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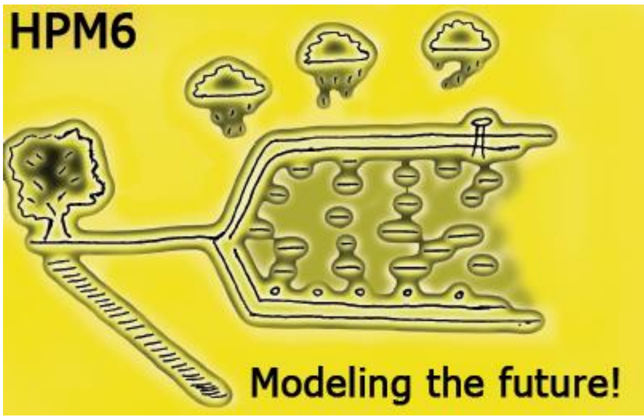

The 6th International Workshop on Hydro-Physico-Mechanics of landfills

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C- and N-balances from a landfill aeration experiment

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INTRODUCTION

Landfilling still represents the dominant method for disposal of municipal solid waste (MSW) on a global scale. Landfills are known to threaten human health and the environment, mainly in terms of leachate, but also through gaseous emissions (Laner et al. 2012). Among the gaseous emissions carbon containing compounds are considered most problematic, mainly CH_4 due to its high global warming potential and potential explosion hazards in adjacent buildings, but also e.g. odorous non methane VOC (volatile organic carbon) compounds. With respect to leachate emissions nitrogenous compounds play a pivotal role, mainly NH_4 due to high aquatic toxicity and eutrophication potential.
Especially for old landfills producing not enough landfill gas for economically feasible utilization, low pressure in-situ aeration was proposed to enhance waste stabilization and reduce methane emissions as well as improve leachate quality (Ritzkowski and Stegmann 2012). During aeration, the anaerobic environment gets continuously oxidized which activates several previously unavailable degradation pathways for microorganisms. This oxidation would ideally result, in dependency of the respective site conditions and technical implementation, in the complete shift of mineralization products from gaseous CO_2 and CH_4 emissions to CO_2 and H_2O emissions with increased carbon turnover rates.

The fate of nitrogenous compounds during in-situ aeration is however less clear, since it was estimated that the majority of nitrogen remains in the solid body of waste during in-situ aeration (Fellner and Laner 2011). Even so, the NH_4 concentrations in the leachate are known to decline during in-situ aeration and nitrification takes place, leading to increased NO_3 leachate concentrations. On the other hand, the highest production rates of the potent greenhouse gas N_2O occur under anoxic conditions, thereby the application of in-situ aeration might enhance its formation.
It is the goal of this work to provide robust balances for all major carbonic and nitrogenous flows and pools during a lab-scale experiment by comparing aerobic degradation set-ups to an anaerobic reference. In the aerated set-ups, a focus was put on the influence of water addition on waste degradation: aerobic degradation was shown to be enhanced with a higher moisture content (Pommier et al. 2008), while during in-situ aeration a higher water content is considered to reduce the air intrusion into the waste matrix (Hrad et al. 2013).

METHODOLOGY

The laboratory experiment conducted lasted 823 days. The experimental setup consisted of six landfill simulation reactors (LSR, total internal volume ~121 l), with two of them each being operated under the same distinct conditions: two were operated aerobically with leachate recirculation, two aerobically without water addition and leachate recirculation and two were operated anaerobically with leachate recirculation. The embedded waste material originated from an old Austrian landfill, closed 1974. The material mainly consisted of MSW and was sieved on-site (mesh width 20 mm).
For the aerobic treatments aeration was initiated after an anaerobic phase of 70 days. The air was introduced from a gas flask (synthetic air, MESSER) and the rather low flow rates (30-40 ml h^{-1}) were measured with digital mass flow meters (EM1NH, Sensirion AG, Switzerland). The anaerobic gas production was assessed with eudiometers: measuring cylinders reversely placed into an acidic solution. The gas concentrations for all treatments were measured roughly twice a week resulting in 350 measurements/LSR throughout the experiment. In total, 27 leachate samples were taken from each LSR operated with leachate recirculation.
The according carbon and nitrogen related measurements are given in Table 1. The leachate was analyzed at each sampling point. The gas concentrations of CH_4 and CO_2 were determined consistently before leachate recirculation. The amount of released NH_3 was assessed with gas washing flasks containing an acidic solution at the outlet. Nitrous oxide (N_2O) was detected 52 times over the whole

time course. The solid concentrations were determined at the start and end points of the experiment in three replicates and once during the aeration period, in case of the aerated treatments.

