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A new economic instrument for financing accelerated landfill aftercare

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ABSTRACT

The key aspects of landfill operation that remain unresolved are the extended timescale and uncertain funding of the post-closure period. This paper reviews the topic and proposes an economic instrument to resolve the unsustainable nature of the current situation. Unsustainability arises from the sluggish degradation of organic material and also the slow flushing of potential pollutants that is exacerbated by low-permeability capping. A landfill tax or aftercare provision rebate is proposed as an economic instrument to encourage operators to actively advance the stabilization of landfilled waste. The rebate could be accommodated within existing regulatory and tax regimes and would be paid for: (i) every tonne of nitrogen (or other agreed leachate marker) whose removal is advanced via the accelerated production and extraction of leachate; (ii) every tonne of non-commercially viable carbon removed via landfill gas collection and treatment. The rebates would be set at a level that would make it financially attractive to operators and would encourage measures such as leachate recirculation, in situ aeration, and enhanced flushing. Illustrative calculations suggest that a maximum rebate of up to ~€50/tonne MSW would provide an adequate incentive.

1. Introduction

Landfill continues to be the mainstay of waste management in many countries and is likely to remain so for several decades. It is recognised as being one of the main technologies that provides a route for the storage of materials in sinks rather than dispersion of materials or their degradation products into the wider environment (Scharff, 2012; Brunner, 2013). Even in regions that are trying to minimise landfill, such as the European Union, landfill may continue to be needed for 10–20% of municipal, commercial and industrial non-hazardous waste, either directly or for residues from pre-treatment processes. The volume of wastes present in existing landfills is estimated to be 7 billion tonnes of non-hazardous waste landfilled over a 7 year period between 2004 and 2010 in 27 Countries of the EU (EuroStat, 2013) and 1.4 billion tonnes of MSW alone landfilled in the US between 2002 and 2011 (EPA, 2013). This indicates that the perception that societies no longer need to be concerned about landfill, its management and impacts, are misplaced. In particular, it is important that arrangements to manage the environmental impact of landfills after closure are fit for purpose, and that "*aftercare is an inseparable element of responsible landfill management*" (Scharff et al., 2013).

For approximately two decades, proven engineering and operational practices have been available for containment of leachate and gas, restriction of water ingress, and extraction and treatment of leachate and gas, so that landfills have no significant impact on local air and water quality. These techniques have become standard practice in most industrialised countries. As a consequence, most aspects of the potential environmental impacts of landfills are now well controlled. The key issues that remain unresolved are the extended timescale and uncertain funding of the post-closure (aftercare) period. This is a problem applicable to most landfills, not only those that contain biodegradable waste but also a range of largely inorganic waste such as bottom ash, APC residues and treated hazardous wastes. This paper summarises these problems and presents a proposal for an economic instrument that could resolve these two issues.

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2. Background

Over the past ~20 years, an increasing awareness has developed that the downside of the impressive containment engineering improvements is that they have created timescales of at least centuries, and possibly millenia, before landfills will reach a point where no active management, monitoring, or inputs of energy or materials are needed, to control the release of contaminants. This point is referred to as Final Storage Quality (FSQ) or Completion. Although there are slightly different interpretations of the meaning of these terms, a commonly accepted view is reflected in guidance published in the UK (Environment Agency, 2005, 2012) which requires that to reach Completion, operators would have to demonstrate that the flux of contaminants to the environment would still be acceptable under the assumptions of, *inter alia*:

- no active management;
- failure of all engineered containment;
- attainment of hydraulic equilibrium (i.e. water or leachate levels in the site have equilibrated with water fluxes into and out of the site in the absence of active management and failure of some or all of the engineered controls);
- no functioning gas or leachate management systems.

The concept of hydraulic equilibrium is important to the technical debate about aftercare (e.g. Hall et al., 2007). During aftercare, active management and the functioning of engineered controls will result in an imposed hydraulic equilibrium, which, in many sites, will mean the majority of the waste is unsaturated. As active management (e.g. leachate pumping) is discontinued and engineered controls (e.g. the cap and/or liner) deteriorate or fail, then a new hydraulic equilibrium will be established that in many cases may involve the slow filling of the site with leachate. For Completion to occur, the regulator must be satisfied that future fluxes to the environment will be acceptable under a range of hydraulic equilibrium situations.

The long timescales needed to reach FSQ arise partly from the difficulty of achieving sufficient degradation of organic matter and partly from the slow rate of flushing of leachate pollutants that results from low permeability capping or low rainfall infiltration rates (e.g. Knox, 1990; Knox et al., 2005). Some technical approaches to managing each of these have been investigated but they remain underdeveloped due to lack of application at full scale. These are discussed below.

