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COMBINED LANDFILL GAS AND LEACHATE EXTRACTION SYSTEMS

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ABSTRACT

There is currently a shift of emphasis in the approach to treatment of landfill gas and leachate. Until recently, there have been two disparate schools of thought concerning the collection and disposal of these two by-products of organic waste degradation within the same bio-reactor. The tendency in the past has been to study gas and leachate as separate problems each of which requiring a separate solution. The reality is that both gas and leachate are consequences of the same processes within landfill sites, and are merely different phases from a common source. The optimum approach would logically appear to be treatment of both gas and leachate within the same system and attended to during the same equipment installation phase. Indeed, following the tenets provided for by the BATNEEC (Best Available Technology Not Entailing Excessive Cost) notes this would appear to be the preferred option, in terms of ease of installation, long term maintenance and, perhaps most importantly in the present climate, cost. As far as prediction of potential production and end treatment solutions is concerned, leachate and landfill gas can be treated as discrete by-products of degradation. However, the testing of theoretical models of production rates, as well as spatial location within a collection network, can be treated together. Technological improvement, and the continued downward trend in material costs allow those who specify systems, and those who buy them, a wealth of options for the safe combined disposal of both landfill gas and leachate.

1.0 INTRODUCTION

One of the main impetuses for the installation of landfill gas collection and disposal systems is the already considerable weight of environmental legislation, driven by an increasingly aware public opinion. For leachate, however, although much has been written on the subject, legislation has, as yet, failed to produce any concrete guidelines for treatment. There remains confusion concerning environmentally acceptable leachate strengths and its concomitant polluting potential, and consequently the cost of treatment remains unrealistically biased towards off-site methods. The situation is unlikely to remain static; change will come, and the well prepared operator will be looking for efficient and cost effective collection and disposal systems which will allow him to fulfil his/her environmental obligations into the twenty-first century.

This paper briefly reviews methods of evaluating production of both landfill gas and leachate and focuses on available technology for a method of co-collection and disposal of both landfill gas and leachate.

2.0 ASSESSMENT OF GAS AND LEACHATE PRODUCTION

Important in the decision pathway as to which method of collection and disposal is most suitable for any particular site, is the evaluation of whether the proposed design will meet its objectives in terms of capacity. It is unfortunately too often the case that specifiers leave this crucial evaluation exercise until the competitive tendering stage, relying on the integrity of contractors to judge the necessity or otherwise of active site investigations. This can potentially result in costly errors of judgement if the winning contractor deems it unnecessary to conduct such trials to achieve the prime commercial objective of winning the work.

There are basically two methods for determining the production of toxic emissions from a landfill site. Both of these can be subject to considerable margins of error relying essentially on the experience of the investigator. However, they do provide an empirical basis for specification which reduces the likelihood of error.

The first method is by using mathematical models, ideally done as part of a desk study of the site; while the second is field based pumping trials which are designed to determine as much as possible about the behaviour of the aqueous and gaseous phases within the landfill. In the case of landfill gas, pumping trials are especially important when utilisation is being considered. Data gathered from the trials can be entered into a cumulative spreadsheet and the real-time production rate compared with predicted values. This also allows for extrapolation of gas production rates into the future.

2.1 Pre-installation studies

It is critical at this stage to learn as much as possible about the site. In many cases this work will have been undertaken by the client. The objective is to ensure a clear understanding as to the nature of the problem. Studies centre around collating as much information about a site as possible.

In order to construct a realistic model of gas and leachate production from the site, it is necessary to gather the following information:

a) Period, method and rate of landfilling.
b) Mass of waste in place.
c) Site dimensions
d) Waste types infilled ie domestic, industrial, commercial, inert and hazardous.
e) Waste configuration ie baled, shredded, compacted.
f) Packing density and moisture content of waste in place.
g) Internal temperature and pH of the waste.
h) Site geology including any borehole logs available.
i) Type of capping and potential gas recovery effectiveness.
j) Gas and leachate monitoring results.
1) Available assays from leachate samples
m) Meteorological conditions and rainfall data.
n) Site hydrogeology and hydrological data, including:

i) surface water run-off
ii) rainfall and evapotranspiration
iii) local water utilisation

2.1.1 Modelling landfill gas production

In modelling landfill gas production the amount of gas that can potentially be generated by a unit of waste is an important parameter, yet difficult to define. Previous studies[1,2] have arrived at an average figure for gas yield of about 150m^3 for every wet tonne, although this figure varies depending on source. Of this it is stated that about 70 - 80% would be recoverable. A rule of thumb estimate is that between 6 to 10m^3 of landfill gas will be produced per tonne per year for ten to fifteen years from placement.