Table 1: Conducted measurements for each treatment in relation to C and N

	Carbon			**Nitrogen**		
Treatment	**Leachate**	**Gas**	**Solids**	**Leachate**	**Gas**	**Solids**
aerated wet	TOC	CH_4, CO_2	TOC, Cellulose, Lignin	NO_3, NH_4, TN	N_2O, NH_3	NH_4, NO_3, TN
aerated dry		CH_4, CO_2	TOC, Cellulose, Lignin		N_2O, NH_3	NH_4, NO_3, TN
anaerobic	TOC	CH_4, CO_2	TOC, Cellulose, Lignin	NO_3, NH_4, TN	N_2O, NH_3	NH_4, NO_3, TN

Notes: Additional explanations are found in the method section. TOC total organic carbon, TN total nitrogen

RESULTS

The presented carbon balance (Fig. 1) indicates that during aeration a higher amount (roughly double) of initially present TOC was released via gas in comparison to the anaerobic treatment. Unexpectedly, not adding water over the whole experiment duration did not result in a reduction of C-discharge. We attribute this observation to occurring microbial water production during aerobic degradation and improved air intrusion for the relatively dry LSR.

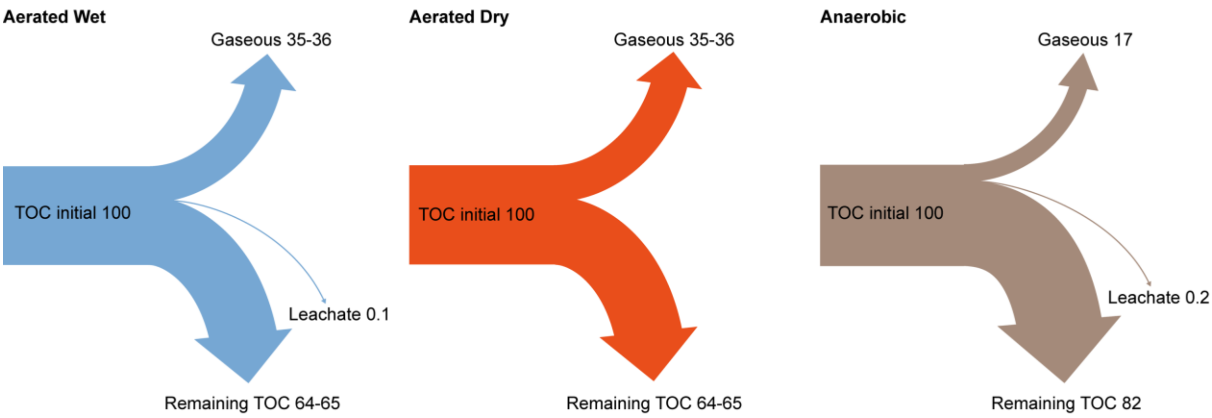

Fig. 1. Carbon balance of the laboratory degradation experiment

Notes: Ranges indicate the differences between the treatment replicates and values are given in % initial TOC. TOC total organic carbon.

For the nitrogen balance (Fig. 2), water addition and recirculation showed a high impact for the aerated treatments in comparison to the carbon balance. In addition to direct leachate losses, the denitrification pathway was facilitated for the aerated wet treatment. For the anaerobic treatment also some N_2 losses could be detected (about 5 % initial TN). We attribute this observation rather to potential air intrusion than to real anaerobic denitrification, since anoxic instead of anaerobic conditions would be required for denitrification. Also the leachate nitrogen losses were relatively highest for the anaerobic treatment. Nonetheless, for all treatments the majority of nitrogen (ranging from 75 – 93 % initial TN) remained in the solids.

