Migration of Landfill Gas From the Soil Adjacent to the Landfill

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ABSTRACT

The migration of LFG is a significant issue in the field of solid waste management. This paper analyses various factors which are responsible for the migration along with its controlling techniques. The emission of migration of LFG potentially have adverse effect on environment including fire and explosion, health risk, odour nuisance, vegetation distress and groundwater contamination. Methane component of the LFG is a potent greenhouse gas, which has been linked to global warming and climate change. Under normal conditions, gases produced in soils are released to the atmosphere by means of molecular diffusion. In the case of an active landfill, the internal pressure is usually greater than atmospheric pressure and both convective flow and diffusion will contribute to the release of LFG. The biochemical reactions that produce the gas typically continue long after a landfill is capped. Both gases CH_4 and CO_2 contribute to global climate change therefore gas collection systems are recommended and sometimes required at landfills. Control systems can be classified as active or passive. The controlling techniques by which the LFG migration is controlled has also been discussed. Biofilters are not yet a proven technology for LFG treatment, however this emerging technique may become an option in the future.

Keywords: LFG, Gas Migration, Active control system, Passive control system, Biofilters

1. INTRODUCTION

Solid waste mass is increasing day by day as the population is increasing. So there is a need to manage the waste mass wisely without affecting the environmental substances (water, air, soil). There may be four ways to treat the solid waste mass. Composting, incineration and landfilling and recycling.

Sanitary landfills are widely used for the disposal of solid waste. Landfills can result in serious environmental problems if not properly managed and operated. The most common problem associated with landfill operations is the generation of leachate and gases. And the other major problem is migration of those gases which are toxic in nature or at particular temperature, pressure and volume conditions they come under explosive limits. For example: methane is explosive when its volumetric concentration attains 5% to 15% (50,000 to 150,000 ppm) in an air mixture [8]. Landfill gas is produced after various phases of mechanism. First when solid waste is dumped in the landfill, the microorganisms in presence of oxygen, which is present in the void space, gives rise to aerobic decomposition during which biodegradable organic materials react quickly with oxygen to form carbon dioxide, water, and other by-products (e.g. bacterial cells) [1]. Carbon dioxide is produced in approximate molar equivalents to the oxygen consumed. Oxygen depletion within the landfill marks the onset of the anaerobic decomposition phase. Although a landfill ecosystem undergoes an initial short aerobic decomposition phase, the subsequent anaerobic phase is the dominant phase in its age and the more important one from the perspective of gas formation. Then after going through hydrolysis, acidogenesis, acetogenesis and methanogenesis the landfill gas is produces having approximately 50% CH_4 and 50% CO_2.

Each stage is having its own significance and its different products. In acidogenesis phase, all the leachate characteristics (COD, VFA, Metal content Fe,Zn) are at their peak except pH, because of presence of high volatile fatty acids the pH is lowest in this phase. Small amounts of non-methane organic compounds (NMOCs) and trace amounts of inorganic compounds comprise less than 1% of the mixture. Heat is also generated during the anaerobic degradation, but at a smaller rate than during the initial aerobic phase. In reality biochemical reactions involved in the mechanism of landfill gas do not occur in a homogeneous manner. Due to local variations in waste composition, moisture content, vicinity of inhibitors and nutrients and temperature, the reaction rates might differ significantly from place to place and all the phases might occur simultaneously through the landfill.

2. CAUSES OF MIGRATION

Gases always follow the path of least resistance. So, Landfill gas migrates vertically or laterally, if the gas is being transported under the effect of gravity then the migration would be vertical. Generally vertical migration enhances the ground water contamination and if the gas is covering some meter distance laterally and then exposing to the atmosphere, which may be lead to the hazards and explosion due the drastic increase in pressure. In lateral migration case, Although most of the methane escapes to the atmosphere, both CH_4 and CO_2 have been found at concentrations up to 40 percent each, at lateral distances of up to 400 ft. from the edges of unlined landfills. Methane concentrations over 5 percent have been measured at a distance of 1000 ft. The movement of landfill gas in unconsolidated soils is controlled by several mechanisms [11]. When gas released to the atmosphere, landfill gas represents a threat to the environment, because both methane and carbon dioxide are greenhouse gases. Also, several of the produced organic compounds present health hazards. The other important reason to control the migration of gases is that methane is also a rich source of energy.