2.1. Achieving sufficient degradation

Data from closed landfills and test cells (e.g. Fig. 1) show that specific gas generation rates fall fairly rapidly during the first ~10–12 years after closure to <2 m^3/tonne per annum, then continue for decades at ~0.5–2.0 m^3/tonne per annum with a remaining gas potential from cellulose and hemi-cellulose possibly as high as ~75 m^3/tonne (Knox et al., 2011). The dramatic slowing of gas generation rates while so much substrate remains, even under optimised conditions, may be due to the fact that much of the degradable content is only partially accessible to bacterial exo-cellular enzymes because of the presence of the lignin matrix. Lignin is regarded as the most significant factor limiting biodegradability of lignocellulose in anaerobic digestion systems (e.g. Van Soest, 1994).

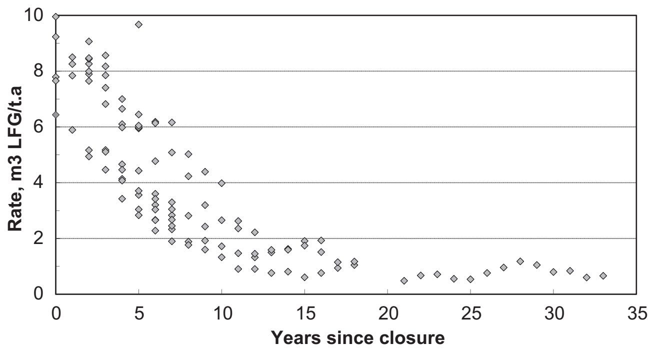

Fig. 1. Gas generation rates at twenty closed landfills in Hong Kong and UK (from Knox et al. (2011)).

The only process that appears able to achieve any improvement on this ‘tail’ of the gas curve is in situ aeration. An accelerated carbon flux of 2–4 times has been reported (e.g. Heyer et al., 2007) during aeration periods that are typically 4–6 years. These rates are reported to be accompanied by considerable reductions in leachate NH_4–N and COD concentrations. However, longer term studies of carbon fluxes are lacking and no documented full scale case studies exist that show sustained leachate improvements in typical containment landfills. One study (Öncü et al., 2011) reported increases in leachate COD, BOD, NH_4–N and chloride. Uptake of this promising technology has been limited and there remains a need for full scale case studies to report quantitative data on aspects such as:

- Gas generation profiles in the years following cessation of aeration.
- Leachate quality profiles, especially NH_4–N, NO_2–N, NO_3–N, TKN, non-degradable (recalcitrant) COD and chloride, both during and after aeration.
- Nitrogen balance including NH_3, N_2O and N_2 in the off-gas and subsequent mineralisation of organically bound nitrogen.

2.2. Flushing of soluble leachate contaminants

Test cell and lysimeter studies have shown that flushing of leachate contaminants over time often approximates to an exponential dilution curve in the short to medium term. Over longer timescales in the field, the limited evidence suggests that a simple exponential decline model may actually under predict reality (Woodman et al., 2007). An unpublished (and anonymous) example is shown in Fig. 2, together with a published data set for the Vestskoven ash landfill in Denmark (Hjelmar and Hansen, 2004; Beaven et al., 2005). Few monitored full scale examples of flushing a landfill to anywhere near FSQ exist: none of them is the result of deliberately accelerated leaching, rather the consequences of local hydrological conditions and the absence of containment engineering.

Approximation to exponential behaviour could be considered as a best case (Beaven et al., 2005) and leads to a requirement for flushing by ~3–5 m^3 water per tonne of waste (Walker et al.,

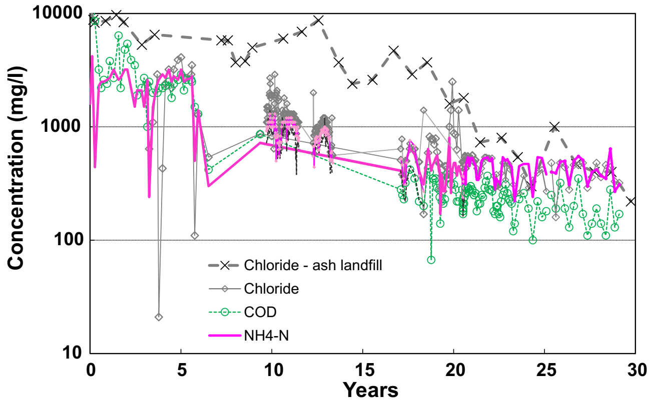

Fig. 2. Leachate dilution at full scale landfills with high water inputs.