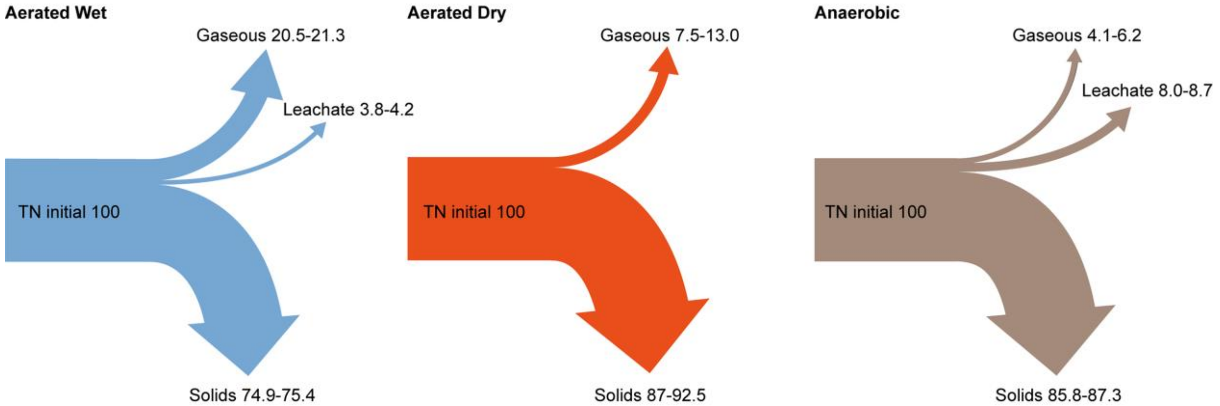

Fig. 2. Nitrogen balance of the laboratory degradation experiment

Notes: Ranges indicate the differences between the treatment replicates and values are given in % initial TN. TN total nitrogen.

CONCLUSIONS/DISCUSSION

Providing a complete carbon balance for an aerobic waste degradation laboratory experiment forms the basis for an in depth understanding of carbon dynamics during in-situ aeration. For the rather old waste material applied, the mineralization of organic matter was accelerated by factor 2 for the aerobic treatments. Leachate losses for carbon were insignificant for all treatments, with the highest carbon loads in the leachate observed under anaerobic conditions. The minor impact of water addition on the carbon balances under aerobic conditions is notably, as this could not be expected. Most probably this can be explained by the water production during microbial degradation and the higher air-filled porosity in the "dry" treatments, which compensated for the a priori sub-optimal moisture conditions, due to the low water content of the embedded waste.

For nitrogen, it was not possible to achieve a closed balance, as N_2 was not directly measured during the experiment. Nonetheless, the observed phenomena could be attributed to distinct degradation processes during in-situ aeration. In particular, for the aerated wet treatment the denitrification process was facilitated and around 20% of the initial nitrogen was mineralized to N_2. Overall, the gaseous N_2 losses were 2-4-fold higher during the aerated treatments than under anaerobic conditions.

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MULTI-PHASE MODELLING OF IN SITU AERATION OF SANITARY LANDFILLS

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Novel approaches for reducing after-care of Municipal Solid Waste (MSW) landfills are based on technological measures to reduce the emission potential present in the waste body within a short time period. Currently full-scale experiments are being prepared at three Dutch landfills where a combination of enhanced infiltration by irrigation and leachate recirculation followed by landfill aeration will be implemented. The aim is to reduce the emission potential as fast as possible by stimulating the biological degradation of organic matter in the waste body.

In order to define the optimal layout of the aeration system a numerical model was developed for quantifying the impact of different scenarios for air injection and air extraction. The model is based on a multiphase approach where the flow of the liquid and gas phase are solved simultaneously. Material properties for waste are obtained from White et al. (2014) and Zekkos (2006). The model is implemented in COMSOL and it is relatively easy to include a wide range of heterogeneity in the concept.

We present results of a number of scenarios which were implemented in order to find the optimal layout of the aeration system for the specific landfill situation of at the three pilots. Scenarios include a situation based on a homogeneous waste body with averaged properties for which the parameters are obtained from literature and where infiltration is based on yearly averaged data. Additional scenarios were analysed where the impact of local heterogeneity is included, for example the presence of an impermeable layer leading to local waterlogged conditions within the waste body combined with a more dynamic situation where infiltration follows the natural dynamics or enhanced infiltration scenarios.

The aim of the model is to identify the optimal design in order to for full-scale aeration of the waste body in the pilot cells. Operational criteria include applied injection and suction pressures, resulting injection and extraction volumes, well spacing, and how these translate to operational cost. Other important criteria are the impact of the aeration system on the emissions of landfill gas to the atmosphere, the effectiveness of treating the targeted volume of the waste body .

Figure 1 shows the steady state result of a base line scenario where in a 2D domain with a periodic boundary condition on the left and right vertical boundary and a drainage level at +1 m, air was injected in the well on the right with a pressure of 0.05 bar and extracted from the well on the left with a pressure of -0.15 bar. The figure shows the steady state air pressure contours, the streamlines (light gray) and the corresponding air flow (red arrows). Clearly air flows in the higher regions of the waste body. This is caused by a higher air permeability which is the result of a lower water saturation in the higher regions of the waste body when compared to the deeper parts of the waste body. The model will be used to design an optimal well system which also allows an effective treatment of the deeper sections of the waste body.