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New DN-ES+S Landfill Aftercare Conception Based on a Fluidized Bubbling Bed Combustion Plant Burning Very Poor Landfill Gas

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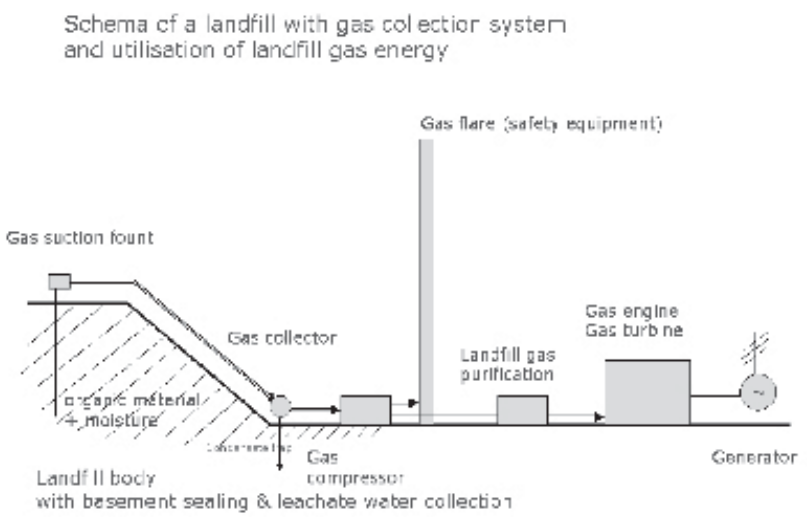
1 Introduction

Depending on the kind and mass of waste stored, a combustible gas - commonly



known as landfill gas - is biologically produced in landfills. Due to the large volume and high methane content this "bio"-gas is normally used in the production of energy .

In Germany and in Austria landfills are equipped with gas collection systems providing for the energetic utilization of the gas. (Fig. 1)

Fig. 1: Diagram of landfill gas utilization

Gas-fired internal combustion engines are used to obtain lower landfill gas production rates whilst to achieve higher production rates gas turbines are used.

