WATER INFILTRATION FOR ENHANCED IN SITU STABILIZATION

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SUMMARY: In order to maintain and intensify landfill gas production, the biological processes in the landfill body should be accelerated. For this purpose, optimization of the water balance in the landfill body by means of controlled moistening is required. Due to the intensified microbial decomposition of organic waste components, accelerated biological stabilization as well as conversion into a low-emission state is achieved. As a basis for the implementation of infiltration measures, determination of the water balance and evaluation of the present and future emission potentials is required. In order to be able to assess the effects of both the existing water deficiency and water infiltration with regard to the stabilization process and landfill after-care, leachate and landfill gas emissions must be determined and both qualitatively and quantitatively forecasted. The required water addition quantity may thus be assessed and technical infiltration systems be selected and installed which are suitable for the respective site.

1. INTRODUCTION

Within a few months of the installation of a surface sealing system, a collapse (partly drastic) in landfill gas production could be ascertained at different landfills. The limited water movement in the landfill body and the effects of desiccation are supposedly the main causes for the latter. Landfills with low rainfall introduction (low climatic leachate formation) or sites where the waste was emplaced in a relatively dry state (water content below moisture optimum) show lower landfill gas production than expected (taking into consideration the waste composition). In order to reduce the emission potential of the landfill body within the shortest possible period of time and, thereby achieve long-term environmental compatibility, further-reaching and controlled degradation of the organic components should be implemented though.

Considering this, the point in question is whether the biodegradation processes and thus the gas production may be maintained (or even optimized) by means of humidification measures.

In cases where uncontrolled humidification due to defect surface sealing takes place subsequent to the completion of the landfill after-care, the increasing microbial activity may lead to unwelcome and uncontrolled emissions of leachate and landfill gas and, as a result, to environmental contamination. In order to avoid this, stabilization of the landfill body within good time should be a target.

Basically, horizontal or vertical infiltration systems are possible technical systems for humidification and irrigation. The choice and design of such systems must be made taking into consideration site-specific aspects as well as the adjustability to the infiltration medium.

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2. TARGETS

Generally, controlled humidification and irrigation of sealed and dry landfill areas aim to:

- avoid the unwelcome delay of the reaction processes in the landfill body due to water deficiency and desiccation effects
- accelerate stabilization of the deposited waste for the sustained reduction of the emission potential of the landfill. This is achieved via the initiation of biochemical processes which lead to the accelerated degradation of the organic waste components and, thus, to their conversion into landfill gas.
- controlled reduction of the emission and risk potential which reduces the expenditure with regard to long-term after-care, meaning that
  - after-care measures require less effort over a shorter period of time
  - the risk of long-term and cost-intensive redevelopment demands due to renewed pollutant mobilization is significantly reduced
- utilize the landfill body as fixed-bed reactor in order to reduce leachate contamination

During humidification, only as much water is introduced into the landfill body as it may take up without leachate effluents worth mentioning occurring at the landfill base whilst irrigation aims to overshoot the water holding capacity of the landfill body in order to use the latter as a percolation reactor. As regards irrigation, water serves as a transport, absorption and extraction medium for the reduction of mobilizable waste components. Due to the accelerated mobilization of waste components, the leachate collection and treatment system may be supposed to meet higher demands. However, the increased treatment expenditure is only required over a determinate period of time. Leaching processes are anticipated by this procedure which, in the medium or long term, leads to a reduction of the treatment expenditure and of the costs involved.

3. BOUNDARY CONDITIONS

3.1 Site conditions

Whether leachate recirculation may be recommended or not, depends mainly upon site-specific individual examination, taking into consideration legal, ecological, technical and economical aspects. The following premises in accordance with the German Landfill Ordinance (Deponie-verordnung – DepV, 2003) must be observed:

- **qualified bottom sealing**: mineral sealing with a thickness of at least 60 cm, with a percolation coefficient of $k < 1x10^{-8}$ m/s; The values measured subsequent to the emplacement, and noted in the reports for approval, are decisive
- **working drainage system**: proof test using the results of the regular camera controls in connection with the leachate quantities drained off during previous years **or** other possibilities of ensured leachate collection, e.g. vertical enclosing of the landfill using a slurry wall in connection with a dewatering system, producing an internally sloping gradient
- **static stability of the landfill body**: examination of the free slopes when infiltration takes place within the area close to the slope and the batter is steeper than 1:5
- **relevant quantities of native-organic substances (usefulness of the measure)**: this premise is met when mainly domestic waste was deposited in the section in question during the preceding years

