UNIVERSITY OF Southampton

Geotechnical hazards associated with closed municipal solid waste landfill sites

William Powrie, David Richards and Richard Beaven

Engineering and the Environment

Outline

- Landfill – a brief history
- Landfill processes, engineering and sustainability:

    - degradation, gassing, settlement and flushing

- Potential geohazards of closed sites

    - settlement

    - groundwater contamination

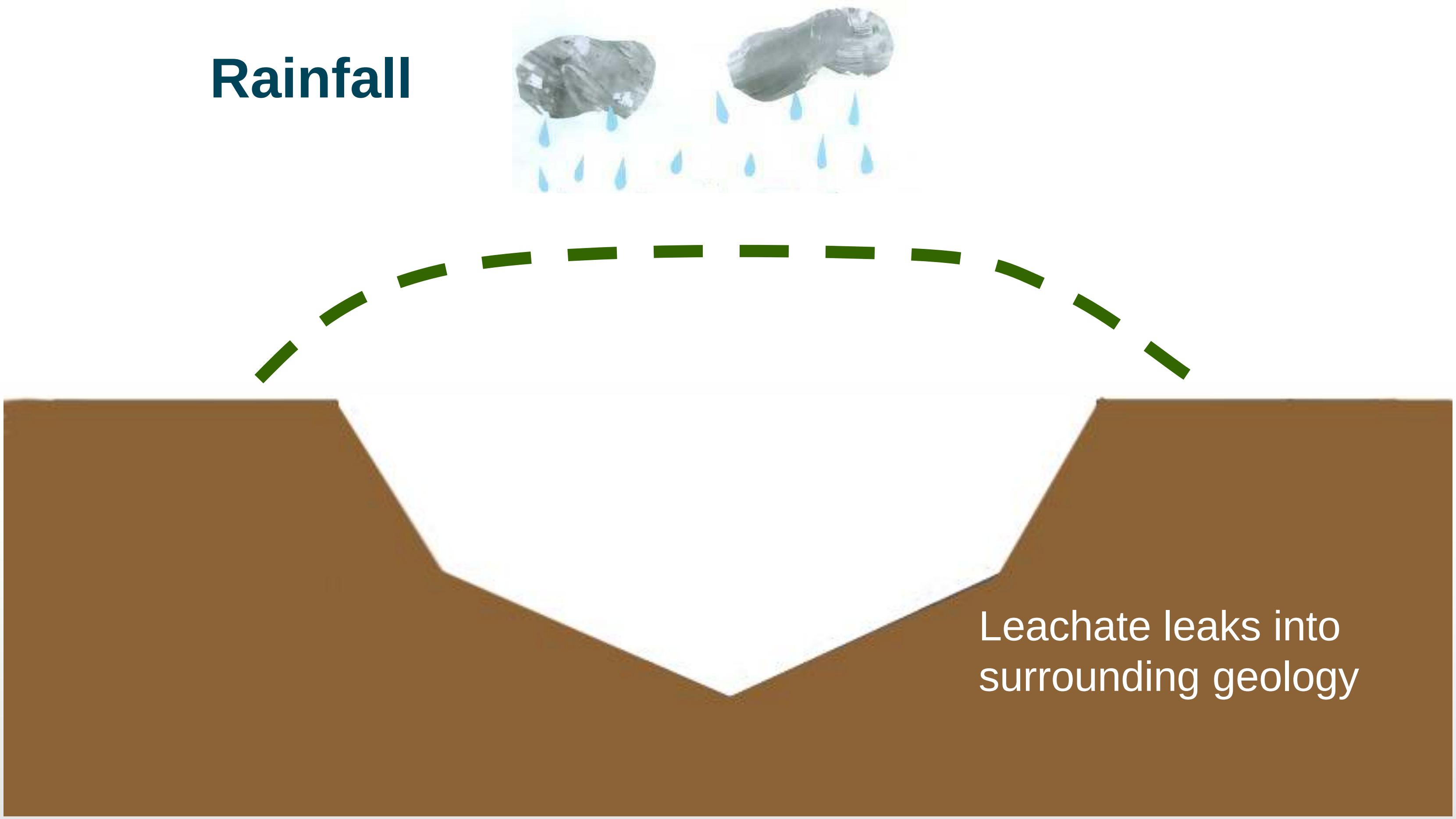
    - gas release

- Concluding comments

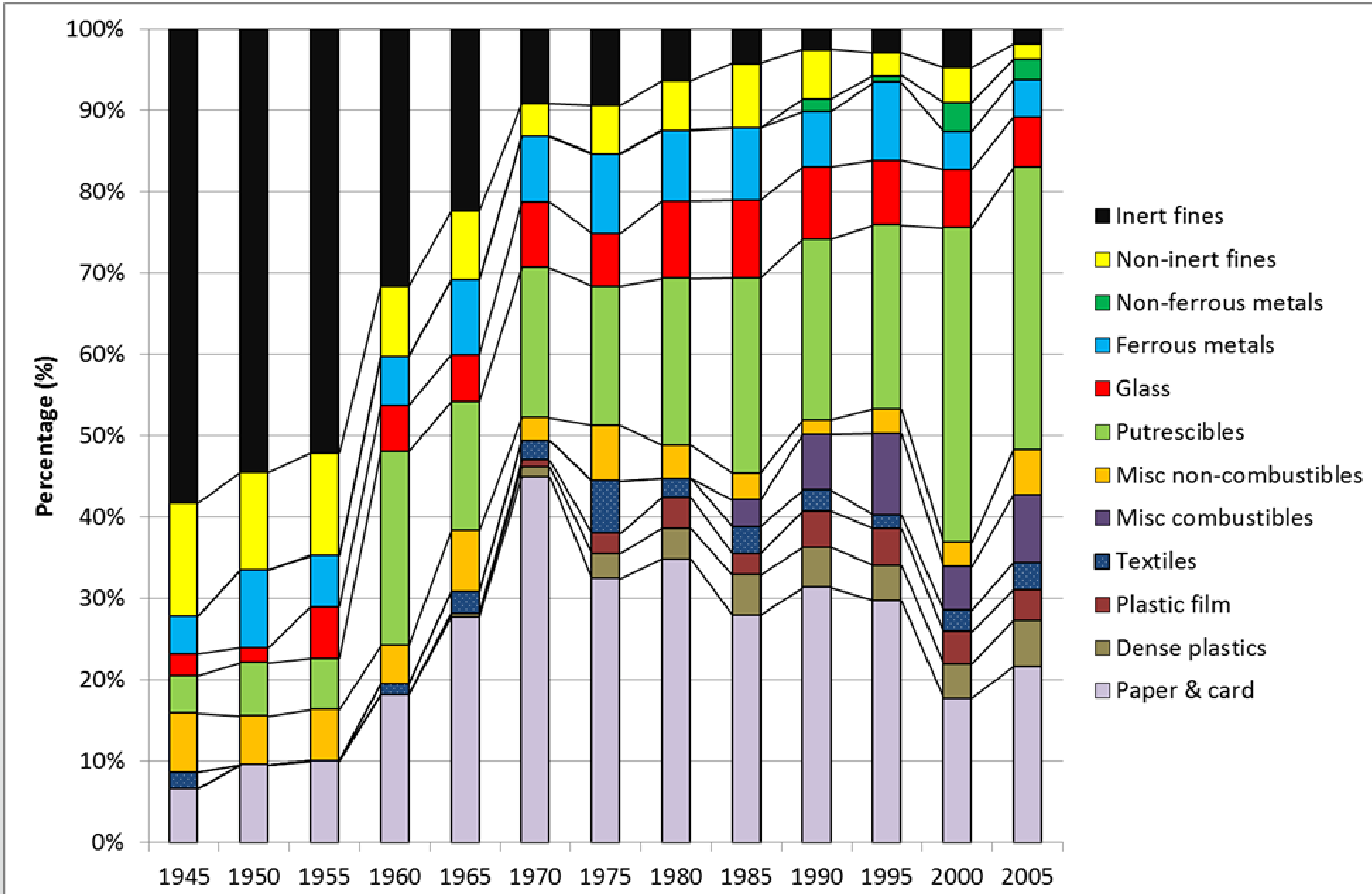
A brief history of landfill

In the beginning…

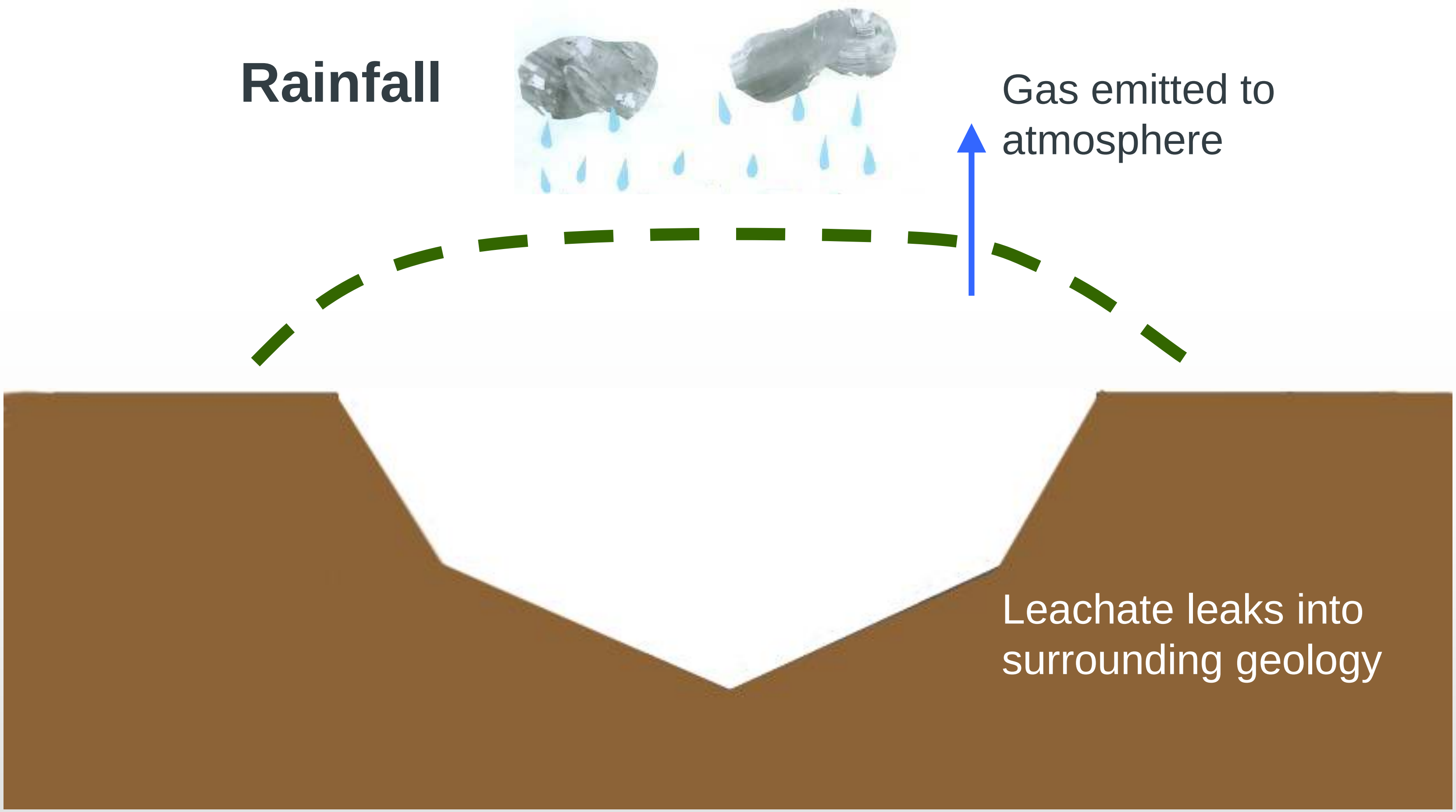
....was the open dump



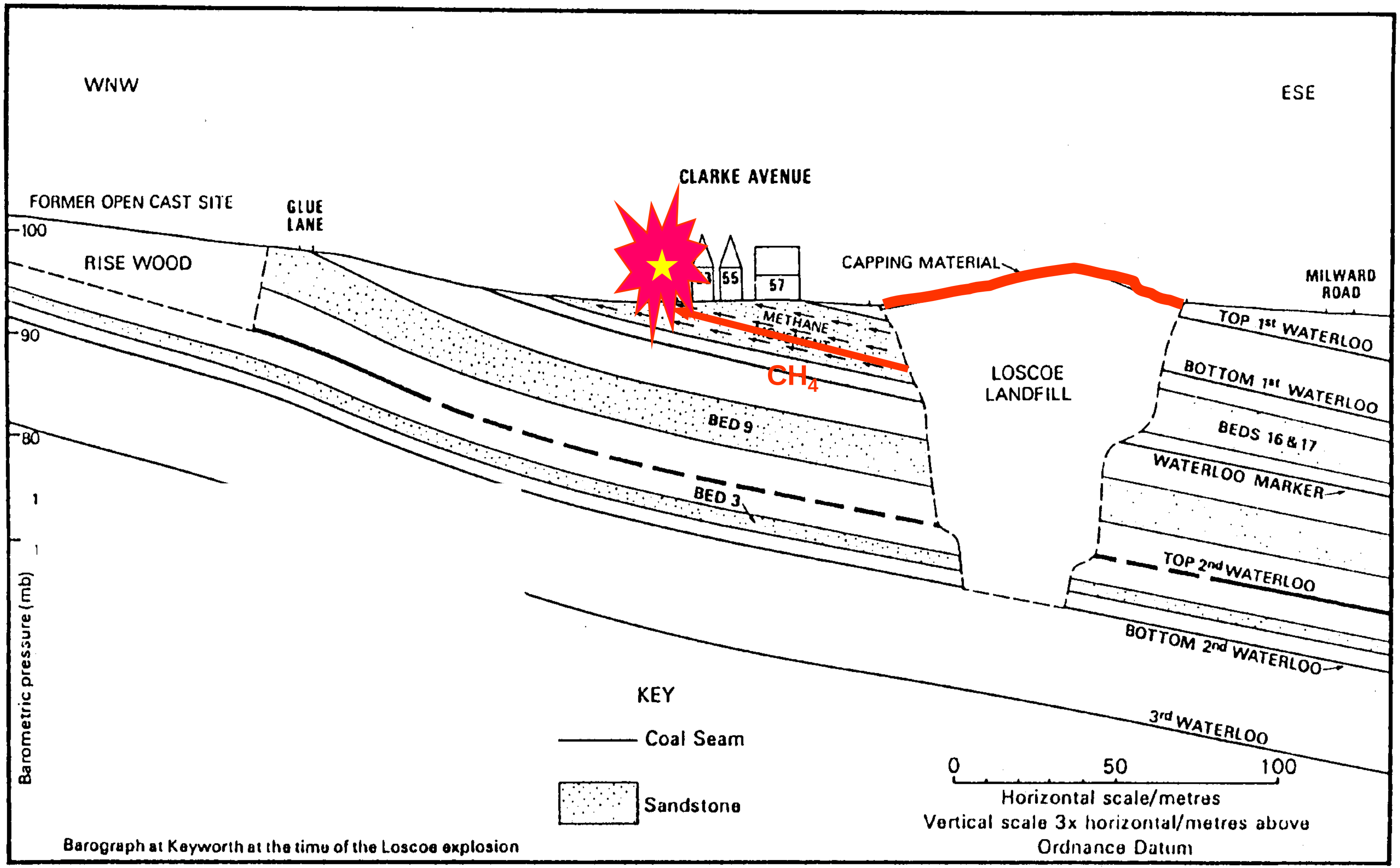
The changing nature of waste



Waste emits landfill gas ($CH_4 + CO_2$) and settles as it waste degrades; other contaminants are flushed out

