Lechner P. (Hrsg.): Waste matters. Integrating views. 2nd BOKU Waste Conference 2007, 16. - 19. April 2007, Wien. Proceedings; Facultas Verlags- und Buchhandels AG, ISBN 978-3-7089-0060-5

Reduction of the Residual Landfill Gas Production by Means of In-situ Aeration

M. Ritzkowski and R. Stegmann
Institute of WasteResourcesManagement, Hamburg University of Technology, Hamburg, Germany

Abstract
Uncontrolled landfill gas (LFG) emissions contribute to the world wide increase in Greenhouse Effect and other risks like the harm of vegetation and human health. This mainly concerns landfills without LFG extraction systems or those, where the gas extraction/utilization is not feasible any longer. In order to minimize the future gas production rates a controlled in-situ aeration can be applied, thus changing the landfill redox-system from anaerobic to aerobic. Our own investigations at a landfill in northern Germany show that the LFG production can be decreased significantly (down to 15% of the initial value within a time frame of 5.5 years) by means of aeration. Furthermore it seems to be realistic that the landfill will remain in a semi-aerobic status after the aeration is completed. This might be aided by simple passive aeration measures, such as the installation of aspirators inducing an air venting effect.

1 Introduction
The deposition of municipal solid waste (MSW) in landfills is the main disposal option worldwide. Biochemical reactions in the course of organic matter degradation lead to significant emissions in terms of landfill gas (LFG) and polluted leachate. If the landfills are equipped with technical protection systems like bottom liners, leachate and LFG collection systems as well as surface covers, these emissions can be widely controlled and/or minimized. However, the LFG utilization by means of conventional gas engines is limited by the actual LFG production rate as well as the concentration of methane (CH_4). Once the utilization is not feasible or economically beneficial anymore, landfills might be aerated in order to minimize their future LFG production potential. This raises the question why uncontrolled methane emissions have to be avoided or minimized, i.e., the question for the ecological driving force of landfill aeration.

Among anthropogenic greenhouse gases, methane has the second largest effect on climate, after carbon dioxide (IPCC, 1996). Methane emissions from anthropogenic sources account for 70 percent of all methane emissions worldwide. Their overall contribution towards the global warming effect is significant because,

over a 100-year time frame, methane is estimated to be 21 times more effective at trapping heat in the atmosphere than carbon dioxide. Since the beginning of the industrialization (end of 18th century) the atmospheric methane concentration has increased by approximately 15% in total and almost tripled during the last 150 years (Keppler et al., 2006). According to various studies a total of 40 to 60 M tons of CH_4 is emitted from landfills and old deposits worldwide, accounting to approximately 11 to 12% of the global anthropogenic CH_4 emissions. This brings the ranking of landfills directly after rice paddies (60 M tons per year) and ruminant livestock (85 M tons per year) (IPCC, 1995) (Lelieveld et al., 1998). In Germany, the CH_4 emissions arising from Municipal Solid Waste (MSW) landfills contributed approx. 3% to the national GHG-emissions in 1990 (Butz, 2005). In other countries of the European Union these values are higher, e.g., Austria showing a contribution of approx. 5.4% in 2001 (Umweltbundesamt, 2003). Considering Europe (EU 15) the CH_4 emission quota of methane arising from landfills adds up to 2,7% of the total GHG emissions in 2002 (EEA, 2004). However, according to the German Federal Environmental Agency (FEA), between 1990 and 2001 a reduction by 21 M tons CO_2 equivalents from absolutely 1.5 M tons to 0.5 M tons CH_4 could be achieved (Butz, 2005).

This reduction is mainly due to improved Landfill Gas (LFG) collection and treatment techniques as well as the increased tendency towards a deposition of either thermal or mechanical-biological pre-treated MSW.

2 Case study Old Kuhstedt Landfill, Germany

The old Kuhstedt landfill was constructed in the middle of the 1960s in an old sand and gravel pit. From 1973 on, the old disposal site was filled under control as combined pit-/land raising landfill. In 1987, when operations stopped, the total waste volume came to about 220.000 m^3, deposited on an area of 3.2 ha. The landfill height is between 8 and 10 m and the base is about 2 – 3 m below the surrounding surface. The landfill can be regarded as typical for a large number of old landfills in Germany regarding its volume, the deposited types of non-pretreated waste (mainly household waste, industrial waste similar to household waste, bulky- and construction waste) and the geological and hydro-geological subsoil conditions. Most of these old disposal sites do not have the necessary equipment for the collection of landfill gas and/or leachate or the equipment does not meet the current requirements.