- **working active degasifier (for the collection of gas during increased gas production)**: proof test concerning the proper state and operation of the plant using the operating log or the annual report
- **controlled infiltration**: introduction using infiltration drains or lances arranged in a grid, spread over the area and equipped with rate meters
- **control of the gas and water balance**: sufficiently available data about the leachate and landfill gas balance of the respective landfill section before infiltration; limitation of the added water quantity to the degree required for sustained activation of biodegradation processes, control of leachate and gas quantities during infiltration

During the implementation of infiltration measures, a site-specific measure-accompanying monitoring program must be installed. On the one hand, the latter serves as success control and on the other as instrument allowing instant reaction to any possible problems that arise. The following characteristic values must be recorded at regular intervals:

- landfill gas production and gas composition
- added water quantities - separately for each landfill section, if required
- leachate collection quantity and leachate quality
- effects of the infiltration measures on the landfill body itself, e.g.
  - moisture content and water distribution in the landfill body
  - mechanical stability of the landfill body – in particular the settling behavior and static stability in the slope areas

3.2 Assessments with regard to the water balance of the landfill body

The contemplation of the water balance is the basis for the planning of the measures regarding controlled humidification / irrigation of the landfill body. In figure 1, the main influential factors on the water balance of the landfill are represented schematically. The water balance of a landfill may be described by means of the water balance equation where L_F describes the proportion of precipitation which, after the reduction of evaporation and surface effluent, is actually introduced into the landfill body:

$$P - V_E - V_T - E_S - S \pm R \pm W_D + W_C = E_B$$

with

P	Precipitation, controlled water addition, if required	R	Retention
V_E	Evaporation	W_D	Water demand / release from biological conversion
V_T	Transpiration	W_C	Consolidation
E_S	Effluent surface	E_B	leachate effluent at the landfill basis (into a drainage system res. into the underground in cases where no bottom sealing exists)
S	Storage		
L_F	Climatic leachate formation $L_F = P - V_E - V_T - E_S$		

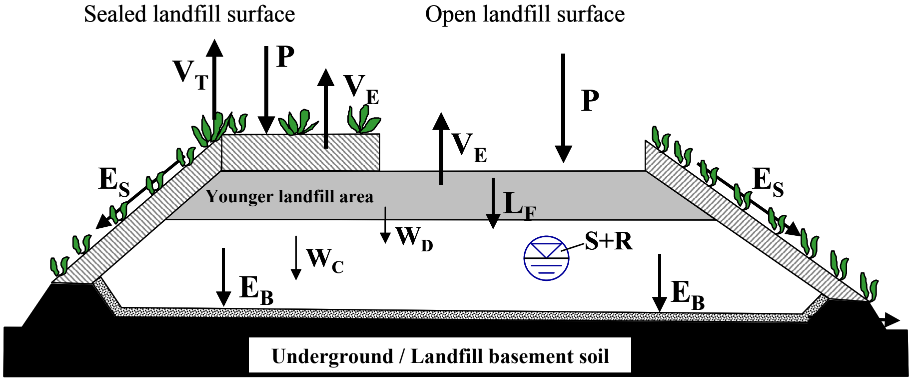

Figure 1: Influential factors on the water balance of a landfill (according to Heyer et al., 2000) These factors should be examined very intensely with regard to site specific aspects, in order to be able (in the preliminary stages already) to assess the influence of infiltration, to avoid negative spin-offs and to carry out the measures cost-effectively.

3.3 Assessment of the water addition quantity for controlled infiltration

By means of controlled humidification, the water content shall be optimized with an aim to increasing the microbial conversion activity and thus, the production of landfill gas. Practice has shown that, although the optimum water content depends upon the waste composition and age, the following effects on the anaerobic degradation processes in the landfill body may be expected:

- biodegradation processes are inhibited, in part significantly, at water contents < 30 %
- biodegradation processes proceed with restrictions at water contents < 40 % (depending on the age and degree of degradation of the waste)
- an optimum biodegradation process occurs at water contents > 40 %

