Landfill leachate and gas flow

Summary:

As the organic fraction of waste in landfills degrades it produces liquid and gas at the expense of the solid phase, and the waste settles as the solid content reduces. The presence and addition of liquid and gas products together with any compression of the pore space caused by settlement, induces the movement of liquid and gas through and potentially out of the body of waste material in the landfill leading to unwanted emissions of greenhouse gases (methane and carbon dioxide), and contaminated liquid leachate that has the potential to pollute neighbouring soils and groundwater resources.

Landfill management technologies mitigate and control emissions: gas extraction and collection; methane oxidation; injection and extraction of water and leachate to effect contaminant flushing and moisture content control; and aeration by the injection of air. Understanding the waste degradation process, and the flow of landfill liquid and gas within the waste contributes to the effectiveness of the design of the landfill engineering systems that apply these landfill management technologies.

Landfill models of landfill leachate and gas flow take the form of flow equations based on Darcy's Law, which relates the flux of a flow component to pressure gradient. There are two distinct pressure fields in the two phase landfill leachate/gas system, one associated with each phase. The relationship between the two has been widely researched in the context of unsaturated groundwater seepage flow in porous media, and is represented by the van Genuchten equations.

Both Darcy's Law and the van Genuchten equations are strongly influenced by the permeability of the porous material. A complication in the case of waste is that the permeability to leachate or gas in a waste material varies significantly with the effective stress applied to the material. This phenomenon is well represented by the Powrie and Beaven landfill waste permeability equations.

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The interest in landfill leachate and gas flow arises because about 900 million tonnes of post-consumer waste are produced worldwide and about 85% of this is disposed to landfills or land raises. The waste is predominantly inert but about 10% is degradable into the greenhouse gases methane and carbon dioxide, and contaminants in the waste have the potential to pollute neighbouring soils and groundwater resources, (Bogner, Ahmed et al. 2007). As the organic fraction degrades it produces liquid and gas at the expense of the solid phase and the waste settles as the solid content reduces (Christensen, Kjeldsen et al. 1996, Environment_Agency 2004), (Ghabaee and Rodwell 1989), and (Lagerkvist and Cossu 2005). The presence and addition of liquid and gas products together with any compression of the pore space caused by settlement, induces the movement of liquid and gas through and potentially out of the body of waste material in the landfill leading to unwanted emissions.

A range of landfill management technologies have been developed to mitigate and control emissions. They include gas extraction and collection, methane oxidation, injection and extraction of water and leachate to effect contaminant flushing and moisture content control, and aeration by the injection of air (Christensen, Kjeldsen et al. 1996, Ritzkowski, Heyer et al. 2006, White, Beaven et al. 2011). They all involve controlling the flow of leachate and gas, and understanding the impact that this has on the bio-chemical degradation of waste and the dissolution of contaminants from the waste. Understanding the waste degradation process and the flow of liquid and gas within the waste contributes to the effectiveness of the design of the engineering systems that apply these management technologies. In particular parametric models of the processes involved, and the numerical models with which they may be associated, provide a framework within which the key questions related to the economic valuation of applying landfill management technologies may be addressed.

Four distinct types of flow in porous media are conventionally recognised. These types of flow are:

- viscous flow of fluids in a fully saturated porous material where the saturating fluid can be either a liquid or a gas.
- diffusion/dispersion and convection of gas as a solute in the liquid phase of flow.
- diffusion of gas in porous media fully saturated with gas.
- two-phase movement of gas and liquids in porous media taking into account the effects of surface tension.

Models of these types of flow take the form of flow equations which relate the flux of a flow component to the pressure or concentration gradient that is assumed to be the driving force behind the generation of the flux. The leachate and gas generated in the pore space of the solid waste material in a landfill will move around in response to changes in pressure.

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The units of pressure are Newtons per square metre (N/m^2) or Pascals (Pa). A useful alternative to pressure is the pressure head (simply 'head') which has the units of length which are expressed as metres of water or metres of gas. Pressure fields may therefore be converted to head fields provided the density of the fluid (water or gas) is known. The reason the concept of head is useful is that it appears in Darcy's Law, which simply states that the flow velocity of a liquid or gas in a porous material is equal to the permeability times the head gradient. A complication in the case of waste, is that the permeability to leachate or gas in a waste material is found to vary significantly with the effective stress applied to the material. This can result in the permeability decreasing with depth by several orders of magnitude in typical landfills.

The waste material thus forms a complex multi-phase material that consists of a solid matrix containing within its pore spaces a mixture of liquid and gas. Since leachate and gas management is one of the key factors in the operation of a landfill, an understanding of the way in which the movement of these fluids take place in a landfill is essential if this management is to be effective. The ways in which key landfill operational areas will benefit from a better understanding of the movement of landfill gas and leachate are:

- the development of a clearer conceptual understanding of landfill processes will assist both regulators and operators of landfills in carrying out their duties.

- models for estimating the stabilisation times for the biodegradation of waste will be improved.

- the long term emissions of gas and liquids from caps and liners will become more accurate.

- interpreting gas pressure and flow data from gas wells in order to assess landfill gas generation rates will become a possibility.
- the assessment of pressure heads on liners and at internal points in landfills to confirm slope stability will become more reliable.
- the relationship between liquid flow, density changes, and waste settlement will become clearer.

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