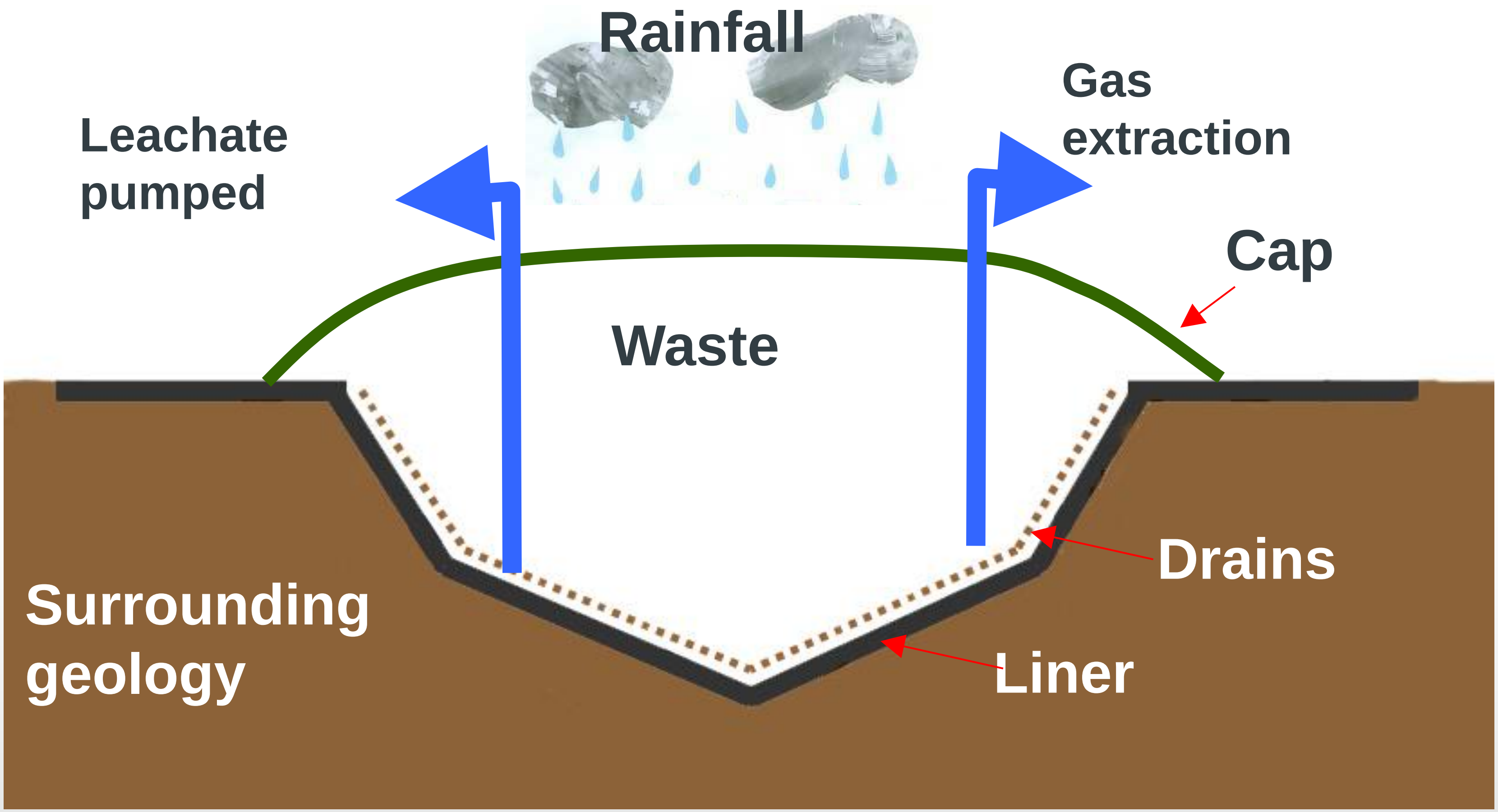


Loscoe explosion: capping to prevent rainfall infiltration is not enough! (the road to hell....)

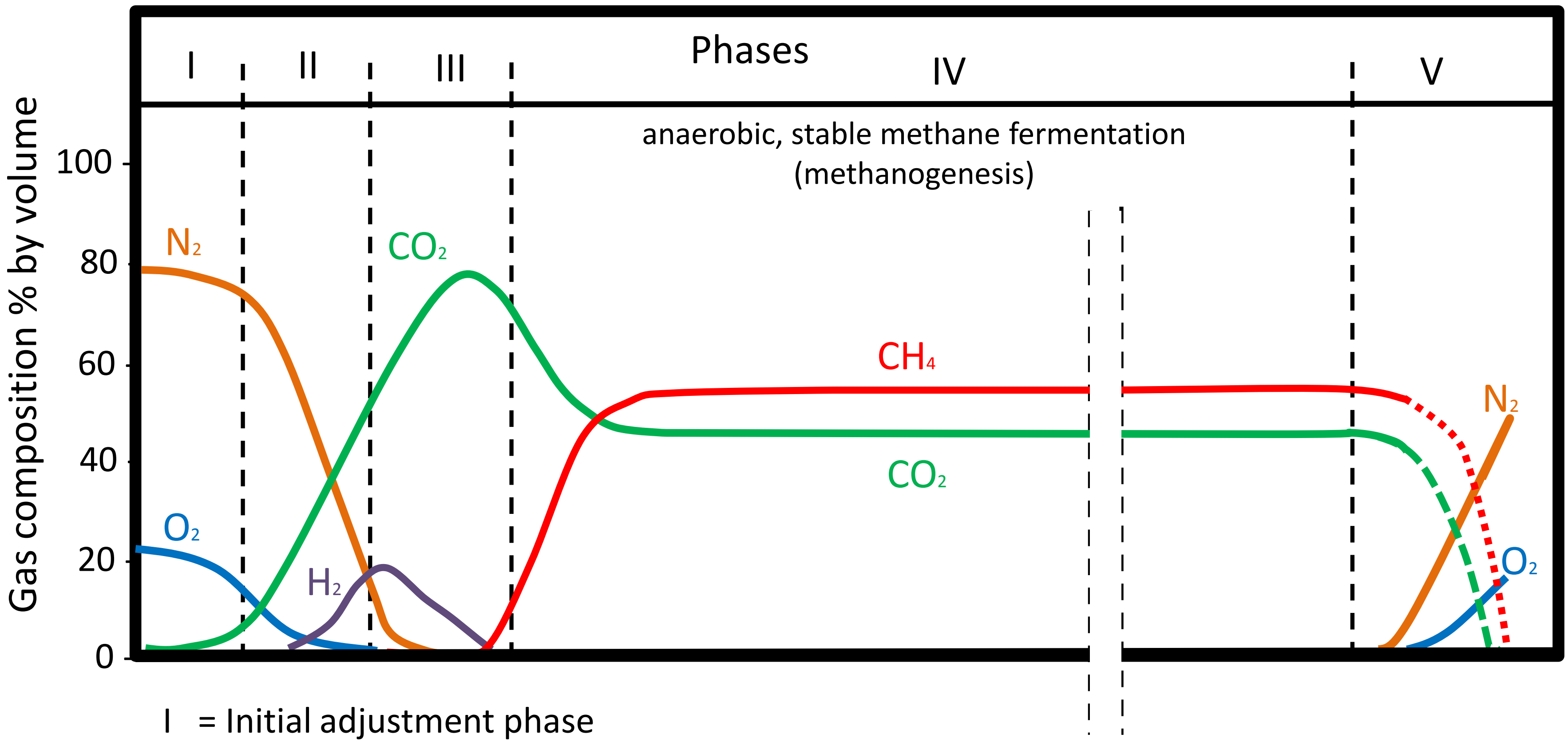


Loscoe explosion

The engineered or containment landfill



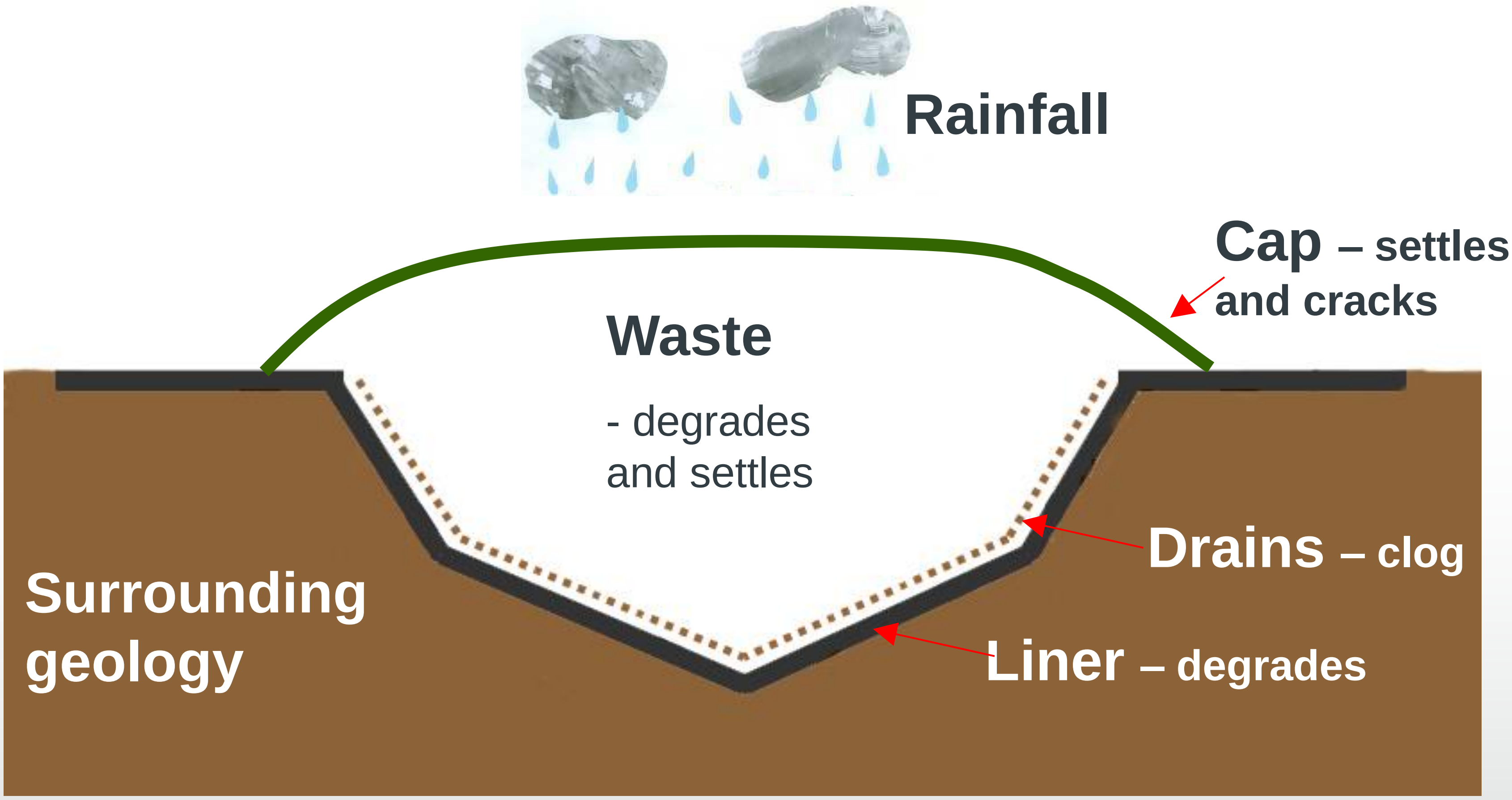
Five phases in the life of a landfill



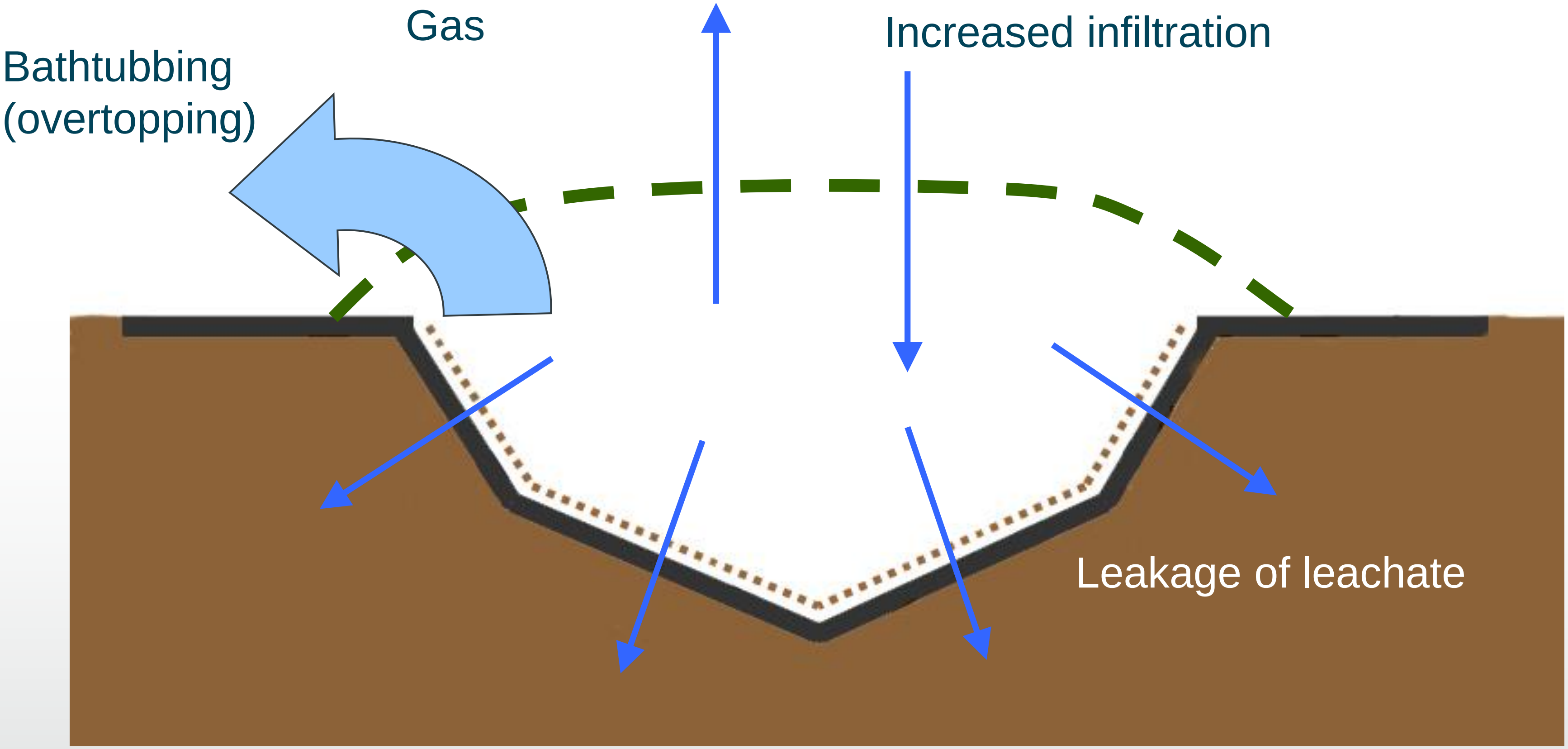
I = Initial adjustment phase
II = Transition phase, beginning of anaerobic decomposition
III = Acid phase, hydrolysis and acidogenesis
IV = Methane fermentation phase, anaerobic methanogenesis
V = Maturation phase, air intake, methane oxidation to CO2

From Hofstetter Gastechnik AG

The waste will degrade and the engineered features will deteriorate over time



Containment system failure modes



Sustainable landfill

1. The contents of the landfill must be managed so that outputs are released to the environment in a controlled and acceptable way
2. The residues left in the site do not pose an unacceptable risk to the environment, and the need for aftercare and monitoring should not be passed on to the next generation [“completion”]
3. Future use of groundwater and other resources should not be compromised

The Role & Operation of the Flushing Bioreactor, CIWM, 1999

Landfill completion

- The landfill has reached a stable state, in hydraulic equilibrium with the surrounding environment with contaminant release at a rate that will not damage the receiving environment
- Degradation, settlement and gas generation have substantially stopped
- Leachate is non-or minimally polluting, i.e. mobile recalcitrant contaminants have been flushed out
- Timescale of centuries with current methods of landfill operation

Development over an old landfill: issues

Will the development cause

- Settlement?
- Gas release?
- Groundwater contamination?

