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METHANE PRODUCTION, EMISSION AND CONTROL DURING MSW LANDFILLING

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SUMMARY: Until quite recently the major emphasis on landfill gas control has related to 'post-completion' of landfill cells or phases, rather than during active waste disposal operations. Increasingly, odour control needs have changed that pattern through *ad hoc* capping and gas collection systems but, to date, there has been little quantitative information available on the scale of methane emissions from the commencement of waste deposition. This applied research project involved extensive surface flux emission monitoring carried out on 21 operational UK landfills. Main findings were that (a) the onset of methanogenesis appears to occur within about 2 months of waste placement and is well-established, with methane at least 40% by volume, after about 6 months; and (b) surface methane flux emissions were detectable within about 1 month after waste placement. Additionally, surface flux data showed that (c) the emission rates from waste side slopes were much greater than from top surfaces, and (d) areas close to landfill edges can have the highest emission rates. Both of the latter findings confirm the high lateral (as opposed to vertical) permeability of landfilled wastes. Moreover, emission rates from top surfaces of waste do not appear to increase significantly with age. The average surface flux rate appeared to peak around 20-24 months (following initial waste placement) at about 1mg. $m^{-2}.s^{-1}$, but this result could be influenced by the particular conditions at the relevant sites. Nonetheless, the flux rate is some 100-times greater than the proposed UK limit for emissions from temporarily capped sites. The main zones where effective reductions can be made in emissions are the waste side slopes and landfill edges. Controls in such areas should be based on horizontal rather than vertical collection systems, reflecting the greater lateral permeability of wastes; such systems would also be more compatible with on-going disposal operations by virtue of minimal disruption to working practices. These control networks could be integrated in due course with permanent gas collection systems for energy recovery.

PROJECT BACKGROUND

As part of the UK Climate Impacts Programme, the UK Government is committed to reducing the overall emissions of greenhouse gases in accordance with internationally agreed targets. The Environment Agency is developing a strategy for emissions-based regulation of landfill gas in order to minimise global impacts of methane and local impacts on health, environment and amenity. This strategy includes guidance on the proposed introduction of a surface methane emissions protocol for permanently or temporarily capped landfills (Environment Agency, 2002).

1. INTRODUCTION

Historically, the pre-completion stages of waste landfilling in cells have not usually been subject to any active gas controls, that is except where local odour controls have been required to reduce impacts on sensitive neighbouring areas. This situation is changing, partly due to implementation of the Landfill Directive which requires increased collection and treatment of landfill gas and changes in the waste composition that may result in significant changes both in the generation and constituent components of landfill gas.

This paper follows a preliminary paper presented at the 2001 Sardinia conference (Barry *et al* 2001) and reports a major applied research project addressing methane emission during the period following waste placement, focusing on the results of extensive surface flux monitoring carried out on 21 operational UK sites. It highlights the scale of emissions that can occur in the period before 'normal' gas controls are introduced following the completion and capping of particular landfill phases (which usually comprise several cells and take several years). This paper also highlights the findings relating to the time taken for the onset of methanogenesis and when surface methane fluxes become detectable. Lastly the paper addresses the practical options for the targeted control of such surface emissions prior to the introduction of the longer-term post-completion gas abstraction systems used mainly for energy recovery purposes.

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2. SITES MONITORED

Flux was monitored at 21 sites (on 32 occasions), with repeat visits made to seven sites, resulting in a total of nearly 650 sets of data. (A further 140 data sets were collected but were discarded for various reasons due to potential unreliability.) The sites varied in age and waste composition, and were situated in various parts of the UK that had different meteorological conditions. The MSW content of the sites varied from about 55% to 100%, and the waste depths at the time of monitoring ranged from about 5m to 40m. The age of the wastes (as defined by the 'oldest' waste in the cell) at the time of monitoring ranged up to about 28 months. Overall, monitoring positions were usually set on some geometric pattern that covered either the top (or horizontal) waste surface (360 positions), or the waste side slope surface (about 240 positions), or, in some instances, near the edge of the landfill (about 50 positions). The emphasis on measuring side slope emissions was based on the early project finding that the emission rates from such slopes appeared much higher than from the corresponding top surfaces. Also, industry experience highlighted that some landfill edges had very high emission rates.