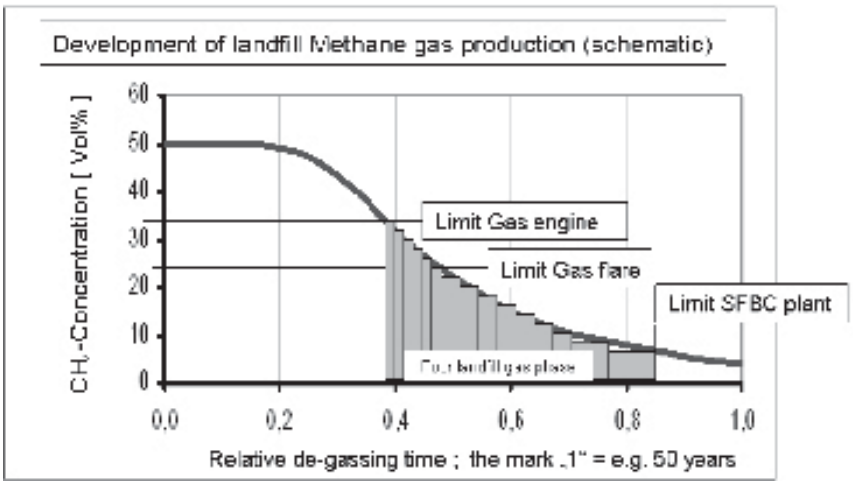


Fig. 2: Schematic development of methane landfill gas concentrations over time

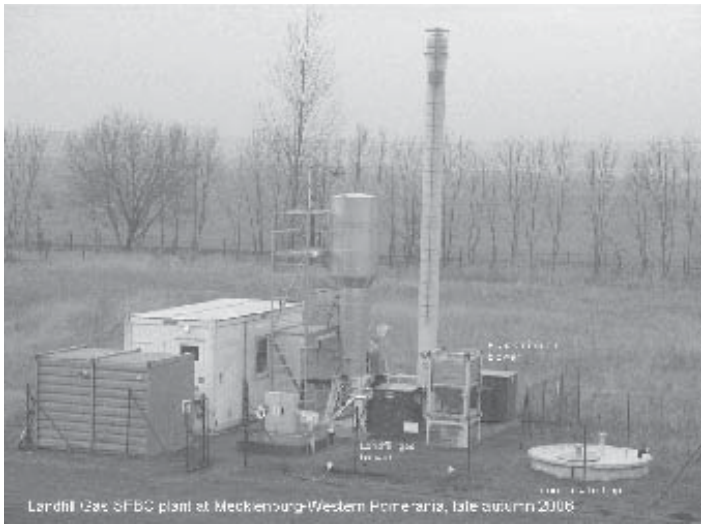


Fig. 3: View of the landfill gas SFBC plant

Piston engines are negatively affected by Silane concentrations in the landfill gas due to the presence of Silicon products in demolition wastes and beauty care materials. During the internal combustion process Silane forms fine SiO_2- (sand-) particles capable of causing serious abrasion problems in the combustion cylin-

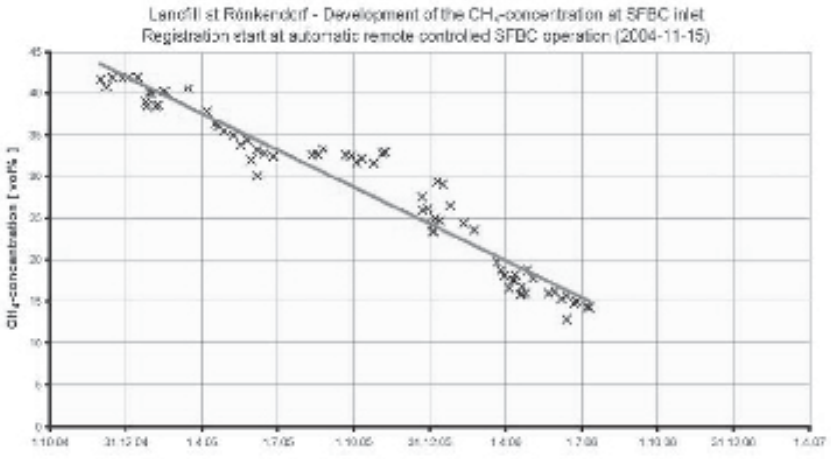


Fig. 4: Decrease of methane concentration in the landfill gas during SFBC operation

ders. This often causes an insufficient operational regime of the engines leading to high maintenance costs.

As the years progress the biologically produced landfill gas becomes poorer and poorer. If the methane concentration in the landfill gas falls below a characteristic concentration level it is not suitable for burning in a gas engine or gas flare (Fig 2).

2 Fluidized Bed Combustion Plant

To achieve an increased thermal removal of this poor "non combustible" gas, the operation of a Stationary bubbling Fluidized Bed Combustion (SFBC) plant may be beneficial. The shaded area in fig. 2 is characteristic of the total SFBC combustion available in landfill gas volume.

Installation of a "common" gas flare is not necessary due to the possibility of operating an SFBC under economic conditions from shut-down of the gas engine to presence of the poorest methane concentration in landfill gas (≈ 8 vol% methane) significantly below limits established for the flare (Steinbrecht et. al., 2006).

This type of SFBC plant has been successfully operated on a closed landfill in Mecklenburg-Western Pomerania in Germany. Fig. 3 illustrates the plant layout.

The SFBC plant is operated with a red-hot sand bed at a bed temperature of T_{SFBC} = 852 °C within narrow temperature limits. The infinite number of red-hot sand particles is a safe ignition source even in the case of very poor fuel gas. The SFBC plant operates under controlled continuous automatic remote conditions. Within a two year period a total of approximately 16 500 operational hours could be achieved, of which 8700 hours in the second year. The landfill gas methane

Supervision of the SFBC emissions

Residue Landfill Gas SFBC Plant at Rönkendorf
Mecklenburg Western Pomerania, Germany

Measurements by the accredited & licensed firm
FUN Umweltanalytik GmbH, Prof. Rettenberger, Germany