    - ongoing (e.g. creep or degradation settlement)

    - new (e.g. in response to increase in load)

    - reactivated (e.g. a change in hydraulic regime)

- Damage to the remaining engineered controls (and does this matter)?

The answer to these questions:

- Depends on the state of the waste (remaining degradation and pollution potential)
- Requires understanding and conceptual / quantitative models to assess

  - Degradation, gassing and settlement and the relationships between them

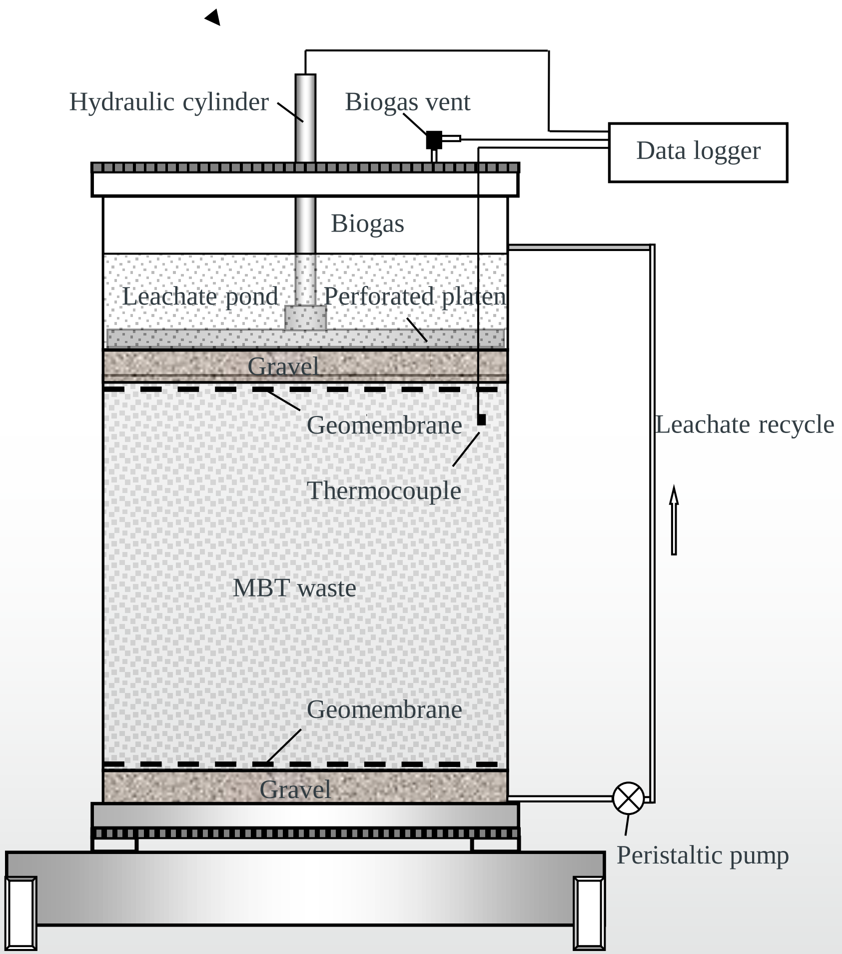
  - Flushing out of contaminants and the impact of the prevailing hydraulic conditions

An old landfill waste

Degradation, gassing and settlement

The Consolidating Anaerobic Reactor (CAR)

- Gas tight Perspex cylinder
- ID=480 mm , ~ 900 mm in height
- Gravel drainage layers
- Waste separated from gravel by geotextile membrane
- Perforated steel load platen through which a constant vertical load is applied using a hydraulic cylinder
- CAR equipped with
  - thermocouple
  - Infra red gas analyser
  - gas measurement system
  - leachate recirculating system



Consolidating Anaerobic Reactors

CAR1
- 40 kg dried waste
- 50 kPa load
- 80L synthetic leachate containing acetic and propionic acids
- ~ 20° C

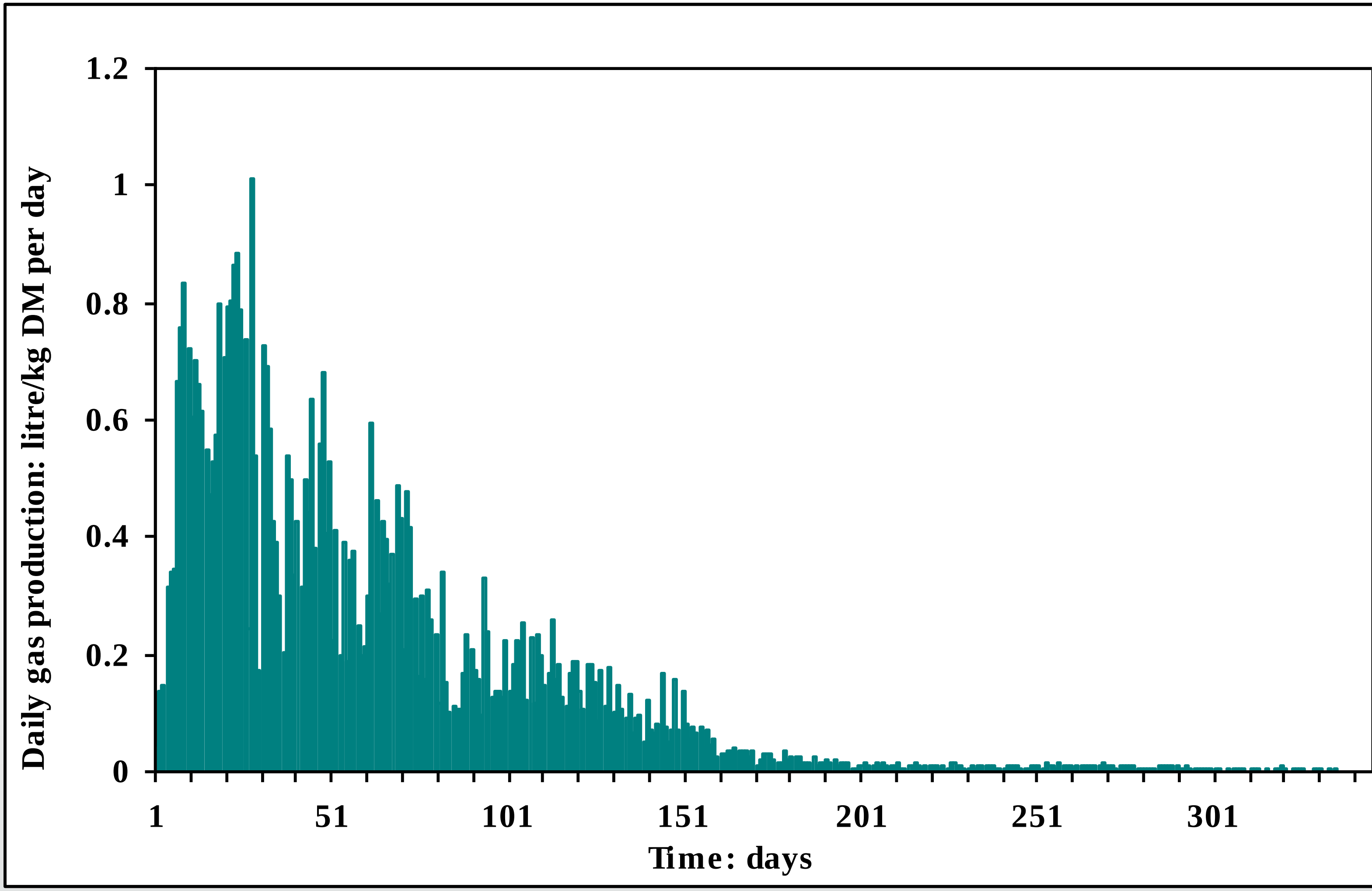
CAR2
- 40 kg dried waste
- 50 kPa load
- 80L synthetic leachate comprising 10% sewage sludge
- 30° C using a heat blanket

CAR1 (control reactor)

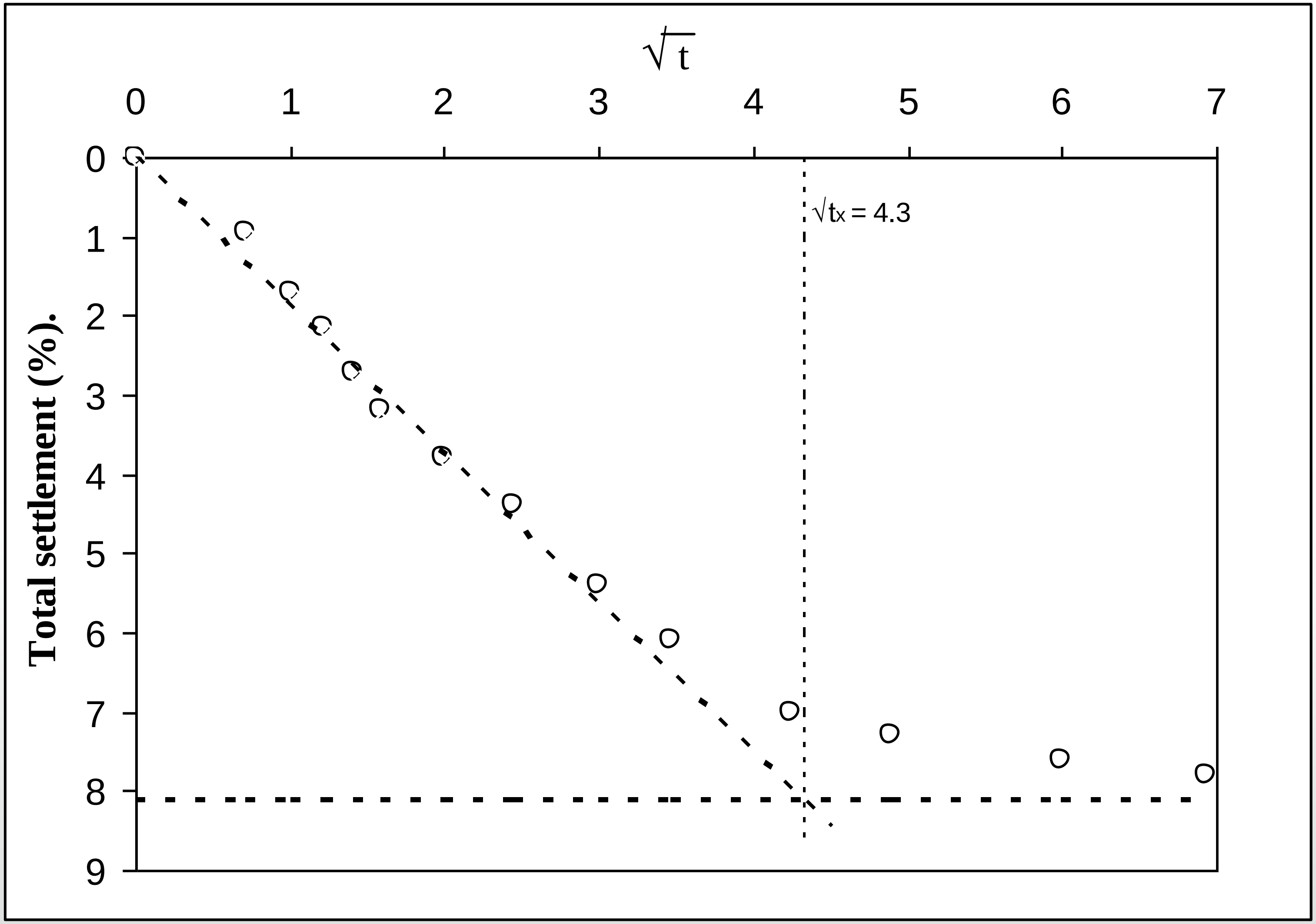
CAR2 (test reactor)

- Both CARS were sealed and sparged with nitrogen gas to remove oxygen
- Leachate was recirculated continuously from the bottom to the top

Daily biogas production: MBT waste at 50 kPa

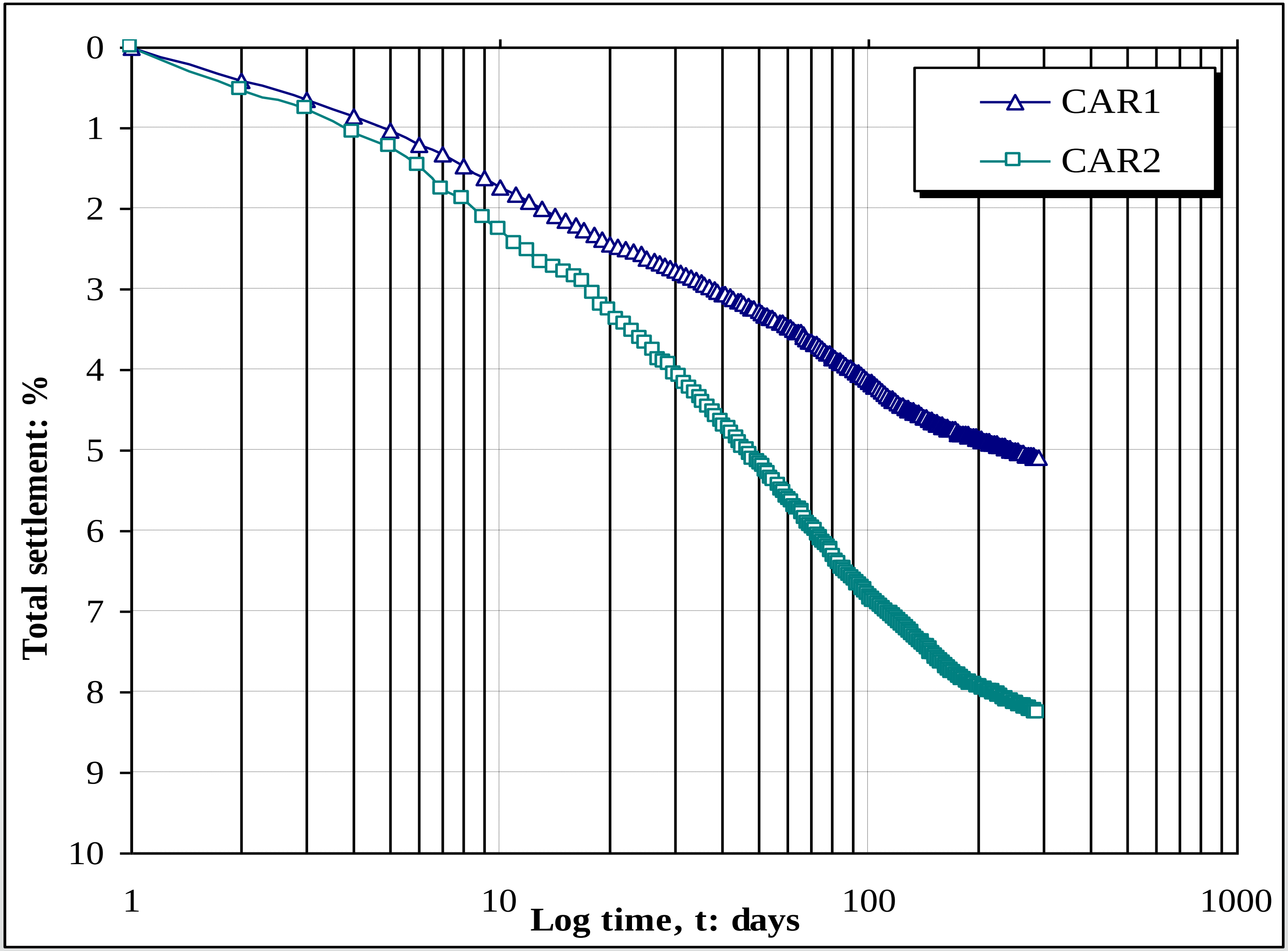


Primary settlement – MBT waste at 50 kPa (Siddiqui *et al.*, 2013)