The old Kuhstedt landfill has been aerated for a period of approximately 5.5 years, starting in April 2001. The aeration was conducted by means of the low pressure aeration AERO*flott*® (Stegmann et al., 2000). A comprehensive LFG monitoring prior to and during the aeration process confirmed the positive effect of aeration regarding the reduction of LFG production. By the in situ aeration of landfills primarily anaerobic conditions are converted into aerobic, thus increasing the carbon conversion rates due to accelerated aerobic metabolism processes of the specific microbes. The intensity of the carbon conversion decisively

depends on adequate ambient conditions for the microorganism (e.g. oxygen concentration, pH, temperature, water content) and the availability of biological degradable organic substances in the landfill material. In comparison with anaerobic metabolism processes, the potential of aerobic micro-organisms becomes even more evident. These microbes are able to convert even semi and hardly-degradable organics like hemicelluloses and lignin which are – to a large extend – resistant against anaerobic degradation processes.

Consequently, active landfill aeration enables a significant reduction of the methanogenic phase as a result of a widely stabilization of the biodegradable organic substances within the landfill. Furthermore it seems to be possible that widely aerobic conditions will remain inside the landfill waste mass, or could be provided by simple technical measures, once the active aeration process is completed. This might be due to the expected none or very low residual gas production enabling the diffuse infiltration of ambient air via the landfill surface.

3 Comparison of LFG production rates under anaerobic and aerated conditions

3.1 Modeling the LFG production from the anaerobic landfill

Landfills are subject to different phases with respect to gas production and gas composition both, during operation as well as during the aftercare period. The gas production is a result of the microbial conversion of organic substances (mainly organic carbon) contained in the waste mass, starting soon after the initial oxygen content originating from the waste emplacement has been consumed. The main compounds of the produced landfill gas are methane as well as carbon dioxide, which occur in a ratio of approx. 55-65% (CH_4) to 35-45% (CO_2) in the stable methanogenic phase (Christensen et al., 1996).

The initial CH_4 concentrations in the old Kuhstedt landfill were determined to approx. 65 % v/v prior to the start of the aeration process. By means of a model approach an estimation of the residual LFG production has been calculated, based on Tabasaran and Rettenberger (1987). The calculation includes the time period between the start of the in situ aeration process (April 2001) and the year 2020. The resulting LFG production diagram is presented in Figure 1. The input parameter for the calculation has been chosen according to the existing data regarding the type of deposited waste, its amount and volume (according to the landfill operators records) as well as the analytically determined moisture content of the landfilled waste (average of 53 waste samples: 29% w/v). In addition to MSW, significant quantities of C&D waste have also been landfilled, the initial biodegradable organic carbon content (TOC_{solid}) was estimated to 140 kg/Mg FS (average), thus approximately 30% below main literature data for untreated MSW (170 - 220 kg/Mg FS, (Tabasaran and Rettenberger, 1987)). The half-life time was assessed to 6.2 years.

From Figure 1 it becomes evident that the largest portion of landfill gas had already been produced during the end of the 1980's (landfill closure: 1987). How-

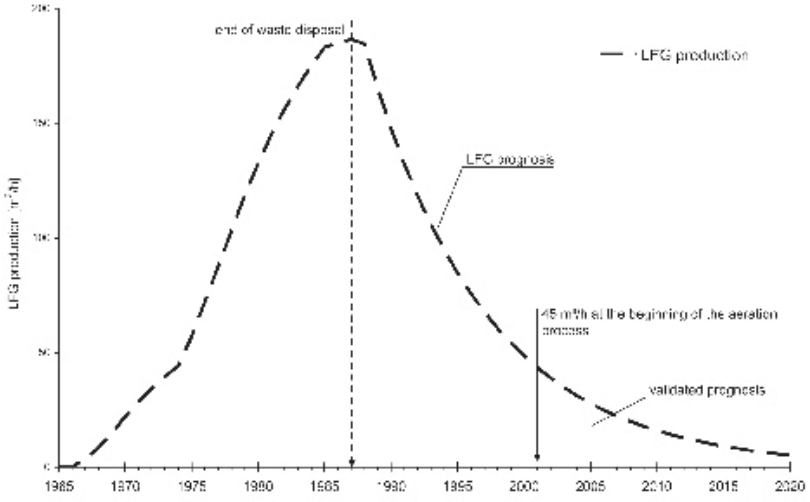


Fig. 1: Calculated LFG production rates for the old Kuhstedt landfill assuming anaerobic landfill conditions during the entire time frame indicated. (Validated prognosis: data revision by means of an extraction test in 1998)

