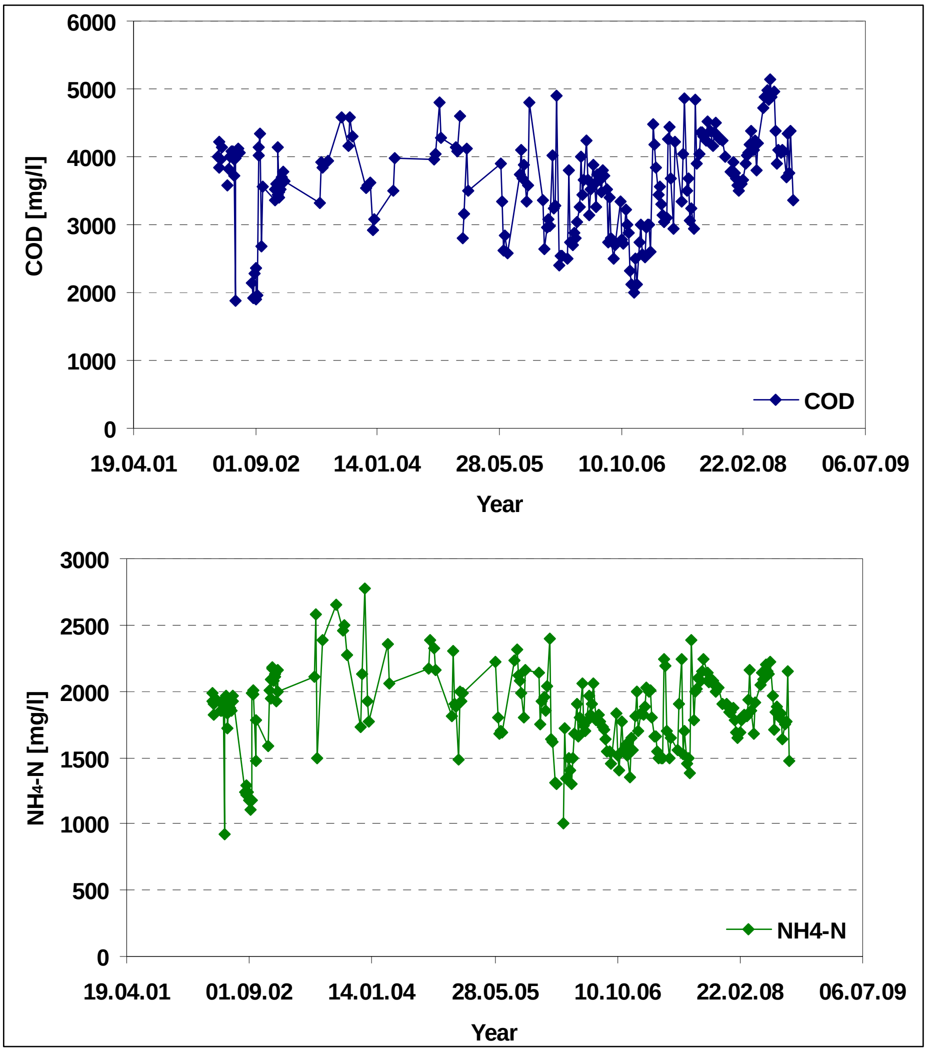


Figure 13.3 COD and NH_4-N in the leachate of the landfill Kragge, 2000 - 2008

The course of emissions in time can be described with an exponential function:

$$C_t = C_0 * e^{-k*t}$$

with:

C_t	= Leachate concentration at time t [mg/l]
C_0	= Leachate concentration at the beginning of the closure period [mg/l]
k	= Factor = $\ln 2/T_{½}$ [-]
$T_{½}$	= Half-life [a]
t	= closure and aftercare period [a]

With idealized conditions for the landfill height and the water balance, the course of emissions can be estimated. The estimations are based on the following starting points and assumptions:

- constant climatic leachate generation of 250 mm per year (this means no impermeable surface sealing, only a permeable soil cover).
- a height of 20 m.
- uniform percolation through the landfill-body.

- infiltration with infiltration rates up to 1,500 mm per year.
- COD leachate concentration at the beginning of the closure period ca. 4,000 mg/l.
- NH_4-N leachate concentration at the beginning of the closure period ca. 2,000 mg/l.

The half-life for the leachate compounds are very difficult to estimate. Scientific investigations (Heyer, 2003[6]) point to half-life values as follows:

- COD with climatic leachate generation of 250 mm/a: $T_{½}$ ca. 30 years
- COD with infiltration / recirculation up to 1,500 mm/a: $T_{½}$ ca. 10 - 15 years
- COD with aeration: $T_{½}$ ca. 7.5 - 10 years.
- NH_4-N with climatic leachate generation of 250 mm/a: $T_{½}$ ca. 40 years
- NH_4-N with infiltration / recirculation up to 1,500 mm/a: ca. $T_{½}$ 15 - 20 years
- NH_4-N with aeration: ca. $T_{½}$ 5 - 10 years (because of nitrification)

With the above mentioned starting points and assumptions the possible development of the COD and NH_4-N emissions in the leachate are estimated (figure 13.4).

From the trends in figure 13.4 the following <u>preliminary conclusions</u> can be formulated:

- A significant reduction of COD and NH_4-N concentrations in the leachate is possible. Maybe the effects of infiltration and aeration are even better or occur faster than estimated. So enhancement of leachate concentrations determined by scientific investigations at the Kuhstedt landfill in Germany pointed to reductions rates of 75 to 87% after 6 years of aeration (without infiltration).
- A reduction of COD concentrations to less than 1,000 mg/l and NH_4-N concentrations to less than 500 mg/l seem to be possible after the end of infiltration and aeration (2022 – 2027, maybe later, if prolonged aeration has still a positive impact on the reduction of COD and NH_4-N in the leachate after 5 years of aeration).
- At the end of the closure period 2022 – 2027 a leachate quality might be reached that would occur after 70 to 100 years of aftercare without stabilization measures.
- The course of emissions can show some deviations from the estimated curves as mobilization processes from the solid waste into the liquid phase sometimes lead to a short-time and temporary increase of the concentrations during infiltration and aeration.
- The aerobic in situ stabilization will have a significant impact on the reduction of the leachate concentrations as some organic compounds can be degraded under aerobic milieu conditions and leave the landfill body via the gas path. NH_4-N will be nitrificated, moreover denitrification takes place in the landfill body so the total nitrogen freight that will be released into the leachate path is reduced significantly. This will save expenditures for leachate collection and treatment in the long-term.

Comparable to the reduction of the carbon potential, these results also show the potential to come to a sustainable landfill by site specific closure and aftercare measures.

