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Aerobic *in situ* stabilization of completed landfills and old sites

Investigations of aerobic *in situ* stabilization of old sites in laboratory-scale tests show that a significant reduction of the nitrogen concentration in the leachate takes place. The degradation and release of organic compounds via the gas phase could be accelerated. The required aeration volumes for the biological stabilization are technically realizable as the total oxygen demand is relatively low.

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Introduction

In Germany approximately 540 landfills are in operation and over 86000 old sites are known in total (BMU 1994). If technical barriers do not exist or if they are insufficient, environmental impact may occur via gas and leachate emission pathways.

Results from research activities by the TU Hamburg-Harburg into the long-term behaviour of landfills show that emission concentrations especially for leachate drop to completely harmless limiting values only after long periods of 100 to 300 years (Heyer & Stegmann 1997).

Completed landfills and old sites without bottom liner can be secured by installing a landfill capping system in combination with active gas extraction. The gas production rate in old completed landfills is low. For this reason landfill gas (LFG) cannot be used for thermal or energetic purposes. Nevertheless LFG has to be treated, e.g. by using catalytic combustion or biofilters. Although the biological activity of old completed landfills is relatively low, leachate represents an emission potential for long periods of time. Landfill capping systems reduce or prevent leachate production but they may fail in function and again leachate production has to be expected. It becomes clear that no real remediation of the landfill can be achieved by the above-mentioned measures but only a securing by reducing emissions whilst conserving the emission potential.

The objective should be to develop suitable remediation measures to reduce the long-term emission potential of a landfill.

Objective of *in situ* stabilization measures

The objective of *in situ* stabilization measures is to transfer the landfill body as soon as possible to a state of low biological reactivity by accelerating the microbial conversion processes. To realize this, treatment procedures with active aeration are suitable. By this means, organic compounds which are not easily biodegradable will be aerobically degraded. As there is a considerable reduction in pollution potential, a less costly soil cover with a topsoil layer which could be used for recultivation should be considered instead of the installation of a liner system. This soil cover should be designed in a way that leachate production is minimized and there is a potential for methane oxidation.

Due to the *in situ* pretreatment, leachate concentration will decrease so that the period for leachate treatment could be reduced. In total, the following economic potentials result from the *in situ* stabilization:

- substitution of a landfill capping system by less costly and long-lasting topsoil cover of sufficient thickness so that a water balance develops;
- lower operating costs for the treatment of the leachate;
- lower costs for the maintenance of the topsoil cover;
- reduction of the aftercare phase for several decades;
- oxidation of trace organics and methane in the top soil cover.

Investigations of *in situ* stabilization of wastes from completed landfills on a laboratory scale

Material and methods

To carry out the investigations on aerobic stabilization, several waste samples from two landfills have been examined. The solid waste samples were taken during gas wells drilling. The age of the wastes was between 8 and 14 years. The presented test results refer to the waste samples of landfill A with extraction depths between 11 and 17 m. The investigations into aerobic stabilization were carried out in three landfill simulation reactors (LSR) at a temperature of 30°C. Further information regarding the experimental set-up of the landfill simulation tests can be found in Heyer *et al.* 1998.

The three landfill simulation reactors were initially operated under anaerobic conditions by leachate recirculation for several hundred test days. This was done to maintain typical environmental conditions of a closed landfill when starting the aeration tests, and in order to be in the position to assess the potential of emission under anaerobic conditions. Subsequently, the reactors were aerated with the aeration rates as mentioned below in: 'Aerobic stabilization of wastes from completed sites'.

Results

Chemical-physical solid examinations

To characterize the waste samples, chemical-physical examinations of the solid samples were carried out before placing them into the landfill simulation reactors, and at the beginning of the aeration period. The results of the solid analyses are shown in Table 1.

The low volatile solid values and the carbon contents of the waste samples at the beginning of the aeration period show that a significant degradation of the organic substance took place during the landfill simulation under anaerobic milieu conditions. At the beginning of the aeration tests, the solid samples B2Z15 in the reactor LSR 5 show the lowest carbon concentrations indicating that these solid samples are already to a large extent stabilized. Thus a faster aerobic stabilization of the solids is expected. The decrease of the nitrogen in the solid matter and the conductivity of the leachate during the anaerobic phase in the LSR is mainly because of dilution, which is the result of taking leachate samples and replacing the same amount of liquid by tap water.