Therefore, a water content of at least 35% should be achieved. For controlled leaching of the waste body (irrigation), the water content is enhanced until the water holding capacity of the waste is exceeded, using the excess water for percolation. The specific water quantity to be added may be determined using the following equation:

$$q_{H2O} = W / M_{ACT} = (w_{req.} - w_{ACT}) / ((1 - w_{req.}) \bullet \rho_{H2O})$$

q_{H2O}	specific water quantity to be added [$m^3/Mg_{wet\ weight}$]
W	water volume for the adjustment of a required water content [m^3]
M_{ACT}	wet weight, of which the water content of the waste shall be enhanced [Mg]
$w_{req.}$	required water content (e.g. maximum water holding capacity) [-]
w_{ACT}	existing water content before the addition of water [-]
ρ_{H2O}	water density 1 Mg/m^3

The required res. optimum water addition quantity and infiltration rate depends on a variety of factors:

- Local conditions
  - climatic conditions
  - landfill geometry (deposition volume and height, landfill surface, in particular the surface sealing and batter, amongst others)

- waste consistency (consideration of different landfill areas, if required): waste composition, thickness of the deposition res. water permeability, available void ratio, storage capacity, potential regarding the formation of landfill gas

- Targets of the treatment
  - humidification in order to enhance the production of landfill gas - water addition quantity: 100 – 200 $l/m^3_{deposition\ volume}$ (empirical values / average quantity in numerous landfills)
  - irrigation for the accelerated leaching of the waste body - water addition quantity: up to 10 times higher than the quantity used for humidification

Calculation example - humidification: The enhancement of the water content of a landfill section (with a height of 20 m and an average moisture density of 1 Mg/m^3) from 30% to 40% within one year would require an irrigation rate of 3.22 $m^3/(m^2{\cdot}a)$ corresponds to $1.02{\bullet}10^{-7}$ m/s (converted). Theoretically, a minimum permeability of approx. $1{\bullet}10^{-7}$ m/s would be sufficient in order that this irrigation rate prevents water damming in the landfill body. However, due to stability requirements, higher permeabilities are required in practice (Heyer, 2003).

Compared with the humidification processes which aim principally to intensify biodegradation processes, significantly higher water throughputs are required for the de-loading of the water-soluble contaminants and the heavily degradable or non-degradable organic compounds.

Calculation example - irrigation: As regards specific irrigation, an irrigation rate of 2 m/a for a landfill section with a height of 20 m (moisture density 1 Mg/m^3) and a water content of 40% (where the waste is water-saturated and no more water storage capacity is available) would amount to a hydraulic retention time (period of time required for the complete exchange of the water volume) of 4 years. With 6 mm/d, the irrigation rate would be 7 times higher (a rough estimate) in this example than the average climatic leachate formation in Germany (Heyer, 2003).

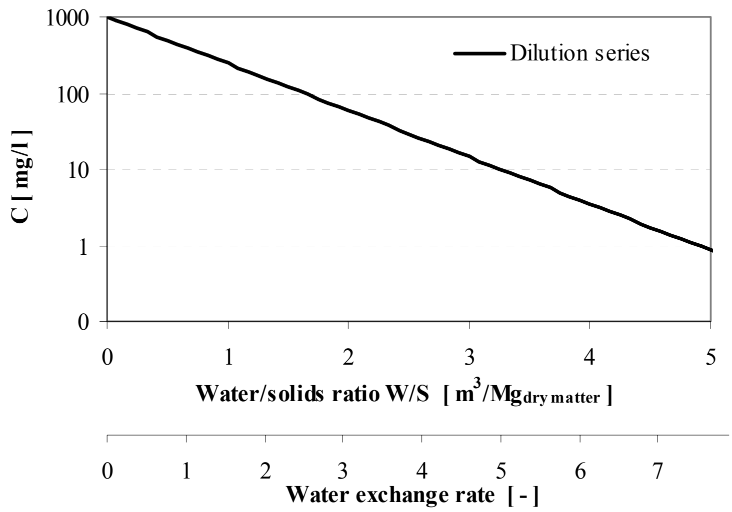

Figure 2: Decrease in the leachate concentration as a result of dilution (Heyer, 2003)

Calculation example - leaching: In order to reduce a leachate concentration of 1,000 mg/l by two decimal powers to 10 mg/l by means of irrigation measures – only using the dilution effect – the water volume, W, must be exchanged almost 5 times. At a water content of 40%, this would correspond to a water/solids ratio of W/S = 3.3 (Figure 2). Over time, the gradual substance mobilization resulting from biological and chemical processes, is not taken into consideration so that the actually required water throughput will be higher for several leachate components, as has been proven by tests carried out in landfill simulation reactors (LSR) (Heyer, 2003).