[6] Heyer, K.-U.: Emissionsreduzierung in der Deponienachsorge. Hamburger Berichte Band 21, Verlag Abfall aktuell, Stuttgart, 2003

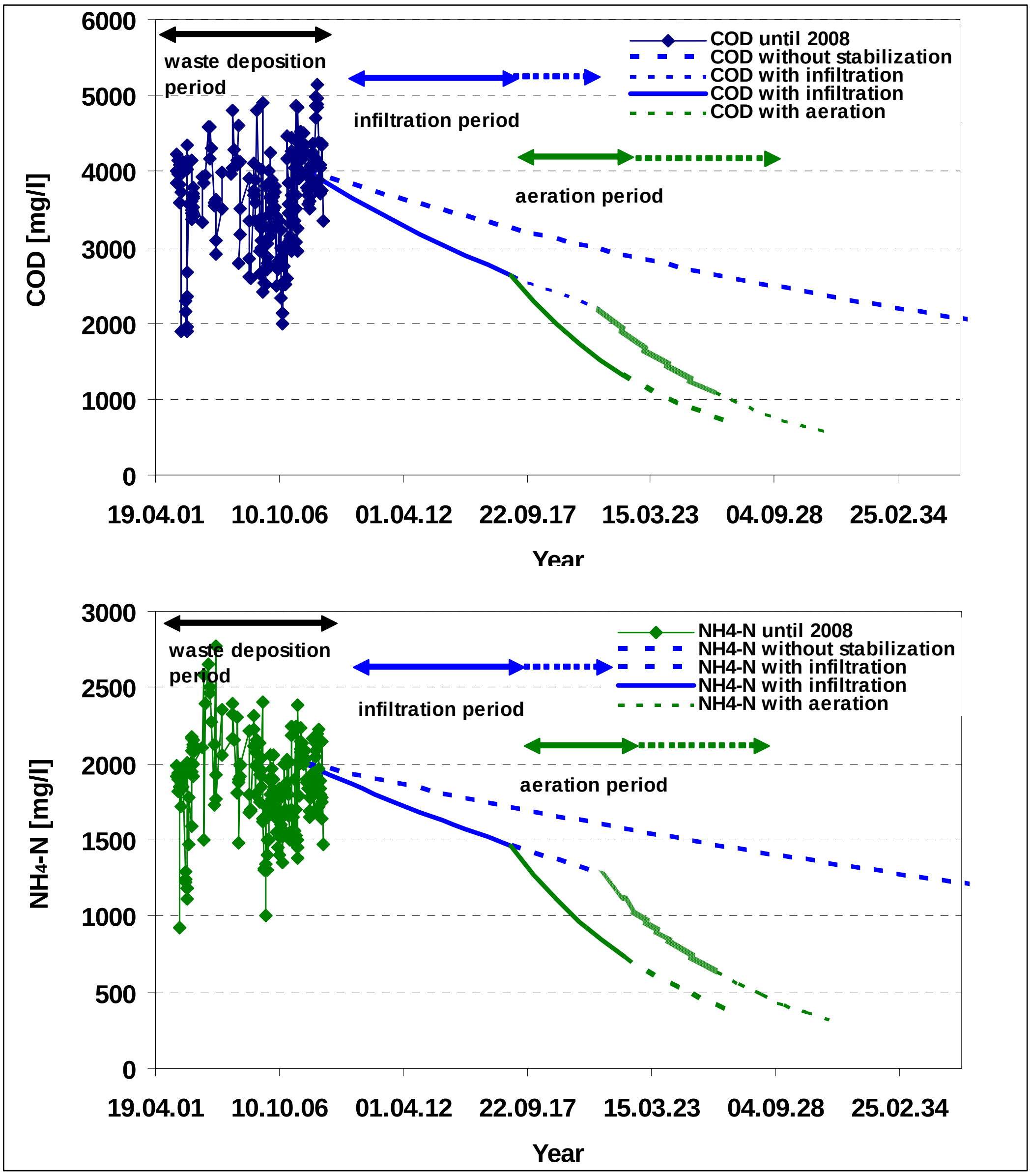


Figure 13.4 Possible course of COD and NH_4-N concentrations in the leachate of the landfill Kragge, depending on infiltration and aerobic in situ stabilization

13.3 Future settlements

Future settlements at the landfill Kragge mainly depend on the biological degradation processes and are determined by several effects:

- reduction of the waste volume by degradation of the organic waste mass.
- reduction of the pore volume by weakening of the mechanical waste structure.
- additional settlements during aerobic in situ stabilization as organic compounds are degraded that were not degradable under anaerobic milieu conditions.

The assumptions explained in chapter 13.1 are used. Moreover empirical results from landfills where the aerobic in situ stabilization was carried out are used:

- The degradation of 10 kg of $C_{bio.}$ refers to (a mass reduction of ca. 20 kg of organic fraction or) ca. 2 cm per meter of landfill height.
- The settlements because of the reduction of the pore volume by weakening of the mechanical waste structure are in the same size.

Figure 13.5 shows the possible effects of the stabilization measures on the settlements.

For the plateau of the landfill Kragge with a height of ca. 20 m, total settlements of about 4 m can still occur. Maybe the settlements in some parts of the landfill are even higher in the period of aerobic in situ stabilization. At the end of the stabilization processes a very low potential for future settlements is 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.

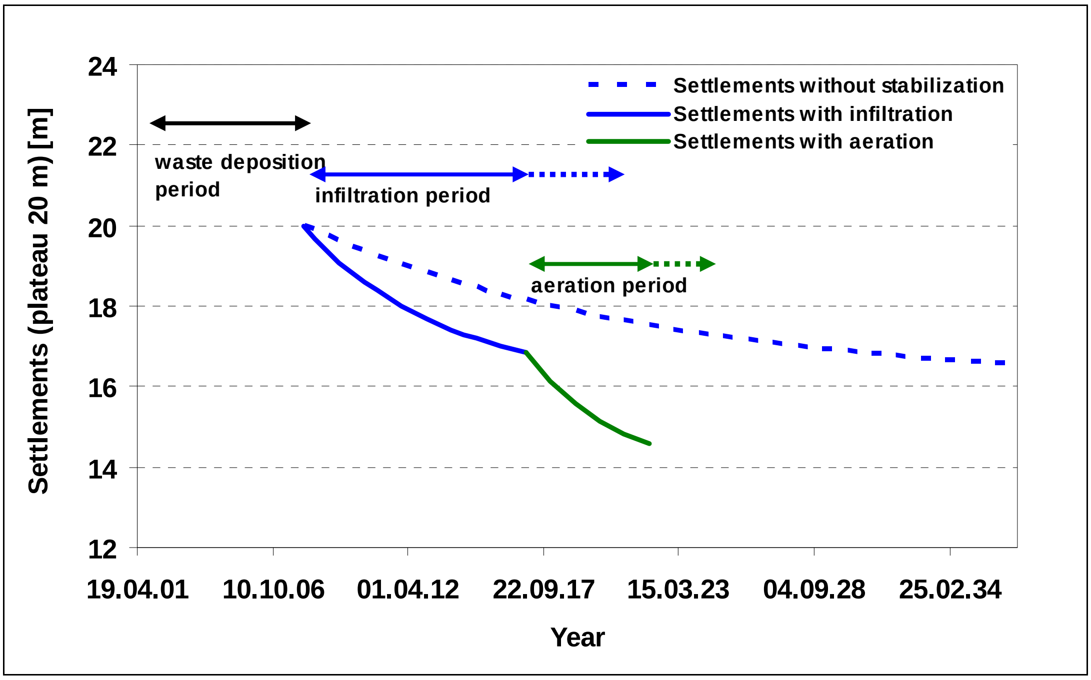


Figure 13.5 Possible development of settlements at the plateau (height of 20 m) of the landfill Kragge, depending on the infiltration and aeration

14 PRELIMINARY COST-ESTIMATES

For the landfill Kragge a preliminary cost-estimate has been established consisting of the investment costs of the installation of the enhancing technical measures infiltration and aeration as well as the yearly costs of maintenance and exploitation of both measures. The cost-estimates are based on the technical specifications of the preliminary design of the technical measures as described in the chapters 8 to 10.

