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ONSET OF METHANOGENESIS IN LANDFILLED MSW

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SUMMARY: This research project (Barry *et al*. 2003, 2004a and 2004b) assessed the time period for the onset of methanogenesis and examined the scale of methane (CH_4) fluxing from waste surfaces during the waste placement phases before gas control systems were installed. The gas regime at one landfill site was monitored over a 16-month period via a series of probes and perforated pipes installed at three different layers as waste disposal operations progressed. Bulk gas concentration data demonstrated that methanogenesis was evident after only ~ 1-2 months, with the CH_4/CO_2 ratio increasing to >1 after ~ 5-6 months from commencement of waste filling. The gas flux from lower waste levels did not appear to influence the period for onset of methanogenesis in the upper, shallower waste layers. This reinforces the conclusion established from overall surface fluxing patterns that higher horizontal gas permeability of the wastes provides the preferential pathway. Surface CH_4 flux was detected within ~ 1 month after waste placement.

PREAMBLE

Although the pattern of gas generation changes in the initial stages of biodegradation (Farquhar and Rovers 1973) have been accepted for many years, the time associated with those pattern changes has not been established. This timescale has relevance to establishing the scale of CH_4 flux that is emitted to atmosphere before landfill gas controls are installed. Such fluxes are of increasing relevance in the implementation of the Landfill Directive (Council of the European Union 1999) as well as government policy with respect to impacts on global atmosphere. Thus, if emission scales are better understood, systems can be developed for controlling gas at an earlier stage.

In order to gain an understanding of the timescales for the onset of methanogenesis and the associated scale of surface flux emissions from waste surfaces during the landfilling stages, a two-year applied research project was initiated (Barry *et al*. 2003, 2004a and 2004b). This paper addresses the findings with regard to the methanogenesis timescales.

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1. INTRODUCTION

There are relatively few published data on the time period for methanogenesis to commence following the placement of wastes in a landfill. It was understood at the outset of the project that because of the continually changing nature of the waste geometry during landfilling operations, there could be many variables influencing that period. For example, the conditions in the initial layer of waste could be significantly affected by the placement of subsequent layers, and so on. Thus, the second (and subsequent layers) could (i) influence the gas generation regimes in underlying layer(s) and, at the same time, (ii) be influenced by the effects of gas generation in those lower layers. Therefore, with the several successive waste lifts in a cell that occur at unprescribed frequencies, the time elapse for actual onset of methanogenesis in each waste lift could vary due to the influences of the wastes both above and below that waste lift. Accordingly, it is likely that a complex series of gas generating regimes could exist throughout the overall depth of the waste. To this end the monitoring programme was designed to assess how those gas conditions can vary at a series of different waste layers within a landfill.

Initially two study sites were selected and in both cases waste deposition was commencing in newly engineered cells, i.e. in neither case was there any older waste that could influence the initial layers being studied. Shortly after the study started however one of the sites had to be abandoned due to practical conflicts with operational activities when the installations became damaged and could not be readily replaced. At the selected site, municipal solid waste (MSW) was being deposited directly onto a basal aggregate drainage blanket, while the landfill sides were near-vertical faces against the edge of the former sand quarry.

2. MONITORING STRATEGY AND PROGRAMME

The monitoring installations were designed to enable ready observation of the gas composition within the wastes at three different layers, with samples being taken from the respective monitoring probes and pipes as the waste height increased. Gas composition monitoring was carried out at approximately 3-4 week intervals using portable analysers to measure O_2, CO_2 and CH_4. Gas samples were taken by pumping from the various probes and pipes. The study area in the selected waste cell measured approximately 40m-50m x 20m-30m (Figures 1a and 1b). A set of vertical-positioned multi-line probes was installed in each of three waste layers, using simple holes set into the waste surface (the probes were subsequently covered by waste during the normal waste placement activity). The vertical positions of the monitoring zones within the wastes were, respectively, 6m, 10m and 16m from the cell base (Figures 1a and 1b).