2005 June 14th

		Limiting value	Dimension	Measurement No. 1	2	3	Mean value
Carbon monoxide	CO	0,10	g/m³	< 0,1	< 0,1	< 0,1	< 0,1
Nitrogen oxides	NO_2	0,35	g/m³	0,046	0,047	0,045	0,045
Inorganic gaseous fluorine compounds	HF	5	mg/m³	1,8	2,4	2,1	2,1
Inorganic gaseous chlorine compounds	HCl	50	mg/m³	0,9	3,6	2,1	2,2
Sulphur oxides	SO_2	0,35	g/m³	< DL	< DL	< DL	< DL
Dioxines & Furanes		0,1	ng/m³	0,002			

DL = Detection limit

Fig. 5: Results of the official emission measurements (Steinbrecht et. al., 2006a; Steinbrecht and Spiegelberg, 2006)

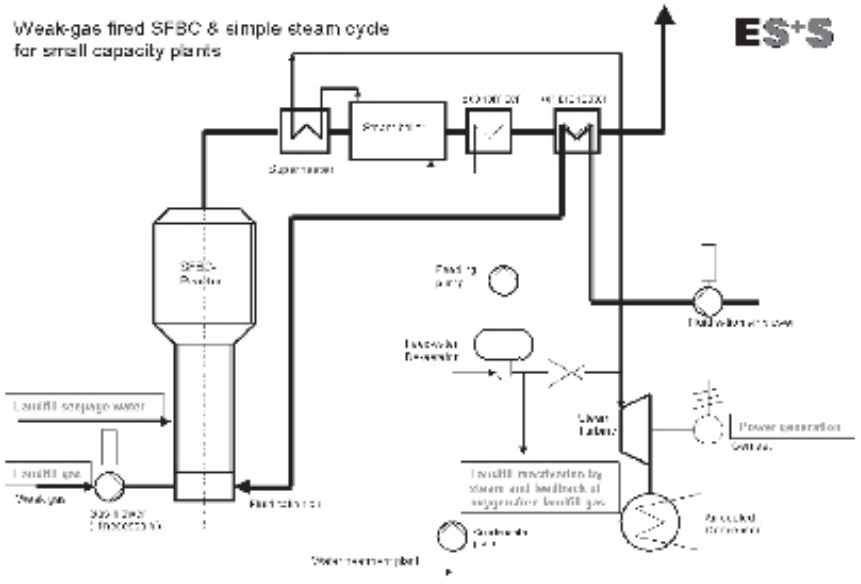


Fig. 6: SFBC plant in combination with a small steam cycle

concentration fell from an initial 35 - 40 vol% in autumn 2004 to ca. 14 vol% in summer 2006, (see fig. 4). This decrease in quality of the gas had been envisaged during planning, but produced no consequences and did not affect reliability of plant operation (Steinbrecht et. al., 2006a; Steinbrecht and Spiegelberg, 2006). A realistic interval for plant maintenance is every 3 - 4 weeks, at which time a little sand must be replaced.
In line with the tendency illustrated in fig. 4**,** shut down of the SFBC plant due to excessively low methane concentrations in landfill gas was expected in the spring of 2007.

The expected low emissions have been confirmed by an accredited measurement firm (fig 5).

3 Generation of electric power

The next step planned is a switch from a "simple" removal of poor landfill gas to a complete small energy system. This principle based on the SFBC as firing equipment in combination with a small steam cycle has been commissioned for 2007. The new SFBC landfill gas plant with higher thermal power is presented in fig. 6. This type of steam cycle is not affected by the presence of SiO_2-particles as a combustion by-product, because "sand" is used in the SFBC as inert fluidization material.

The electric power produced by the generator is not fed into the public grid but is used in substitution of energy from the public grid to fuel the landfill plants. Economic calculations have emphasized the advantage of this practice, due to the fact that benefits obtained by feeding power back into the public grid are significantly smaller compared to the high costs incurred in supplying the plant directly from the public grid.

Based on the SFBC plant experience a comprehensive landfill aftercare system known as DN-ES$^+$S[1] has been introduced. In fig. 6 the key issues are reported in red. The crux of the matter is to achieve an SFBC capable of burning even the poorest landfill gases. Through application of the DN-ES+S technology to exploit the energy content of the weak landfill gas, the following aims can be achieved:

- generation of electric power by a small steam cycle
- thermal removal of heavily loaded leachate
- an anaerobic methane reactivation of "dead" landfill sections developed by ES$^+$S GmbH (Steinbrecht and Spiegelberg, 2006)

Numerous experiments have been performed to verify the aspects mentioned above.

