Utilization of Landfill Gas and Emission Mitigation

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Dwindling Landfill Gas - Relevance and Aftercare Approaches

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Abstract
In the long–term, gas produced by landfills is characterized by a low methane content, scarce propensity for use in economically-sound energy recovery procedures and requires treatment due to its global warming potential. Low-cost technologies must be found, either to extend the phase of profitable landfill gas utilization, or methods developed to shorten the landfill gas aftercare phase and mitigate long-term emissions. This paper provides a general review of possible aftercare strategies with respect to dwindling landfill gas.

1 Introduction
Due to its high content of methane, landfill gas can be regarded on the one hand as a useful alternative source of energy, when collected and utilized, whilst on the other hand, when released unused and untreated into the atmosphere, it causes considerable harm to the environment, contributing substantially to the manmade greenhouse effect, and to global climate change, respectively. Although modern, sanitary landfills in most developed countries usually operate a gas extraction system, a large amount of gas still escapes into the atmosphere. This fact is clearly indicated by the currently available data concerning national and global landfill methane emissions. In Europe for instance, an estimated 20 – 25% percent of anthropogenic methane emissions are from landfills (EEA, 2206). In 2003, the calculated total amount of approximately 3.34 kilotons of methane were emitted from waste disposal in the European Union (EEA, 2006). In the US, methane emissions from waste disposal are more than twofold higher than those reported for the European Union (USEPA, 2006). Thus, landfills are among the largest anthropogenic methane sources worldwide, ranking third after agriculture (livestock farming and rice cultivation) and losses from fossil fuel distribution, processing and mining (IPCC, 2001). Moreover, methane is also emitted from older and smaller landfill sites, where the subsequent application of a gas collection system is too costly and inefficient, as well as from open, unauthorized dumpsites, and - of course - from closed, sanitary landfills during the aftercare phase, when the existing gas disposal technique is no longer adequate or appropriate.

2 State of the art of landfill gas recovery and disposal

State of the art engineered gas extraction systems, by means of which the produced landfill gas is actively sucked off due to an under-pressure induced in the landfill body are applied during gas collection and capturing procedures. The efficiency of these extraction systems depends on the landfill geometry and design (particularly the capping properties), the waste compaction, density and water content, the atmospheric pressure and wind conditions, the design of the extraction wells and collectors and the technical management of the extraction system (sucking rate, distance of the gas wells/collectors,…). Following intensive field investigations on different landfills in France, Morcet et al. (2003) and Spokas et al. (2006) concluded, that conservative rates for active gas recovery (including vertical wells and horizontal collectors) are 35% for an operating landfill cell, 65% for a temporary covered cell, 85% for a clay final covered cell, and more than 90% for a geo-membrane final covered cell. Based on their findings, a mean gas recovery rate of about 60% can be assumed considering the total life-time of a landfill.

The utilization of the captured landfill gas with a methane content exceeding 45%, in combined heat and power plants (CHP) is the most feasible state-of-the art treatment method, mainly used in the operational phase or shortly after landfill closure. This method affords the possibility of substituting fossil fuels and obtaining an additional economic gain by feeding the electricity produced into an existing grid (Haubrichs and Widmann, 2006). Moreover, landfill gas utilization and the consequential reduction of landfill gas emissions have recently been linked to carbon credits and trading schemes, representing an additional financial commodity for landfill operators on national or even worldwide markets. However, the production and composition of landfill gas varies in time, indicating a decrease in methane content and the total amount of landfill methane produced in the long term. The time-dependent behavior of gas generation is affected by several factors and processes, such as meteorological conditions (e.g., temperature, precipitation, barometric pressure), waste properties (e.g., amount of biodegradable organic matter, water content), top cover design (permeable or tight), and kind of landfill operation and management. The latter all produce a strong impact on chemical and biological processes occurring in the landfill during the degradation of organic compounds, leading to gas generation.