Time t in hours

Secondary settlement: MBT waste at 50 kPa (Siddiqui *et al.*, 2013)



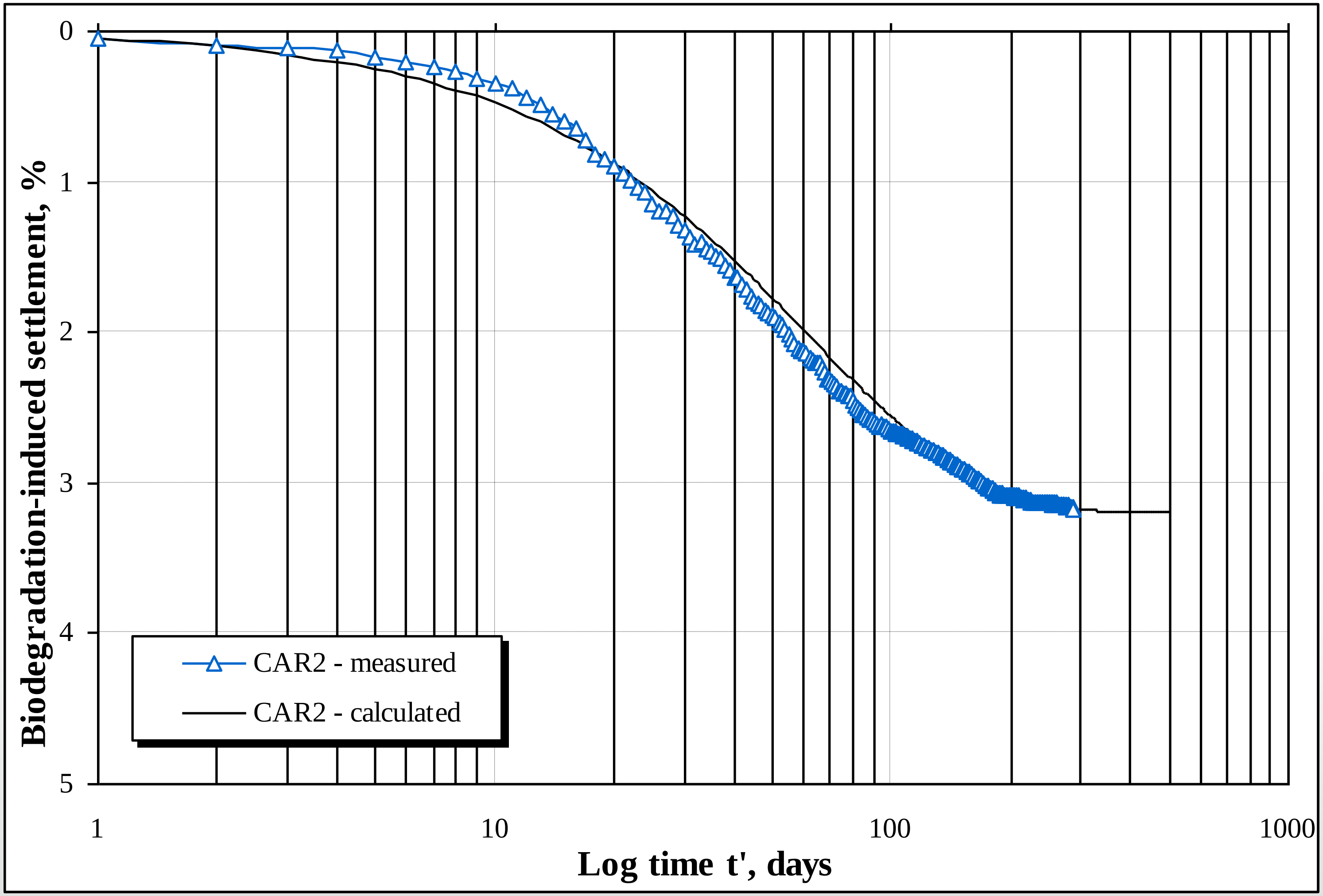
Kinetic model for biodegradation settlements

$$\varepsilon_b = \varepsilon_{bt}.(1 - e^{-kb.t'})$$

where

- ε_{bt} is the total eventual settlement due to biodegradation
- kb is a biodegradation rate constant
- t' is the elapsed time since the start of degradation

Comparison of measured biodegradation settlement *vs* fitted kinetic model, MBT waste at 50 kPa (Siddiqui *et al*., 2013)



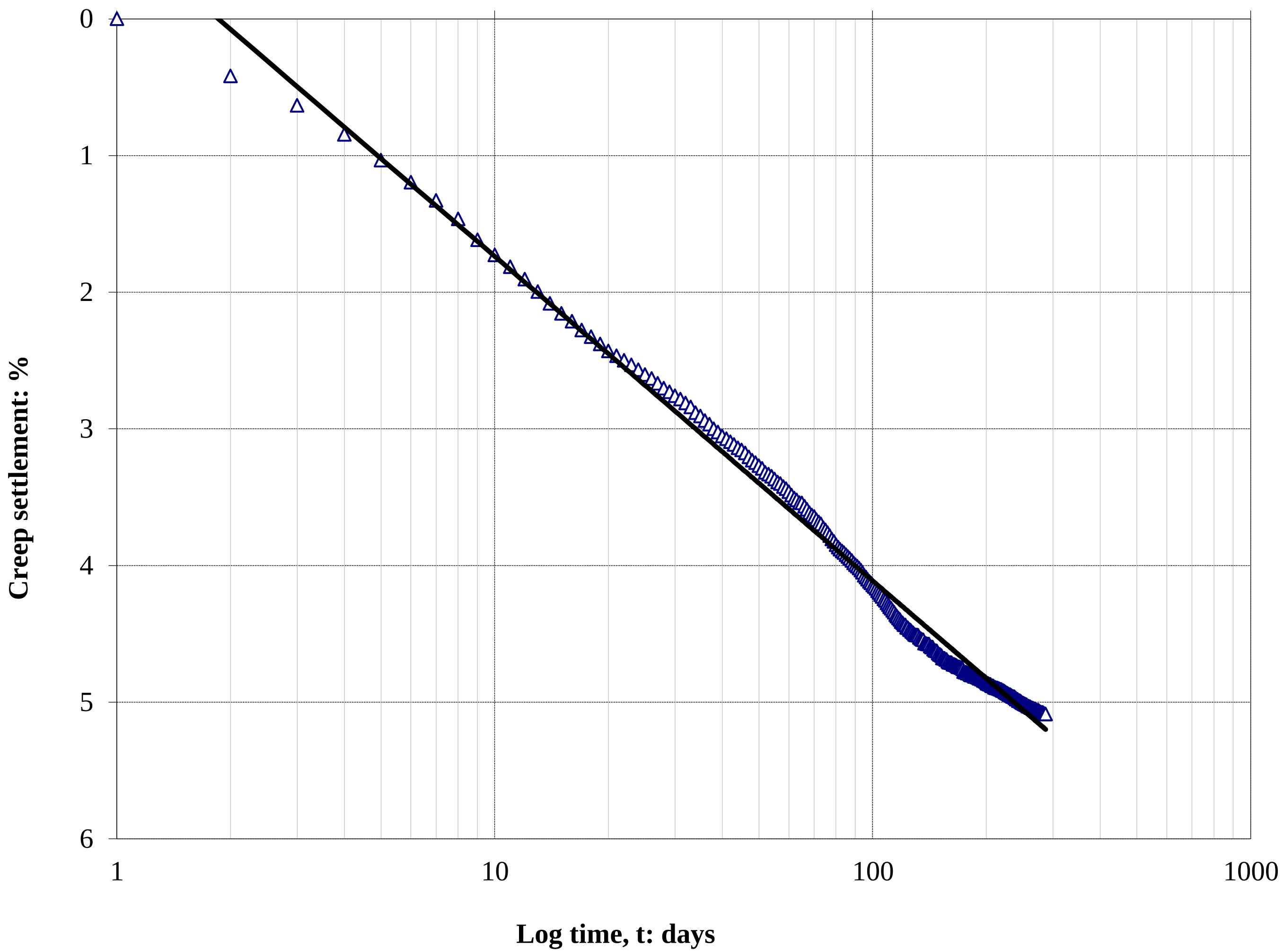
Logarithmic model for mechanical creep

$$\varepsilon_c = C_{\alpha\varepsilon}.\log_{10}(t/t_1)$$

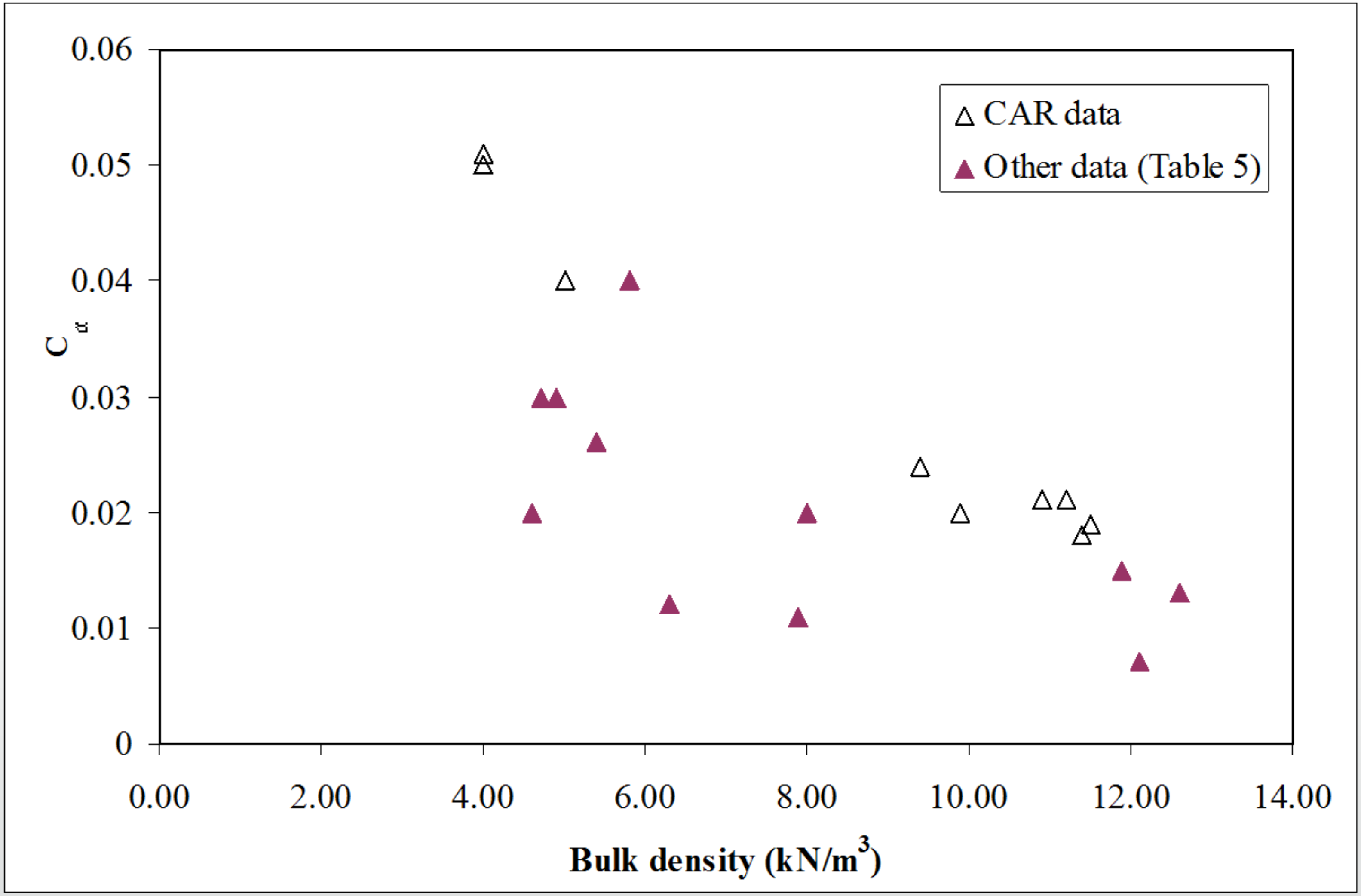
where

- $C_{\alpha\varepsilon}$ is a coefficient of secondary settlement
- t is the time following the application of stress
- t_1 is a reference time

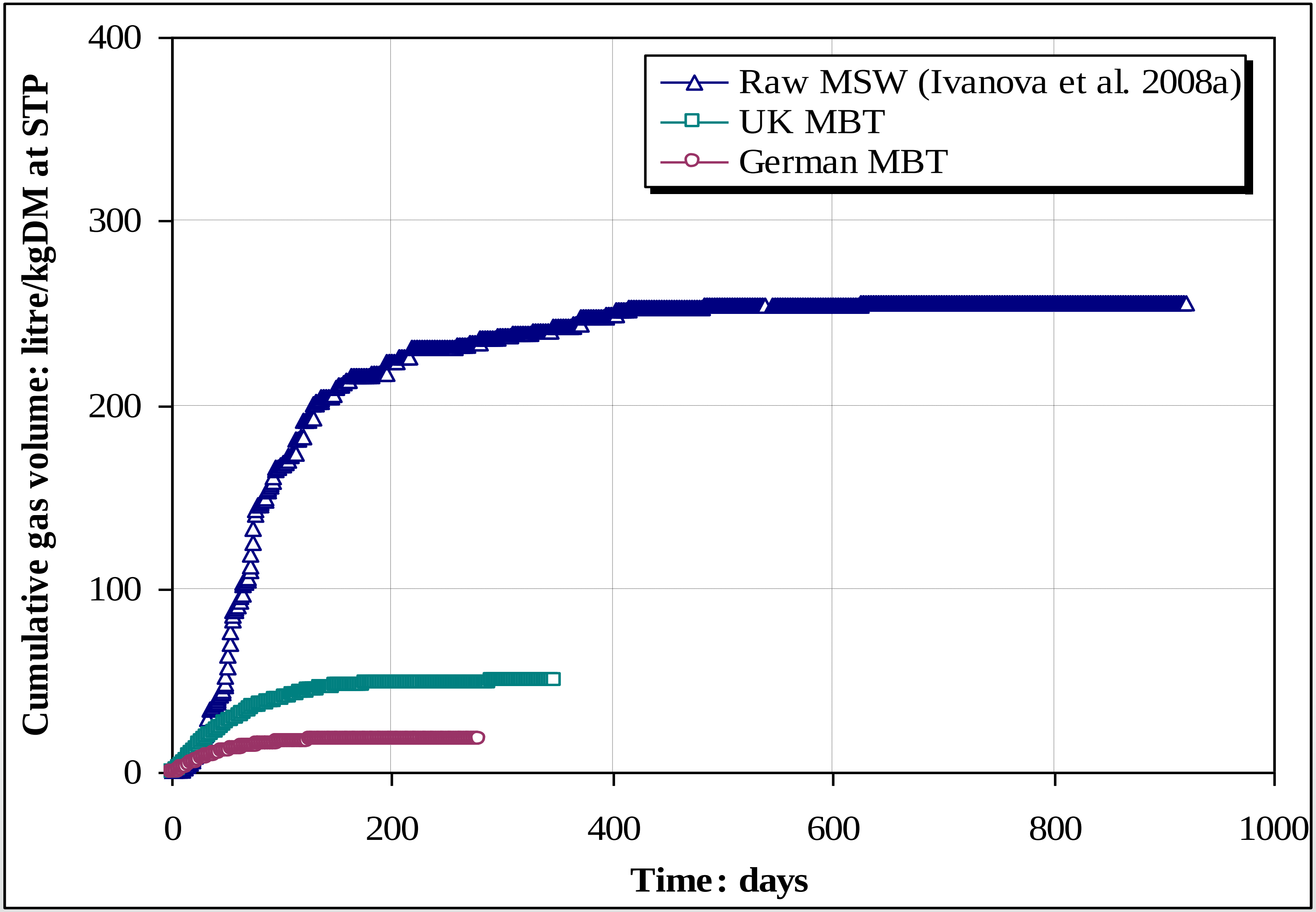
Measured creep settlement *vs* fitted logarithmic model, MBT waste at 50 kPa (Siddiqui *et al.*, 2013)