However, because of the small and vulnerable nature of these probes and the associated small-bore sampling lines, it was considered prudent to have a parallel more robust monitoring system consisting of long perforated pipes, as described later. For both systems, the monitoring pipe connections were brought to a common point at the edge of the landfill and then brought upwards in a common 150 mm diameter duct. This duct was used for each successive layer of probes and pipe connections. The probe tubing, pipe and ducting was extended periodically in accord with the rise in waste levels so that probes and pipes from all the monitoring levels remained easily accessible from a common point on the prevailing waste surface.

The first layer of probes and pipes was installed in mid-September 2001 when the study area had already received two waste lifts that were placed in quick succession on top of the basal drainage layer. Thus the base waste was some four weeks old at the commencement of gas monitoring,

which continued to the end of December 2002 (~ 16 months). By that time a total of more than 25m waste had been placed in the quarry.

The overall monitoring system design attempted to ensure that, as far as possible, both spatial and vertical variations in the gas regimes could be sampled and studied. In this regard, however, it was recognised that the inevitable movement of gases within the waste mass meant that the sampled gases at any particular location would not necessarily originate exclusively from that immediate area of waste. The focus of the study was on bulk gas composition; moisture content and temperature were not monitored.

3. MONITORING INSTALLATIONS AND PARAMETERS

As indicated earlier, a dual monitoring system was installed to help ensure that the exercise was not excessively compromised by the risk of equipment damage to any one system. The probes sampled the gas conditions in that locality but sampling from the perforated pipes related more to a composite wider gas regime around the pipes.

The probes were 300mm long, 32 mm diameter MDPE tubing drilled with 7mm holes, and inserted into basic pre-formed holes in the active waste surface. The probe design was intended to provide a discrete response zone around the probe assembly. The modest volume of gas present within the sample line could be readily drawn through the monitoring line by a portable analyser. The surface connections were terminated with a valve and a sampling facility.

The perforated pipes were 30m long and were installed generally alongside the probes and were 25 mm diameter MDPE, perforated with pairs of 7 mm holes at 500mm intervals along each pipe length. These were set at the same waste levels as the probes and laid open-ended on top of the waste surface. A monitoring pipe was taken from each of the perforated pipes to the waste surface alongside the probe sampling lines. These pipes were also terminated with valves and a provision for connecting to a gas analyser. The pipes were buried soon after installation by the advancing face of waste.

By their very nature the samples taken from the perforated pipes would represent the general gas regime within the pipes, reflecting the gas diffusion through the pipe perforations. It was recognised that there could be a lag in the time taken for the pipes to reflect the local gas regime and that the gas regime along the perforated pipe length could vary. This means that the gas sample could be dominated by the gas regime at the sampling end of the pipe. This was not considered to be an important factor in establishing the timescales for gas concentration changes. In any event, attempting such precision in landfill gas monitoring on an operational site was considered unrealistic and a degree of pragmatism was essential.

The bulk gases O_2, CO_2 and CH_4 were monitored in each of the multi-line probes and perforated pipes during the course of the 16-month monitoring period. The monitoring frequency of ~ 3-4 weeks was selected at the outset of the study and this was not generally adjusted to try to capture any gas pattern changes in shorter time scales.

Measurements of CH_4 flux from the waste surface were also made at regular intervals (on six occasions in total) in the monitoring area, using flux boxes as used elsewhere in the research project.

4. MAIN RESULTS

In any interpretation of data collected from landfill sites it is considered that the principal emphasis should be placed on the patterns and trends in those data, rather than on the individual values. Thus, attempting to define when precisely a particular condition commenced or ended would be to place too much reliance on the data accuracy at any point in time, i.e. there are inevitable variations in any established landfill gas regime, let alone in a developing gas generation regime, such as being addressed here.

In the assessment of when methanogenesis commences and when it is fully established, there are two key and simple considerations, namely (a) when are CH_4 concentrations consistently detectable for the first time, and (b) when is the CH_4/CO_2 ratio ≥ 1. In regard to the former, and in the light of the earlier comments about data reliability, it was considered appropriate in this case to take 10% CH_4 and 3% O_2 as being the base threshold values without compromising the project objectives.

