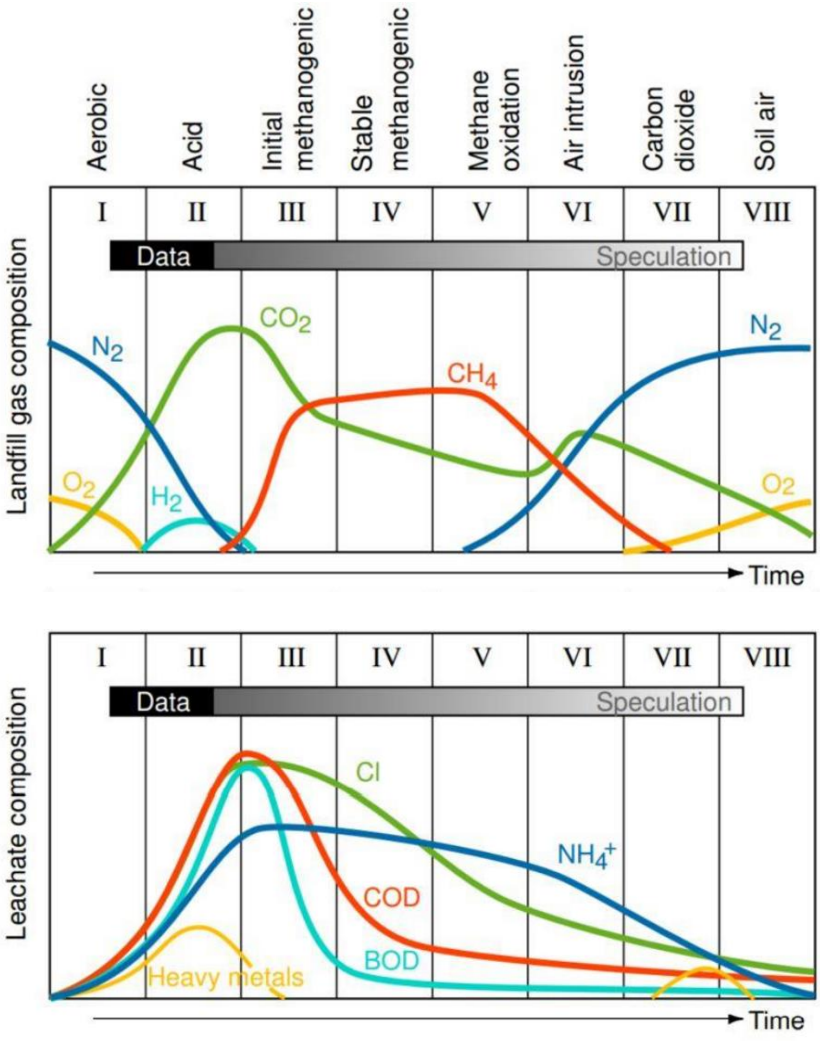
Transient characteristics of gas and liquid components in real landfills

The note **Gas and leachate emission results** and its accompanying Excel Template may be downloaded by clicking on the links in the LDAT website page Help\Get Started\Some results. The note contains details of an analysis of the gas and leachate emission data contained in the results from the passive version of the Ten Element Stack model.

These results may be compared to the transient characteristics of key parameter values that have been observed in real landfills. The characteristics that are most commonly used for this purpose are set in a context that is attributed to Farquhar and Rovers (1973) and has been extended most recently by Kjeldsen et al (2002). In this context the degradation of landfill waste and the composition of landfill gas and leachate products is portrayed as a series of Stages. Additional commentary and observations set within this context may be found in a UK Department for the Environment Food and Rural Affairs (DEFRA) by Brown et al (2018). Two Figures from this report are shown below for illustration.



Note that no time scale is provided. It is expected that the time scale of each stage will be different and be landfill dependent. Farquhar and Rovers (1973) identified the first four stages for gas emissions from laboratory scale tests and observed that the point at which steady state conditions, that is after the completion of the first three stages, could be anything between 180 and 500 days. This period could be extended considerably for large scale, real landfill situations.

Stage four will last for as long as the landfill is operating, and the length of the remaining Stages will depend on the success or otherwise of post-closure rehabilitation. Some estimates for the post-closure period are alarmingly large – of the order of 40 years for gas and 500 years for leachate, Brown, D. et al (2018).