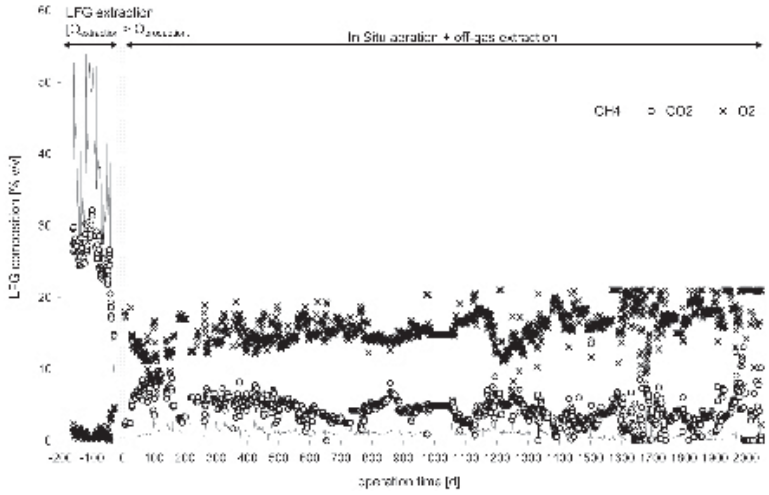


Fig. 2: Substantial change of the LFG composition during landfill aeration. Presented data taken from the old Kuhstedt landfill.

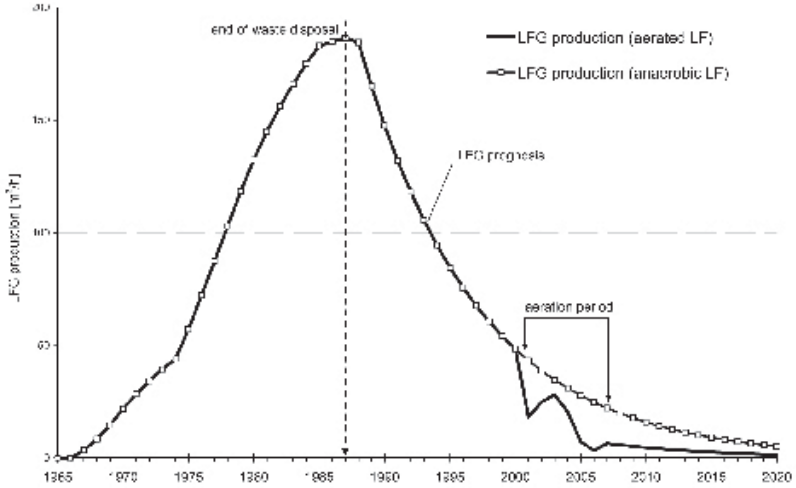


Fig. 3: Comparison of the LFG production rates for both, anaerobic LF and aerated LF. LFG production for anaerobic LF and aerated LF before and after aeration calculated by means of a model approach.

ever, calculating the residual LFG production from 2001 (beginning of the in situ aeration process) until 2020, a total volume of approx. 3.1 M m³ of LFG can be expected. This corresponds to approx. 1,500 Mg carbon to be discharged, assuming an average LFG composition of 55% CH_4 and 45% CO_2.

By the year 2020 the LFG production rate decreased to 5 m³/h, according to < 0.2 l/m²*h. Assuming an unchanged CH_4 content this corresponds to < 0.1 l CH_4/m²*h accumulating under the landfill surface cover. By calculating the residual potential for further carbon discharge (biodegradable fraction of the remaining organic carbon fraction) from 2020 by the time when quasi zero-emissions are reached, another 400,000 m³ LFG could be produced. This corresponds to an additional carbon discharge of 200 tons.

3.2 Calculating the LFG production from the aerated landfill

During the aeration process a comprehensive monitoring program yielded to reliable data regarding the gas composition inside the landfilled waste mass. Due to these data the conversion of the redox system could be followed as a result of operation phases both the primary gas extraction with flow rates exceeding the gas production (resulting in a gradual passive aeration of the landfill caused by the infiltration of ambient air through the LF surface) and the subsequent active aeration. Figure 2 shows the chart of the gas composition (LFG main components) for both phases during the first 5.5 years of the aeration process.