4.1 Oxygen concentrations

In terms of the differences between the three layers, the O_2 reduction pattern (in both probes and pipes) seemed more consistent in the upper layer monitored (Layer 3 at 16m) than in the other two layers. However, Layer 2 (10m) showed very low initial O_2 concentrations in both probes and pipes, and at the same time the concentrations of CO_2 and CH_4 were both relatively elevated (phenomena that were not easily explained). The relationship between O_2 and CH_4 concentrations appeared quite logical in that no significant CH_4 concentrations were recorded while O_2 levels were high.

4.2 Methane and carbon dioxide concentrations

Figure 2 show the trend in CH_4 /CO_2 for Layer 2, a trend that was generally reflected in the other two layers, showing similar anomalies that highlight the probable complexity of actual conditions, as well as reflecting possible effects of the monitoring process. Nonetheless, the trend is unarguably similar to that which was to be expected, except there is now a timescale attached.

For CO_2, not surprisingly, some high concentrations were noted almost immediately in probes and pipes in the three layers. The overall patterns of increasing concentrations and the subsequent decline towards steady state conditions, seemed much more consistent in the perforated pipes than in the probes. In any event, the steady state concentrations were found to be ~ 45-55% in all layers (probes and pipes) but those steady state conditions seemed to occur in Layers 2 and 3 in a shorter timescale than for Layer 1.

CH_4 concentrations (from the assumed 10% base value) were shown to increase progressively from ~ two months after waste placement (i.e. start of monitoring) in the Layer 1 probes; this rate of increase appeared to be slightly slower in the perforated pipes, a factor that is consistent with the essential differences between probe and pipe sampling. In Layer 2, however, there appeared to be a quicker start up time for CH_4 in both the probes and pipes (generally < 2 months), while in Layer 3 the start up time was between that of the other two layers.

The differences in start up times were not so significant that they could be explained by the potential effects of gas fluxing effects from the lower waste zones, i.e. causing a displacement of

O_2 in the upper waste layer and thereby creating anaerobic conditions at an earlier stage and potentially accelerating the methanogenesis process in the upper layers. The apparent lack of significant influence of any rising gases could be simply related to the lesser vertical gas permeability of the wastes, in contrast with the lateral permeability, a phenomenon that was evident from the measurement of surface fluxing.

Overall, if the time taken to reach >40% CH_4 is taken as a reference level, then the differences between the three layers did not appear to be significant, i.e. in each case this concentration was reached ~ six months after waste placement in the particular layer.

4.3 Overall gas concentration patterns

Figure 3 shows the profiles for the three bulk gases over the monitoring period. These profiles were calculated using a polynomial function, but the initial parts of each profile was forced through their respective origins.

Despite the considerable fluctuations in the respective average gas concentration, the profiles clearly reflect the classic pattern depicted in the schematic representation of landfill gas during Phases I to III (Farquhar and Rovers 1973). Phase IV (*ibid*.), stable landfill gas production, appears to be reached after ~ 1 year from placement of wastes.

4.4 Other observations

The gas pressures measured in the probes were highly variable, with low pressures being generally recorded in all cases except for a four month period in Layer 1. That high pressure coincided with a significant increase in surface flux monitored on one occasion, when the atmospheric was exceptionally low at 978 millibars. This high pressure differential was not recorded in Layers 2 and 3; layers that would be expected to respond to a low atmospheric pressure. However, the measurements may have been influenced by moisture droplets in the small diameter tubes connected to the probes, a phenomenon that could explain the more stable pressures generally observed in the perforated pipes.

Measured pressures were generally in the range 0 - 2 mbars, with the majority of readings being <0.5 mbars. Overall, therefore, it was not fully established that the high flux rate was directly due to the low atmospheric pressure, even though general experience of landfill gas behaviour dictates that the low pressure probably had some effect on the surface emissions.

