Is it possible to quantify emission potential from high resolution monitoring of leachate dynamics?

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Introduction

Modern sanitary landfills are one the most important final storage solutions for safely storing waste in modern society. Many countries around the world have implemented regulations in order to protect the environment from adverse emissions from the landfills. Generally these regulations require the installation of protective barriers which inhibit contaminants within the waste from migrating to the surroundings. After the active phase of landfilling, regulations require after-care to be carried out the landfill in order to ensure that no migration of contaminants take place. The after-care can be considered to be completed when the landfill no longer poses a threat to human health and the environment. The question that has to be answered is, when does a landfill no longer pose a threat to human health and the environment?

Although it is not easy to answer to this last question, we would like to try. First we assume that any technical barrier implemented in order to prevent migration of contaminants to the surroundings of the landfill will eventually fail. If in such a case the landfill still contains a significant amount of emission potential, we can be certain that a threat to the surroundings will occur. Therefore, the only way we can assume that the landfill no longer poses a threat to human health and the environment is when we can ascertain that the emission potential within the waste has reduced to levels at which the migration of contaminants has become very low. It is important to realise that emission levels will never be really zero so “acceptable” emission levels need to be defined. These levels have to be based on criteria which protect the surrounding ecosystem and need to be implemented in regulations. Quantification of the remaining emission potential is a major challenge. This paper presents the approach we are investigating in order to address this challenge.

Leachate emission

Leachate develops because rain infiltrates into the landfill and migrates through the waste from which it drains as leachate. During the time water is flowing through the waste body it interacts with the waste and many processes occur. Minerals present in the waste dissolve or precipitate depending on the local chemical thermodynamic conditions. Therefore, flow of water leads to the flow of solutes within the waste body. Many dissolved species increasingly accumulate in the flowing water while if flows through the waste body. In addition, the flow of water has a significant impact of the activity of micro-organisms living off the organic compounds present in the waste. Enhancing the flow of water through landfills has been shown to significantly enhance the microbial production of methane. Therefore, the longer water remains within the waste body the more influenced by the waste it will be.
Rainfall dynamics lead to variable flow rates within the landfill. Because leachate levels in modern landfills are controlled at low levels (about 1 meter above the bottom liner) in the landfill will be present under unsaturated conditions. Variation in flow rates will therefore also lead to significant variations in local water pressures and water content. As a result, the relative permeability of the waste will be highly variable, both in time as well as in space. This local variability is enhanced by the intrinsic heterogeneity of the waste itself. Impermeable materials such as plastics will block and diverge the flow path of water, maybe even lead to local ponding. We hypothesize that as the water moves deeper into the waste, presence of impermeable barriers will increasingly lead to a funneling of water into an increasingly smaller volume of the landfill. As a result the water will more and more flow through a limited number of preferential flow paths. The volume fraction of these preferential flow paths is dynamic and depends on the rainfall rates. High rainfall rates will lead to significant preferential flow in which the rain is funneled through the landfill in a relatively short time. Leachate produced during dry periods, however, has drained slowly from the surface of the waste. Water present in the waste is therefore moving at a wider range of velocities and therefore individual water drops have a wide range of residence times in the waste. As a result, the leachate produced during high rainfall rates will have relatively low concentrations of waste related species, whereas, leachate produced during dry conditions has been influenced by the waste for a significant period and as a result the concentration will be high.

Assessment of Leachate Emission and Landfill Emission Potential

Coupling detailed high frequency measurements of leachate production and leachate quality to rainfall rates and rain quality will allow us to develop an understanding of the dynamic nature of leachate production and leachate quality. We aim to use these measurements, possibly combined with a set of simple experiments, in order to characterize the probability distributions of residence times of water drops in the waste. Our hypothesis is that residence time is a key parameter relating the the final concentration of waste related species in the leachate to the emission potential of these species in the waste. In this context we consider the emission potential to be similar to an emission source term which slowly loads the leachate with waste related species during the residence time of the leachate in the waste. The rate of loading depends on the bio-geochemical processes that take place in the waste and the challenge is now to quantify the loading rates from the dynamics in leachate production and leachate quality.

The reason why we want to quantify the landfill emission potential from the leachate data is related to the scale of the landfill and the heterogeneous nature of the waste. A landfill has a surface area of several hectares and often heights of several tens of meters. The waste volume of several hundred thousands of cubic meters. Taking samples from such a volume is not a trivial activity. Questions such as what size should the samples have and how many samples should be taken, are not easy to answer. In addition there are significant technical issues that need to be overcome in order to take samples of the deeper sections of the landfill. The consequence of these challenges will be that sampling will have a high cost. We are currently developing a probabilistic modeling framework in which we combine process based models with a data assimilation approach to quantify unknown parameters which the source term in the waste is one of the most important.