Respiration activity of waste samples from closed landfills

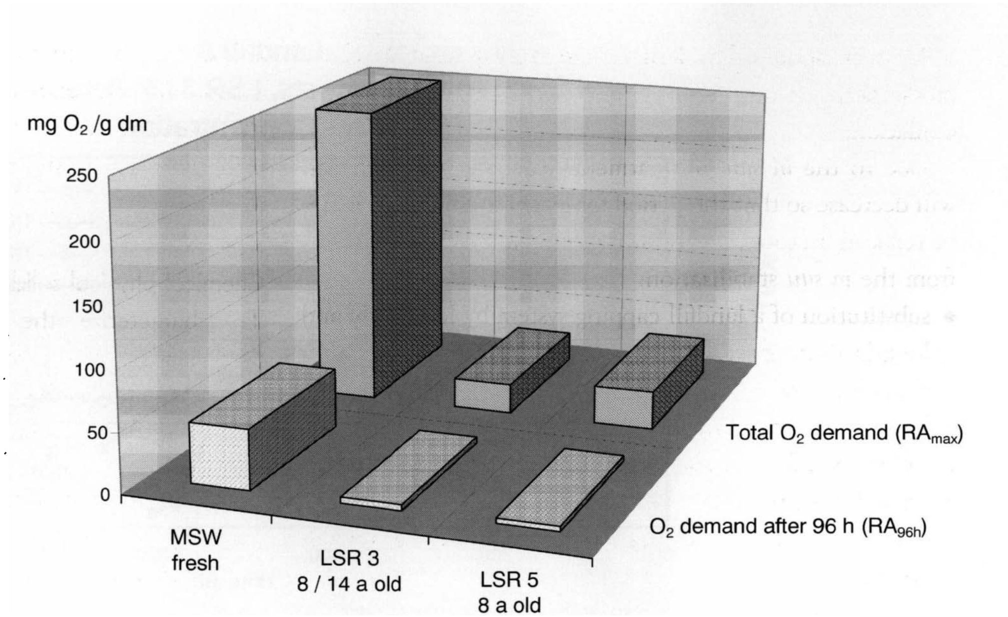
The biological activity of the solid samples was determined by means of respiration activity (RA) examinations with the Sapromat (Voith, Heidenheim, Germany). The way a Sapromat functions is described in Leikam & Stegmann 1995. Apart from the usual determination of the oxygen consumption after 96 h, long-term investigations of 500 h – and partly of more than 1000 h – have been carried out. Via these long-term investigations the maximum oxygen

Table 1. Results of the solid analysis landfill

LSR/sample	deposition period [a]	volatile solids [wt. %]	C [wt. %]	N [wt. %]	conductivity [mS cm^{-1}]	pH [-]
Analyses before placing into LSR						
1/B1N13	13	15.95	11.38	0.51	0.89	7.37
3/B1B2	8 and 14	24.52	16.82	0.75	1.55	7.62
5/B2Z15	8	16.06	12.31	0.52	1.49	8.18
Analyses at the beginning of aeration						
1/B1N13	13	–	–	–	–	–
3/B1B2	8 and 14	20.34	12.28	0.48	0.59	7.73
5/B2Z15	8	13.41	8.41	0.33	0.30	8.37

(Leikam *et al.* 1997) LSR=Landfill simulation reactors.

Fig. 1. Oxygen demand of solid samples after 96 h ($RA_{96\,h}$) and calculated maximum oxygen demand ($RA_{max.}$) according to Lineweaver-Burk (in Krämer *et al.* 1993).



demand of the solid samples can be ascertained. The oxygen consumption is related to dry matter (dm).

The respiration activity has been determined before placing the solid samples into the landfill simulation reactors. Fig. 1 shows the respiration activities after 96 h ($RA_{96\,h}$) and the maximum respiration activities (RA_{max}) for LSR 3 and LSR 5 compared to 'fresh residual wastes'.