Inputting the raw data concerning waste fractions, amounts deposited and periods of deposition into a computer programme results in exponential decay curves. These curves can also model varying concentrations of methane within the gas stream and an input of maximum potential collection efficiency will allow an initial assessment as to the size of system required.

2.2 Landfill Gas Pumping Trials

A landfill gas pumping trial is generally conducted after all the known data concerning the site has been gathered and a theoretical exercise such as described above has been carried out. One of the main objectives of the trial is to ensure that the design under consideration is of the correct order of magnitude in terms of capacity, and provides a test for the calculations carried out previously. If conducted correctly this relatively inexpensive measure will result in avoidance of costly remedial actions. It may allow savings to be made at the beginning of the project by reducing the capacity specification. It may also offset many of the direct expenses, such as the drilling of boreholes which can be used again, from the final cost.

During the pumping trial data is gathered concerning the amounts and quality of gas being produced. The objectives of conducting a pumping trial on a landfill site can be summarised as follows:

a) Investigation the radius of the zone (or cone) of influence being effected by individual extraction wells. This is obtained using an array of piezometers around individual wells; from this the optimum spacing of wells can be deduced. Alternatively, existing monitoring boreholes can be used, with the 3-D resolution being increased if multi-level piezometers are used.

b) Defining well-head gas flow characteristics. These describe the behaviour of individual wells under passive and active conditions.

c) Quantifying probable landfill gas production rates. These are obtained by active abstraction over a period of time, increasing flow rate until air is introduced into the system, and the quality of the recovered gas falls. This test can, however, be dependent on the quality of the capping. It is also critical to allow for seasonal variation as gas production may be higher in the summer months.

d) Defining required abstraction pressures, which in turn enables correct sizing of the permanent abstraction equipment. The final sizing of the equipment will be a function of gas production rate versus flow rate, which should be extrapolated to include the whole site at the post-trial stage.

e) Investigating the effect of active extraction on the incidence of far-field migration from the boundaries of a landfill site. This is of particular significance where the landfill site is located within or close to a sensitive area.

Tests may be designed to gather data from local or restricted parts of the site or from individual gas wells, and can be expanded to cover the entire site by connecting to networks of pipe and wells.

The most common method is to test a small part of the site and then to extrapolate the results to incorporate the whole site.

2.2.1 Strategy for the trials

Trials consist of installing extraction wells within a representative section of the site, and connecting these to an extraction rig. Ideally, at least two wells should be drilled in each worked phase of the site in order to allow for possible blinding of extraction wells and in order to gather representative data from the whole site.

Extraction wells will ideally be drilled to the base of the site and be lined with a perforated liner and suitable filter medium. 110 mm liner is generally sufficient for short term trials, although the diameter will depend on the use to which the well will be put after the pumping trial is finished. If the test is to be run in tandem with a pumping trial for leachate then it will be necessary to install larger bore liner in order to allow enough room for the installation of the pumping mechanism as detailed below.

Once conditions within the site have stabilised following well drilling, and before connecting the wells to an active abstraction system, it is advisable to conduct static tests on each of the wells to establish the following:

a) static pressure in milli-bars to monitor whether internal pressures exist;
b) average gas temperature at the top, middle and bottom of the well;
c) percentage by volume of CH_4, CO_2, $O_{2;}$ (At this stage some samples should be taken for gas chromatographic analysis.)
d) atmospheric pressure, again in milli-bars. (Over time this often shows a mirror-type relationship with gas pressures, although a definitive relationship has yet to be shown.)

After connecting to the extraction rig, the dynamic phase may commence. Tests during this stage are designed to investigate the physical characteristics of the wells and of the surrounding waste when under active pressure. During the tests gas quality should be frequently monitored to note the relative change as the test proceeds.