- Although liners and leachate collection systems minimize leakage, liners can fail and leachate collection systems may not collect all the leachate that escapes from a landfill. Leachate collection systems require maintenance of pipes, and pipes can fail because they crack, collapse, or fill with sediment.
- Upon the completion of a landfill, the waste is covered by a low permeability capping system which limits the water infiltration and minimizes the leachate generation, the cover also hinders the landfill gas emission to the atmosphere but the lateral migration of the gas can be enhanced if not properly treated. Lateral migration of methane is also enhanced if higher-permeability soils such as sand and gravel, or fractured till are present adjacent to the landfill.

3. RESPONSIBLE FUNDAMENTAL PROCESSES

Migration occurs via two ways either by diffusive transport or advective transport. Diffusive transport is caused by the variation in gas concentrations in the soil because the concentration of landfill gas in atmosphere is very low so a gradient develops. Advective transport is caused by the pressure gradient. The pressure inside the landfill can be quite high and can result in a large pressure gradient. Changes in barometric pressure can change the pressure gradient. The gas pressure and composition vary during the active life of the landfill. Methane and Carbon dioxide generation leads to increase in pressure and corresponding partial pressures. These changes create pressure gradients leading to gas advection, as well as concentration gradients that lead to gas diffusion [10].

4. INFLUENCING FACTORS

The primary factors that influence the distance gas migrates from the landfill are the permeability of the soil adjacent to the landfill, and the type of ground surface cover around the landfill.

- Generally, the greater the permeability of the soil, the greater the possible gas migration distance. As methane is lighter than air, it tends to rise and escape preferentially through the landfill cover, whenever the cover is sufficiently permeable [9].
- Heat generation also influences gas migration because of its effect on the thermodynamic properties of the fluids [9].
- Generally, increases in ambient temperature result in increased rates of gas migration, as it enhances the diffusion of the gas through the soil. However, phenomena like snow cover or frozen soil have a more profound effect on methane gas migration than the ambient temperature itself.
- The methane concentration can even be higher in very wet landfills due to a higher solubility of carbon dioxide in water. In older landfills the production of landfill gas reduces and atmospheric air can enter the landfill. The landfill gas can contain significant amounts of nitrogen. And with the oxygen from the air methane can be oxidised. This results both in a reduction of the methane percentage and an increase of the carbon dioxide percentage. Therefore the quality of landfill gas in older landfills can vary considerably. Landfill gas can

also contain traces of other ((poly) aromatic) hydrocarbons, halogenated hydrocarbons and sulphur compounds.

Modelling of Migration of Landfill Gas

Gases are transported by a buried source by two mechanisms:

Convection(advection) due to pressure gradient

Diffusion due to concentration gradient

The migration under such conditions is mathematically represented by mass conservation equation of diffusing species [7]:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial Xi}\left(D_{ij}^{\alpha\beta}\frac{\partial C}{\partial Xj}\right) - V_i'\frac{\partial C}{\partial Xi} \tag{1}$$

The volume averaged velocity rather than the mass averaged velocity is used because the fluid system is inhomogeneous. The relationship between the two velocities is given by:

$$V_i' = V_i^* + D_{ij}^{\alpha\beta}\frac{\partial \rho}{\partial Xj} \tag{2}$$

The mass averaged velocity is obtained from the mass conservation of gas mixture and Darcy's law