CH_4 flux was measurable on the surface of the waste in the monitoring area, almost from the outset of monitoring. For example, the low CH_4 concentrations in Layer 3, ~ 10% in May 2002, coincided with quite high flux measurements; the CO_2 concentrations at that time were ~ 50% in the Layer 3 probes. Thus, surface fluxing conditions were recorded before the CH_4 concentrations in any of the underlying wastes had reached 40%. Since overall surface flux can be considered as a function of both advection and a concentration gradient, the slack concentration gradient for CH_4 in this case means that it is being carried by CO_2 advection.

5. CONCLUSIONS

For the first time a timescale can now be applied to the initial phases of landfill gas generation at the field scale. This finding, at one UK operational landfill site and which was reflected in the wider study of surface flux rate for a wide variety of UK landfill sites, clearly shows that there is a considerable CH_4 emission from an early stage of landfilling. The methanogenic process was

found to have commenced effectively after ~ two months and was well-established after ~ 6 months, before reaching steady state conditions after ~ 12 months. The CO_2 concentrations were found to reach 60+% within 2-3 months.

One interpretation of the data is that gases from the lower waste layers do not appear to have any significant effect on the gas regimes in the upper layers, an effect that was originally expected. This, in turn, supports the conclusion reached elsewhere in the project that vertical gas permeability can be relatively low. Additionally the evidence of early and relatively significant surface fluxing of CH_4 suggests that surface fluxing may be dominated by advection processes rather than concentration gradients.

