Laboratory scale delineation of ‘preferential flow’ in landfill

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Outline

• What is preferential flow and why do we care?

• Methods for detection of flow paths at lab scale
  – CT scanning
  – Tracer tests
  – Cutting
  – Deconstruction

• Future work

• Conclusions
Pore-structure of wastes – why do we care?

The pattern of flow affects the long-term physical and chemical behaviour of the landfill.....affects the leachate concentration and timing of ‘completion’

- Where does the water go?
- How are contaminants moved?
- What happens to gas?
- What are areas of dry waste / unflushed regions like?
- What happens with time?
- Effect of scale, type of waste etc..?
Conceptual uncertainty

• Pore and flow geometry is largely unknown

• Non-uniqueness means inverse methods are unlikely to reveal anything other than very basic properties

• ‘Guessed’ lumped phenomenological models (imported from the soils/groundwater literature)

• Misrepresenting key facets of geometry, flow, scale and physical process could result in poor ability to predict

...yet, we have broad evidence suggesting ‘preferential flow’ is important.
On postulating new models

In presence of conceptual uncertainty how deal with the large choice of models?

- Classical deduction (Woodman et al., 2005)
- Bound problem using extreme cases (Woodman, 2007)
- Try out large number of models (‘multiple-model approach’ Beaven et al., 2005)
- Adopt an empirical approach (Zacharof & Butler, 2004)
- Revised models where failure to adequately explain data OR...produce new models, based on direct observation

....We concentrate on the last of these today...
Some different conceptual models

Dual-permeability, Dual-porosity

MIM exchange to 'slow-immobile zone'

Channel (kinematic wave)

Adective transfer (MIM - empirical)

MIM exchange to 'fast-immobile zone'

MIM exchange to 'slow-immobile zone'

Range of block sizes

Bendz et al, 1998
Multiple-streamtubes (Woodman & Beaven, 2011)

Also, see Rosqvist & Destouni, 2000
CT Scanning
Early attempts to examine waste structure

Would it be possible to see gas flow paths used/created by gas release during anaerobic degradation?

- 35l anaerobic reactors filled with shredded biodegradable portion of MSW. Constant leachate recirculation
  - Allowed to degrade for 2 years.
  - On 3 occasions, frozen and taken to medical CT scanner for examination
Apparatus
- X-ray attenuation resolution is 12 bit (4096) greyscale
- The human eye can only see 90 shades of grey so images are displayed as 8 bit (256) greyscale
- 8 bit window can be moved through 12 bit data – Windowing
- Window level or centre controls the centre point of the 8 bit window
- Window width controls the contrast
Findings - top
Findings - base
Findings
• Large gas filled voids after degradation
• No evidence of flow paths at ~1mm scale
Pore size distribution vs Particle size distribution in degraded MSW

Number of pores with size < 0.0001 0.001 0.01 0.1 1 10 100

Pore size distribution
Particle size distribution

Size (mm)
Tracer Tests
Flow path detection

If flow paths do not make themselves apparent through obvious structural changes, can we use tracers to detect them?

- Small scale trials (~2 l) on MBT at or near field capacity have been conducted using diluted (1:1) emulsion paint
- A ~5mm hole was pushed through the MBT to try and create a flow path
- Samples gently taken apart to see if artificial flow paths were easily detectable.
Flow path detection

Does a sample have a unique set of flow paths or are they dependent on the flow regime? If the latter, can we detect the different flow paths in a single sample?

- Tests were carried out adding a second paint/dye based tracer to samples previously flooded with white paint.

- Brilliant blue has been added to a sample which has already had paint added. The method followed that of Andreini & Steenhuis (1990) on top soils. MBT was at field capacity and brilliant blue (0.2%) was sprayed onto the surface at a rate intended to avoid ponding until it appeared in the fluid collection container at the base of the cell. They found light and dark blue and undyed areas which showed regional flow but not pathways.

- Dilute red emulsion was added in upward flow from the sample base to a sample which had previously had white paint added from the top surface.
Sample Cutting
Observing the structure

*Is it possible to slice or thin section waste samples and build up a picture of the structure this way?*

- Waste is difficult material due to presence of wide variety of materials of vastly different density, stiffness, strength, toughness, maleability etc.

- Presence of glass (needs diamond blades) and aluminium (clogs diamond blades) likely to cause problems.
Cutting tests

• Tests carried out on 2 samples:
  
  – Sample from consolidating anaerobic reactor (CAR) – 80mm shredded MSW, loaded to 50 kPa (Ivanova et al., 2008)
  
  – “Undisturbed” tube sample from Pitsea compression cell. This was also 80mm shredded MSW but had been subjected to stresses up to 600 kPa
Cutting
Thin sections (8mm thick)
Cutting Thin sections (8mm thick)
Pitsea samples
Sample Deconstruction
Can we find an alternative to cutting that will enable us to view the structure of wastes?

• Decided to try and adapt archaeological techniques to deconstruction of samples.

• Tests carried out on two samples:
  – Red paint tracer sample as previously described
  – 100mm shear box sample
Future Work

- The ambition is to be able to create 3D images of flow paths in real waste. To do this, we need:
  - More controlled imaging, probably using at least 2 cameras & controlled lighting
  - Better method for measuring depths, probably off-the-shelf software to generate depths from multiple images
  - Calibrate tracer concentrations in waste
  - Reliable method for deconstructing waste, possibly freezing then cutting or more systematic method of disassembling samples

- Effects of scale – can we adapt to larger sample size?
- New/improved conceptual models based on observations
- Combine work at the metre scale with geophysics at larger scales?
Conclusions

• CT can be useful but in order to scan at meaningful resolution to detect flow paths, we need to scan much smaller volumes but these are unlikely to be large enough to be representative.

• Tracers have shown some evidence of dual porosity. Also seen patterns and inhomogeneities which suggest method is worth pursuing.

• Cutting can work well and produce a clean surface, enabling flow path imaging and analysis, but this is very dependent on the waste type.

• Deconstruction using methods inspired by archaeology can be successful at revealing the structure of waste and allowing flow path imaging but can be extremely time consuming.
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References:


Thank you