The determination of the maximum oxygen demand was effected after a test period of 500 h or 1000 hours by means of reciprocal plots according to Lineweaver-Burk (in Krämer & Sprengler 1993).

It becomes evident that the samples taken from inside the landfill only show approximately 10% of their initial biological activity (fresh residual wastes of households $RA_{96\,h}$ = 50 to 80 mg O_2g dm^{-1}). The total air volume needed for *in situ* stabilization of 1 t deposited waste can be calculated from the determined maximum oxygen demand of the solid samples (RA_{max} = 25 to 32 mg O_2 g dm^{-1}). The total air demand of waste sample B1B2 (LSR 3) is approximately 105 m^3/t^{-1} dm and for the sample B2Z15 (LSR 5) approximately 85 m^3 air t dm^{-1}.

Aerobic stabilization of wastes from completed sites

The aeration tests were started after an anaerobic phase in the LSR of approximately 350 to 400 test days. The start of aeration is marked by means of arrows in Fig. 2. The aeration of the three landfill simulation reactors was effected at intervals. The aeration rates were as follows:

- LSR 1/B1N13 approximately 0.09 l kg^{-1} dm in approximately 1 min. The aeration was carried out two to four times per week.
- LSR 3/B1B2 approximately 1.8 l kg^{-1} dm h^{-1} for approximately 4 h. The aeration was carried out every seventh and every fourteenth day.
- LSR 5/B2Z15 approximately 1.8 l kg^{-1} dm h^{-1} for approximately 4 h. The aeration was carried out weekly.

Leachate

The pH-value in the leachate changes as a function of the aeration rate. Whilst a significant increase of the pH-value >pH 7.0 can be stated for the reactors LSR 3 and LSR 5, where higher aeration rates were applied, the low aeration rate for LSR 1 does not have an effect on the pH-value.

The sulfate content in the leachate increase pattern is quite similar to the parameter pH-value. An influence of the aeration on the stronger decrease of the bicarbonate content cannot be found for the different aeration rates and intervals. The lime-carbonic acid balance does not seem to be disturbed at these aeration rates.

The chosen aeration rates scarcely have an effect on the organic contaminants in the leachate. The chemical oxygen demand (COD) concentration does not show significant changes but it has to be taken into consideration that the COD content is within the range of 400 to 500 mg l^{-1} and already very low at the beginning of the aeration tests. After an aeration period of 200 days, the COD concentrations are below 200 mg l^{-1}. The BOD_5 contents (biological oxygen demand) in the leachate at the beginning of the aeration tests are only at 25 to 50 mg l^{-1} and decrease relatively fast to values below 20 mg BOD_5 l^{-1}. Due to the very low concentration, a faster decrease of the BOD_5 value during