3. MEASURED FLUX EMISSION RATES

3.1 Introduction

As discussed in the 2001 paper (Barry *et al* 2001), taking flux measurements on operational sites with daily cover is fundamentally more difficult than on sites with final/temporary capping due to (a) very uneven surfaces by virtue of the inherent nature of the temporary waste cover, and (b) the far greater scale of temporal and spatial variations in fluxing conditions (see Figure 1).

Accordingly, any measurement method can be seen as being more relative than absolute in its accuracy.

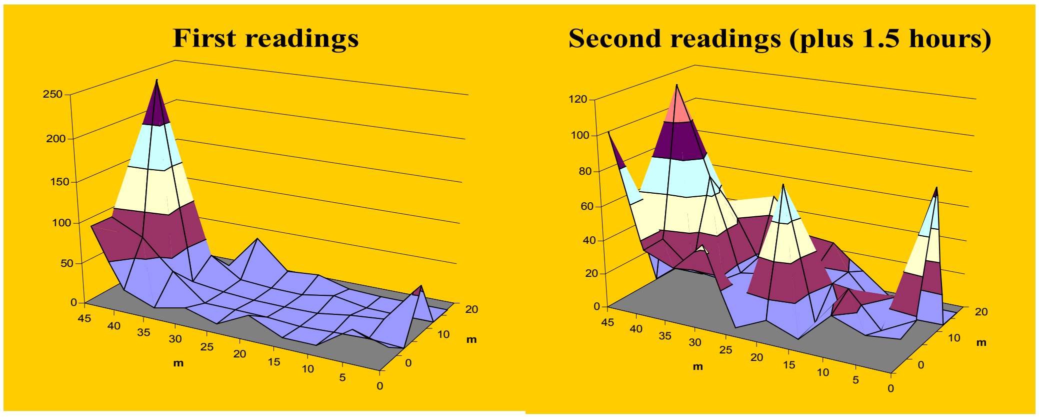


Figure 1. Example of spatial and temporal variations in methane surface concentrations*

** Concentrations measured just above the waste surface (ppm)*

3.2 Main findings

Collected flux data were examined statistically with respect to many factors and the most significant correlation was found to relate to waste age, though this also has a close relationship with waste depth. Figure 2 shows the basic flux rates measured for the 'top' and 'slope' surfaces of all the individual landfill sites, with sites grouped in age sequence (age, in this case, represents the 'average' age of the waste e.g. 10 months represents a waste mass that varies between 0 and 20 months old). The data show that even with sites of apparently similar ages, there are significant differences in their measured emission rates.