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial Xi}(\rho V_i^*) = 0 \tag{3}$$

$$V_i^* = -\frac{k_{ij}}{n\mu}\frac{\partial p}{\partial Xj} \tag{4}$$

Upward Migration of Landfill Gas: The principal gases, methane and carbon dioxide, can be released through the landfill cover into the atmosphere by convection and diffusion. The diffusive flow through the cover can be estimated by

$$N_A = D \propto^{4/3} \frac{(C_{Aatm} - C_{Afill})}{L} \tag{5}$$

Typical values for the coefficient of diffusion for methane and carbon dioxide are 0.20 cm^2/s (18.6 ft^2/d) and 0.13 cm^2/s (14.1 ft^2/d), respectively (Lang and Tchobanoglous, 1989). It is also common to assume dry soil conditions, thus $\alpha_{gas} = \alpha$. Assuming dry soil conditions introduces a safety factor in that any infiltration of water into the landfill cover will reduce the gasfilled porosity and thus reduce the vapor flux from the landfill. Typically, porosity values for different types of clay vary from 0.010 to 0.30 [10].

Downward Migration of Landfill Gas: Ultimately, CO_2, because of its density, can accumulate in the bottom of a landfill. If a clay or soil liner is used, the carbon dioxide can move from their downward primarily by diffusive transport through the liner and the underlying formation until it reaches the groundwater (note that the movement of carbon dioxide can be limited with the use of a geomembrane liner). Because carbon dioxide is readily soluble in water, it usually lowers the pH, which in turn can increase the hardness and mineral con-tent of the groundwater through solubilisation [10].

5. LANDFILL GAS MIGRATION CONTROL

When landfills have reached the maximum amount of waste they can hold, several feet of cover material are placed over the landfill mass. Gas collection wells are then installed throughout the capped landfill. These wells are made of perforated pipes which give the gas an easy path to move vertically to the surface rather than laterally (outward) toward off-site locations (e.g., buildings). As the gases enter these wells they are either vented into the outdoor air, passed through a flame and broken down by burning, passed through a filter, or used in an energy recovery program. Landfill gas vents need to be kept drained and clear of obstructions such as snow and debris. Older landfills and smaller dumps may not have gas control measures.

Landfill gas components may be absorbed onto by soil particles, transferred to water and oxidized by methane consuming bacteria (methanotropic). This phenomena may reduce emissions and migration of landfill gas from the site [4].

6. DETECTION OF THE LANDFILL GAS MIGRATION

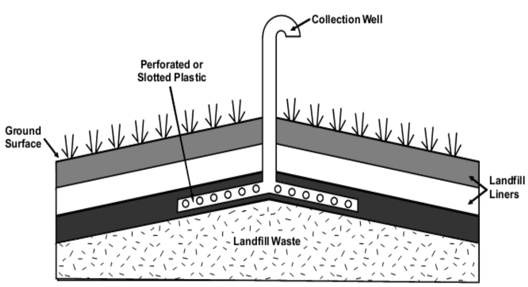
The probe is installed by boring a hole into the ground to at least the same depth as the landfill. A perforated pipe is placed into the hole and the space between the original soil, and the pipe is filled with sand. Clay is packed around the pipe near the ground surface to pre-vent air from leaking into the probe. Two types of measurements are conducted. Gas pressure is measured with a gauge or manometer. A positive reading indicates that LFG is moving past the probe because of pressure built up within the landfill.

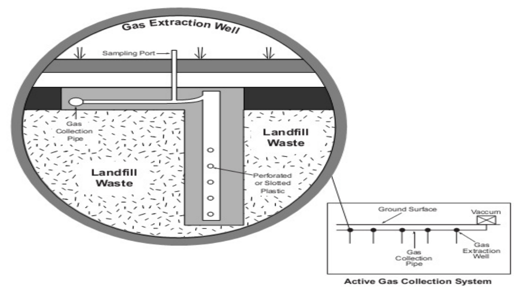
Negative pressure typically results when a probe is installed near a LFG recovery well. The concentration of methane in the soil atmosphere also is measured with a calibrated meter. A concentration greater than 5 percent methane indicates migration may have dangerous consequences if the gas enters a building. Because migration patterns and methane concentrations change rapidly, frequent measurements are required to obtain an accurate picture of the gas migration pattern. At sites where a high degree of concern about gas migration endangering residences exists, daily measurements should be conducted until the crisis has passed [6].

7. GAS VENTS AND RECOVERY SYSTEMS

Passive vents and active gas pumping systems are used to control LFG migration.