At a gas methane content lower than 35 – 40% and a total landfill gas production of about 30–50 m^3/h, treatment in CHP plants becomes technically and economically unsuitable, limiting the use of landfill gas for heat and power production to a certain period of time (Haubrichs and Widmann, 2006). Landfill gas with methane values decreasing down to about 20 – 25 % v/v, and a flowrate of 10 – 15 m^3 gas/h, respectively, is mostly treated in high temperature flares, converting methane into carbon dioxide. Below these values the treatment of poor landfill gas becomes more expensive and intricate, requiring use of methods such as fluidized bed combustion or catalytic oxidation. Moreover, poor landfill gas with a concentration of > 0.3% methane by volume can be oxidized in a non-catalytic

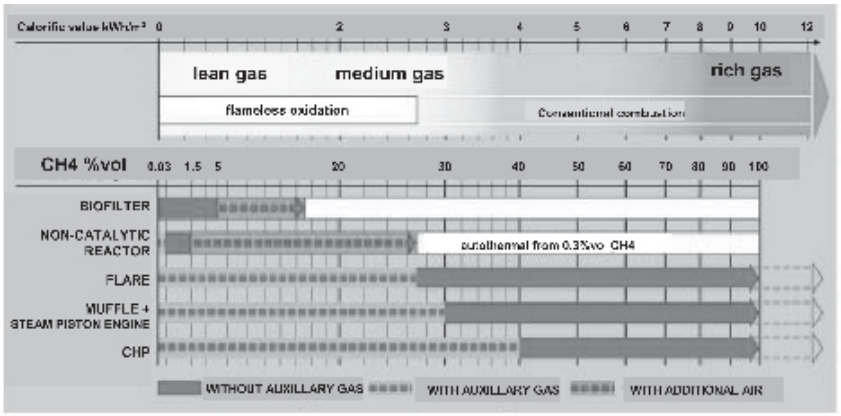


Fig. 1: Operation ranges of gas utilization and disposal facilities (Stachowitz, 2001)

reactor bed, even in an auto-thermal reaction, once the reactor is heated to its operating temperature of 1,000°C (Stachowitz, 2001). Figure 1 summarizes different stages of landfill gas quality, utilization and disposal techniques according to Stachowitz (2001).

Finally, on a long term basis, landfills produce gas with low calorific values, this period of time being estimated to last much longer than that characterized by beneficial gas utilization (Haubrichs and Widmann, 2006). For this time period, the use of cost-efficient and simple techniques becoming increasingly important. The biological oxidation of poor landfill gas in technical biofilters or engineered landfill covers ("biocovers") using specific microorganisms to convert methane into water, carbon dioxide and biomass is a particularly promising and proper method, that has already been tested and the efficiency demonstrated in several international investigations (Humer and Lechner, 2001, Felske, 2003; Streese and Stegmann, 2003; Barlaz et al., 2004; Huber-Humer, 2004; Bogner et al., 2005; Gebert and Gröngröft, 2006; Haubrichs und Widmann, 2006; Zeiss, 2006; Stern et al., 2006).

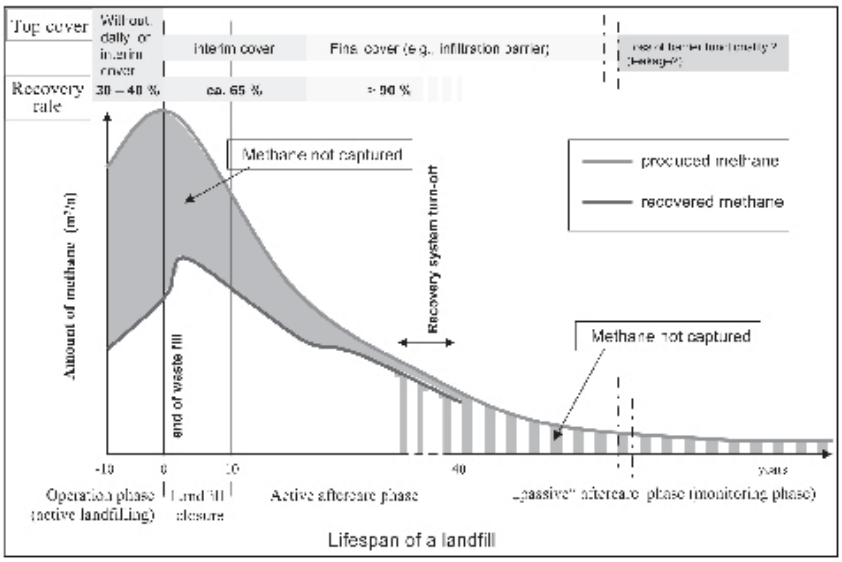
3 How long do we need landfill gas aftercare? – Relevance of gas emissions