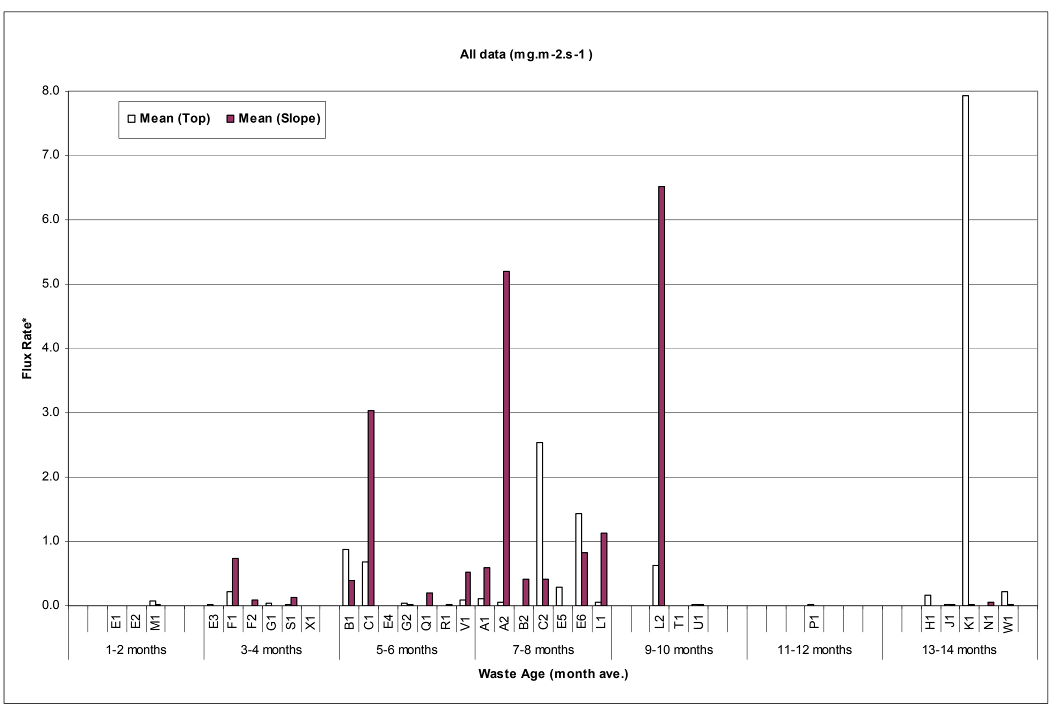


Figure 2. Individual site surface flux rates (averaged) for 'tops' and 'slopes'

Figure 3 shows the same basic information but with the sites condensed to 'age groups' (of 2 months 'average' spans).

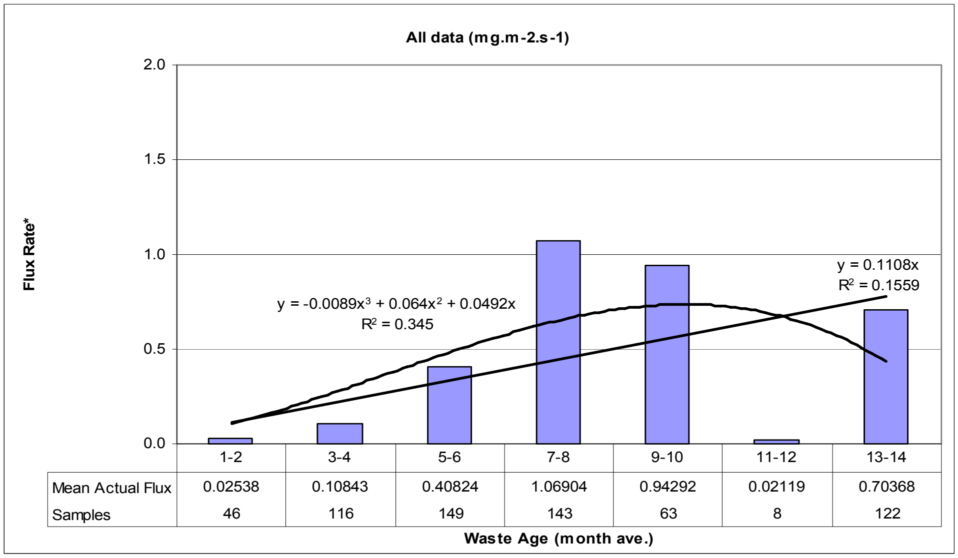
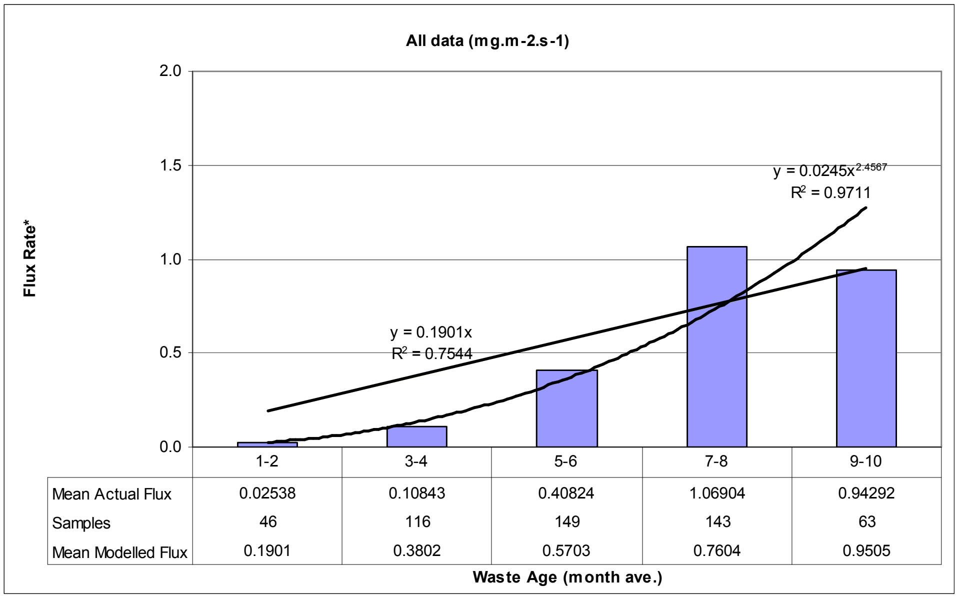