Andreottola, G. and Cannas, P (1992) added a fifth stage in which the landfill gas emissions fell to zero and the pore space gas in the waste aerated naturally to soil gas levels for Oxygen and Nitrogen. They also introduced a leachate composition plot based on the same Stages context.

The Andreottola fifth stage was expanded speculatively by Kjeldsen et al (2002), to create a total of eight stages with the names given in the following Table.

Phase/Stage	Title
1	Aerobic
2	Acid
3	Initial methanogenic
4	Stable methanogenic
5	Methane oxidation
6	Air intrusion
7	Carbon dioxide
8	Soil air

Note that the vertical scale for the gas plots is intended to be values of gas concentrations in % volume. In the case of the leachate plots the units of the vertical scale are generally mg/litre.

The references below contain details of the expected transient behaviour of the components of landfill leachate and gas, together with supporting data. A summary of the observations contained in these references relating to the key components in the first four Stages is given in the following Tables.

Stage No.	1	2	3	4
Stage Name	Aerobic	Acid	Initial methanogenic	Stable methanogenic
Time scale	180 - 500 days (Farquhar and Rovers (1973))			Whilst Landfill Operating
Description	Uses initial oxygen to degrade aerobically	CO2 predominantly generated accompanied by H2 and acids both of which peak at the end of this stage and die off – as do most other indicators, COD NH4+, SO4 2-, and Heavy metals.	CH4 starts being generated and slightly exceeds CO2 rate by end of the Stage.	Low dissolved solids and VFA's. Gas coming from both acetic and methanogens.
Component				
Gas phase relative concentrations % volume				
Methane CH_4	Suppressed by methane oxidation and pH	Suppressed by pH	Starts being generated and slightly exceeds CO2 rate by end of this stage.	Stabiises and declines
Carbon dioxide CO_2	Rises as product of degradation	Continues to rise, peaking at the end of this stage	Falls	Falls
Oxygen O_2	Falls - consumed by aerobic degradation	Negligible	Negligible	
Nitrogen N_2	Falls - displaced by CO2 generation	Negligible	Negligible	
Hydrogen H_2				

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Component				
Leachate mg/litre				
COD	Rises - source (see calcs)	Continues to rise, peaking at the end of this stage. BOD5/COD > 0.7 - BOD5 >10,000 mg/litre	Falls rapidly	Fall continues - beginning to level off at the end of the stage
Ammonium ion NH_4^+	Rises as Protein degrades	Continues to rise, peaking at the end of this stage. '"Ammonia" 500 - 1000 mg/litre	NH4+ slowly decays during this and later stages	Slow decay continues
Chlorides		Continues to rise, peaking at the end of this stage	Steady fall throughout this and following stages	
BOD		>10,000 mg/litre	Follows shape of COD curve remaining less than COD value. BOD/COD progressively reduces to a low value	
Heavy metals			Drops to a minimum near zero at mid-stage	
Dissolved solids				
Acids	Rise as dissolved solids degrade		Drops to a minimum near zero at mid-stage	
Sulphate SO_4^{2-}		Continues to rise, peaking at the end of this stage	Drops to a minimum near zero at mid-stage	
Carbonic acid HCO_3			Rises? Who says?	
pH	Falls with increase in acids	Continues falling to a minimum at the end of the stage in line with increasing COD and acids. Value range 5 - 6.	Rises and stabilises	
Bacteria	Utilises NH4+ to grow and facilitate degradation of dissolved solids	Methanogens suppressed by pH conditions (and redox).	Slow growth of methanogenic bacteria. Note presence of acids above 6,000 – 16,000 mg/litre lowers pH enough to kill methanogenic activity. These need pH in range 6-8.	

References

Farquhar, C. J. and Rovers, F. A. (1973) Gas production during refuse decomposition. Water, Air and Soil Pollution, 2, 483-95

Andreottola, G. and Cannas, P (1992) Chemical and Biological Characteristics of Landfill Leachate in Christensen, T. et al (1992) Landfilling of Waste: Leachate Published by E & FN Spon.

Christensen, T. et al (1996) Gas-Generating Processes in Landfills in Christensen, T. et al (1996) Landfilling of Waste: Biogas Published by E & FN Spon.

Brown, D. et al (2018) Landfill Aftercare Scoping Study – UK Department for the Environment Food and Rural Affairs. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20039&FromSearch=Y&Publisher=1&SearchText=WR1919&SortString=ProjectCode&SortOrder=Asc&Paging=10