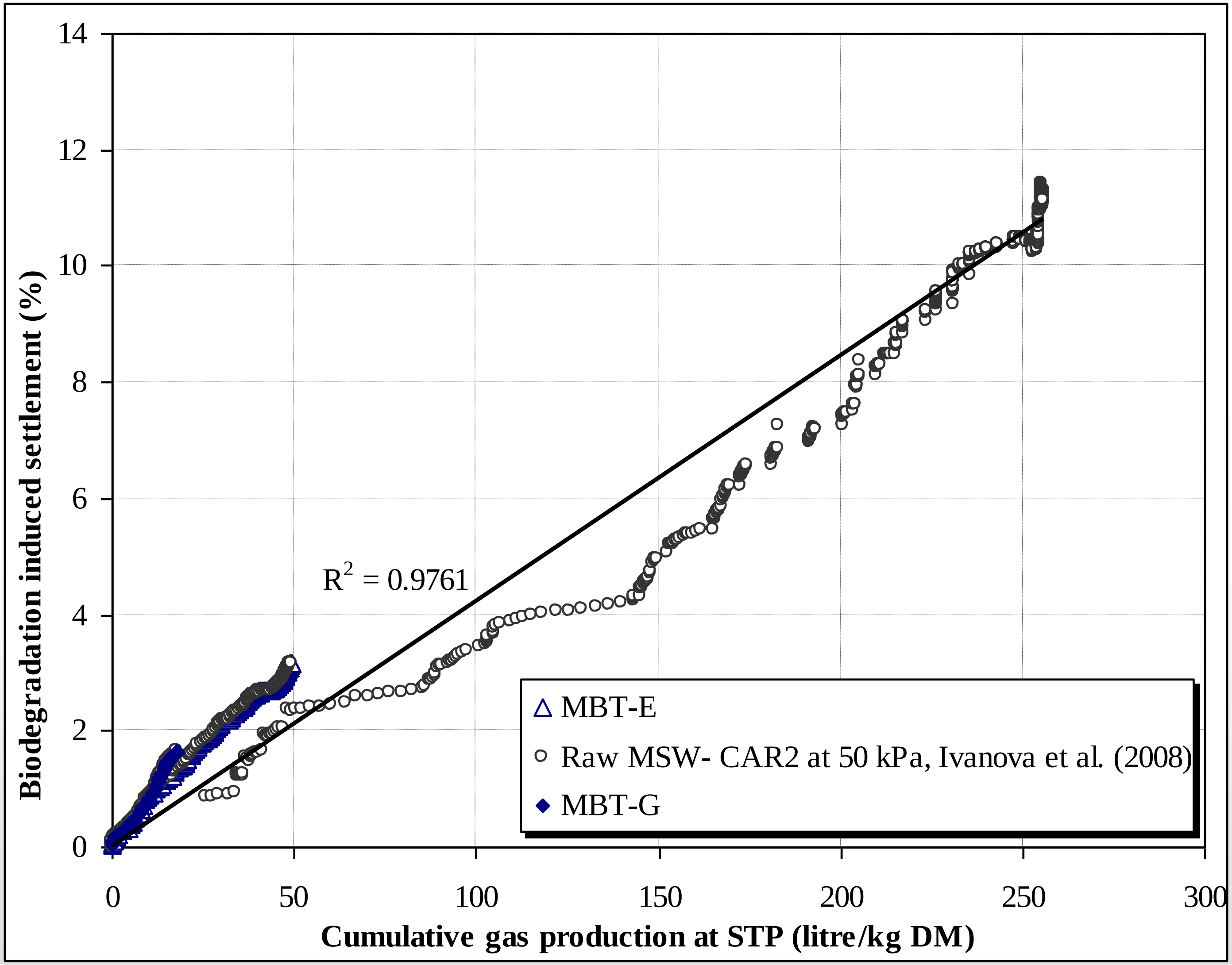
Variation of creep parameter $\alpha_{c\varepsilon}$ with bulk density: CAR and other data ($\alpha_{c\varepsilon}$ is in natural log, ln, rather than $\log_{10}$)



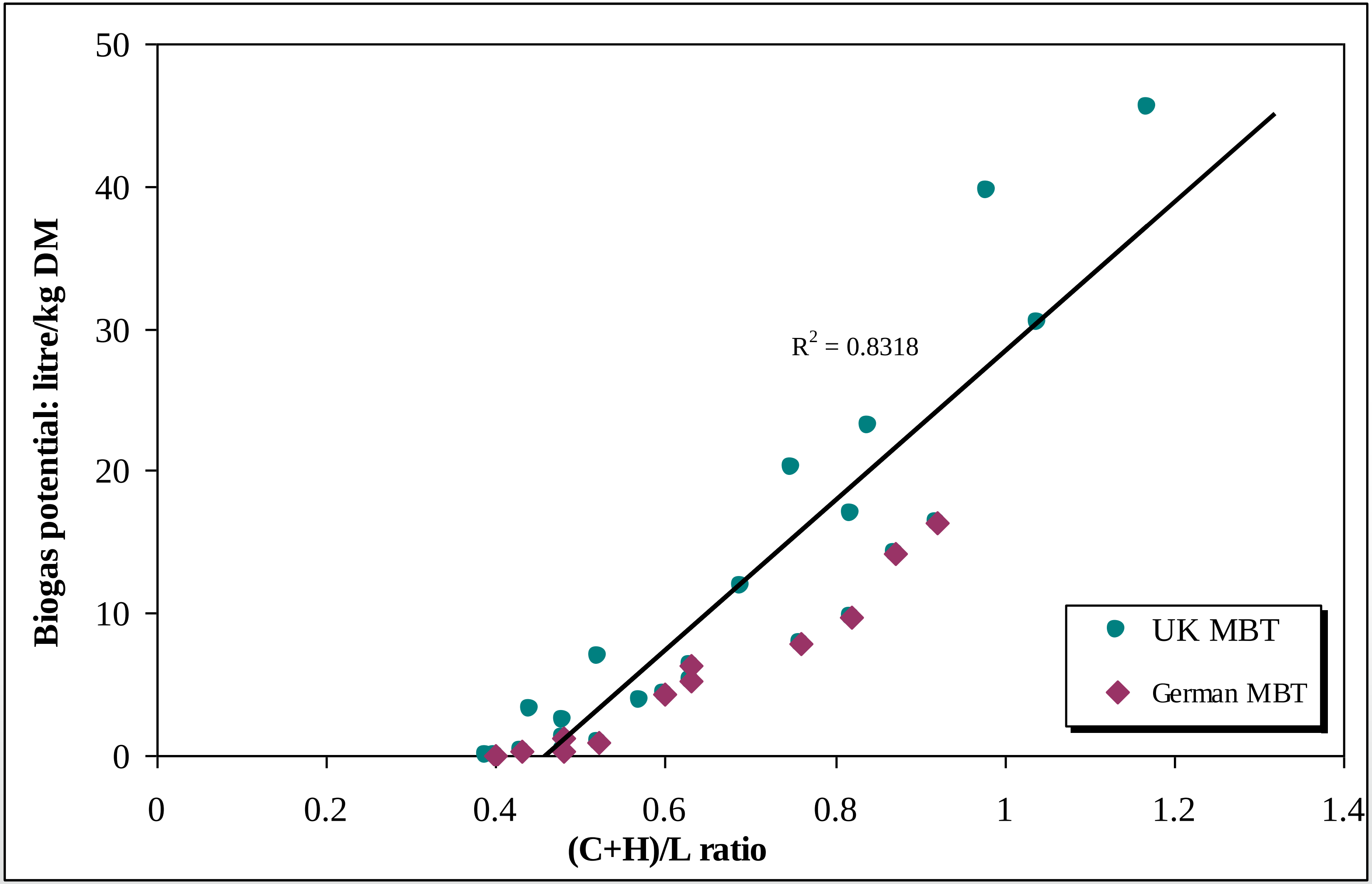
Cumulative biogas production: raw and MBT wastes



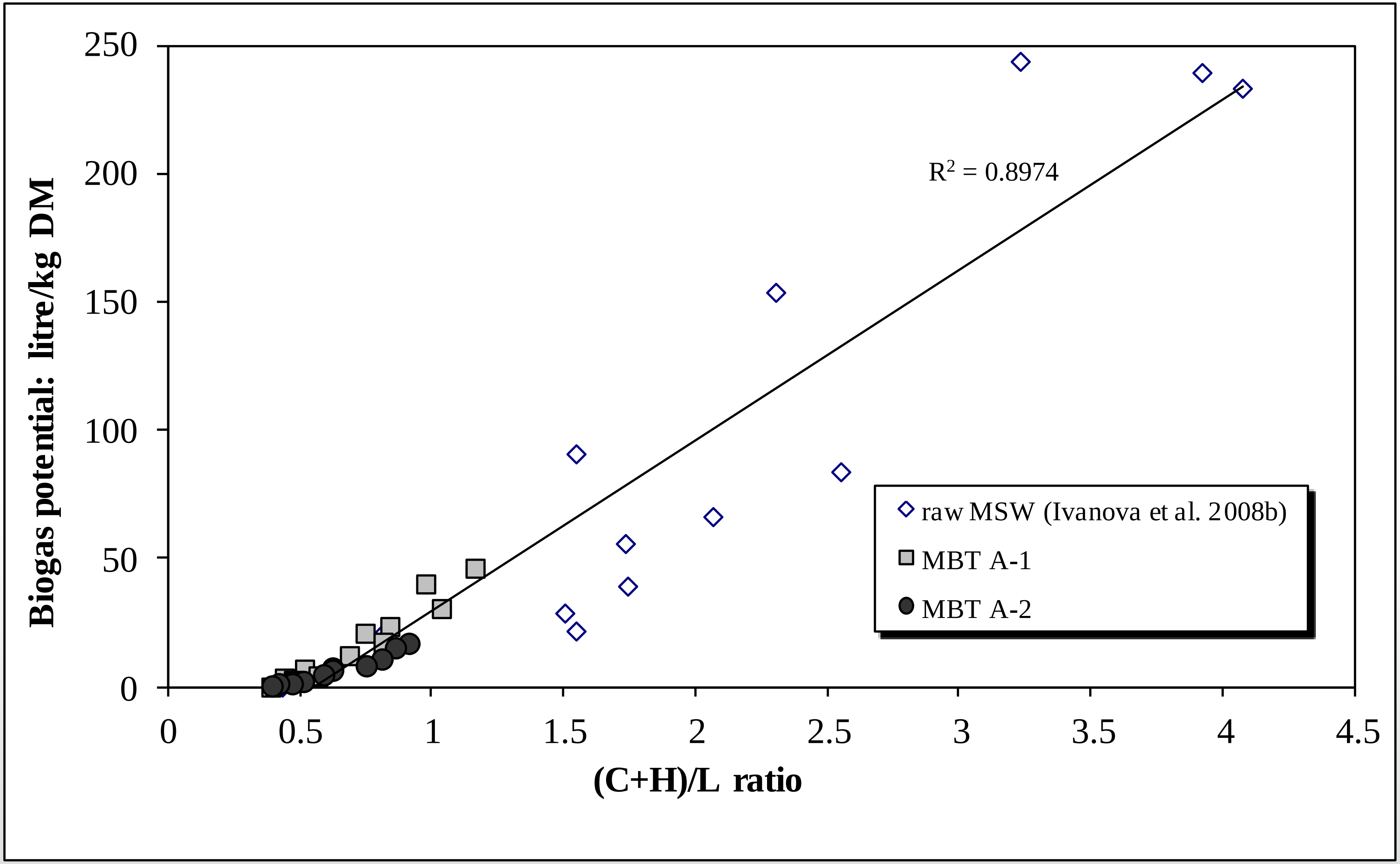
Correlation between biogas production and biodegradation settlement, raw and MBT wastes



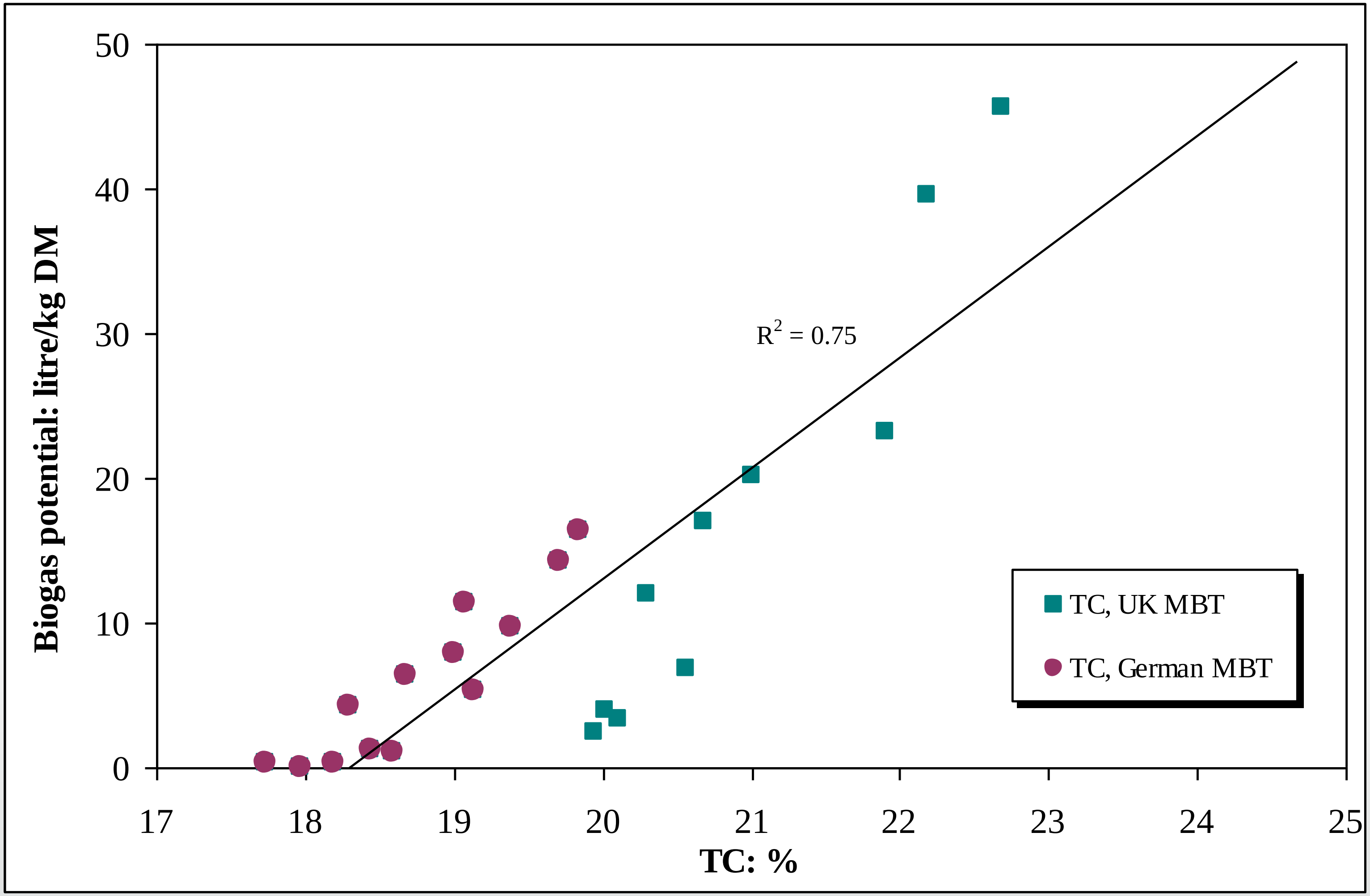
Biogas potential *vs* (C+H)/L: two types of MBT