Figure 3. Mean surface flux rates for sites grouped by age to 14 months

The results show that the overall flux rate from sites older than about 10 months 'average' (i.e. more than 20 months since waste placement commenced) has slowed down and even reduced by the time the waste is some 14 months old on average (i.e. 28 months after placement). Indeed, as can be seen from Figure 3, the flux rate in the 13-14 month age group (average) would be much reduced if the data from the single most gassing site monitored on the project was discarded (i.e. Site K1 in Figure 2). However, the number of data sets (122) in that 13-14 month age group represents about 20% of the total database, and so must be considered significant. On the other hand, the effective lack of data for the 11-12 month age group complicates the interpretation of the flux pattern from the wastes older than about 10 months (average).

The cubic regression 'best fit' line shown on Figure 3 shows a good correlation with the flux/age data, while a similar best fit line showed a comparably good correlation with the flux/depth data. Thus, taking both the apparent maximum flux rates from the age and depth assessments, and the known relationship between age and depth for the monitored sites, it was concluded from the monitoring data that the time at which the maximum (average) flux is reached is likely to be about 20-24 months after commencement of waste placement.

Although the reason for the apparent reduction in surface emission rate after this time is not known, this conclusion does not affect the findings of this project which is primarily aimed at establishing the emissions during the earlier part of the landfill life. Thus, the emission assessment can be concentrated on the more explicit flux patterns measured from the 'younger' wastes, i.e. up to 10 months (average) age. Indeed, when the flux data for this period are examined (see Figure 4) it can be seen that a 'best fit' line with a very high correlation (R^2 = 0.9711) can be defined.



	1-2	3-4	5-6	7-8	9-10
Mean Actual Flux	0.02538	0.10843	0.40824	1.06904	0.94292
Samples	46	116	149	143	63
Mean Modelled Flux	0.1901	0.3802	0.5703	0.7604	0.9505

Figure 4. Mean surface flux rates for sites grouped age to 10 months

3.3 Differential emission rates

An evaluation of the data amplified the well-known complexity of gas generation and emissions from an operational landfill. Not only were there considerable spatial differences between monitoring positions but it was also noted that flux rates near to adjacent capped waste cells were higher than positions further away. Whilst such findings indicate changes in emission patterns, the database covering these aspects is not robust enough to deduce a meaningful quantification of the observed effect.