4 Thermal removal of heavily loaded landfill leachate

Landfills do not only produce landfill gas, they also produce landfill leachate. In several cases the latter is heavily loaded with organic components. In the majority

1 DS-ES$^+$S = Deponie-Nachsorgesystem der Fa. ES+S GmbH

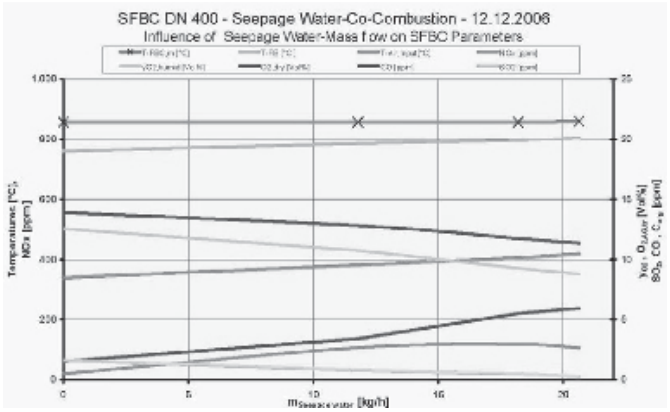


Fig. 7: Test results of co-combustion of highly loaded landfill leachate (Steinbrecht and Spiegelberg, 2006).

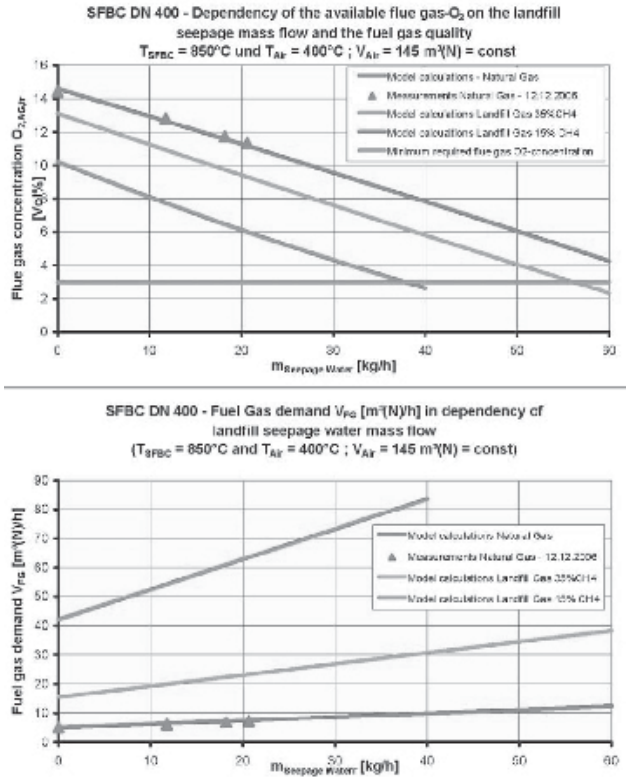


Fig. 8: Model tests performed to assess the impact of fuel gas quality and leachate mass flow on flue gas oxygen concentration and fuel gas demand

of cases purification of leachate in communal wastewater treatment plants is not feasible. The use of special leachate treatment plants implies high costs which can be avoided by providing for thermal removal (co-combustion) of landfill leachate within the SFBC plant.

To verify the conditions required for co-combustion of leachate tests have been carried out using the SFBC DN 400 at the University of Rostock (Steinbrecht and Ramke, 2006). The main fuel was "normal" natural gas. The landfill leachate burnt, characterized by a COD = 18 850 mg/l, was fed into the SFBC at a variable mass flow (four different mass flows) by means of a special input device. The feed mass rates during the tests are marked at the line of "bed temperature" in Fig. 7. summarizing the experimental results obtained; the measured concentration of organic compounds C_{org} in the flue gas was zero at all seepage load points. This parameter $C_{org} = 0$ indicates that all organic compounds contained in the seepage and in the primary fuel are completely oxidized into inorganic compounds during the fluidized bed combustion process.