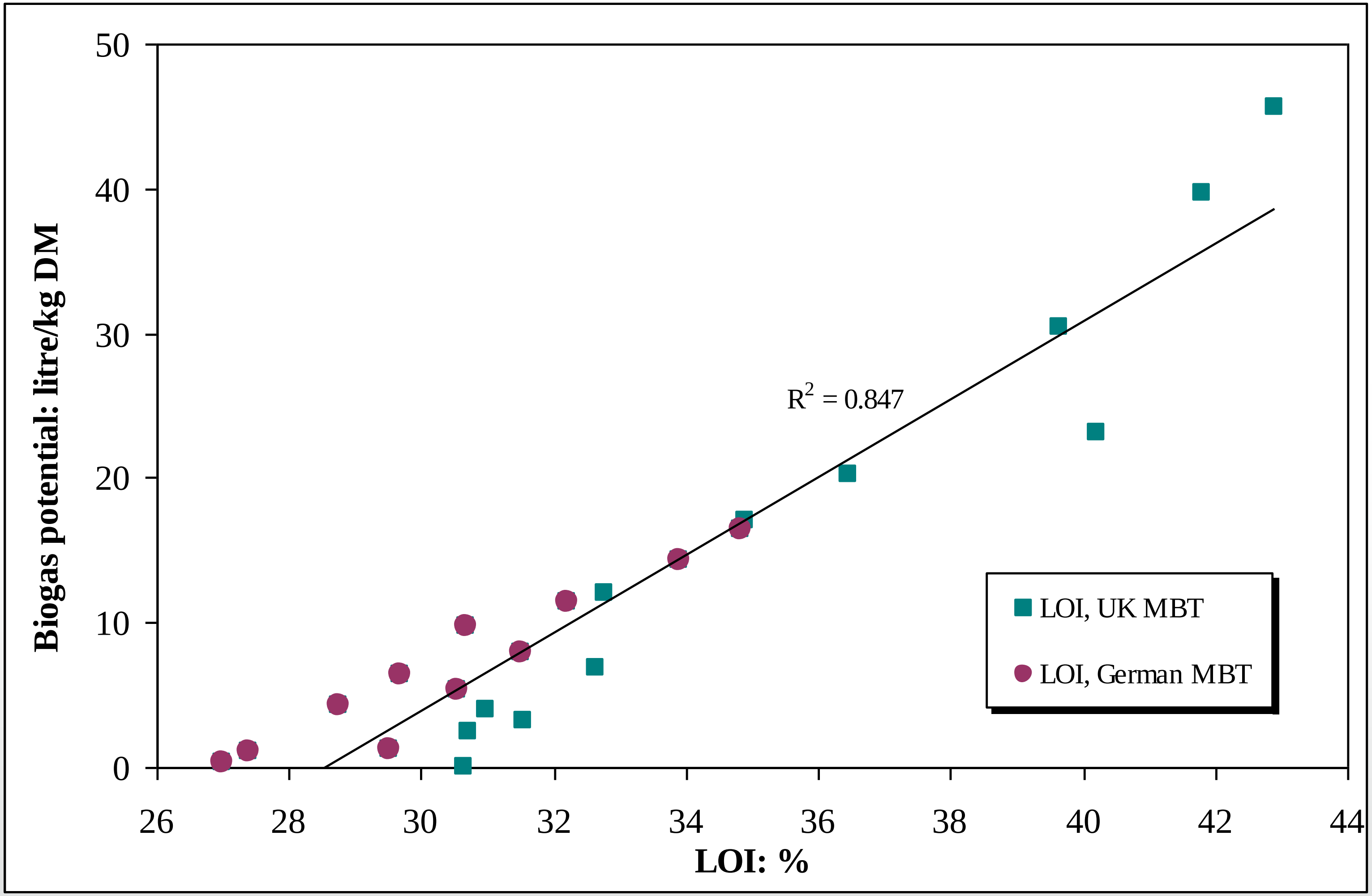
Biogas potential *vs* (C+H)/L: MBT and MSW



Biogas potential *vs* TC: two types of MBT



Biogas potential *vs* LOI: two types of MBT



Summary: settlement and gassing

- Primary settlement of saturated waste follows classic consolidation
- Secondary settlement is due to both biodegradation and creep
- Pre-degradation of the waste reduces the amount of biodegradation settlement in the landfill
- Biodegradation settlements (kinetic) and creep settlements (logarithmic) must be considered independently (or properly coupled)
- Biodegradation settlement correlates with amount of gas produced
- Biogas potential correlates well with (C+H)/L ratio, LOI and TC contents of the waste

Flushing

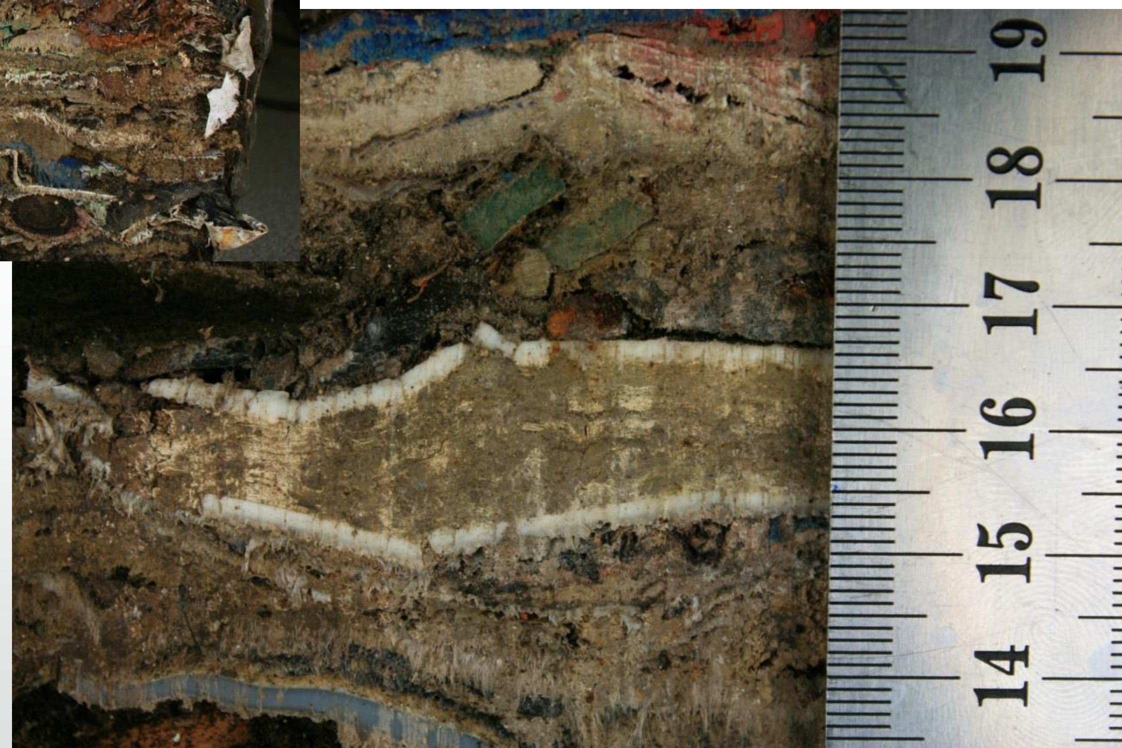
Landfill processes: the role of liquid

- Water content
  - encourages microbial degradation: >35% water content needed for methanogenesis
- Water flow
  - transports seed bacteria and nutrients for anaerobic degradation
  - flushes out non-degradable contaminants
- Both processes essential for "completion"

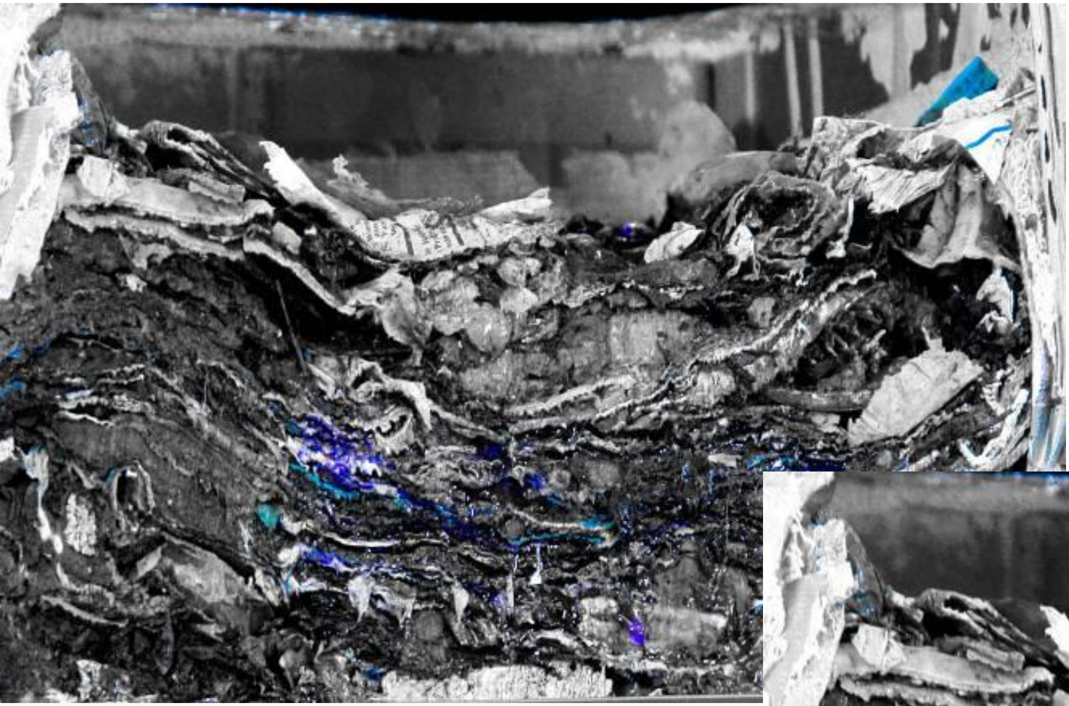
The sustainable landfill bioreactor – a flexible approach to solid waste management. W Powrie & J P Robinson. *Sustainable solid waste management in the Black Sea region* (eds B Nath et al), Kluwer, 2000

Waste has structure

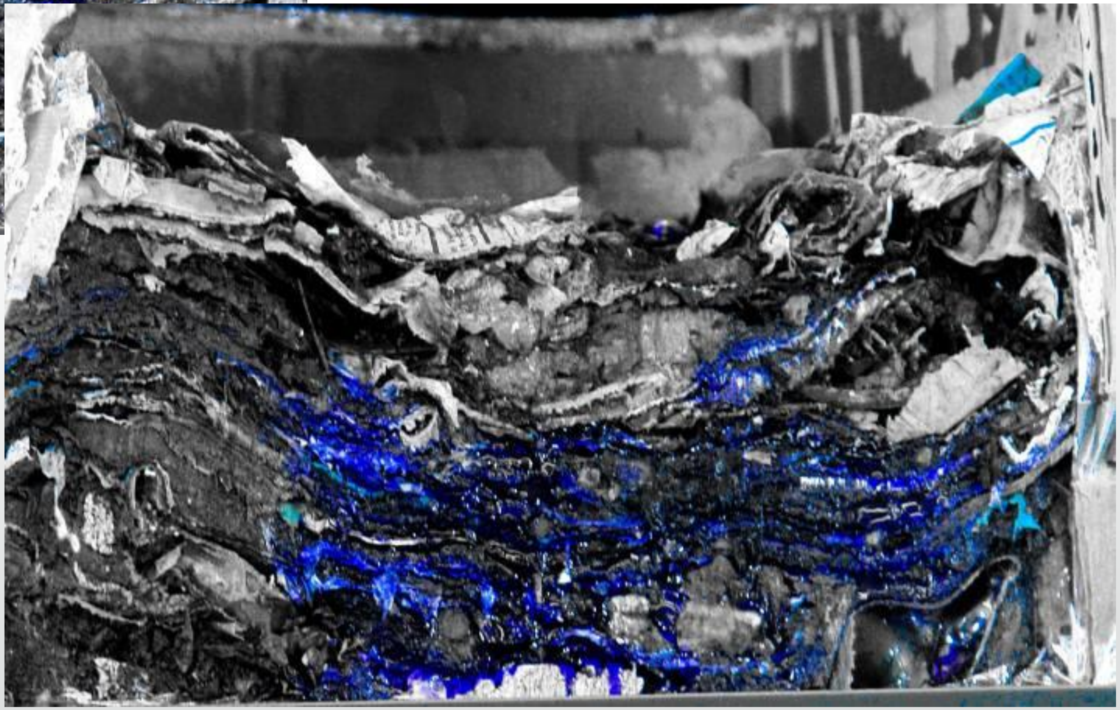
Degraded MSW after CAR experiment



Flowpaths in degraded waste



1 minute after dye injection



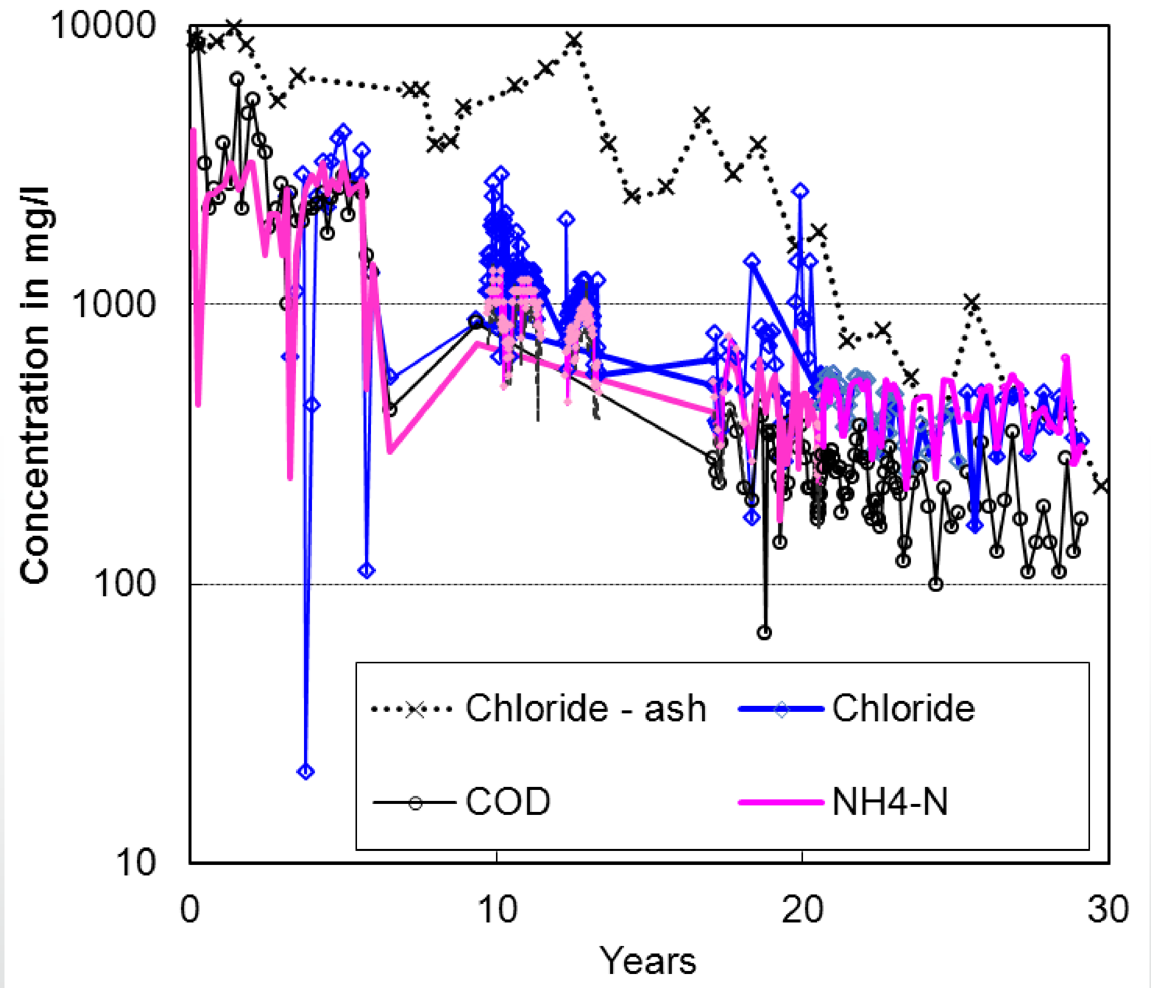
60 minutes after dye injection

Landfilled raw MSW

Newspapers recovered from a landfill

Flushing to completion?