Based on the detected CH_4-concentrations in the extracted off-gas and the spe-

cific flow rates inside the gas extraction system (both continuously measured) the residual LFG production rates were calculated. The calculation assumes a CH_4-content of the produced LFG in the range of 65% v/v. Figure 3 shows the comparison between case scenarios both, the anaerobic landfill and the aerated one. For the aerated landfill an additional estimation of the future LFG production rates following the completion of the aeration process was made based on a gas extraction test as well as the model approach used for the anaerobic landfill scenario.

Under the influence of the aeration process the CH_4 concentrations as well as the LFG production rates decreased significant due to the creation of widely aerobic conditions inside the waste mass. However, due to the very heterogeneous waste characteristic some anaerobic zones remain, in particular during the first 36 months of aeration. In this period the temporarily increased methane formation rates are also attributed to the specific operation mode, including the interruption of the continuous aeration process for additional tests and measurements. In order to reliably control this residual methane production during this phase a qualified off-gas treatment by means of a regenerative thermal oxidation process (RTO) is strongly recommended. By means of the RTO a complete oxidation of the extracted methane can be achieved, causing only a minor additional energy demand.

Approximately 3 years after the start of the aeration process the LFG production rates declined significantly. The landfill had been transformed into a widely aerobic stage showing a minimized gas formation potential and a reduced oxygen demand. Beside the extensive biodegradation of organic substances the long term effect of oxygen diffusion (additionally to the short term effective convection processes) might be a reason for this observation. However, following the decline of the methane concentrations in the extracted off-gas its further treatment can be conducted by means of a qualified biofilter system.

3.3 Comparison of anaerobic and aerated LF by means of a carbon balance

Apart from the residual LFG production in the aerated landfill the increased and accelerated biodegradation of organic substances can be understand best by considering the overall carbon balance. In this connection only the carbon mobilization via the gas phase is of interest as previous investigations in lab scale showed only minor carbon discharge rates via the leachate (Ritzkowski et al., 2006) (Prantl et al., 2006). Serving as a reference the theoretical LFG-production under anaerobic landfill conditions was converted into carbon discharge rates and compared with the data gained from the aerated landfill (Figure 4).

After a starting phase of approx. 120 days (technical and operational optimization of the plant) a significantly increased carbon discharge could be observed for the aerated landfill in comparison to the calculated anaerobic landfill. Here the dominating component is CO_2 as the main product of the aerobic metabolism and the biological CH_4-oxidation. The amount of CH_4, as a result of the residual LFG formation in the landfill body, accounts to only 14% of the total carbon discharge.

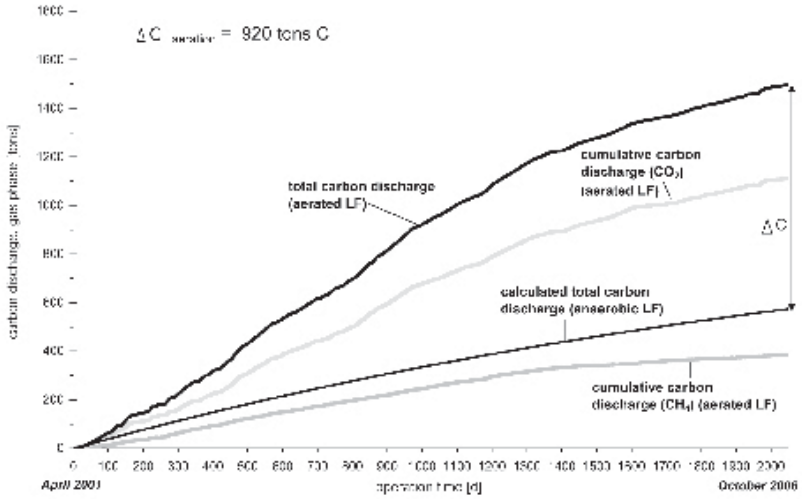


Fig. 4: Carbon discharge via the extracted off-gas (by main components and total) from the aerated landfill. Comparison with the C-discharge as calculated for the anaerobic landfill.

By the end of October 2006, approx. 5.5 years after starting the aeration process, the additional carbon discharge caused by aeration amounts to approx. 920 tons representing an increase by the factor 2.6 in comparison to the calculated carbon discharge from the anaerobic landfill. In total approx. 1,500 tons carbon has been discharged through an aeration volume of approx. 51 M m³ air since April 2001. The discharged carbon was released into the atmosphere in terms of CO_2 which is classified as climate neutral due to its anthropogenic origin.