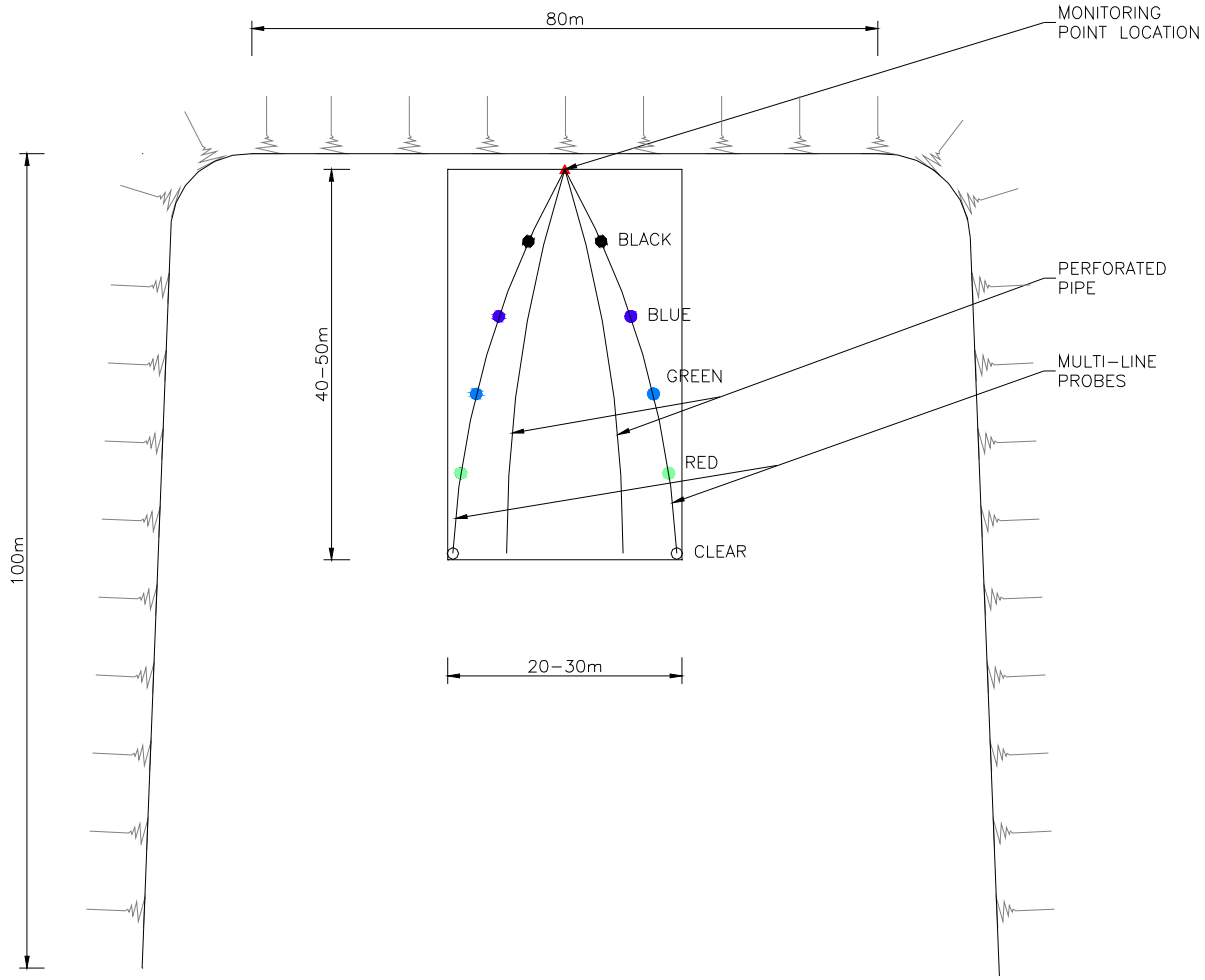

Figure 1a. Plan layout of monitoring systems in the study cell

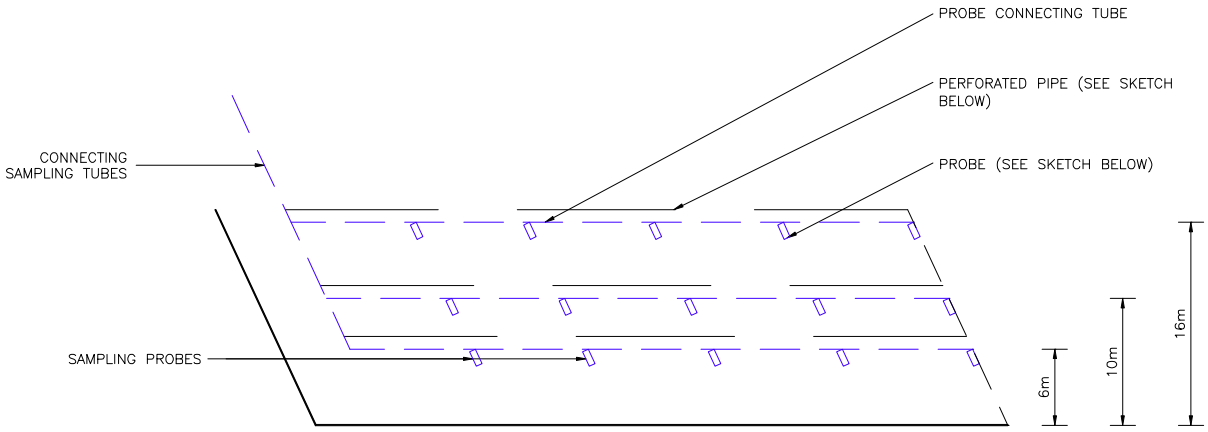

Figure 1b. Section layout of monitoring systems in the study cell

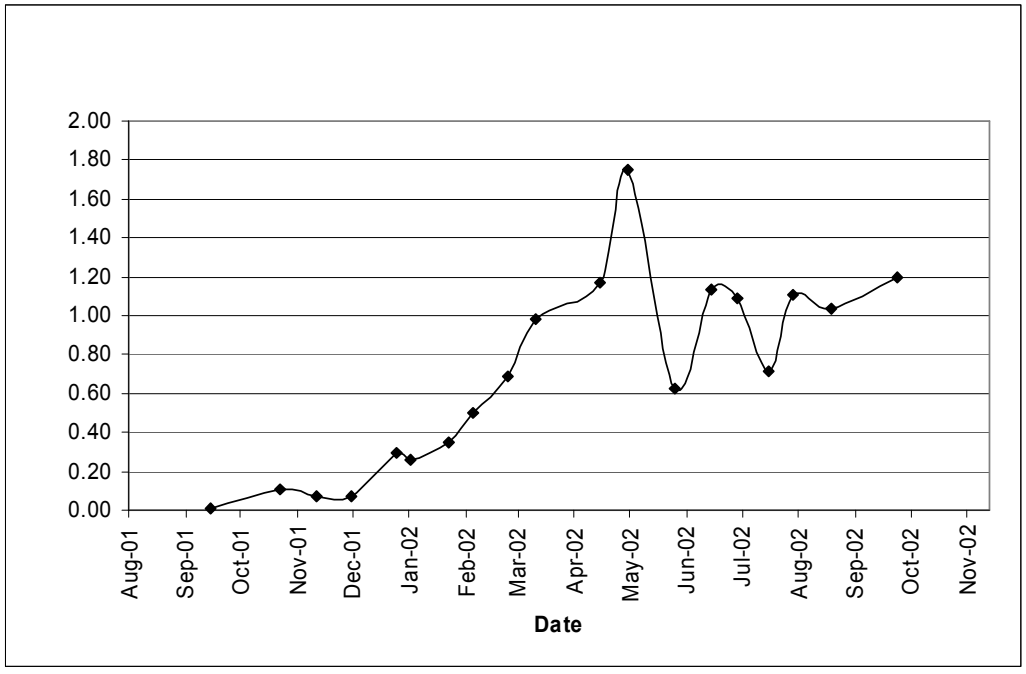