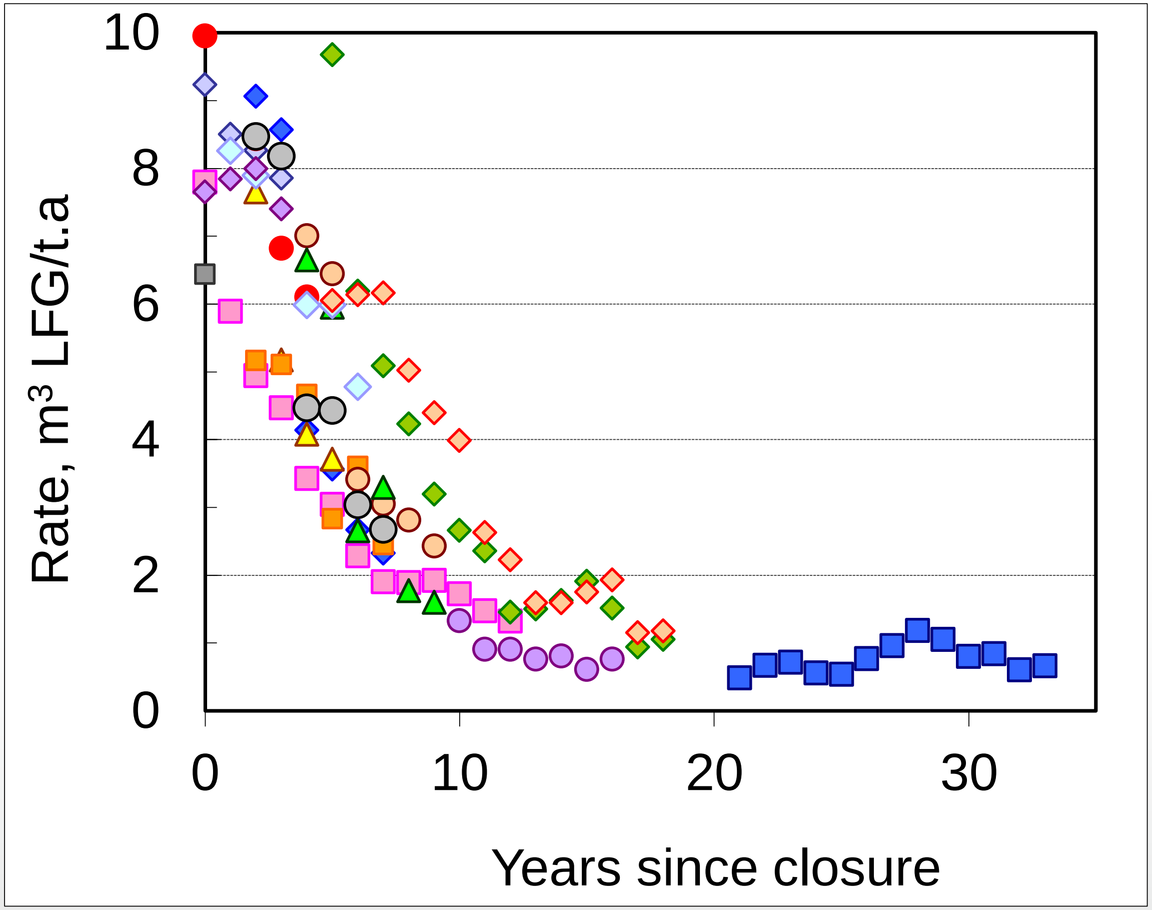
- ~exponential decline
- ~3-5m³ water /tonne waste required (~7 bed volumes)
- Few full scale examples



Leachate dilution at full scale landfills with high water inputs

Tail end of Landfill Gas (LFG) curve

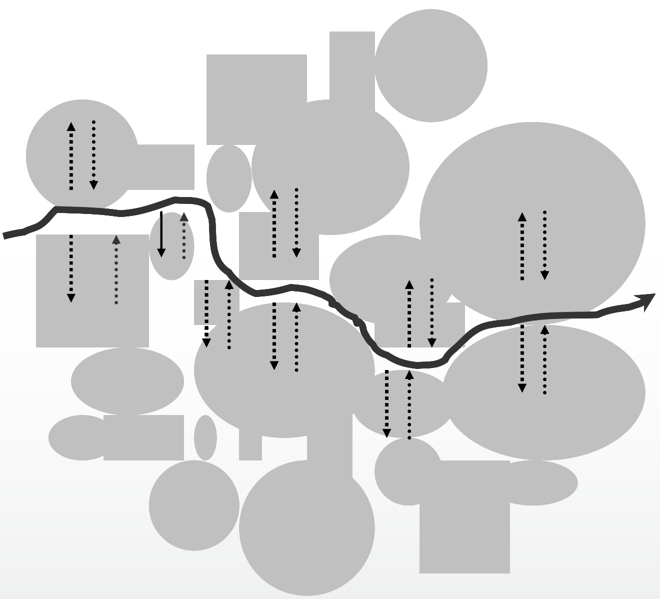
- LFG generation drops to 0.5 to 2 $m^3/t.a$
- Remaining gas potential 75 m^3/t (out of ~250 m^3/t)



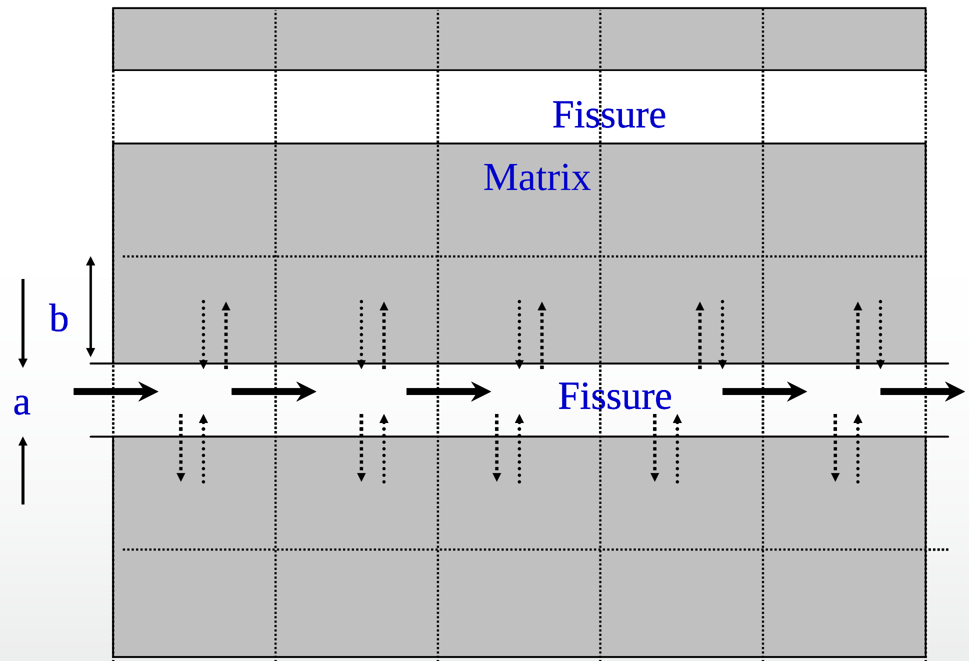
Data: Knox, K., Cheng, K. and Hayward-Higham, S. (2011) Uncertainties in understanding and measuring the completion of waste degradation. Paper no 168 in Proceedings of Sardinia 2011, Thirteenth International Waste Management and Landfill Symposium, Cagliari: CISA

Dual porosity (DP) model: saturated flushing (John Barker)

(a) conceptual model



(b) a representation in DP-Pulse: Slab Geometry



Diffusion between fissure and matrix

Advective flow from cell to cell in fissure

Saturated flushing (DP models)

- Advection time in the mobile zone:

$$t_a = \frac{L}{V}$$

- Diffusion across a zone of immobile water:

$$t_{cb} = \frac{b^2}{D_a}$$

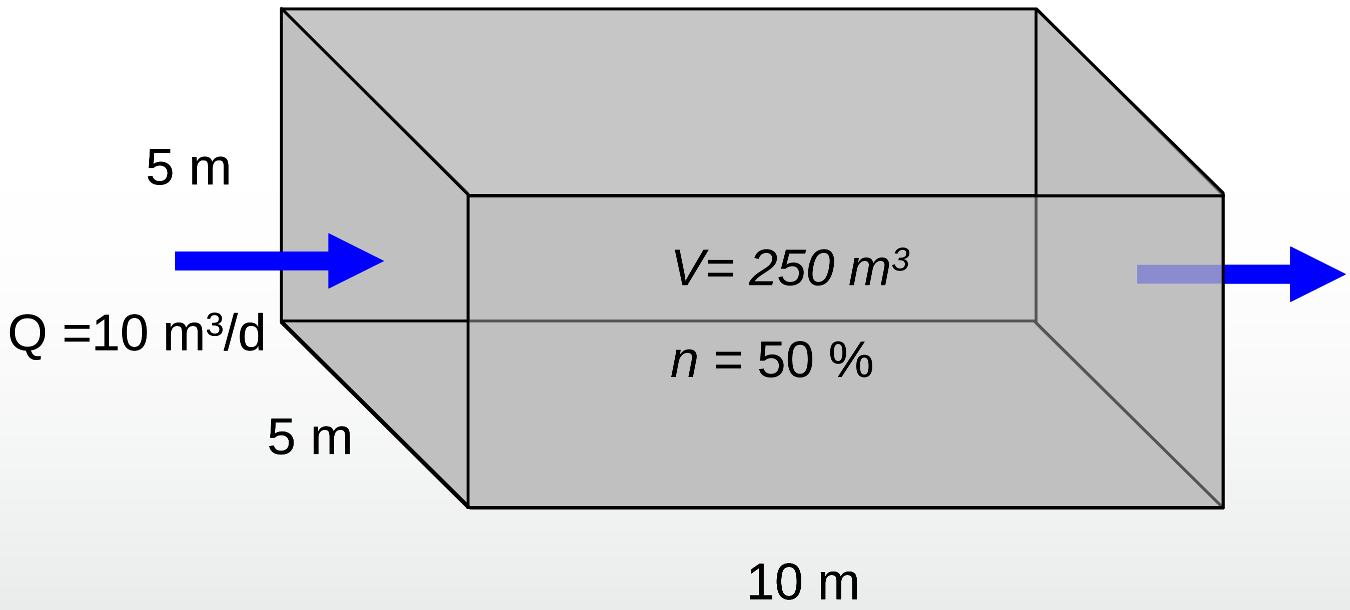
- Ratio of immobile to mobile porosities:

$$\sigma = \frac{2b\phi}{a}$$

$D_a = 3\text{x}10^{-10}\ \text{m}^2/\text{s}$

Illustrative simulations

Consider a 250 m³ zone of waste below the leachate table, flushed at a rate of 10m³/day



$\sigma = 10$

Simulations

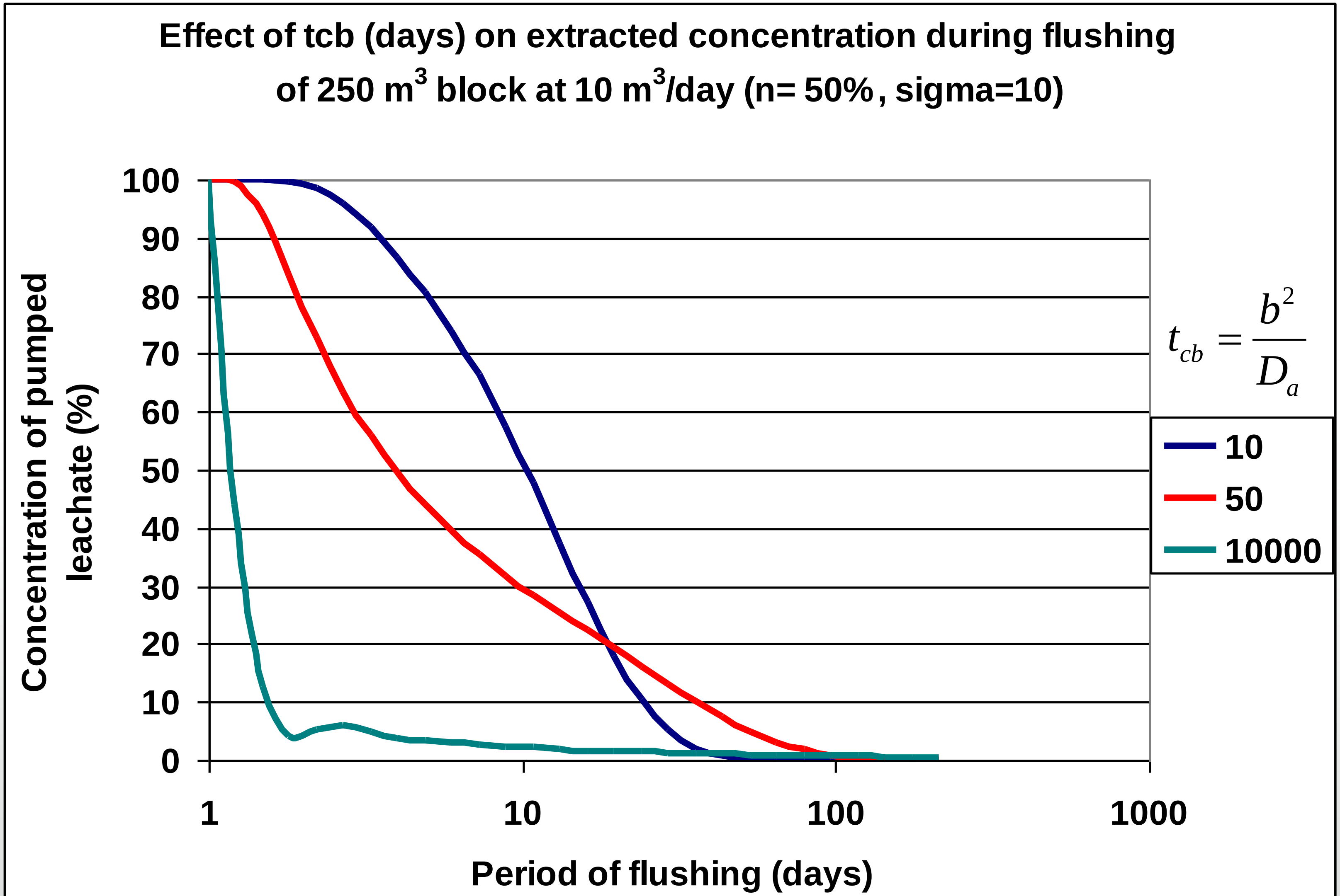
Consider both

- the concentration in the leachate emerging from the “mobile zone” (i.e. what would be seen in a drainage blanket); and
- the average concentration remaining in the immobile blocks (i.e. the potential remaining)

and the effect of t_{cb} varying from

- 10 days (block size ~ 1.6 cm) to
- 10,000 days (block size ~ 50 cm)