While 90% of the carbon broken down in a bioreactor landfill is found in landfill gas, only 10% remains in the organic load of leachate. At a proper temperature and water content the decomposition of the organic matter in the landfill proceeds efficiently, meaning that utilizable gas formation and environmentally relevant gas emissions may occur mainly for a period of two to three decades. A small amount of gas formation is estimated to remain up to 100 years. Relevant

leachate emissions can emerge considerably longer, in particular with regard to parameters such as COD (chemical oxygen demand) and nitrogen compounds. Investigations performed by Kruse (1994), Höring and Ehrig (1997) and Krümpelbeck (1999) show that these parameters decrease very slowly over time. Accordingly, leachate from MSW-landfills must be treated for 100 to 200 years to comply with stringent legal enforcements. Thus, leachate quality is the determining factor in establishing the time span of landfill aftercare. Nevertheless, leachate can be collected quite easily at modern landfills with engineered techniques. Moreover, leachate emissions are mainly limited to a local scale, as experiences derived from old landfills without bottom liners have shown (Kjeldsen, 1996; Krümpelbeck 1999), whereas landfill gas is far harder to capture, even using modern facilities; indeed, because of the high methane content the resulting gas emissions are of paramount importance on a global scale. Withal, if the infiltration of water into landfills containing a considerable amount of organic matter is hindered or restricted by impermeable covers, and consequently biological and chemical degradation processes are retarded, it can not reliably be estimated how long the formation of relevant gas amounts will actually occur. On landfills capped with an impermeable cover organic matter can persist over remarkably lengthy periods. As first experiences from landfill operation with top barriers in Austria and Germany (Schoder, 1997; Nienhaus, 1997; and verbal information by landfill operators) show, landfill gas production declines rapidly after the installation of an impermeable top cover. When the top barrier fails at some later date, water will infiltrate again and microbial decomposition rates in the waste will increase, leading to relevant gas formation, most probably at a time when gas recovery systems are no longer operational. Consequently, the premature sealing of a landfill leads to unforeseeable and scarcely predictable time spans for landfill aftercare.

The EU landfill directive (Council Directive 1999/31/EC) stipulates in article 10 that landfill operators must ensure financial security for landfill closure and aftercare measures for a period of at least 30 years. This time-span is also often interpreted as the "active aftercare phase" for a landfill site, including gas extraction and treatment, leachate collection and disposal. However, from a scientific and technical point of view, the real aftercare period will most probably last longer in order to achieve environmentally harmless emissions - particularly regarding leachate quality. With respect to landfill gas, under optimal decomposition conditions, the greater part of methane formation in the landfill may already have taken place within 30 years after landfill closure. At first sight, compared to the amount of methane produced in the operational or landfill closure phase, methane released in or even after the aftercare phase seems to be negligible. Nevertheless, in the latter phase gas extraction systems are most probably no longer in continuous operation, flares running sporadically due to automatic turn-offs, since gas volumes and methane contents are excessively low. In a study performed to investigate conditions present in many older landfills in Germany, Krümpelbeck (1999) discovered that considerable methane emissions occur par-