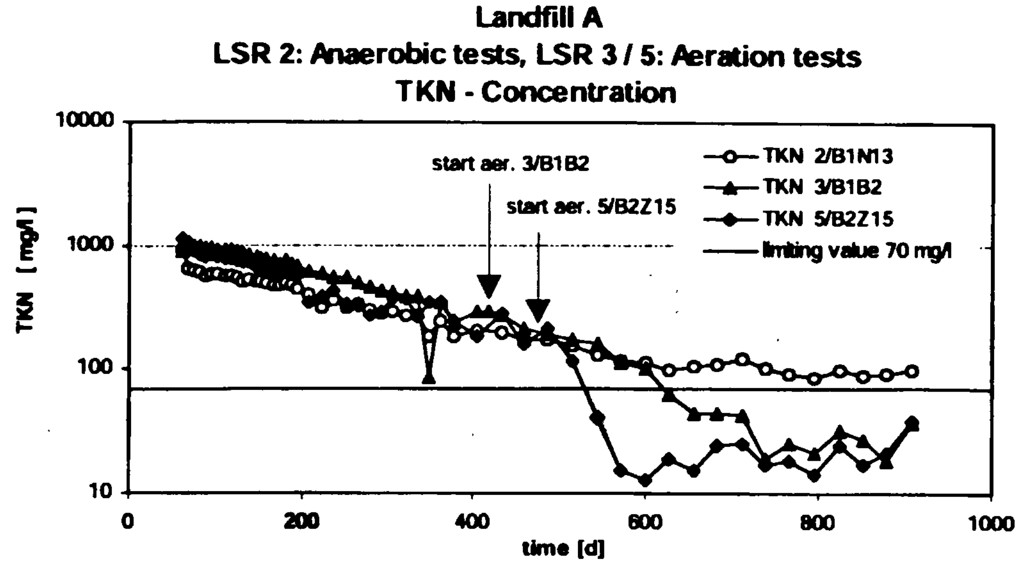


Fig. 2. LSR 3/B1B2: aeration (1.81/kg dm*h in 4 h) from day 407 on
LSR 5/B2715: aeration (1.81/kg dm*h in 4 h) from day 454 on
TKN in the leachate landfill A, LSR 2 (anaerobic) LSR 3/5 (Leikam *et al.* 1997).

the aeration phase could not be found compared with the strictly anaerobic landfill simulation.

The nitrogen content in the leachate of reactor LSR 1/B1N13 only changes to a small extent. The decrease of the TKN concentration (Total Kjeldahl Nitrogen) in the leachate of reactors LSR 3/B1B2 and LSR 5/B2Z15 is clearly discernible (see Fig. 2). The TKN concentration for reactor LSR 3 is far below 70 mg l^{-1} after 200 days of aeration whilst the concentration for reactor LSR 5 is far below 70 mg l^{-1} after only 50 days of aeration. An increase of the nitrate concentration in the leachate of reactors LSR 3 and LSR 5 could not be found. Part of the nitrogen is released via the gas pathway as ammonium in condensate and as ammonia in exhaust air.

Fig. 2 shows the TKN content in the leachate of the landfill simulation reactor (LSR 2) operated under anaerobic conditions which was also filled with waste samples from landfill A. Even after 900 days, the nitrogen content in the leachate of reactor LSR 2 hardly falls below 100 mg l^{-1}. As a result of the aerobic *in situ* stabilization, the nitrogen content in the leachate can be reduced significantly in a few months (LSR 3/5). This effect is very important as especially the parameter nitrogen influences significantly the aftercare-period (see Heyer & Stegmann 1997).

The heavy metal content in the leachate was extremely low for all examined landfill simulation reactors. Even at the beginning of the aeration no increased release of heavy metals could be found, e.g. as a consequence of a possible demobilization or oxidation of metal sulfides.

Gas

At the beginning of aeration, the gas atmosphere in the landfill simulation reactors showed typical gas composition for the stable methane phase of a landfill.

The low aeration rates for reactor LSR 1/B1N13 were chosen to simulate 'natural' change from anaerobic to aerobic environmental conditions of an old deposit.

Due to the low air supply in LSR 1/B1N13 the oxygen is consumed immediately after the addition (5 l d^{-1}) which is indicated by the low oxygen content and the slight increase of the CO_2 concentration in the produced gas (see Fig. 3). By the aeration and the involved dilution of the landfill gas produced anaerobically, the methane concentration decreases and the inert gas portion of nitrogen increases. The organic substances in the solids are converted aerobically dependent upon the amount of air supplied. After complete oxygen consumption the anaerobic degradation continues. An inhibition of the anaerobic microorganisms is not detectable. A stimulation of the microorganisms is more likely as the carbon release, in the form of methane, still increased after the beginning of the aeration (see Fig. 4). In LSR 3/B1B2 anaerobic conditions are also restored after several hours of intensive aeration (100 l air h^{-1} = 1.8 l air $^{-1}$kg dm h^{-1}). Thus methane concentrations between 15 and 35 vol. % in the landfill gas are found at the end of the 'non-aeration' phase. During the aeration phase, the methane concentrations decrease to zero. In the reactor LSR 5/B2Z15 similar fluctuations of the gas composition are ascertained. At the end of the 'non-aeration' phase, the methane concentrations amount to only 10 vol. % and less.