The LSR test results may be considered in order to assess the influence of chemical and biological processes on the substance output via the water path. Table 1 shows the concentration ranges of the leachates in the LSR which more or less correspond to the leachate consistency of the landfill sections where samples were taken. Furthermore, the limiting concentrations and the water/solids ratios (required to reach the latter concentrations) are indicated for the purpose of examining the following:

- the water/solids ratios required as a result of purely physical processes (dilution)
- the water/solids ratios required as a result of both physical and biochemical processes (taken from LSR results)

The comparison shows that the level of substance output via the water path is not only a question of physical leaching but also of mobilization processes occurring as a result of chemical reactions and biodegradation processes. The medium and long-term mobilization processes of organic compounds, nitrogen and, in part, chloride and AOX, result in a larger water/solids ratio in comparison to dilution-only methods, until the limiting concentrations are reached.

Table 1: Substance output via the water path: required water/solids ratios (W/S) as a result of physical processes (dilution), taking into consideration long-term biochemical processes (LSR results; DM: dry matter; Heyer, 2003)

Parameters	C_E Limiting concentration [mg/l]	C_0 Concentration at the outset of irrigation [mg/l]	W/S until C_E dilution is reached [m^3/Mg_{DM}]	W/S until C_E in the LSR is reached [m^3/Mg_{DM}]
COD	$C_{E\text{-}51^{st}append.}$ = 200 mg/l	500 – 12700	0.7 – 3.0	1.0 – 6.0
	Mean value	3000	1.9	2.4
N_{total}	$C_{E\text{-}51^{st}append.}$ = 70 mg/l	200 – 2100	0.8 – 2.4	2.6 – 7.7
	Mean value	900	1.8	4.4
AOX	$C_{E\text{-}51^{st}append.}$ = 500 µg/l	390 - 2380 µg/l	0.0 – 1.1	0.1 – 3.5
	Mean value	1600 µg/l	0.8	1.4

Mean values: constituted using the results of all LSR tests carried out under anaerobic milieu conditions

Limiting concentration: in accordance with the values listed in the 51st appendix (German Waste Water Ordinance – AbwV, 1997)

4. INFILTRATION METHODS

4.1 Infiltration media

For the selection of the infiltration method, the quality and quantity of the infiltration medium are important. The essential parameters which determine the infiltration capacity and behavior are the following:

- components of the infiltration medium (organic contamination, nitrogen and salt content etc.)
- dry matter content and particle size distribution of the dry matter
- blockage and incrustation behavior and corrosion behavior which must be taken into consideration particularly when selecting the material for the infiltration system.

The following infiltration media are applied, depending on the local conditions and the chosen infiltration system:

- surface water
- landfill leachate:
  - pretreated / purified (varying treatment intensities),
  - untreated (raw leachate)
  - liquid leachate purification residues (e.g. concentrate) – quite often only suitable to a lesser extent

The infiltration of uncontaminated process or surface water, but also of purified leachate offers the advantage that no partial recirculation of soluble leachate components into the landfill body occurs as well as the fact that negative effects of the infiltration medium on the infiltration system are unlikely. Furthermore, using this method, the seemingly "cost-effective disposal of contaminants res. leachate" is excluded right from the start.

As for the pretreated leachate from a leachate treatment plant (e.g. permeate from a reverse osmosis device), it must be checked whether or not the former is sufficiently available in order to guarantee optimization of the waste moisture by means of infiltration. This also applies to raw leachate and liquid leachate purification residues. In cases where the available quantity of corresponding infiltration media is too small, different media may be used "in parallel".

Apart from optimizing the humidity of the waste, the terminable application of untreated infiltration media (e.g. raw leachate or process water) or liquid leachate purification residues in younger landfill sections offers the possibility to increase the supply of already water-dissolved, and hence, bioavailable substances in the landfill body by infiltrating media rich in nutrients. In addition, this has a positive effect on landfill gas production and may be particularly relevant to younger biologically active landfill sections. A further-reaching degradation of organic compounds (BOD, "residual COD", and AOX) may be achieved. However, it must be observed that the infiltration of highly contaminated media is a terminable measure which should only be carried out as long as there is still sufficient biological activity in the landfill body. Otherwise, there exists a danger that soluble infiltration components will pass rapidly through the landfill body during infiltration, and collect at the landfill base, then requiring costly re-purification. This would not only result in the increase of the leachate purification costs, but, above all, in a prolongation of the landfill after-care as the low-emission state of the landfill body is reached at a later time.