ticularly in the transition period between active and passive aftercare measures, when active gas extraction, gas-utilization and/or flaring are no longer operating smoothly. Moreover, the period of "unusable" methane formation may last from several decades up to 100 years, finally accumulating to provide an amount of gas which is consequently no longer negligible, particularly with respect to global warming. Figure 2 schematically illustrates the quantity of methane emissions released during the operational and in the "aftercare phases". The amount of methane emissions depends on the gas recovery rate and operation time and is affected by the top cover layer (compare Spokas et al, 2006). As can be observed, the highest methane emissions may occur during the operational phase, when efficient covers have not yet been emplaced and the gas extraction system is not yet fully established, although considerable emissions may also be manifested in the aftercare phase when recovery systems are switched off. Schematic considerations reported in Figure 2 do not take into account the emission mitigation po-



tential due to microbial methane oxidation in the cover. If engineered biocovers are applied as an additional security to gas extraction systems or as a subsequent, passive mitigation measure, methane emission can be markedly reduced, both during the operational phase as well as in the aftercare phases.

Fig. 2: Schematic time-dependent methane production and recovery curve over the life-span of a landfill, as well as quantity of methane emissions (methane not captured) affected by the type of top cover and gas recovery rate; emission reduction through methane oxidation not accounted; gas recovery rates according to Spokas et al. (2006)

National regulations in some countries (e.g., Austrian Waste Water Emission Ordinance) set limit values for the direct discharge of landfill leachate into the environment. This values may be also taken as reference values or qualitative criteria for use in rating the endpoint of active landfill aftercare with regard to leachate, whereas in the majority of cases, such regulatory criteria are missing with respect to landfill gas formation or emission. Heyer et al. (2006) discuss criteria regarding the end of the aftercare phase for landfill gas. The authors suggest abandoning the phase of active landfill gas treatment when over a ten year period the methane formation does not exceed 25 m^3 CH_4/h for the entire landfill, and 5 m^3 CH_4/h per hectare, respectively. In that case, they recommend passive gas disposal via methane oxidation in the landfill cover as a proper solution, whereby the methane load introduced into the cover should be lower than 0.5 l/m^2h, and remaining methane emissions at the top of the cover are lower than 25 ppm CH_4. As a quantitative criterion, methane emission rates released from natural wetlands, swamps, etc. could also be considered as a reference parameter. Methane emissions from landfills (such as "anthropogenic eco-systems") cannot be expected to be lower than natural ones. Typical methane emission rates from boreal wetlands range between 0.02 – 0.41 g/m^2d (= 0.03 – 0.6 l CH_4/m^2d) (Göttlich, 1990; Bellisario, 1999; Sadredin et al., 1996; Bubier et al., 1995)

4 Landfill Gas Aftercare Approaches

As already mentioned in section 2, state of the art is to use the extracted and collected landfill methane as long as possible for energy production. Subsequently, lean landfill gas should be flared or treated in biofilters. Landfill covers that foster microbial methane oxidation can be a polishing measure at both stages, on the one hand to capture methane emissions that escape gas recovery as well as to mitigate methane emission when the extraction system is turned off. Engineered landfill covers (biocovers) provide a simple and cost-efficient solution, since there is no further operation of technical systems and no energy input needed on the landfill for efficient gas emission mitigation. Moreover, biocovers can be planted and re-vegetated, therefore possibly acting as an evapo-transpiration layer, leading to a clearly reduced leachate amount.

Many efforts are being made today to extend the gas utilization phase, even with lean landfill gas. Research and pilot projects focusing on new flaring, burning and methane upgrading techniques are in progress. Steinbrecht and Spielberg (2006) have developed a concept for burning lean landfill gas based on fluidized bubbling bed combustion (SFBC), able to thermally treat gas with methane concentrations down to 5-8%vol, and coevally to utilize the energy amount of the lean gas for electric power generation (small plant for 45 kW electric power is intended). Moreover, leachate water can be treated in the SFBC-reactor, and a part of the generated steam can be re-injected into the landfill body to maintain or stimulate anaerobic decomposition processes within the landfill.