3.4 Changing of the LFG formation potential (LSR-test and GP_{21})

Prior to the beginning of the aeration process (August 2000) as well as 22 and 46 months after the aeration started waste samples were taken in the course of drilling bore holes. The waste was taken out of the landfill as mixed samples, representing the total height of the wastes. The individual samples had a volume of approximately 120 l each and were investigated in both, Landfill Simulation Reactors (LSR, volume = 100 l) as well as small test vessels (volume = 500 ml). Detailed information about the LSR set-up and operation as well as the performance of the GP_{21}-tests had been published elsewhere (e.g. Ritzkowski et al., 2006).

The results of the investigations basically confirm the data that have been gained through the off-gas monitoring during the aeration process. A significant reduction in landfill gas production under optimized lab scale conditions could

be observed, indicating the proceeding stabilization process of the aerated waste mass. Within an aeration period of 22 months the gas formation potential (GP_{21}) could be reduced by 77% compared to the initial value prior to aeration. By aerating another 24 months the GP_{21} could be further reduced. At that time the residual gas formation potential accounts for less than 20% of the original value.
By investigations in LSR long term test with larger waste volumes were conducted aiming to collect information about the maximum LFG production to be expected for the aerated landfill. Results of GP_{21}-tests and LSR-tests are in relatively good concordance. Through the comparison of three different points in time during the LSR operation it becomes obvious that particularly the easy degradable organic substances (causing mainly the LFG production in shorter time periods) have been degraded during the aeration process (LFG production reduced by 86% after 10 weeks of LF aeration) whereas the moderate and hardly degradable organics were reduced to a smaller extend (LFG production reduced by 70% after 10 weeks of LF aeration). Figure 5 shows the development of the LFG production for samples taken after different aeration durations both, by GP_{21}-tests and LSR-tests.

3.5 Landfill gas extraction test after 65 months of LF aeration

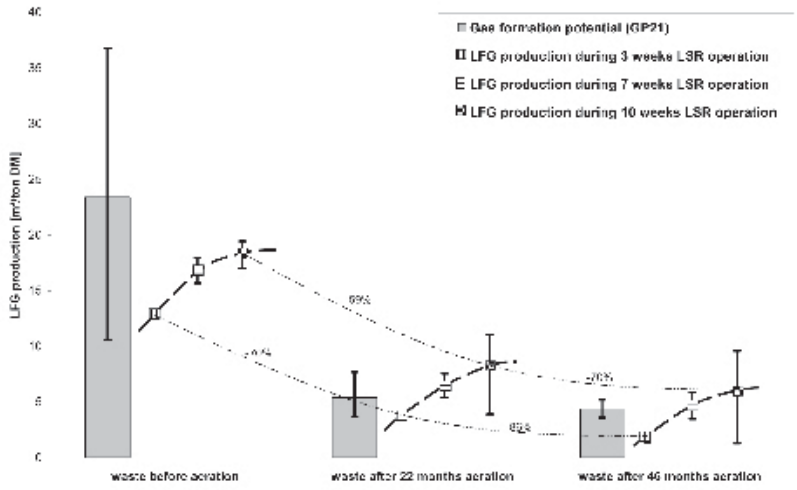


Fig. 5: LFG production for solid waste samples taken before and during landfill aeration. Indicated results for GP_{21}-tests and LSR-tests; gas production in LSR for different investigation times.

After a period of approx. 5.5 years the aeration process was interrupted for a period of 2.5 weeks to investigate the development of the gas quality inside the landfill. At the end of this period average CH_4 concentrations of 20% v/v were detected. Subsequently, a LFG extraction test was conducted which showed very low residual gas production rates of approx. 6.6 m³ LFG/h. In comparison with the initial LFG production rate before the beginning of the aeration process (approximately 45 m³/h) a reduction by 85% could be realized. This value corresponds quiet well with the data obtained from the lab investigations of solid waste samples (see chapter 3.4).

4 Passive aeration of the aerobically stabilized landfill

Once the active aeration process is completed one should ensure that – at least partly or semi – aerobic conditions will remain inside the landfilled waste mass. The principle of the semi-aerobic landfill has been developed in Japan where its application is widely spread. Semi-aerobic landfills offer significant advantages over anaerobic landfills in terms of minimized LFG production rates and improved leachate quality, thus reducing the efforts (financially and technically) during the landfill aftercare period.