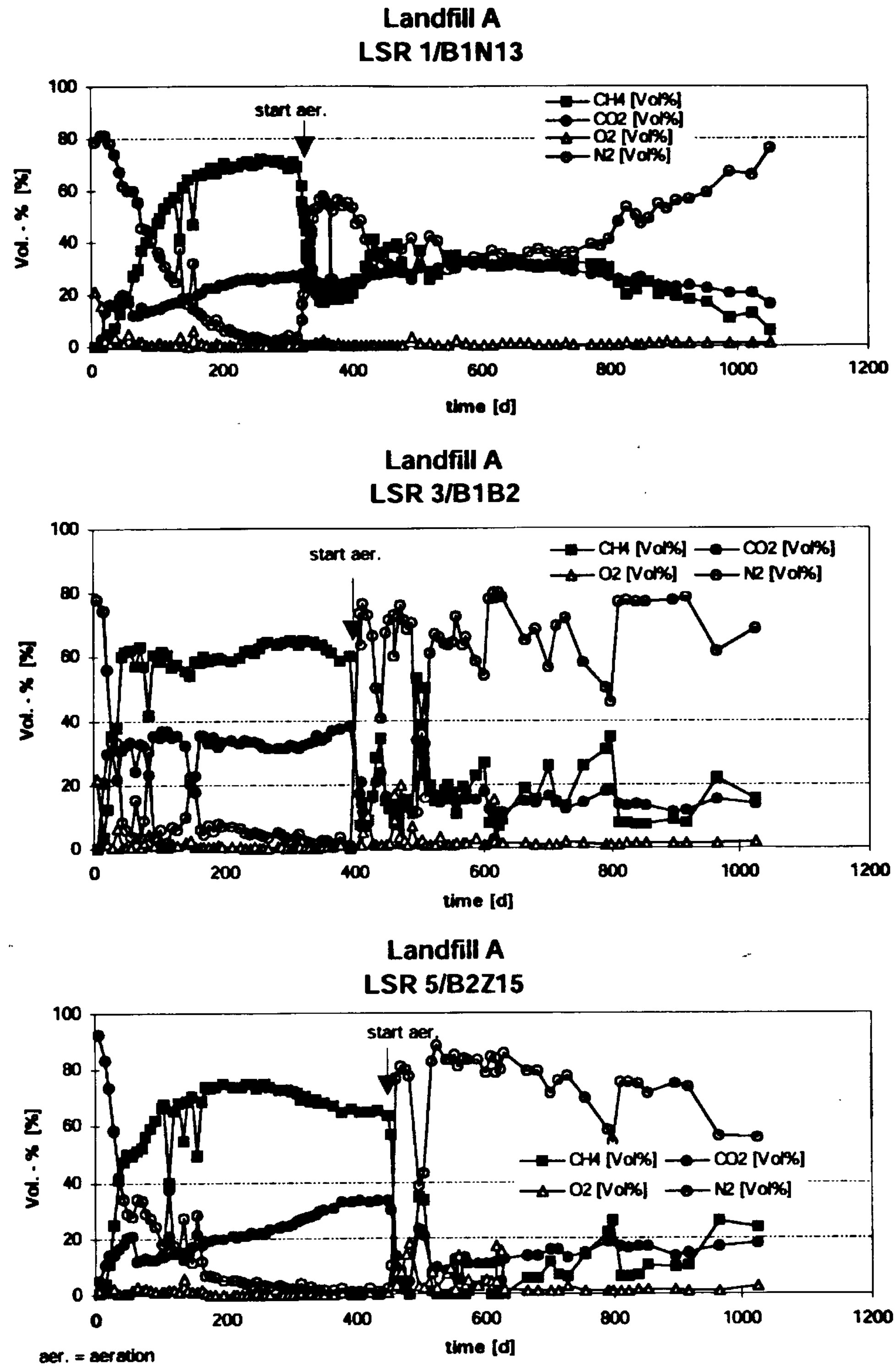


Fig. 3. Gas composition in the LSR 1/3/5, landfill A.
LSR 1/BIN 13 : aeration (0.09 l kg^{-1} dm in 1 min) from day 321. on
LSR 3/B1B2 : aeration (1.8 l kg^{-1} dm*h in 4 h) from day 407. on
LSR 5/B2Z15 : aeration (1.8 l kg^{-1} dm*h in 4 h) from day 454. on