Similarly, data taken from near the edges of three landfills (all of which had containment membrane barrier systems) showed emission rates several orders higher than for surface locations further away from the edge. Thus, the conclusion was drawn that there is a preferential pathway at the edges of a site such that the ‘edge’ behaves like an open side slope except that it concentrates the flux into a relatively narrow surface strip. It was considered inappropriate (due to the relatively small data base) to suggest the width of such a zone from the database collected.

The emission rates from side slopes (and edges) were demonstrated to be considerably higher than for top surfaces, a finding that is considered to reflect a greater lateral gas permeability. Thus, although the top surface flux rate might be relatively low, on most sites the top surface is much greater than the slope surfaces. However, that ratio changes with increasing waste height, as addressed below. (Figure 5 shows the principal zones of surface emission on a typical landfill.)

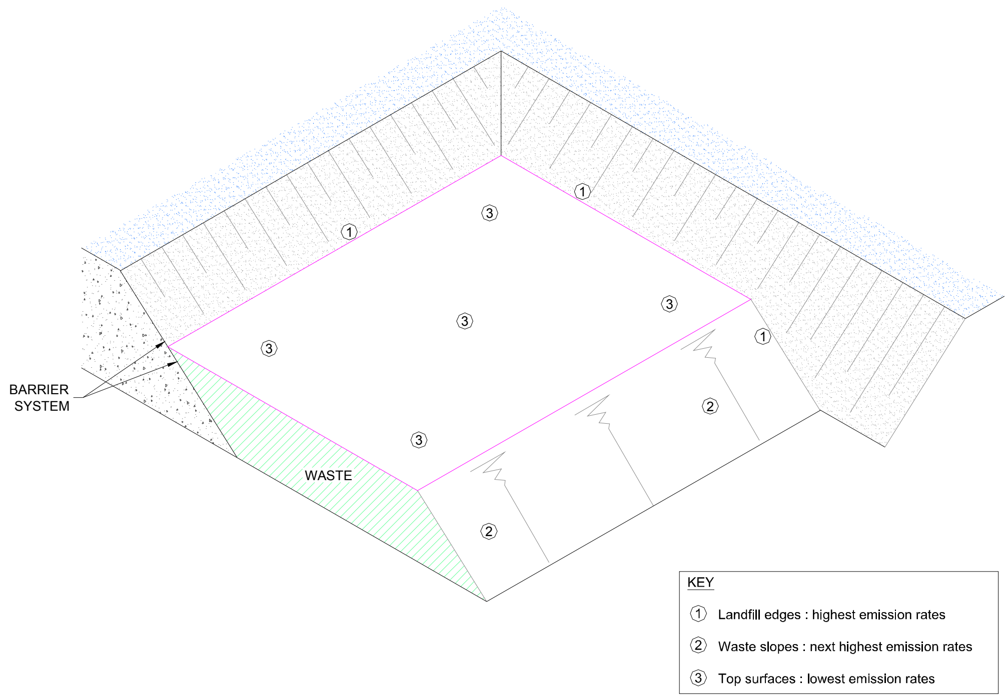


Figure 5. Main surface emission zones

4. OVERALL EMISSIONS

The emission rates from operational sites were found to be highly variable and ranged over a spectrum covering some 9 orders of magnitude. Converting all these data into an overall emission volume for a particular operational site (which, by definition, varies constantly in age and shape) is very complex. However, in order to assess the potential overall scale of emission volumes from typical landfills, a series of hypothetical landfill scenarios was assessed involving waste cell areas from 1ha to 4ha, and some 25m deep. The assessment related to the placement of 500,000m^3 waste at different filling rates, with different flux emission ratios between top and slope surfaces that varied from 1:2 to 1:10.

This simplified assessment of total flux emissions, showed that, for the chosen landfill geometry, (i) slope surfaces could amount to about 50% or more of the total surface emissions, and (ii) placing waste in smaller cells can result in considerably lower overall flux than when larger cells are used. This apparent benefit from using smaller cells was shown to decrease with an increase in the slope/top emission ratio, a change that amplifies the importance of slope surface areas in overall flux emissions. Also, as might be expected, faster filling rates can significantly reduce the total flux emissions simply because it can be assumed that gas controls can be introduced at a comparatively early date, i.e. soon after completion of waste placement.