Passive vent system: Passive systems rely on natural pressure and convection mechanisms to vent the gas into the atmosphere. Gas venting pipes, installed within the landfill and vented into the atmosphere have been used to allow gas from a landfill's interior regions to escape. These natural vents may be equipped with flares to burn-off the gas and to prevent odours. Passive vents do not always effectively remove LFG from under the cover. This causes vegetative stress and accompanying erosion problems on the cover. Passive vent failure generally is attributed to an insufficient pressure gradient within the landfill to push the gas to the venting device. Passive vents also can be problematic when alternating periods of high and low barometric pressure cause atmospheric air to enter the landfill when barometric pressure rises. Passive systems are not considered reliable enough to be the sole means of protection in areas where there is a significant risk of methane accumulation in buildings [4].





Passive Gas Collection System **Active Gas Collection System**

Active Gas Recovery Systems: Active gas collection systems remove LFG under a vacuum from the landfill or the surrounding soil formation, with the gas literally being pumped out of the ground [4]. Active gas collection systems include vacuums or pumps to move gas out of the landfill and piping that connects the collection wells to the vacuum. Vacuums or pumps pull gas from the landfill by creating low pressure within the gas collection wells. The low pressure in the wells creates a preferred migration pathway for the landfill gas. The size, type, and number of vacuums required in an active system to pull the gas from the land-fill depend on the amount of gas being produced.

8. FLARE SYSTEM

A common method of treatment for landfill gases is thermal destruction, in which the methane and any other trace gases (including VOCs) are combusted in the presence of oxygen to CO_2, sulfur dioxide (SO_2), oxides of nitrogen, and other related gases. The thermal destruction of landfill gases is usually accomplished in a specially designed flaring facility [3]. A typical requirement might be a minimum combustion temperature of 1500°F and a residence time of 0.3 to 0.5s, along with a variety of controls and instrumentation in the flaring station. Where the landfill gas contains less than 15 percent methane, supplemental natural gas or propane may need to be supplied to the flare to sustain combustion. Installation of a carbon filter is an alternative approach to flaring for control of VOCs [10].

9. FUTURE RECOMMENDATION

Biofilters: Boifiltration is an air pollution control technology in which we utilize the activity of microorganism for the biologically degradation of pollutants [4]. A biofilter is essentially a packed bed reactor containing microorganism, growing in an active biofilm. This biofilm is formed on the surface of the biofilter bed material usually consist of some type of compost, peat or soil material. The contaminated vent stream having LFG passes through the filter medium where the pollutant (trace components) is transferred from the vapour phase to the biofilm and degraded by microorganism. But there might be a problem in biofilters which is biofauling. Biofouling is a process defined as the undesirable accumulation of microorganisms, their products and deposits including minerals and organic materials, and macro-organisms on substrate surfaces [2].

10. NOMENCLATURE

$C=C(Xi,t)=\rho_\alpha/\rho_{\alpha 0}$ = non dimensional concentration of α species

$\rho_{\alpha=}$ mass densities of α species

$\rho_{\alpha 0=}$value of ρ_α at the source

$x_{i=}$Cartesian frame of reference

$D_{ij}^{\alpha\beta}$ = tensor of diffusion coefficients (α species diffusing into β species) in soil

V_i'=volume averaged velocity

V_i^*= mass averaged velocity

ρ= mass density of the fluid mixture

Kij = tensor of intrinsic permeability

n= porosity of soil

μ= absolute viscosity of mixture of gases

p=scalar pressure field

N_A= gas flux of compound A, $g/cm^2\cdot s$ ($lb\text{-}mol/ft^2\cdot d$)

D = effective diffusion coefficient, cm^2/s (ft^2/d)

α=total porosity, cm^3/cm^3 (ft^3/ft^3)

C_{Aatm}= concentration of compound A at the surface of the landfill cover, g/cm^3 ($lb\text{-}mol/ft^3$)

C_{Afill}= concentration of compound A at bottom of the landfill cover, g/cm^3 (lb-mol/ft^3)
L = depth of the landfill cover, cm (ft)

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