In contrast to technologies enhancing landfill methane extraction and utiliza-

tion in the aftercare phase, another strategy was developed during the past years, focusing on the acceleration of decomposition processes and the stabilization of organic matter in the landfill, so that methane generation, and consequently emissions, will no longer occur at an environmentally relevant level. This technology, called In-situ Aeration, has already been applied on technical scale to several old landfills in Germany (Heyer et al., 2005; Ritzkowski, 2005; Ritzkowski and Stegmann, 2005), Austria (Prantl et al., 2005 and 2006) and Italy (Cossu et al., 2005). Biological stabilization of old landfills using In-situ Aeration provides the possibility to reduce both the actual gas and leachate emissions, as well as the long-term emission potential of the waste material. Therefore, ambient air is blown into the landfill (low pressure) over several years using injection wells (or already existing gas-wells), and the resulting gas mixture is extracted and treated (e.g., in a biofilter). Under the induced aerobic conditions organic matter is mineralized and stabilized faster, and carbon is mainly emitted in form of $CO_{2,}$ which is 23-times less greenhouse active than methane. Moreover, under specific conditions In-situ Aeration could be combined with watering measures to foster the decomposition and leaching processes in the landfill. By these measures the period for landfill closure and aftercare can be clearly shortened and long-term costs reduced (Heyer et al., 2005).

Prantl et al. (2006b) defined target values and criteria for ending the In-situ Aeration process on a landfill, based on the experiences made at an old landfill in Austria. They suggest determining respiration activity (RA_4), as well as leaching tests (BOD_5, COD and NH_4-N) of the solid phase of the landfilled waste to define the emission potential. Statistical analysis of numerous samples showed that RA4 < 1,5 mg O_2/gDM, and leaching tests with BOD_5 < 300 mg O_2 kg^{-1} DM, COD < 1.500 mg O_2 kg^{-1} DM and NH_4-N < 400 mg kg^{-1} DM indicate a waste with very low residual emission potential. Moreover, newly adapted analyzing methods (infrared spectra of solid waste samples) (Tesar et al., 2005; Lechner et al., 2006), provide information on the stability of the waste. The absence and presence of indicator bands and the determination of certain band heights can be used as stabilization criteria. The absence of the bands at wave-numbers 1550 cm^{-1},1320 cm^{-1} and 1250 cm^{-1}, as well as the ratio between the band heights at 2925 cm^{-1} and 1630 cm^{-1} of < 0,35, indicate a high biological stability correlating with the above defined target values (Prantl et al., 2006b). Moreover, the remaining methane generation potential of the aerobically treated landfill should be smaller than the methane oxidation capacity of its cover layer. A methane generation rate below 3 l CH_4/ m^2h should be targeted, to enable full oxidation of possible subsequent methane emissions in the cover layer without any difficulty, thus avoiding the need for any other type of gas disposal system. The authors assume that depending on the initial quality of the organic matter in the landfilled waste, an In-situ Aeration period between 4 – 6 years is needed to reach above mentioned criteria, which characterize biologically stabilized waste conditions over the long-term.

5 Conclusions

The period of poor landfill gas production will last significantly longer than the operational phase of the landfill and the time of landfill gas utilization, thus representing in the long term an expense. Therefore, cost-efficient technologies must be developed, capable of either extending the period of profitable gas utilization (usage of poor landfill gas down to scarce methane content) or shortening the landfill gas aftercare phase. Currently, techniques in progress to address the first issue are comparatively complex and expensive, although attempts are being made to render them more practical and economical. Strategies focusing on the second issue are usually lower-cost, but may need new efficient monitoring methods to validate the effectiveness of the treatment over a longer period. However, technologies such as In-situ Aeration or the application of biocovers not only address landfill gas issues, but also the leachate quality and quantity and its long-term development. Although landfill gas emissions are of global environmental importance due to their high greenhouse activity and global warming potential, the time-determining factor (and thus most probably the cost factor) for landfill aftercare, particularly with respect to local and regional realities (such as groundwater protection etc.), will be represented by leachate treatment.

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