Figure 2. CH_4/CO_2 ratio in Layer 1 (perforated pipes)

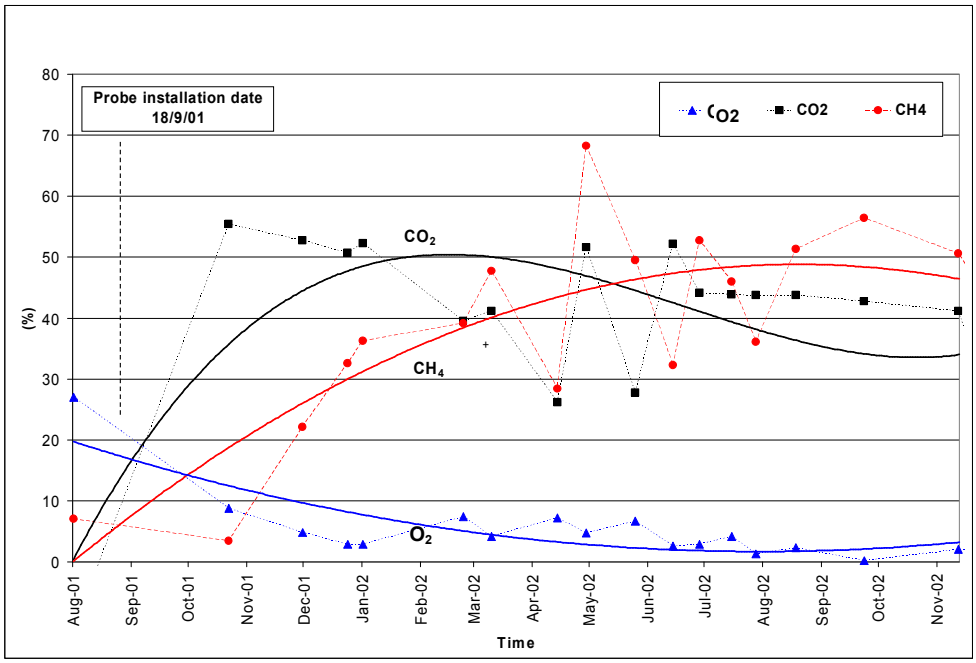

Figure 3. Bulk gas concentration profiles over the 16-month monitoring period (best fit)

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