To reiterate, it is recognised that methane emission assessment through surface flux monitoring is likely to underestimate significantly the actual scale of emissions. Accordingly, it is considered that the monitoring data, which show clearly that not only are there high average emission rates but that the emission rates from slopes and landfill edges can be very high, confirm that a considerable proportion of gas has escaped to atmosphere before 'conventional' gas controls have been installed.

5. ONSET OF METHANOGENESIS

The time period for onset of methanogenesis was assessed through monitoring the gas regime at one particular site over a 16-month period. This involved the installation of ten probes and two long perforated pipes at three different layers as waste disposal operations progressed. Concentration data for oxygen, carbon dioxide and methane were measured at about monthly intervals. Surface flux measurements were also taken on six occasions (the data from which were included in the main flux database discussed earlier).

Figure 6 shows how the concentrations of the three main gas components varied over time and followed the 'classic' patterns (note that the concentration lines were forced through the respective 'origins' by introducing 'dummy data'). Although, due to operational difficulties, some of the data from the 'lower' layer of monitoring points were ultimately considered unreliable, there was a clear pattern that the oxygen levels became depleted and methane/carbon dioxide ratio increased to >1 after about 5-6 months. Further, some measurable surface methane flux rates (6.21×10^{-3} $mg.m^{-2}.s^{-1}$, or about 6 times the proposed Environment Agency emission standard for completed landfills) were recorded within about 1 month of waste placement. It is considered that this scale of surface methane fluxing confirms that the driving mechanisms for surface flux involve both advection and diffusion processes; in other words, the carbon dioxide (>50%) dominated early gas appears to be 'carrying' the methane.

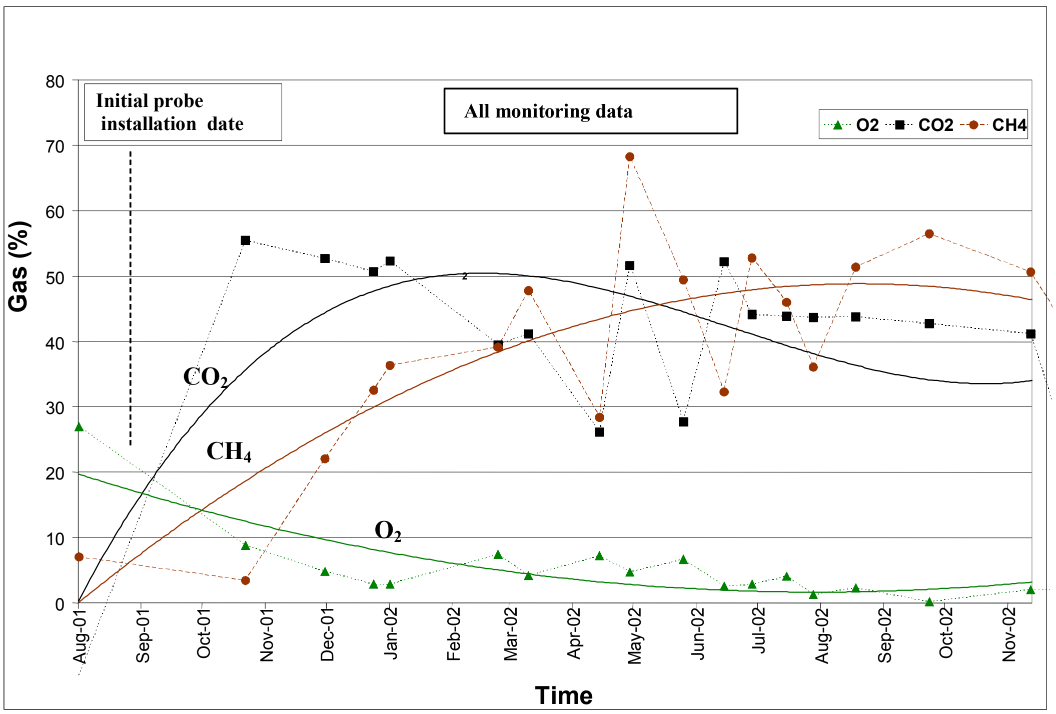


Figure 6. Onset of methanogenesis: gas concentration profiles in probes with associated trendlines