Test results were verified by the "Thermodynamic SFBC Model" developed earlier at the Chair of Environmental Technology, University of Rostock. The model confirmed the suitability of all measured load points. This model has also been successfully used for other predictions, e.g. to ascertain the real behavior of "very poor fuel gases" (Steinbrecht et. al., 2006b) as basis for the landfill gas SFBC plant described above. The predicted results are very realistic.

Based on the actual measurements obtained with natural gas, new SFBC model investigations have been made to overcome the technical limits encountered in co-combustion of landfill leachate. Furthermore, the effect of the burnt leachate on the heat removal process and on the steam cycle efficiency was investigated.

Tests revealed the feasibility of performing co-combustion in an SFBC plant. The concentration and availability of methane gas flow produce a marked impact on the removable seepage load. Technical limitations to maintaining the required energy balance are manifested if the available oxygen concentration in the SFBC dry flue gas falls below a "critical" value (here assumed at $O_{2,dry} = 3$ Vol%).

For example, the SFBC DN 400 is capable of removing more than 50 kg/h or 1200 kg/day landfill leachate using landfill gas characterized by 35 vol% methane (i.e. at the beginning of the aftercare phase). If the available gas flow is high enough, removal of more than 30 kg/h or 720 kg/day is realistic even with a methane concentration of 15 vol%.

An SFBC plant with a higher thermal power is able to remove higher quantities of leachate. It follows therefore that such an SFBC plant could contribute considerably towards increasing leachate removal whilst at the same time saving on operational costs. However, in view of the actual composition of leachate it may prove necessary to provide for gas cleaning steps in the process.

The influence of water evaporation on heat removal processes during the co-combustion of leachate should be further investigated. On the one side, the decreasing flue gas oxygen concentration leads to an increased efficiency in heat