Next to the costs of the technical measures it selves, the cost-estimate also comprises the costs of preparation, pré-investigations, final design and tendering procedure, measurements and monitoring, supervision and last but not least communication. An overview of the main cost-items taken into account is listed below:

- Installation of additional sampling and measuring equipment;
- Pré-investigation program;
- Final design and tendering procedure;
- Installation and construction of infiltration equipment;
- Installation and construction of the aeration equipment;
- Yearly costs for monitoring and control of infiltration period (2009-2014);
- Yearly costs for monitoring and control of aeration period (2014-2019);
- Yearly costs for communication and PR
- Post pilot waste characterization tests in 2019.
- If relevant: overhead contractors, construction supervision and contingencies in terms of percentages of the general budgets.

A highly specified break-down of these main cost-items is presented in annex 2.
All costs are related to the price-level of 2008. The cost of materials and manpower are based on unit prices conformable to the Dutch market. In order to be realistic, minimum (best-case) and maximum (worst-case|) unit-rates are taken into account. An overview of the average costs has been compiled in table 14.1

From a point of view of capital expenditure, it can be decided to postpone some investments to a later stage (see dotted lines in figure 5.1). This especially concerns the final design of aeration and the installation of the gas wells for the aerobic in situ stabilization, for which two schedules are possible:

a) Installation in parallel to the infiltration fields, as showed in figure 5.1. In this case the additional gas wells can be used for an improved gas collection rate (reduced uncontrolled emissions into the atmosphere, improved climate protection, higher energy production), before the aeration process is started (recommended option).
b) Installation at the moment when the gas production is too low to go on with the gas collection and gas utilization. Then installation of the gas blower station for aeration, gas extraction and gas purification. This is indicated by the dotted line in figure 5.1.

Standard activities with regards to operation and monitoring measures at regular intervals may be carried out by the personnel of the landfill operator working at the disposal site, or by third parties.

Table 14.1 Preliminary average cost-estimate demonstration project landfill Kragge (price level 2008)

Cost-items		Investments costs (€)	Yearly costs (€)
1	Additional measurement equipment (1)	451,000	n.a.
2	Pré-investigations	227,000	n.a.
3	Final design & final cost-estimates	34,000	n.a.
4	Tendering	35,000	n.a.
5	Infiltration (installation/maintenance) (2)	968,000	16,000
6	Infiltration (monitoring) (3)	n.a.	141,000
7	Aeration (installation/maintenance) (4)	331,000	16,000
8	Aeration (monitoring) (5)	n.a.	207,000
9	Communication & PR	n.a.	20.000
10	Post pilot waste sampling	103,000	n.a.
Totals		**2,149,000**	**2,100,000 (6)**

(1) Including drilling of 24 additional gas wells, which can be postponed to a later stage

(2) Investment in 2009

(3) during 5 years from 2009 to 2014

(4) investment in 2014

(5) during 5 years from 2014 to 2019

(6) over 10 years, but not capitalized (5 years of infiltration and 5 years of aeration)

15 LITERATURE

1. "Feasibility study sustainable emission reduction at he existing landfills Kragge and Wieringermeer in the Netherlands, generic report: Processes in the waste body and overview enhancing technical measures", Royal Haskoning/IFAS, Final report, 20 March 2009.
2. "Feasibility study sustainable emission reduction at he existing landfills Kragge and Wieringermeer in the Netherlands, specific report: Current state of the landfill Kragge", Royal Haskoning/IFAS, Final report, 25 March 2009.

Annex 1
Validation gas prognoses by TNO-model
(Oonk et al, 1994)

Introduction
Haskoning and IFAS made a feasibility study for sustainable landfilling at Kragge II. In the course of this project, IFAS made a prognoses on current gas formation and extent of stabilization for Kragge II. The prognoses are validated, based on TNO´s experiences.

Prognosis Kragge II
Prognoses here are based on the TNO model (Oonk et al, 1994). This model is a first order decay model, based on assumptions for organic carbon content in the waste. The model is validated, both in a comparison with results of landfill gas recovery projects and in a comparison with landfill gas (methane and carbon dioxide) emission measurements. First a comparison of the prognosis of the whole of Kragge II with realization of landfill gas extraction. The result is shown in the graph below.

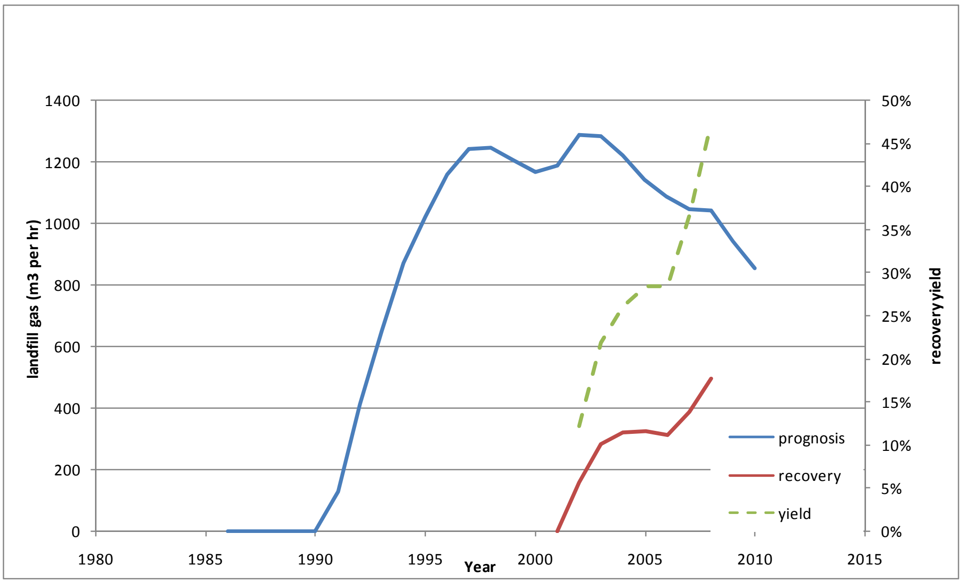


Figure 1: expected landfill gas formation and actual recovery at landfill Kragge II.

Recovery only started after 2000, and the recovery system is expanded in the period 2002/2003. At the moment recovery efficiency is about 50%, which is slightly below the expected value after closure (Boerboom, 2001). Except for the last two years it is not really possible to compare prognosis with actual recovery, so it is difficult to conclude whether the prognosis holds ground. However considering the agreement in the last few years, there is also no reason to conclude the prognosis is way off.