Concentration in effluent leachate

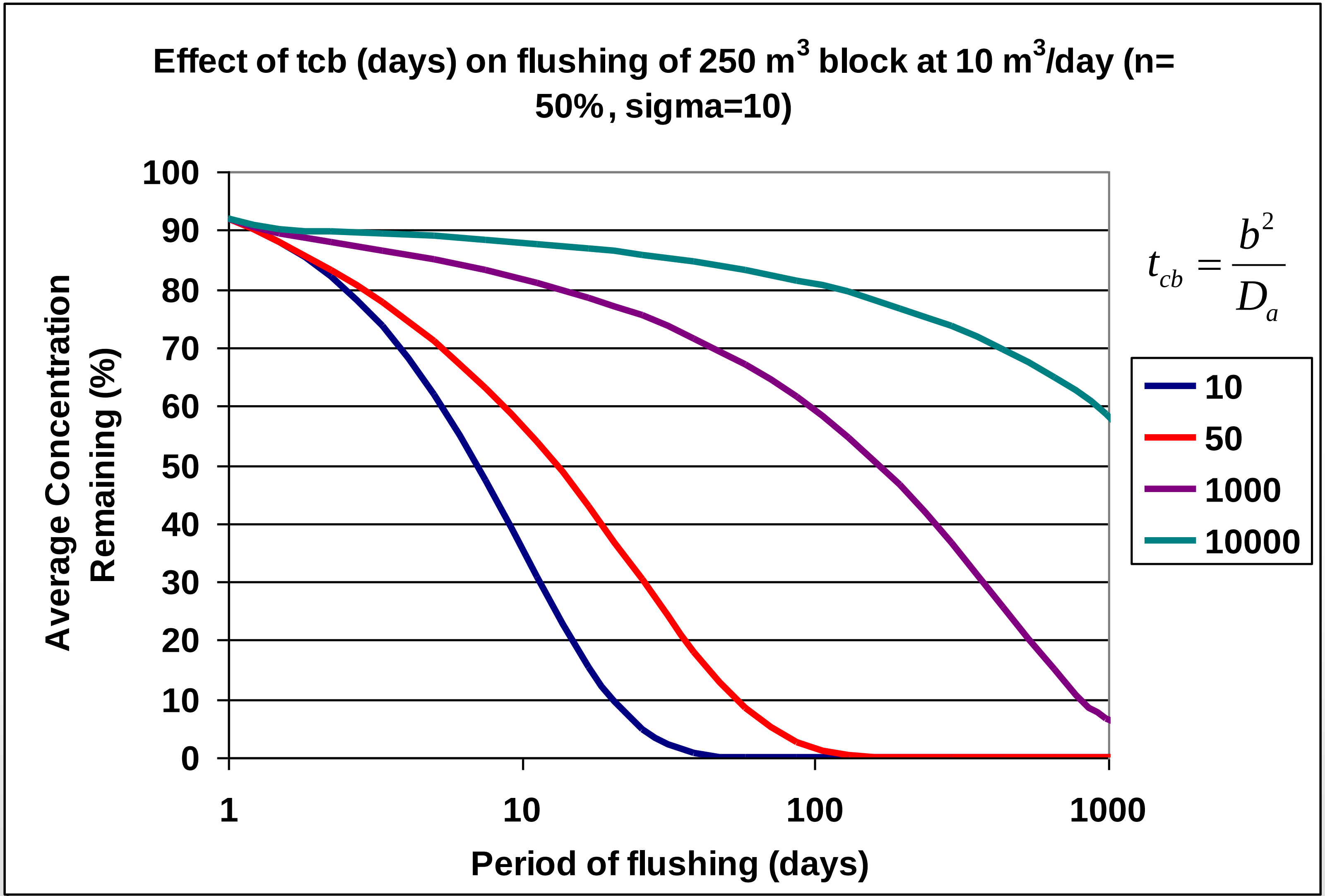


$$t_{cb} = \frac{b^2}{D_a}$$

Block size b

Block size b
1.6 cm
~ 50cm

Average concentration remaining in immobile zone



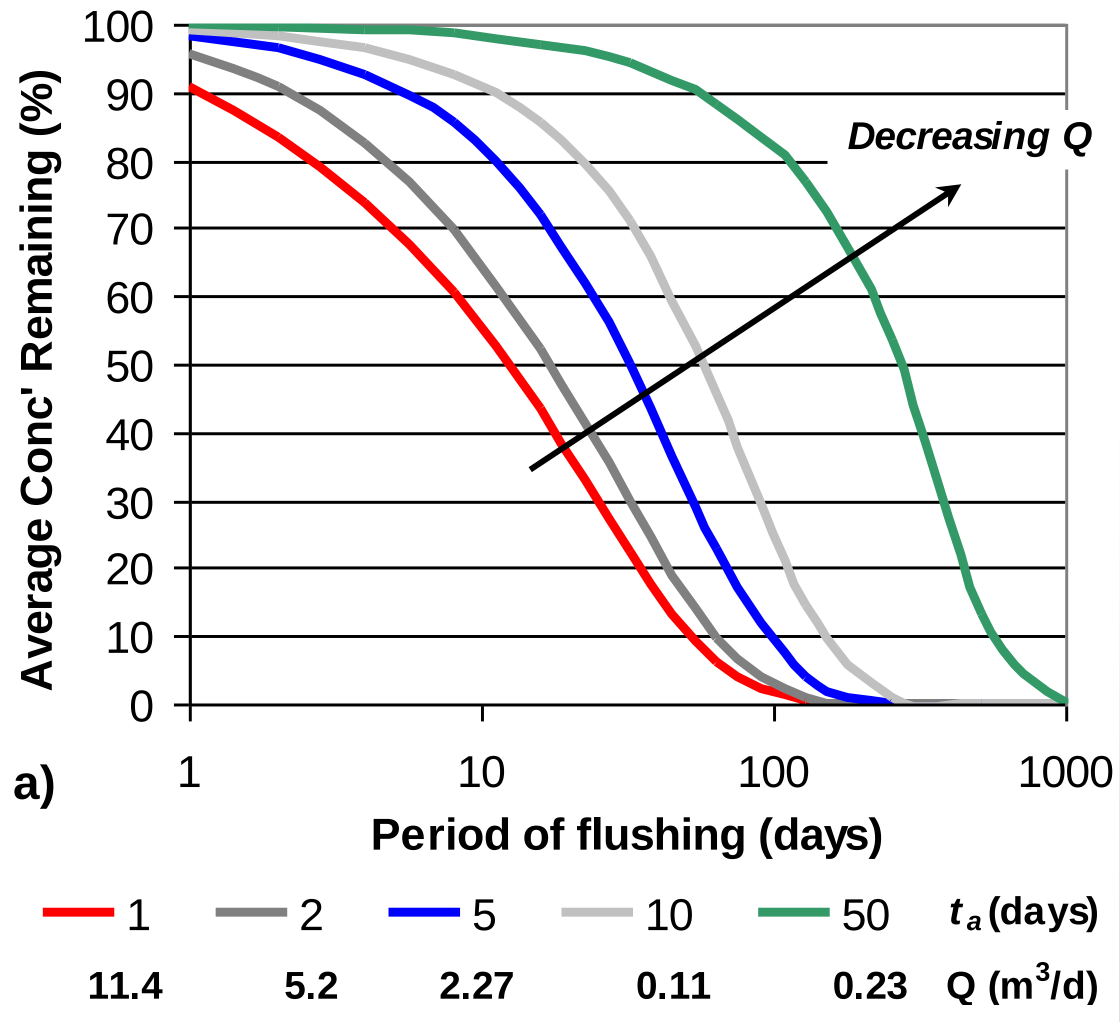
$$t_{cb} = \frac{b^2}{D_a}$$

Block size b

1.6 cm

~ 50cm

Effect of Pumping Rate on concentration remaining in the immobile zone (t_{cb}=50 days)



$$t_{cb} = \frac{b^2}{D_a}$$

What about unsaturated flow? Experimental data (MuMS tests)

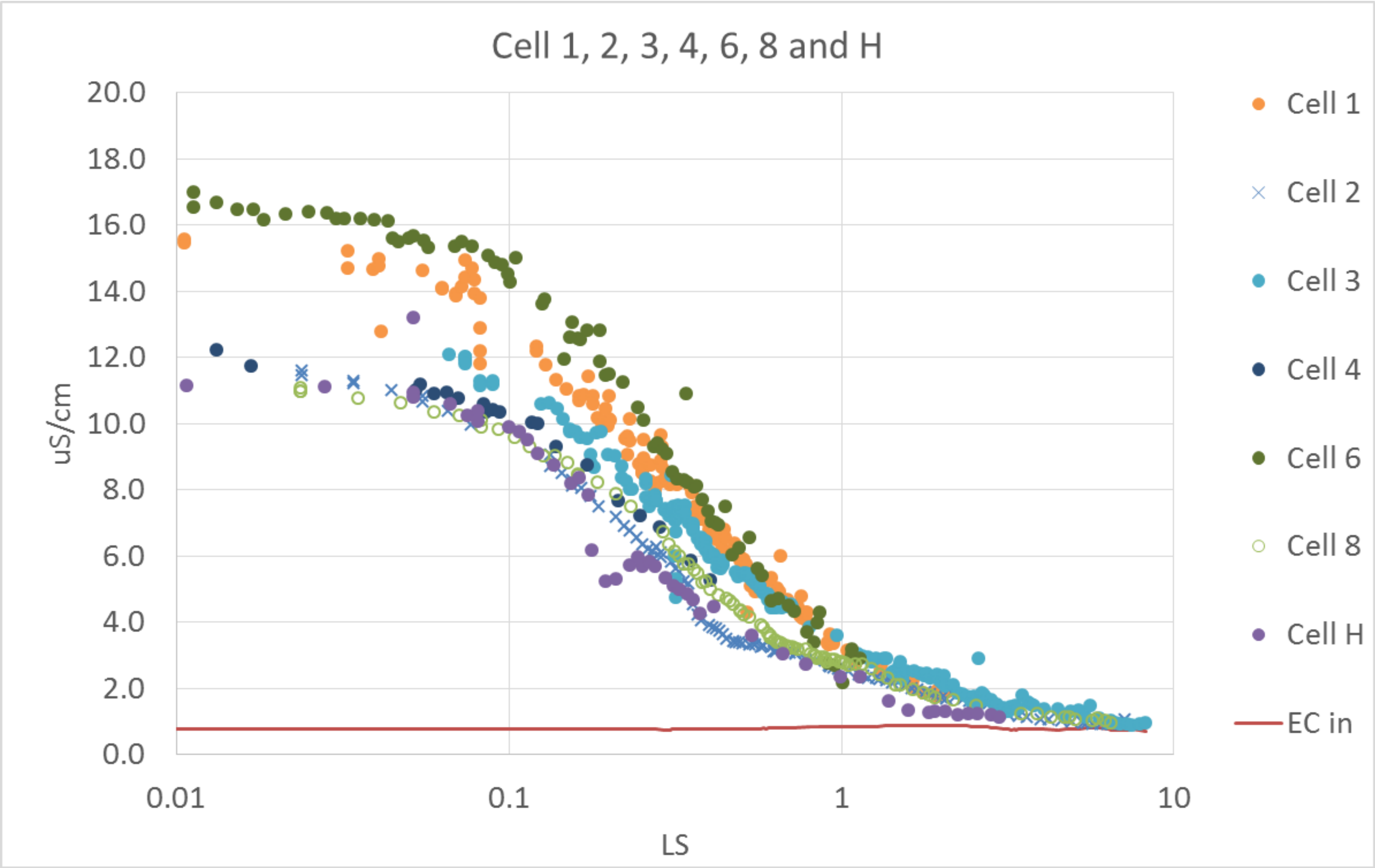
- Eight cells (~0.5 m^3 reactors) containing shredded, aged MSW
- Variable flow regimes (saturated and unsaturated)
- Variable flow rates
- Two different applied loads (vertical stresses)

MSW used in MuMS tests

Above: Homogenizing the waste

Right: Applying compression

Effluent leachate conductivity: all cells



Summary: flushing

- A large block size is not necessarily disadvantageous in terms of completion; contaminant concentrations in the effluent leachate are reduced because contaminant remains locked up in the immobile zone
- Form of response is similar in saturated and unsaturated flow
- However, a change in hydraulic regime (eg an increase in flowrate, or turning off leachate control systems) will alter the contaminant concentration in the effluent leachate

Implications for development over old landfill sites

1. Degradation and settlement

- Simple tests (BMP, LOI, C+H/L) give a good indication of the remaining degradation potential of the waste
- From these, the remaining potential for gas generation and degradation settlement can be estimated
- Simple models can be used to assess the components of settlement due to an increase in the imposed load, biodegradation and mechanical creep by considering each mechanism separately
- Consolidating Anaerobic Reactor tests can be used to obtain the parameters needed for these simple models

2. Groundwater pollution potential

- Dual porosity (block-and-matrix) nature of landfilled waste means that the remaining pollution load and the current “equilibrium” state depend on the prevailing hydraulic regime
- A change in the hydraulic regime (due to either development, or the failure of engineered drainage and pumping systems) must be expected to change the pollution release rate
- A dual porosity flow model can be used to quantify these effects

3(i): Integrity of containment - cap

- Settlement will occur anyway, and is likely to disrupt the cap
- Adapt cap functionality as appropriate to post-aftercare requirements
- The cap leaks gently – allowing water in to flush the waste at a suitable rate
- Residual methane generated is oxidised as is passes up through the cap
- Leakage of water (in) and gas (out) must be uniform, i.e. the cap must not crack

3(ii): Integrity of containment - liner

- Leachate levels and flow (flushing) rates must not change in the post-aftercare period (or if they do change the effects must be understood)
- Post-aftercare leachate level must not rely on active pumping
- Need a liner that will maintain a sustainable leachate level without pumping, even with leakage through the cap
- Inflow through cap balanced by leakage through liner, enabling waste flushing

Acknowledgements

- John Barker, Andrew Hudson, Tristan Rees-White, Asif Siddiqui (University of Southampton)

- This work was supported by EPSRC grant: EP/E041965/1: “Science and strategies for the long-term management and remediation of landfills”

EPSRC
Engineering and Physical Sciences Research Council

Thankyou for listening