Dynamic tests may include:

Flow against suction pressure: The test has a duration of about five minutes and the results are plotted as a graph of gas flow (m^3/hr) versus applied suction. The test is designed to show how easily gas can be extracted from the vicinity of the well. In general it is expected that wastes with low permeabilities will require greater rates of suction than those with high permeability. Flow rate is usually measured either at the extraction wells or at the flare stack, although it is important to ensure that there is laminar flow within the gas stream at the point of measurement.

Pumping test: This can be subdivided as follows: single and multiple well testing. Single well testing is designed to calculate the zone of influence of an individual extraction well. This is obtained by measuring pressures within the sample borehole and comparing these with readings taken from a series of observation wells located at pre-set distances from the active well. The sphere of influence is defined when relative pressure within the observation well is measured to be the same as the static pressure established earlier. The zone of influence can be further defined by installing an array of piezometers radially around the well. These may also be installed vertically to obtain a 3-D representation of the zone of influence within the waste . This test defines the extent of influence within a particular body of waste and may have a direct bearing on the final number of extraction wells which will be installed for the permanent system.

Multiple-well testing is carried out by connecting a network of wells and is used to determine the production rate within the site. In this test the emphasis is on determining the maximum abstraction pressure which the site can sustain before significant air is pulled into the system. The test is carried out over a number of weeks (six weeks is usual) and the total gas flow rate is recorded. As the methane concentration falls away the flow rate is stabilised to fulfil the equation:

$$\text{Flow rate} = \text{Generation rate}$$

This will be evidenced by constant methane concentrations in the region of 50% by volume methane.

2.3 Leachate

One of the objectives of investigatory trials may be to define leachate production rates and flow characteristics within the landfill. To this end a leachate pumping trial will form part of an hydrogeological study of the site with the objective of determining a method of removing leachate from the lower part of the hydraulic system and directing it to the point of treatment and/or point of disposal.

During the desk study all available hydrogeological data should be collected, as listed above. It may be possible to arrive at a first appraisal of basic hydrogeological parameters such as groundwater contours, leachate production rates, water balance and the categorisation of hydrogeological regime, ie is the site saturated - below the local water table, damp - water retained within the body of the waste, or dry - especially in the case of contained sites ?

Model predictions of leachate production rates generally centre around a water balance analysis, which is given by the equation:

$$Q = I - E - aW$$

where : Q - Free leachate generated (m^3/year)
I - Total liquid input including liquid waste (m^3/year)
E - Actual evaporation losses (m/year)
a - Absorptive capacity of the waste (m^3/tonne) W - Weight of waste deposited (tonnes/year)

Essentially, this balances liquid inputs against liquid outputs[3]. Refinements to the model introduce considerations of the effects of preferential pathways through the waste. Once this type of exercise is conducted, leachate production curves can be produced.

This phase will result in a report with recommendations for further action which will ideally include a pumping trial.

2.3.1 Field Investigations

Typically, this phase will encompass all the operations needed to complete a hydrogeological model. In particular this may include:

a) Pumping trials.

Drilling one or more test wells within a representative area of the site, together with a pattern of observation boreholes (ideally two or more to each well). The latter would be used to observe the range over which the effect of pumping is noticeable. The objective of this is to define the transmissivity and retentive capacity of the waste, transmissivity of the country rock if relevant, specific yields and recharge rates of test wells.

Specific tests that would be carried out on each well would normally include a step-draw-down test (one working day duration), a constant discharge test (minimum 24 hours) and a draw-down and recovery test. It should be noted that obtaining a reliable overall value for permeability will be difficult for a landfill situation, although the value of the trial will be to study the rate of recovery of the piezometric level within the waste.

Leachate pumping trials would normally be carried out at the same time as gas extraction trials. The pumping equipment can be installed in the same boreholes and the tests can also define the behaviour of the leachate piezometric level when under active extraction conditions.

b) Collection of samples for chemical analysis and instigation of a medium to long term monitoring programme.

c) Detailed analysis of dispersion patterns by the use of tracers such as pyronine or fluorescene.

Once this phase is complete it will be possible to put forward an analysis of the problem and from this to recommend a design for the collection and treatment of leachate.

3.0 LANDFILL GAS AND LEACHATE CO-COLLECTION AND TREATMENT

3.1 Components of the system

In a combined leachate/landfill gas system it is important to ensure that the collection method can be easily serviced in the event of failure or modification. Extraction systems rely on a series of boreholes drilled to the base of the site. These are suitably lined and wellheads, adapted for both gas and leachate extraction, are installed.