Prognoses Kragge II compartments 3, 4 and 5.
Using the same method, a prognosis is made for Kragge II, compartments 3,4 and 5. The result is given in the figure below.

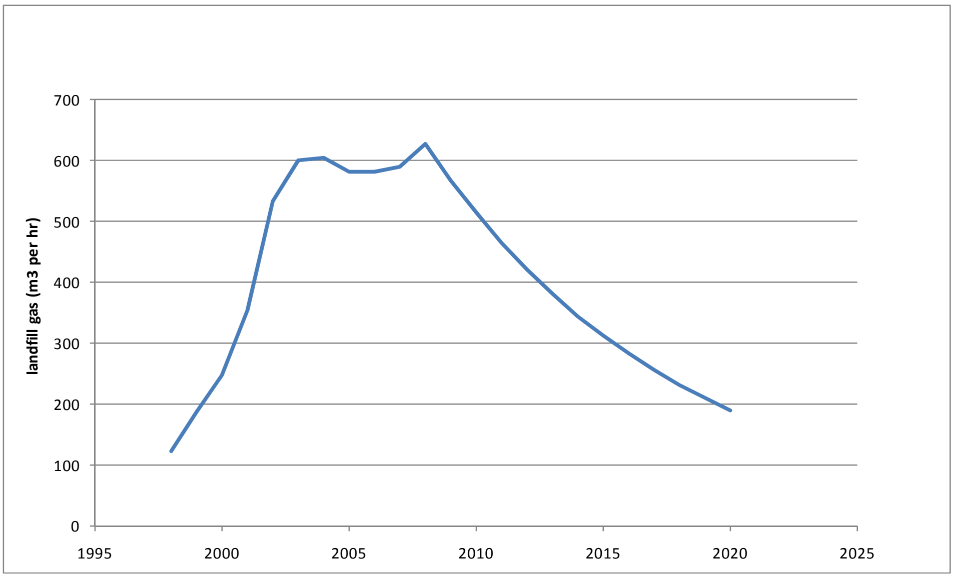


Figure 2: expected landfill gas formation at landfill Kragge II, compartments 3, 4 and 5.

Prognosis is well in line with the lower prognosis of IFAS, with a present landfill gas formation of about 600 m^3/hr, falling down to levels of about 300 m3-hr in 2015. The formation model is based on an estimation of total organic carbon, of which in reality only a limited amount (58%) will be converted to landfill gas. Figure 3 shows the expected development of average total organic carbon content, compared to the 42% of the initial organic carbon that will not be dissimilated.

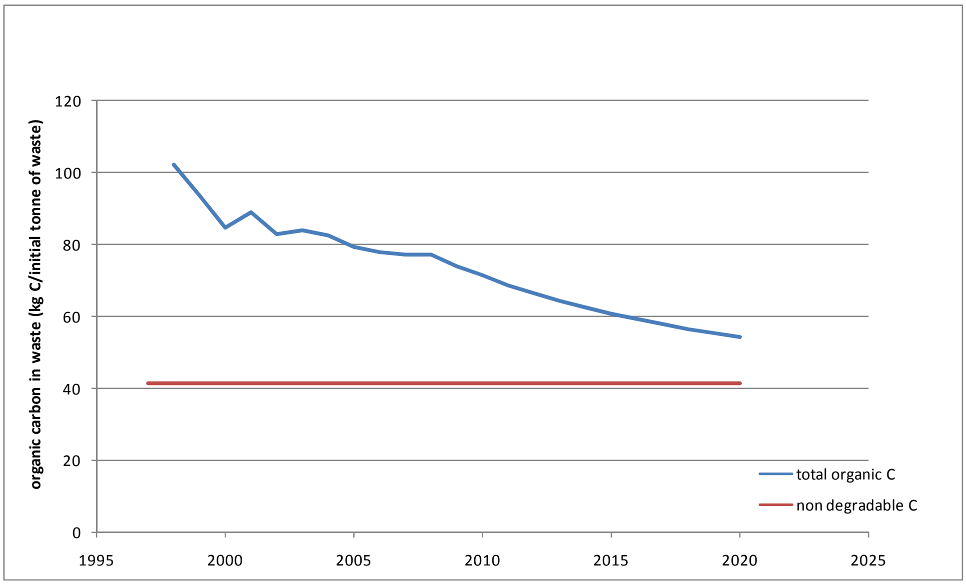


Figure 3: development of total organic carbon in the waste at Kragge II, compartments 3, 4 and 5.

At the moment (2009), about 40 kg C per ton of initial waste is still waiting to be converted to landfill gas. This is in agreement with the prediction of IFAS. So we are quite far away (about 15 years) from the remaining potential of 10 kg C per ton of initial waste, that IFAS considers a limit for aerobic conversion to be feasible.

When leachate is injected, methanogenisis will be speeded up, and halftime of biodegradation might even be reduced by 50%. This means that the limit of 10 kg C per ton of initial waste might be reached by the year 2016. However this prediction is uncertain since a) the effect of leachate infiltration on halftime is not entirely clear and b) also dissimilation (the 58% of organic carbon that in actual landfills is converted to landfill gas) might be increased as well.

Conclusions

Main conclusion is that the prognoses of IFAS are in line with the TNO prognosis. At the moment compartments 3, 4 and 5 of Kragge II still produce a lot of gas. Under normal conditions it might take 15 years before the limit value of 10 kg C per ton of initial waste is reached and aerobic landfilling becomes feasible. Under enhanced conditions this might be enhanced, but it will last at least until 2016 before it is feasible to turn Kragge II into an aerobic landfill.