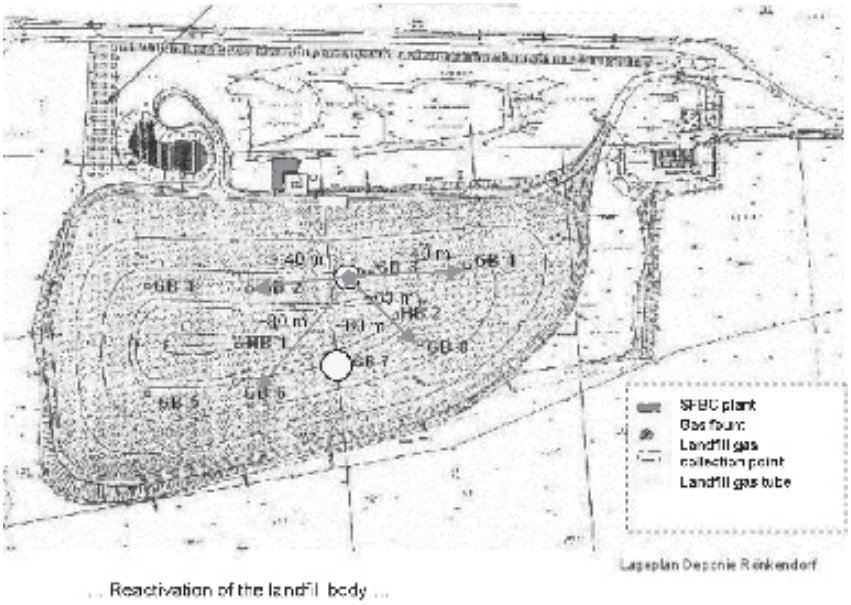


Fig. 9: Situation during landfill fount reactivation

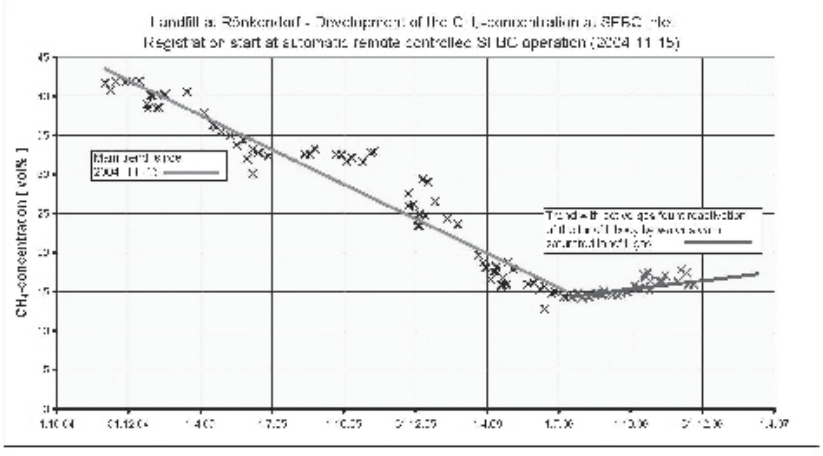


Fig. 10: Influence of landfill body reactivation on methane concentration in landfill gas

exchange (steam boiler). On the other hand, the flue gas mass flow and the heat capacity flow increase in line with the evaporated seepage mass. The above fluctuations however produce only negligible effects on efficiency.

5 Anaerobic methane reactivation of "dead" landfill sections

As illustrated in fig. 4 the SFBC was expected to be shut down in spring 2007 due to the presence of excessively low methane concentrations in the landfill gas. The dramatic decrease in gas quality occurred due to the effect of excess oxygen concentrations on almost all gas sources.

The observed decrease in landfill gas quality was not caused by the absence of organic material but rather by the absence of moisture within the landfill body. In agreement with the landfill management and the Environmental Authorities of Mecklenburg-Western Pomerania, a landfill reactivation program was initiated.

The patented idea was to transport the moisture required for a renewed start-up of the biological processes into the landfill body. However, it is an acknowledged fact that the introduction of liquid moisture will cause detrimental results leading to the continued production of leachate and the absence of gas. It is more advisable to introduce the "medium water" during the gaseous phase. However, steam at atmospheric pressure is characterized by a temperature of 100°C which does not enhance the necessary biological processes. In order to avoid these problems another solution was identified:

Part of the oxygen-free landfill gas is not burnt within the SFBC, but is compressed by the gas blower and transported by a separate tube back to the landfill gas collection point where it is fed back into the gas fount. At the gas source the feedback gas is mixed with steam and fed back into the landfill body. This procedure avoids unacceptable temperatures and the moisture (in gaseous phase) is widely distributed throughout the landfill body (see fig. 9).

The reactivation procedure was started in May, 2006. During the first weeks only a decrease of oxygen concentrations in the "inactivated" founts could be observed, marking the initialization of biological activity. During this period no improvements in methane concentration were detected, with values falling to an absolute minimum of 12.8 vol% methane (June 14th, 2006).

At the beginning of July 2006 it was observed that the landfill gas methane concentration had risen to the present values of 16 - 17 vol% methane (see fig. 10).

Increase in methane concentration was observed at all gas founts, thus providing confirmation that internal moisture had been distributed throughout the landfill body. Fig. 10 represents the continuation of the "landfill methane gas trend registration" illustrated in fig 4.

On-going operation of the SFBC plant at this landfill following the successful reactivation of the landfill body would seem to be a distinct possibility.

6 Summary

On the basis of local conditions the following procedures may be applied to an

SFBC plant with the aim of providing an optimal solution:

- Generation of electric power
- Thermal removal of heavily loaded landfill leachate
- Anaerobic methane reactivation of "inactivated" landfill sections

The effect of application of these combined procedures is fundamental with a view to climate protection. In addition, the landfill operating company may benefit from the use of such a system in view of the economical advantages afforded when faced with the mandatory aftercare scenario.
By means of the DN - ES$^+$S system the aim of achieving complete anaerobic conversion of the organic fraction may be envisaged. Further, the need for aftercare will be reduced and climate-friendly policies will be fulfilled. CO_2-reduction certificates are of particular interest due to the 21-fold climatic relevance of methane in comparison to CO_2 and to the high volumes of very poor landfill gas to be disposed of (fig. 2). Likewise, expenditure required during the aftercare period will decrease considerably. The DN-ES$^+$S system will represent an important step in achieving these fundamental goals.

7 Acknowledgement

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