In total, infiltration adjusted to the behavior of the landfill body, may be effected using different media within the period of realization of the infiltration measures. The type, duration, and extent of infiltration are updated continuously by means of the accompanying monitoring program.

4.2 Technical methods for the infiltration of water into landfill sections

Technical methods for water infiltration must be planned in such a way that controlled and even moisture penetration of the landfill body is guaranteed. Likewise, short circuit currents and preferred seepage paths must be avoided using suitable measures.

There are different technical methods available for employment with regard to the infiltration of water into the landfill body. At the same time, the effect of the infiltration plants on existing surface sealing systems or on systems which are yet to be installed is of great importance. They may be damaged seriously in parts, so that costly repairs may be required subsequent to the infiltration. In order to avoid this, the surface sealing and infiltration method must be technically coordinated. The choice of infiltration system is additionally determined by the quality of the infiltration medium (see above) and the quantity to be infiltrated.

Having regard to the landfill boundary conditions and the targets of infiltration, the following infiltration methods may be applied (Bothmann, 1997; Stegmann et al., 2001; Drexler, 2001):

- horizontal infiltration systems below the surface sealing
  - two-dimensional infiltration methods
  - linear-shaped infiltration methods
- vertical infiltration systems
  - utilization of existing vertical gas collectors
  - vertical deep-wells
  - infiltration lances in short screen distances

Combinations of the individual infiltration systems may also be employed.

The experience gained so far with regard to controlled infiltration may be summarized as follows:

- *positive experience*
  - enhancement of the gas production: up to three times higher
  - longer economic life of the gas
  - accelerated stabilization of the waste body
- *negative experience*
  - blockage and incrustation in the infiltration system (infiltration system not adjusted to the infiltration medium)
  - shearing-off, rupture, buckling of pipes
  - uneven water introduction / no water introduction in sub-areas

5. IFAS CONCEPT FOR WATER INFILTRATION

5.1 Procedure

Once ascertained a decline in landfill gas production to the extent that lasting gas utilization appears no longer possible in landfills in which non-pretreated municipal solid waste is deposited, the following consequences must be observed:

- The proceeds from the energetic landfill gas utilization decline.
- Landfill gas collection and treatment only lead to additional costs.

Once established that process-related causes may be excluded (e.g. cessation of the gas wells), the waste body itself must be investigated. Subsequent to the examination of all waste-relevant documents, and taking into consideration the heterogeneity of the waste body, representative solid waste samples must be taken and analyzed in the laboratory.

- Sampling (spread over the area at a variety of deep horizons): drilling / prospecting
- Analyses in the laboratory – essential parameters:
  - Content of organic substances
  - Water content / waste humidity
  - Degradation potential / microbial activity

In case the laboratory tests show only low degradation and emission potentials, either long-standing poor gas treatment or accelerated stabilization by means of aerobization will be required (Heyer et al., 2003). In case the investigations should indicate a high and economically usable degradation and gas formation potential at an optimizable waste humidity (for anaerobic milieu conditions), infiltration measures for the optimization of the waste humidity may be initiated.

5.2 Infiltration system

Usually, “technically robust”, meaning long-term stable and cost-effective infiltration systems should be installed, enabling an even moisture penetration throughout the landfill body. Based on the experience gained on different landfill sites, a combination of two-dimensional (infiltration fields) and vertical infiltration systems (well shafts) was developed which meets the requirements. The combined infiltration system is designed as follows:

- Well shafts are installed at the landfill surface for a controlled water addition.
- Below the well shafts, infiltration fields (gravel fields) are laid out in order to distribute the infiltration medium over the area.
- The charging of the well shafts / infiltration fields may be implemented using tank trucks (Figure 3) or a largely automated water distribution system, consisting of distribution buildings and piping (Figure 4). For long-term infiltration measures, the elaborated piping and distribution system should be employed when the main settlements are largely decayed in order to avoid damage of the piping.
- In cases where the installation of the corresponding infiltration system results in a raise of the landfill body, a raising of the existing well shafts may also be required. Further infiltration units may be installed on the raised landfill area subsequent to the completion of filling (Figure 4).