Annex 2
Specified cost-estimates demonstration project landfill Kragge

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Pre-investigation program, first half of 2009 (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
Analyses on waste samples										Basic assumption: analyses on 2 samples per drilling
Sample pretreatment	2	day	800	1.000	1.600	2.000				Samples taken while drilling of 24 new gas wells
Duplicate pH-stat test, 2 compartments	4	pcs.	3.200	4.000	12.800	16.000				
Duplicate percolation leach test, 2 compartments	4	pcs.	2.800	3.400	11.200	13.600				
8 batch leach tests on individual samples, 2 compartments	2	ls.	4.900	6.000	9.800	12.000				
DOC fractionation in leachates (native pH)	4	pcs.	600	750	2.400	3.000				
Reactive organic matter, solid matrix	4	pcs.	600	750	2.400	3.000				
Reactive Fe/AL-oxydes	4	pcs.	400	500	1.600	2.000				
Carbon content analysis	24	pcs.	50	100	1.200	2.400				
Water content analysis	24	pcs.	15	30	360	720				
Water holding capacity (field capacity) analysis	24	pcs.	25	50	600	1.200				
Biological activity by respiration tests	24	pcs.	250	350	6.000	8.400				
Biological activity by gas formation tetst	24	pcs.	250	350	6.000	8.400				
Materials	1	ls.	1.800	2.200	1.800	2.200				
Geochemical modelling of leaching mechanisms	8	day	800	1.000	6.400	8.000				
Interpretation and reporting	8	day	800	1.000	6.400	8.000				
Subtotal							70.560	90.920	80.740	
Aeration tests at 10 existing gas wells during 5 weeks										
Rent of mobile aeration system	35	day	160	220	5.600	7.700				Assumed blower capacity ~ 100 - 250 m3/hr.
Supervision, maintenance and control	35	day	800	1.000	28.000	35.000				
Interpretation and reporting of test results	10	day	800	1.000	8.000	10.000				
Subtotal							41.600	52.700	47.150	
Leachate composition										
Sampling from the involved leachate collection pit (3 samples from the pit)	3	pcs.	90	100	270	300				
Analysis for NA-parameters	3	pcs.	175	175	525	525				
Analysis for ECN-parameters	3	pcs.	140	140	420	420				
Interpretation and reporting of NA and ECN parameter (current state of stabilization)	5	day	1.000	1.200	5.000	6.000				
Subtotal							6.215	7.245	6.730	
Geo-electrical measurements (by TNO)										
Geo-electrical measurement + EM31 (based upon 10 days of fieldwork)	1	ls.	37.500	50.000	37.500	50.000				
Interpretation and reporting	4	day	800	1.000	3.200	4.000				
Subtotal							40.700	54.000	47.350	
Reporting the final reference situation of the current status										
Integrated interpretation	3	day	1.000	1.200	3.000	3.600				
Preparation and supply of a draft report	2	day	1.000	1.200	2.000	2.400				
Consultations with the client	2	day	1.000	1.200	2.000	2.400				
Preparation and supply of the final report	1	day	1.000	1.200	1.000	1.200				
Subtotal							8.000	9.600	8.800	
Projectmanagement and coordination										
Project management based on an average input of 1 day per month	6	day	1.200	1.400	7.200	8.400				
Coordination and finetuning based on an average input of 1,5 days per month	9	day	800	1.000	7.200	9.000				
Subtotal							14.400	17.400	15.900	
General subtotal							181.475	231.865	206.670	
Contingencies (Technical)	10	%					18.148	23.187	20.667	
Total costs for the pre-investigation program (excl. VAT)							**199.623**	**255.052**	**227.337**	

Kragge landfill: Cells 3, 4 and 5

Preliminary Cost Estimate: installation of additional sampling and measuring equipment, first quarter of 2009 (Price level 2008)