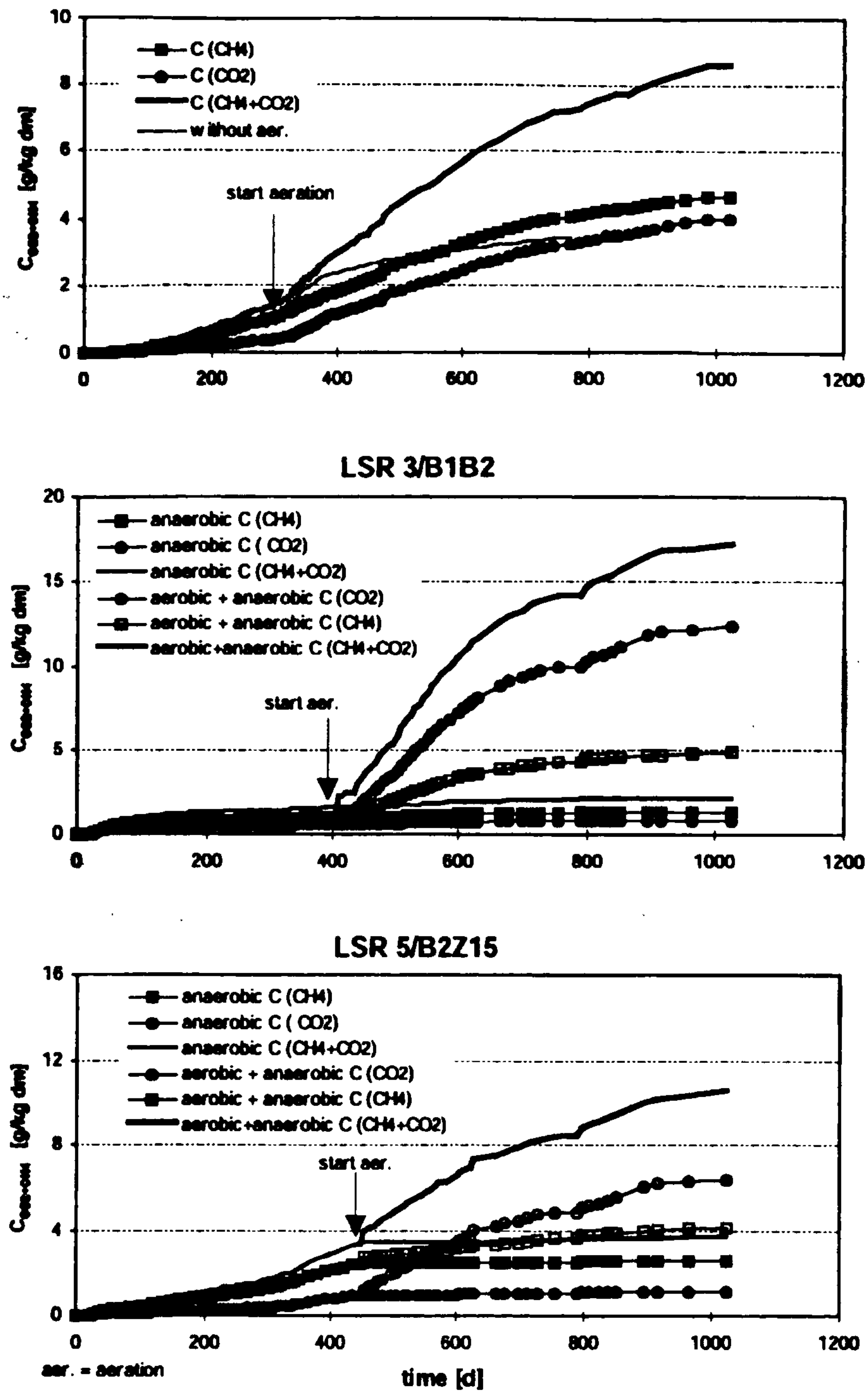


Fig. 4. Carbon release via the gas pathway in LSR 1/3/5, landfill A.