6. GAS CONTROLS DURING WASTE DISPOSAL OPERATIONS

6.1 General current practice

As indicated earlier, during the past few years gas emission controls for active waste disposal areas have been installed largely for odour abatement purposes. In all cases, however, there are no established best practice guidelines and so current systems have evolved largely by trial and error, using knowledge gained from conventional gas abstraction and collection systems. In terms of adapting existing 'odour control' systems, the most likely option is considered to be a horizontal system, possibly connected to a vertical system, whether now or at some future date when the relevant part of the landfill site has been completed. This design choice does not pose any significant operational difficulties (in contrast with vertical wells) and is also less prone to physical damage.

The main types of horizontal systems used to date involve either perforated pipes or high permeability gas pathways, or both, and are usually constructed in a trench excavated into a waste layer. Pipes are normally laid in 'rock-filled' trenches in order to support and protect the pipe; the backfill material also acts as a gas pathway. Further, this backfill medium can be also be particularly important in reducing the risks of the pipework becoming 'water-logged' by perched leachate conditions, a factor that is fundamental to the effectiveness of the abstraction system. It is recognised that while larger 'high permeability' trenches provide a higher efficiency of gas collection, these trenches can also consume 'expensive' void space (quite apart from the materials and operational costs for their installation).

The typical vertical frequency of such systems is about every 5-8m (or about every 2 to 3 waste lifts), with pipes/pathways placed at 20-25m intervals. This differential horizontal/vertical spacing reflects the different permeability values in the wastes. This factor was established both in this project and in US studies (Lofy, 1996**)** which suggest that suction influence is 7-8 times greater in the horizontal direction than in the vertical direction.

Whatever the overall design layout, the final 10-15m section of the pipe/pathway system approaching an open waste face usually comprises a solid pipe so as to minimise the risk of air ingress to the wastes, and the consequent risk of inducing combustion through enhanced oxidation. This risk is seen as being very significant and so quite a conservative stance is taken in the design and operation of such systems.

In some instances the control system involves a combination of both horizontal and vertical pipe networks. One site that employs this method has constructed 150m long x 1m x 1m trenches, dug into fresh waste at 6m vertical spacing. The trenches, which were laid out in a regular grid 40m pattern, were filled with building rubble and car tyres prior to being capped with clay.

6.2 Potential future design principles

Taking account of the study findings and recognising potential implications for operational practices, it is considered that the most cost-effective controls are likely to focus on emissions from the waste side slopes and from the landfill edges (see Figure 7). While both of these areas might be relatively modest in comparison with the top surfaces, the emission rates can dictate that they represent the most significant volume of emissions.