Description	Amount	Unit	Unit rate min	Unit rate max	Subtotal min	Subtotal max	Totals min	Totals max	Totals average	Remarks
Installation of additional sampling / measuring equipment										For sufficient amounts of leachate to be infiltrated during the pilot test, 3 leachate pits will supply leachate to the infiltration system to be installed.
Supply and installation of a flow/volume meter in the leachate collection pit	1	ls.	2.000	2.500	2.000	2.500				
Supply and installation of 24 divers in 24 newly installed gas wells	24	pcs.	1.000	1.200	24.000	28.800				Divers suitable for measurement of temperature and watertable
Supply and installation of additional settlement beacons on top of the concerned cells	15	pcs.	300	400	4.500	6.000				
Subtotal							30.500	37.300	33.900	
Installation of 24 new gas wells										
Drilling in waste, 24 holes, diameter 400 mm, average depth 15 m	480	m	200	250	96.000	120.000				New gas wells are drilled in this project stage for waste sampling and installation of initial measurement equipment. Connections to aeration and extraction equipment are foreseen to be installed in later project stages (2014 and later)
Supply and installation of perforated filter pipe DA110 PN6	290	m	18	24	5.220	6.960				
Supply and installation of solid pipe DA110 PN6	270	m	18	24	4.860	6.480				
Supply and installation of end caps on perforated filter pipes	24	pcs.	20	30	480	720				
Supply and installation of gas well heads	24	pcs.	300	400	7.200	9.600				
Supply and installation of gas butterfly valves DN 100	24	pcs.	400	550	9.600	13.200				
Supply and installation of flexible tubes	24	pcs.	50	70	1.200	1.680				
Supply and installation of gravel/filter material around well shafts	52	m3	40	65	2.080	3.380				
Supply and installation of clay/mineral sealing around well shafts	8	m3	50	70	400	560				
Subtotal							127.040	162.580	144.810	
Connection of existing gas wells to the aeration/extraction system										
Supply and installation of gas butterfly valves DN 200	2	pcs.	450	600	900	1.200				
Supply and installation of flexible tubes	4	pcs.	50	70	200	280				
Supply and installation of solid pipe PEHD 200 SDR 17,5	280	m	22	28	6.160	7.840				
Preparation for laying of pipelines (digging trenches, preparing materials)	280	m	12	18	3.360	5.040				
Supply and installation of pipe support material and sand filling	44	m3	20	22	880	968				
Installing pipe covering of former excavated and stored soil, thickness 0.2 – 0.3 m	44	m3	4,5	6,5	198	286				
Supply and installation of T-branches	3	pcs.	150	200	450	600				
Subtotal							12.148	16.214	14.181	
Pipes										
Supply and installation of pipes PEHD DA110 PN6	2.300	m	16	20	36.800	46.000				
Supply and installation of flexible tubes	12	pcs.	50	70	600	840				
Supply and installation of connection tubes DA 110 (with stub flange and backing ring)	24	pcs.	70	90	1.680	2.160				
Supply and installation of condensate traps	10	pcs.	250	300	2.500	3.000				
Preparation for laying of pipelines (digging trenches, preparing materials)	2.300	m	8	10	18.400	23.000				
Supply and installation of pipe support material and sand filling	370	m3	20	22	7.400	8.140				
Installing pipe covering of former excavated and stored soil, thickness 0.2 – 0.3 m	370	m3	4,5	6,5	1.665	2.405				
Subtotal							69.045	85.545	77.295	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: installation of additional sampling and measuring equipment, first quarter of 2009 (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
Gas collection and distribution station										
Supply and installation of a container, 40 ft	1	pcs.	3.500	4.500	3.500	4.500				
Supply and installation of a sampling pipe system complete, coated steel (1 for aeration and 1 for suction)	2	pcs.	4.000	6.000	8.000	12.000				
Supply and installation of gas butterfly valves and gauge connection NW 100	48	pcs.	400	550	19.200	26.400				
Supply and installation of connection tubes (connections including sampling pipe and tube)	24	pcs.	170	200	4.080	4.800				
Supply and installation gas butterfly valves for main sampling pipe NW 160	2	pcs.	400	550	800	1.100				
Supply and installation of electronic installations (1 light + 1 connection point)	1	ls.	200	500	200	500				
Supply of complete sets of documentation concerning all installed technical equipment and operation procedures	4	pcs.	1.500	2.500	6.000	10.000				
Subtotal							41.780	59.300	50.540	
Waste sampling during drilling of the new gas wells										
On site assistance during sampling	1	day	800	1.000	800	1.000				
During drilling of 24 gaswells sampling at depths of 3, 10 and 18 m below groundlevel	36	pcs.	150	200	5.400	7.200				
Subtotal							6.200	8.200	7.200	
General subtotal							286.713	369.139	327.926	
Overhead contractors										
Implementation costs	3	%					8.601	11.074	9.838	
General costs, profit and risk	7	%					20.070	25.840	22.955	
Construction supervision										
Supervision, contracting, commissioning	15	%					43.007	55.371	49.189	
Subtotal							358.391	461.424	409.908	
Contingencies (Technical)	10	%					35.839	46.142	40.991	
Total costs for installation of additional sampling and measuring equipment (excl. VAT)							**394.230**	**507.566**	**450.898**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Final design & Tendering, second quarter of 2009 (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
Final design of infiltration and aeration equipment										Estimates are based on Design & Construct types of contracts
Draft design	15	day	1.000	1.200	15.000	18.000				
Draft cost-estimate	5	day	1.000	1.200	5.000	6.000				
Consultation with client	3	day	1.000	1.200	3.000	3.600				
Final cost-estimate	5	day	1.000	1.200	5.000	6.000				
Subtotal							28.000	33.600	30.800	
Tendering										Estimates are based on Design & Construct types of contracts
Preparation of tender documents	10	day	1.000	1.200	10.000	12.000				
Tendering procedure	15	day	1.000	1.200	15.000	18.000				
Contracting	4	day	1.000	1.200	4.000	4.800				
Subtotal							29.000	34.800	31.900	
General subtotal							57.000	68.400	62.700	
Contingencies (Technical)	10	%					5.700	6.840	6.270	
Total costs for the design and tendering (excl. VAT)							**62.700**	**75.240**	**68.970**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: installation and construction of infiltration equipment, middle of 2009 (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
General items										
Installation and maintenance construction site on and near the concerned landfill cells	1	ls.	23.000	27.000	23.000	27.000				
Employment and emission protection during construction	1	ls.	5.000	10.000	5.000	10.000				
Measurements prior to construction works	1	ls.	3.000	4.000	3.000	4.000				
Use of office facilities	1	ls.	5.000	7.000	5.000	7.000				
Use of instruments, computers, etc.	1	ls.	2.000	2.400	2.000	2.400				
Making as-built drawings	1	ls.	4.000	6.000	4.000	6.000				
Subtotal							42.000	56.400	49.200	
Power supply (for aeration equipment too)										
Preparation and installation of power connections to exsisting on site facilities	1	ls.	3.000	5.000	3.000	5.000				
Supply and installation of a buried three phase cable, power capacity 40 – 60 kW	300	m	20	25	6.000	7.500				
Supply and installation of a buried three phase cable, power capacity 10 – 20 kW	300	m	18	22	5.400	6.600				
Supply and installation of wire protection sleeves	600	m	2	5	1.200	3.000				
Subtotal							15.600	22.100	18.850	
Infiltration fields										
Excavation works for 14 infiltration fields. Outcoming soil to be put in nearby on site storage	15.000	m3	4	6	60.000	90.000				
Supply and installation of gravel/recycling material, thickness 0.5 – 0.8 m	5.000	m3	25	55	125.000	275.000				
Supply and installation of slotted filter pipes DN 100	1.200	m	10	15	12.000	18.000				
Supply and installation of PEHD well shafts in the infiltration fields	14	pcs.	2.500	3.500	35.000	49.000				
Supply and installation of permeable protective sheets on the infiltration fields	10.000	m2	5	6	50.000	60.000				
Installation of a soil cover from on site available material, thickness 1 m	10.000	m3	3,5	4,5	35.000	45.000				
Supply and installation of 4 piezometers per infiltration field	56	pcs.	200,0	250,0	11.200	14.000				
Subtotal							328.200	551.000	439.600	
Supply pipes										
Supply and installation of leachate transport pipes DN 60 PN 10	1.600	m	18	24	28.800	38.400				
Subtotal							28.800	38.400	33.600	
Water distribution unit										
Supply and installation of a container, 40 ft	1	pcs.	3.500	4.500	3.500	4.500				
Supply and installation of a complete distribution bar	1	ls.	2.500	3.000	2.500	3.000				
Supply and installation of leachate valves DN 60	14	pcs.	400	550	5.600	7.700				
Supply and installation of flexible connection tubes DN 60 (connection between distribution bar ai filling pipes)	14	pcs.	150	200	2.100	2.800				
Supply and installation of a flow control unit, fully integrated in the system control	1	ls.	2.000	2.500	2.000	2.500				
Supply and installation of a self-priming pump 80 - 120 m3/hr, fully integrated in the system control	1	pcs.	4.000	5.000	4.000	5.000				
Supply and installation of all necessary electronic installations	1	ls.	20.000	30.000	20.000	30.000				
Subtotal							39.700	55.500	47.600	
Leachate storage tank										
Supply and installation of a leachate storage tank with valves etc., volume 30 m^3	4	pcs.	6.000	7.000	24.000	28.000				
Supply and installation of automatic water level registration equipment, fully integrated in tl system control	4	ls.	1.500	1.700	6.000	6.800				
Subtotal							30.000	34.800	32.400	
Filter for leachate purification / settlement tank										
Supply and installation of a complete encapsulated sand filter for high pressures, including pipe valves and other auxiliairy equipment. (Designed for high pressure)	1	ls.	14.000	20.000	14.000	20.000				
Subtotal							14.000	20.000	17.000	
Leachate supply pump, main supply pipe and excavation works										
Supply and installation of self-priming pumps with electricity supply, valves and auxiliai equipment, installed inside the pumppits north of the landfill, fully integrated in the system control. Pump capacity: ~5 m3/hr each.	3	pcs.	4.000	5.000	12.000	15.000				
Supply and installation of the main leachate supply pipe DN 80 PN 10 (tank filling pipe fro shaft/pumppit)	500	m	18	24	9.000	12.000				
Preparation for laying of pipelines (digging trenches, preparing materials)	2.100	m	12	18	25.200	37.800				
Supply and installation of pipe support material and sand filling	336	m3	18	22	6.048	7.392				
Installing pipe covering of former excavated and stored soil, thickness 0.2 – 0.3 m	630	m3	4,5	6,5	2.835	4.095				
Subtotal							55.083	76.287	65.685	
General subtotal							553.383	854.487	703.935	
Overhead contractors										
Implementation costs	3	%					16.601	25.635	21.118	
General costs, profit and risk	7	%					38.737	59.814	49.275	
Construction supervision										
Supervision, contraction, commissioning	15	%					83.007	128.173	105.590	
Subtotal							691.729	1.068.109	879.919	
Contingencies (Technical)	10	%					69.173	106.811	87.992	
Total costs for installation and construction of infiltration equipment (excl. VAT)							**760.902**	**1.174.920**	**967.911**	