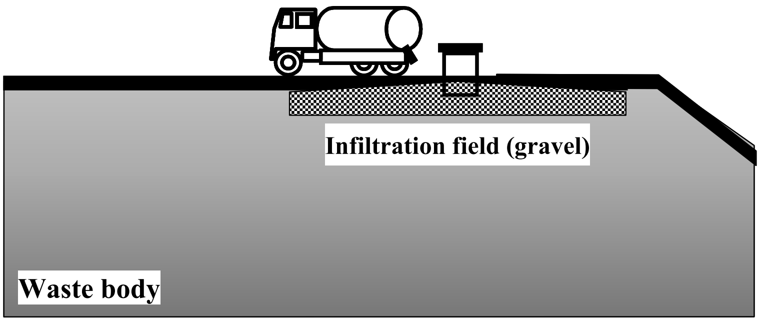

Figure 3: Schematic representation of a well shaft / infiltration field system – charging using a tank truck

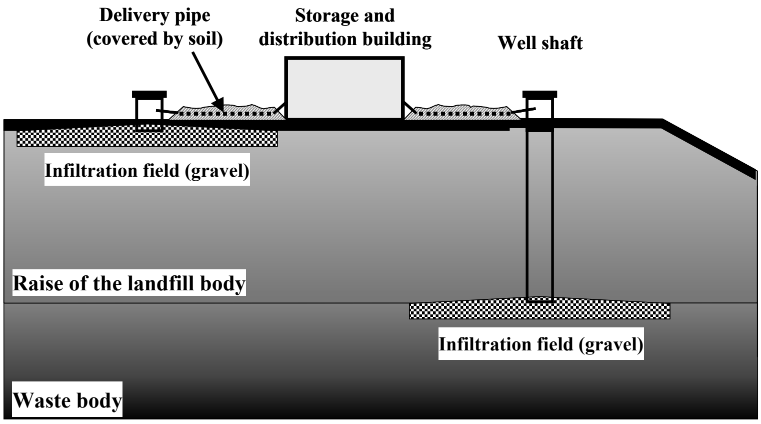

Figure 4: Raise of an existing well shaft and installation of a new well shaft / infiltration field system with water distribution system (integrated into a surface sealing, if required)

The 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.

In order to avoid uncontrolled gas emissions with regard to this system, the area of the infiltration field may be equipped with a gastight covering/sealing. The well shaft is water and gastight. For even moisture penetration throughout the waste body, a terminable accumulation of leachate within the infiltration field is useful in order to achieve distribution of the infiltration medium over the entirety of the infiltration field. The possibility of leachate accumulation must be taken into consideration during the planning phase and may be realized in a process-related and structural manner.

In order to reduce res. avoid plugging, incrustation or precipitation, uncontaminated or pretreated waters should be sued for the most part. Leachate or concentrate should be treated system-specifically when recirculated into the infiltration system. For the reduction of BOD_5, COD, iron and carbonate content and of other substances contained in the leachate, cost-effective and effective pretreatment of the water before its introduction into the infiltration system should be aimed for. While biological pretreatment is useful for “young” leachate, it is, usually, sufficient to merely aerate “old“ leachate. Apart from settling tanks or sand and gravel filters, flocculation/precipitation or flotation systems with high purification efficiency may be employed for the separation of solid material. The respective pretreatment methods must be adjusted to the chosen infiltration system and the infiltration medium.

6. OUTLOOK

Apart from local conditions, the available infiltration media must be taken into consideration when designing the infiltration systems. The latter should be robust, requiring only low maintenance, and designed in such a way that their functional efficiency with regard to even, controlled humidification of the landfill body is guaranteed in the long term. In cases where contaminated infiltration media are used (e.g. raw leachate), the operational reliability of the system may be improved by means of adequate aerobic pretreatment.

Within the scope of the infiltration measure, the water addition quantities must be adjusted regularly to the results of an accompanying monitoring program. Besides meteorological ratings, the latter records and documents the gas and water balance, as well as the settling behavior.

Although the landfill-specific positive potentials of water infiltration could be shown within the frame of the investigations on technical and labscale so far, deficits in knowledge still exist. Site-specific preliminary tests continue to be essential for the planning of a plant. Based on the experience gained until present, it may be stated that the employment of robust systems, consisting of well res. charging shaft and infiltration field appears useful. In practice, site-specific optimization will then be required.

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