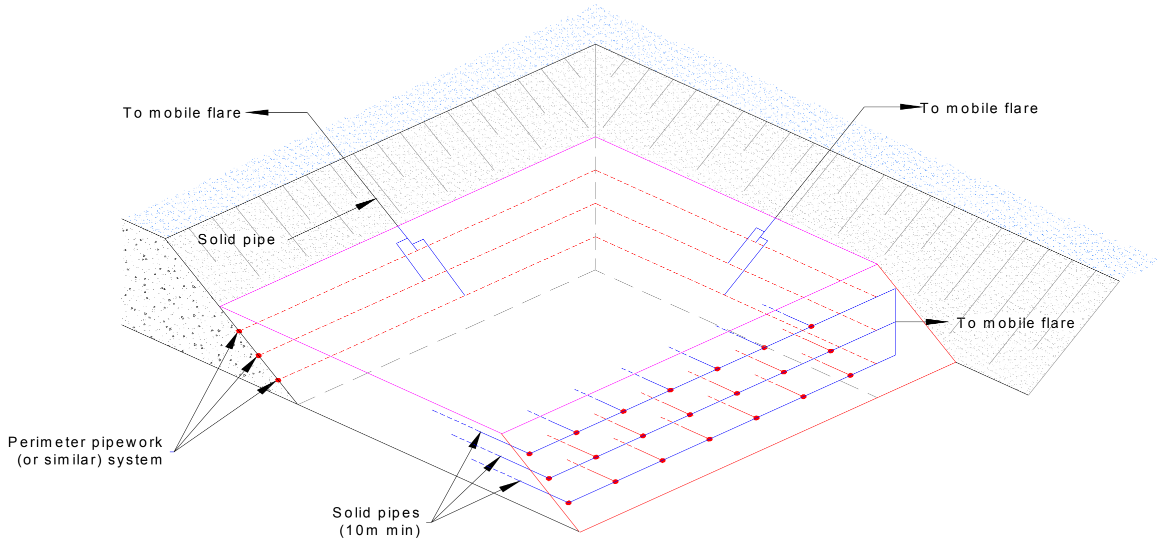


Figure 7. Potential operational cell design for optimising methane emission control

In the case of the side slopes, the emphasis should be on 'intercepting' the gas before it reaches the slope and so, in theory at least, the gas collection system need only extend into the waste only, say, 20-30m (with the first 10m being of solid pipe). The benefits of extending it further are unlikely to be significant because, whatever the length, the suction will be most effective close to the point of application. For cell edges, the gas control measure can be in the form of a perimeter perforated pipe/pathway, connected to the surface by solid pipe at regular intervals (say 50m). In both cases the suction should not be applied until at least 5m of waste has been placed on the relevant pipe network. For edge controls, the deeper pipe system will probably continue to be necessary with the increasing waste height because the volumes of gas will inevitably increase.

It is considered that any attempt to control top surface emissions is unlikely to be cost-effective. This is because the monitoring data suggest that such emissions can be as much related to the shallower wastes as to the deeper wastes and controlling shallow gas sources carries a risk of induced combustion.

7. CONCLUSIONS

Field data has reinforced the extreme complexity in gas generation and surface emissions rates, rates that can also be affected by a wide range of variables, both physical (such as daily cover) and meteorological (such as rainfall and pressure). The potential effect of each variable was not discernible although an attempt was made to assess if data from apparently similar sites showed any correlations with prevailing conditions. Despite the range of complexities, the collected data clearly showed a progressive increase in the overall surface flux rates and that this increase was principally manifest on side slopes and landfill edges, with the top surface showing relatively little increase with age. This finding highlights the areas where the greatest benefits can be gained from the introduction of gas controls, bearing in mind, however, that the lower flux rates can apply to proportionately high areas of an active site.

The project confirmed that methanogenesis effects can be evident after only 1-2 months and that surface methane flux can be detected in a similar timescale, a process that is considered to reflect both advection and diffusion mechanisms. However, from monitoring the series of *in situ* probes it was not apparent that the gas flux from lower waste levels affected the rate of methanogenesis in the upper, shallower waste layers. This reinforces the conclusion, already established elsewhere (Lofy, 1996), that lateral gas permeability is far greater than vertical permeability in a landfill.

The maximum flux rate appears to be reached about 20-24 months after commencement of waste placement, with a reduction in rate after that point. However, the data should be seen as being an underestimate of the actual flux rates and so the time taken to reach a specific flux rate is likely to be less than that suggested by the data.

The relatively high rates of average flux after about 12 months (actual time), which were measured at some 40-times the proposed UK standard for temporarily capped sites would appear to justify the need to activate control measures after such a period. By focussing any controls on the key emission areas, the system can be optimised whilst having a minimal effect on operational activities and being readily incorporated into long-term systems.

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