Kragge landfill: Cells 3, 4 and 5 Preliminary Cost Estimate: installation and construction of aeration equipment in 2014 (Price level 2008)										
Description	**Amount**	**Unit**	**Unit rate**		**Subtotal**		**Totals**			**Remarks**
			min	max	min	max	min	max	average	
General items										
Installation and maintenance of the construction site on and near cell 6	1	ls.	23.000	27.000	23.000	27.000				
Employers and emission protection during construction	1	ls.	5.000	10.000	5.000	10.000				
Measurements prior to construction works	1	ls.	3.000	4.000	3.000	4.000				
Use of office facilities	1	ls.	5.000	7.000	5.000	7.000				
Use of instruments, computers, etc.	1	ls.	2.000	2.400	2.000	2.400				
Making as-built drawings	1	ls.	4.000	6.000	4.000	6.000				
Subtotal							42.000	56.400	49.200	
Gas blower station (extraction and aeration)										
Supply and installation of a container, 40 ft	1	pcs.	3.500	4.500	3.500	4.500				
Supply and installation of ventilators for climate control in the container	1	pcs.	1.000	1.500	1.000	1.500				
Supply and installation heating systems for climate control in the container	1	pcs.	1.000	1.500	1.000	1.500				
Supply and installation of a complete aeration system: gas filter, automated valves, thermomete flow meter, pressure control, integration in system control etc.	1	ls.	10.000	15.000	10.000	15.000				
Supply and installation of a side channel compressor, total capacity 2500 m^3/h with integrated system control	1	pcs.	45.000	60.000	45.000	60.000				
Supply and installation of a complete landfill gas and exhausts suction system: automated valve thermometer, flow meter, pressure control, integration in system control etc.	1	ls.	10.000	15.000	10.000	15.000				
Supply and installation of a rotary piston compressor, total capacity 2500 m^3/h with integrated system control	1	pcs.	45.000	60.000	45.000	60.000				
Supply and installation of gas analysis equipment for CH_4, CO_2 and O_2, integrated in system control	1	ls.	2.000	3.000	2.000	3.000				
Supply of complete sets of documentation concerning all installed technical equipment ar operation procedures	4	pcs.	1.500	2.500	6.000	10.000				
Supply and installation of all necessary electronic installations	1	ls.	5.000	7.000	5.000	7.000				
Supply and installation of all necessary safety devices, equipment and procedures	1	ls.	20.000	25.000	20.000	25.000				
Supply and installation of a pipe system, connecting to the gas distribution station NW 16coated steel/PEHD PN 6 (2 * 10 m)	2	pcs.	1.000	15.000	2.000	30.000				
Subtotal							150.500	232.500	191.500	
Subtotal							192.500	288.900	240.700	
Overhead contractors										
Implementation costs	3	%					5.775	8.667	7.221	
General costs, profit and risk	7	%					13.475	20.223	16.849	
Construction supervision										
Supervision, contraction, commissioning	15	%					28.875	43.335	36.105	
Subtotal							240.625	361.125	300.875	
Contingencies (Technical)	10	%					24.063	36.113	30.088	
Total costs for installation and construction of aeration equipment (excl. VAT)							**264.688**	**397.238**	**330.963**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Yearly costs for monitoring and control of the infiltration period (2009 - 2014), Price level 2008

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
On site sampling and measurements										
Weekly measurment of:										
- Volume of leachate from the collection pit to the local discharge facility										
- Volume leachate from the collection pit discharged to the storage tank for infiltration										
- Volume of leachate infiltrated in each individual infiltration field (14 fields)										All weekly measurments performed in a 1 day per week campaign
- Leachate level in each of the 14 infiltration fields	52	day	500	600	26.000	31.200				
Volume of landfill gas collected in each of the 47 gas wells every 14 days	26	pcs.	50	60	1.300	1.560				
Reading out the divers (temperature and water level) in 47 gas wells once a month	12	pcs.	50	60	600	720				
Measuring of settlements in every trimester (~38 settlement beacons)	4	pcs.	2.000	2.500	8.000	10.000				
Sampling leachate from cell 3, 4 and 5 discharged to purification plant every two months	6	pcs.	180	200	1.080	1.200				
Sampling leachate from the infiltration tank to infiltration fields every two months	6	pcs.	90	100	540	600				
Measuring gas composition (CH_4, CO_2, O_2) in 47 gas wells every month	12	pcs.	2.000	2.400	24.000	28.800				
Subtotal							61.520	74.080	67.800	
Chemical analyses										
Leachate analysis (NA + ECN) from cell 3, 4 and 5 to purification plant every two months	6	pcs.	975	1.050	5.850	6.300				
Leachate analysis (NA + ECN) from iniltration tank to infiltration fields every two months	6	pcs.	325	350	1.950	2.100				
Subtotal							7.800	8.400	8.100	
Maintenance										
Yearly small maintenance of the infiltration equipment and related facilities.	1	ls.	15.000	17.000	15.000	17.000				
Subtotal							15.000	17.000	16.000	
Operation costs										
Yearly operational costs, specifically connected to the pilot projects	1	ls.	10.000	20.000	10.000	20.000				
Subtotal							10.000	20.000	15.000	
Management of data, interpretations and over all project management										
Collection of daily meteorological data every month	12	pcs.	50	60	600	720				
Collection, processing and management of all data (Dbase/Remedy)	6	day	800	1.000	4.800	6.000				
Projectmanagement and coordination (1 day every month)	12	day	1.000	1.200	12.000	14.400				
Meetings (once a year) 10 persons per meeting	10	day	1.000	1.200	10.000	12.000				
Progress reports once a year	1	pcs.	5.000	6.000	5.000	6.000				
Subtotal							32.400	39.120	35.760	
General subtotal							126.720	158.600	142.660	
Contingencies (Technical)	10	%					12.672	15.860	14.266	
Total costs for the pre-investigation program (excl. VAT)							**139.392**	**174.460**	**156.926**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Yearly costs for monitoring and control of the aeration period (2014 - 2019), Price level 2008