The influence of the aeration on the degradation of the organic components becomes evident. The release of the converted organic components takes place via the gas path in the form of methane and carbon dioxide. Fig. 4 describes the influence of aeration on the carbon turnover.

The increase in carbon release by aeration is apparent for the low aeration rate for LSR 1 as well as for the aeration rates for LSR 3 and LSR 5. The influence of the aeration on the degradation processes is quite significant, especially in LSR 3. By aeration the degradation of organic substances was approximately five times higher compared to the degradation under anaerobic conditions over the same period of time.

In LSR 5, the degradation rate of the organic substances could be more than doubled. The lower carbon release of reactor LSR 5 compared to reactor LSR 3 is probably due to higher gas production during the anaerobic phase of treatment (until the 420th day of the test) which results in less lower biodegradable substances at the beginning of the aeration tests.

The laboratory-scale tests regarding the aerobic stabilization of solids waste samples from completed landfills show that, by aeration, a strong reduction of the nitrogen concentration in the leachate can be achieved. The data in Fig. 2 show that, due to aeration, the target value of the 51st appendix of the German waste water regulation (Rahmen-AVwV) is reached more than 400 to 500 days earlier compared to reactor LSR 2 which operated under strictly anaerobic conditions. Therefore, it can be expected that the period required for leachate treatment can be significantly reduced by several years.

The carbon turnover is increased significantly during the aeration phases. Organic substances medium–difficult or difficult to degrade, which can only be degraded over a long period of time in an anaerobic environmental, are increasingly converted during the aeration phases.

After a test period of approximately 500 days, there are still also anaerobic environmental conditions present. When evaluating the data from the laboratory scale tests it has to be taken into consideration that aeration was only effected once a week or every 14 days – that means that due to lack of oxygen between the aeration measures there was always a change in environmental conditions from partly aerobic to completely anaerobic. By practising longer periods and shorter intervals of aeration, aerobic degradation processes will become more significant. This may result in a faster mineralization of the waste. Further investigations to optimize these intervals are necessary.

Transfer of the laboratory test results to actual completed landfills

An assessment of the maximum oxygen demand can be made via the long-term test in the Sapromat – as described in 'Respiration activity of waste samples from closed landfills' above. The maximum amount of air needed is between 85 and 105 m^3/t^{-1} dm for the waste samples derived from landfill A (deposition age between 8 and 14 years). On the basis of the laboratory aeration tests it is assumed that for the aerobic *in situ* stabilization a maximum period of 1 to 1.5 years may be necessary.

Assuming an aeration period of 1 year and an average water content of the wastes of 35% (wet waste) as well as a total air supply of 100 m^3/t^{-1} dm, a daily aeration rate results in up to 0.18 m^3 t^{-1} wet waste^{-1} (= 0.0075 m^3 wet waste h^{-1}). As the calculated air supply rate only covers the required oxygen demand, the aeration rate should be higher to cover inevitable losses (e.g., incomplete utilization of the oxygen). It becomes evident that the air supply rate is relatively low and that the aeration can easily be realized without causing technical problems.

Conclusion

The investigations of the *in situ* stabilization carried out on a laboratory scale showed that, by aeration measures, a significant reduction of the nitrogen concentration in the leachate takes place within a few months. Furthermore, the degradation and release of organic compounds via the gas phase could be significantly accelerated. It can be concluded from the test results obtained up until now that the aerobic *in situ* stabilization is suitable for the stabilization of old deposits in so far that the hazardous potential is significantly reduced.

The required aeration volumes for the biological stabilization are technically realizable as the total oxygen demand of the deposited wastes is very low (in the order of 100 m^3 t dm^{-1}). The advantages involved with *in situ* stabilization are the reduction of environmental impacts and cost savings, where a well designed soil covering system, instead of a capping system is installed; which is less costly in construction, operation and maintenance. In addition the phase of aftercare is significantly reduced.

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