As during the active aeration process the biodegradable organic substances have been already widely reduced a significant LFG production from the aerobic stabilized landfill can not be expected. However, by means of simple, cost effective and easy to maintain equipment in combination with the existing infrastructure (e.g., gas wells) the passive long term aeration of biologically stabilized landfills is currently investigated at the old Kuhstedt landfill. The system installed consists of wind driven aspirators which are mounted directly at the gas wells heads. These aspirators induce, depending on the wind speed and the temperature difference between the landfill body and the ambient, a slight negative pressure inside the landfilled waste mass. Through open gas wells the surrounding air is passively sucked into the waste thus keeping them (semi) aerobic. Due to the fact that temperature differences are important for the satisfactory operation of the aspirators their application following an in-situ aeration process is reasonable because landfill temperatures as a rule are elevated.

5 Summary

The residual production of LFG, after gas utilization is not feasible or economically sound anymore, might become a problem regarding both, economical and ecological aspects. The gas has to be captured and treated reliably, either by means of thermal or biological processes. However, in both cases the landfill remains anaerobic, so that gas extraction and treatment as well as other aftercare measures (e.g. leachate treatment) have to be carried out for long periods of time (at least decades).

By the application of landfill in situ aeration the redox system inside the waste mass is altered from anaerobic to aerobic thus allowing both, an accelerated bio-

logical waste stabilization as well as significant reduced LFG production rates. Further more aeration has to be conducted only for a limited time period (several years) but shows a sustainable effect regarding the long term stabilization.

The old Kuhstedt landfill has been aerated since 2001. By means of a comprehensive monitoring program it could be shown that LFG production rates can be significantly reduced (down to 15% of the initial value measured prior to the aeration process) and future gas production can be widely minimized. In combination with a subsequent passive aeration the long term biological stability of the landfill can be achieved, leading to reduced efforts (financially and technically) during the landfill aftercare phase.

References

Butz, W. (2005): Treibhausgasemissionen aus Deponien: Berichtspflichten, Berechungsansätze und Ergebnisse. In: Trierer Berichte zur Abfallwirtschaft, Bd. 16, Stilllegung und Nachsorge von Deponien – Schwerpunkt Deponiegas 05. Rettenberger/Stegmann (Hrsg.), Verlag abfall aktuell, Stuttgart, pp. 5-23

Christensen, Th.H., Kjeldsen, P., Lindhardt, B. (1996): Gas-generating processes in landfills. In: Christensen, Th.H., Cossu, R., Stegmann, R. (Eds.), Landfilling of Waste: Biogas. E&FN Spon Verlag, London, ISBN 0 419 19400 2

EEA (European Environment Agency) (2004): Annual European Community greenhouse gas inventory 1990–2002 and inventory report 2004. In: http://www.eea.eu.int

IPCC (1995): Climate Change 1994: Radiative Forcing of Climate Change. Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom.

IPCC (1996): Climate Change 1995: The Science of Climate Change. Inter-governmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom.

Keppler, F., Hamilton, J.T.G., Brass, M., Röckmann, Th. (2006): Methane emissions from terrestrial plants under aerobic conditions. In: Nature, January 12, 2006

Lelieveld, J., Crutzen, P.J., Dentener, F.J. (1998): Changing concentration, lifetime and climate forcing of atmospheric methane. Tellus 50B, pp. 128-150.

Prantl, R., Tesar, M., Huber-Humer, M. (2006): In-Situ Aerobisierung als Sanierungs- bzw. Nachsorgemaßnahme. In: DepoTech2006, Lorber, K.E., Staber, W., Menapace, H., Kienzl, N., Vogrin, A. (Hrsg.), VGE Verlag GmbH, Essen, pp. 729-732. ISBN-13: 978-3-7739-6023-8

Ritzkowski, M., Heyer, K.-U., Stegmann, R. (2006): Fundamental Processes and implications during in situ aeration of old landfills. In: Waste Management 26, Volume 4, 356-372, Elsevier Ltd., ISSN 0956-053X

Stegmann, R., Hupe, K., Heyer, K.-U. (2000): Verfahren zur abgestuften beschleunigten in situ-Stabilisierung von Deponien und Altablagerungen. Patent Nr. 10005243. Deutsches Patent- und Markenamt, München

Tabasaran, O., Rettenberger, G. (1987): Grundlage zur Planung von Entgasungsanlagen. Müllhandbuch. Erich Schmidt Verlag, Berlin.

Umweltbundesamt (2003): Luftschadstofftrends in Österreich 1980-2001. Umweltbundesamt GmbH (Federal Environment Agency Ltd) (Hrsg.), ISBN: 3-85457-683-8