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
On site sampling and measurements										
Weekly measurment of:										
- Volume of leachate from the collection pit to the local discharge facility										
- Volume leachate from the collection pit discharged to the storage tank for infiltration										
- Volume of leachate infiltrated in each individual infiltration field (14 fields)										All weekly measurments performed in a 1 day per week campaign
- Leachate level in each of the 14 infiltration fields	52	day	500	600	26.000	31.200				
Volume of landfill gas collected in each of the 47 gas wells every 14 days	26	pcs.	50	60	1.300	1.560				
Reading out the divers (temperature and water level) in 47 gas wells once a month	12	pcs.	50	60	600	720				
Measuring of settlements in every trimester (~38 settlement beacons)	4	pcs.	2.000	2.500	8.000	10.000				
Sampling leachate from cell 3, 4 and 5 discharged to purification plant every two months	6	pcs.	180	200	1.080	1.200				
Sampling leachate from the infiltration tank to infiltration fields every two months	6	pcs.	90	100	540	600				
Measuring gas composition (CH_4, CO_2, O_2) in 47 gas wells every month	12	pcs.	2.000	2.400	24.000	28.800				
Subtotal							61.520	74.080	67.800	
Chemical analyses										
Leachate analysis (NA + ECN) from cell 3, 4 and 5 to purification plant every two months	6	pcs.	975	1.050	5.850	6.300				
Leachate analysis (NA + ECN) from iniltration tank to infiltration fields every two months	6	pcs.	325	350	1.950	2.100				
Subtotal							7.800	8.400	8.100	
Maintenance										
Yearly small maintenance of the infiltration equipment and related facilities.	1	ls.	15.000	17.000	15.000	17.000				
Subtotal							15.000	17.000	16.000	
Operation costs										
Yearly operational costs, specifically connected to the pilot projects	1	ls.	20.000	30.000	20.000	30.000				
Subtotal							20.000	30.000	25.000	
Exhaust gas treatment unit										
Rental costs of a fully equipped, connected and functioning gas treatment unit	1	ls.	45.000	55.000	45.000	55.000				
Subtotal							45.000	55.000	50.000	
Management of data, interpretations and over all project management										
Collection of daily meteorological data every month	12	pcs.	50	60	600	720				
Collection, processing and management of all data (Dbase/Remedy)	6	day	800	1.000	4.800	6.000				
Projectmanagement and coordination (1 day every month)	12	day	1.000	1.200	12.000	14.400				
Meetings (once a year) 10 persons per meeting	10	day	1.000	1.200	10.000	12.000				
Progress reports once a year	1	pcs.	5.000	6.000	5.000	6.000				
Subtotal							32.400	39.120	35.760	
General subtotal							181.720	223.600	202.660	
Contingencies (Technical)	10	%					18.172	22.360	20.266	
Total costs for the pre-investigation program (excl. VAT)							**199.892**	**245.960**	**222.926**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Yearly costs for Communications & PR (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
Communications & PR										Estimates are based on Design & Construct types of contracts
Preparation of papers, seminars, external communication, workshops, press releases	1	ls.	8.000	10.000	8.000	10.000				
Communication with competent authorities (Province Zuid-Holland, IPO, VROM, EU, VA)	1	ls.	8.000	10.000	8.000	10.000				
Subtotal							16.000	20.000	18.000	
General subtotal							16.000	20.000	18.000	
Contingencies (Technical)	10	%					1.600	2.000	1.800	
Total costs for the design and tendering (excl. VAT)							**17.600**	**22.000**	**19.800**	

Kragge landfill: Cells 3, 4 and 5

Preliminary Cost Estimate: Post-pilot waste characterization tests, 2019 (Price level 2008)

Description	Amount	Unit	Unit rate		Subtotal		Totals			Remarks
			min	max	min	max	min	max	average	
Waste sampling during drilling of the new gas wells										
On site assistance during sampling	1	day	800	1.000	800	1.000				
Drilling and sampling on 24 predefined places at depths of 3, 10 and 18 m below groundlevel	36	pcs.	250	400	9.000	14.400				
Subtotal							9.800	15.400	12.600	
Analyses on waste samples										Basic assumption: analyses on 2 samples per drilling
Sample pretreatment	2	day	800	1.000	1.600	2.000				Samples taken while drilling of 24 new gas wells
Duplicate pH-stat test, 2 compartments	4	pcs.	3.200	4.000	12.800	16.000				
Duplicate percolation leach test, 2 compartments	4	pcs.	2.800	3.400	11.200	13.600				
8 batch leach tests on individual samples, 2 compartments	2	ls.	4.900	6.000	9.800	12.000				
DOC fractionation in leachates (native pH)	4	pcs.	600	750	2.400	3.000				
Reactive organic matter, solid matrix	4	pcs.	600	750	2.400	3.000				
Reactive Fe/AL-oxydes	4	pcs.	400	500	1.600	2.000				
Carbon content analysis	24	pcs.	50	100	1.200	2.400				
Water content analysis	24	pcs.	15	30	360	720				
Water holding capacity (field capacity) analysis	24	pcs.	25	50	600	1.200				
Biological activity by respiration tests	24	pcs.	250	350	6.000	8.400				
Biological activity by gas formation tetst	24	pcs.	250	350	6.000	8.400				
Materials	1	ls.	1.800	2.200	1.800	2.200				
Geochemical modelling of leaching mechanisms	8	day	800	1.000	6.400	8.000				
Interpretation and reporting	8	day	800	1.000	6.400	8.000				
Subtotal							70.560	90.920	80.740	
General subtotal							80.360	106.320	93.340	
Contingencies (Technical)	10	%					8.036	10.632	9.334	
Total costs for the pre-investigation program (excl. VAT)							**88.396**	**116.952**	**102.674**	

Kragge landfill: Cells 3, 4 and 5
Preliminary Cost Estimate: Grand Total Summary

Description	Year																	
	2009			2010			2011			2012			2013			2014		
	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg
Installation of additional sampling and measurement equipment	394.230	507.566	450.898															
Pre-investigation program	199.623	255.052	227.337															
Final design & Tendering	62.700	75.240	68.970															
Installation and construction of infiltration equipment	760.902	1.174.920	967.911															
Installation and construction of aeration equipment																264.688	397.238	330.963
Yearly costs of operations and monitoring for infiltration	69.696	87.230	78.463	139.392	174.460	156.926	139.392	174.460	156.926	139.392	174.460	156.926	139.392	174.460	156.926	69.696	87.230	78.463
Yearly costs of operations and monitoring for aeration																199.892	245.960	222.926
Total yearly costs																		
Communications & PR	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800
Post-pilot waste characterization tests																		
Not capitalized grand total (excl. VAT)	**1.504.751**	**2.122.007**	**1.813.379**	**156.992**	**196.460**	**176.726**	**156.992**	**196.460**	**176.726**	**156.992**	**196.460**	**176.726**	**156.992**	**196.460**	**176.726**	**551.876**	**752.428**	**652.152**

Preliminary Cost Estimate: Grand Total Summary

Description															
	2015			2016			2017			2018			2019		
	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg
Installation of additional sampling and measurement equipment															
Pre-investigation program															
Final design & Tendering															
Installation and construction of infiltration equipment															
Installation and construction of aeration equipment															
Yearly costs of operations and monitoring for infiltration															
Yearly costs of operations and monitoring for aeration	199.892	245.960	222.926	199.892	245.960	222.926	199.892	245.960	222.926	199.892	245.960	222.926	199.892	245.960	222.926
Total yearly costs															
Communications & PR	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800	17.600	22.000	19.800
Post-pilot waste characterization tests													88.396	116.952	102.674
Not capitalized grand total (excl. VAT)	**217.492**	**267.960**	**242.726**	**217.492**	**267.960**	**242.726**	**217.492**	**267.960**	**242.726**	**217.492**	**267.960**	**242.726**	**305.888**	**384.912**	**345.400**

Year	**Not capitalized costs (excl. VAT)**		
	min	max	avg
2009	1.504.751	2.122.007	1.813.379
2010	156.992	196.460	176.726
2011	156.992	196.460	176.726
2012	156.992	196.460	176.726
2013	156.992	196.460	176.726
2014	551.876	752.428	652.152
2015	217.492	267.960	242.726
2016	217.492	267.960	242.726
2017	217.492	267.960	242.726
2018	217.492	267.960	242.726
2019	305.888	384.912	345.400
Totals	3.860.450	5.117.027	4.488.738