3.1.1 Borehole construction

Drilling boreholes within landfilled refuse is now common practice. Experienced contractors, while ever conscious of the cost implications of various methods of drilling, are moving away from conventional techniques such as shell and auger, to more reliable methods of achieving the required diameter without incurring expensive stoppages. These include rotary air flush drilling techniques and barrel auger drilling. A novel way of installing gas and leachate extraction wells uses techniques borrowed from the piling industry. This method uses a string of concrete liners, inserted by a large percussion drilling rig. This technique ensures that a pre-lined well is installed and obviates the need either to insert a gravel pack or to remove spoil resulting from drilling operations. The system is highly attractive, because, although mobilisation costs are high, the rate of drilling is rapid; a typical drilling schedule would include 30 boreholes to ten metres depth in about five days.

Whatever technique is used it is recommended that a minimum borehole diameter of 3OOmm is achieved. This ensures that there is plenty of space for insertion of pumps or eductors, which will require liner of at least l60 mm.

<u>Liners</u>

With conventional drilling techniques it is usual to install HDPE liners slotted at between 10 and 20% of the surface area. Some operators have opted for the insertion of steel liners, however, unless the expensive option of stainless steel is chosen, the lifetime of such liners is limited due to continued exposure to highly aggressive chemicals.

In a standard water well, designed to service public consumption, stainless steel liners are commonly used. These are screened to prevent blinding of the liner by fine material. In a saturated landfill site, however, there is potentially such a high concentration of fine material that the use of screens may be counteractive; blinding may occur more rapidly. Experience shows that a conventional well construction with a slotted liner and suitable annulus fill is sufficient to ensure a long-term operational lifetime. Should it later be observed that the efficiency of the well is being reduced by blinding it may be possible to reinstate the well with high pressure water jets, either mounted on a rotary drilling rig or inserted on the end of a hose.

The third form of liner system is by the use of a column of concrete shells. These are installed as described above, and the concrete can be mixed to ensure that the grade will withstand the aggressive nature of the environment into which it is being introduced.

As the operation of each extraction well is of paramount importance to the system efficiency, it is recommended that wells are tested periodically by short duration pumping trials, both step-draw-down and constant discharge tests and, if necessary, routine maintenance performed.

3.1.2 Leachate Collection

a). Leachate pumps

There are many types of leachate pump available on the market today, from narrow bore pumps designed for down-the-hole operation, to pumps that can control a series of extraction wells. It is worth noting the various criteria that such a unit must meet when used as part of a gas and leachate extraction scheme:

i) it must be easy to install and remove
ii) it must be of robust manufacture, ~ body stainless steel, hoses MDPE
iii) it must have minimum moving parts
iv) it should be capable of a variable flow rate, as conditions will vary widely throughout the seasonal cycle. A range of from about 60 litres an hour to greater than 1m^3/hour would be realistic for a pump located within a borehole
v) the pump should ideally be capable of running dry with no harm being done to its operation
vi) the pump should be designed for low maintenance
vii) it should be capable of handling varying quantities of fine material and sludge that often accompanies leachate production, perhaps with additional protection being afforded by filtration
viii) it must have sufficient head

b) Eductors

An alternative to leachate pumps is a unit known as an eductor, or ejector. This unit is positioned within and close to the base of the borehole. It is connected to a surface mounted pump which in turn controls up to ten individual eductors. The advantages of units such as these are: firstly, they are lightweight and streamlined for use within relatively narrow boreholes, secondly, there are no moving parts and thirdly they are relatively inexpensive.

Eductors operate by circulation of water within a semi-closed system through a venturi located within the body of the eductor. This creates a pressure differential within the bottom of the borehole and causes leachate to be sucked through the eductor to the surface. There are basically two types available: these are concentric eductors, where flow and return water is directed within a concentric hose (Figure 9), and non-concentric eductors, fabricated as a single cast iron body in which flow and return water are contained within separate hoses (Figure 10). An additional criterion that may be considered when deciding on which type of eductor to use may be that the parts within the eductor can be replaced should fouling or failure occur.

c) Pneumatic pumps

Pneumatic pumps have become a favourite method of leachate collection for many companies extracting leachate from landfill sites. They have many advantages over the electric motor and the eductor systems. These include the following:

i) The pumps are built from materials that ensure long-term trouble free operation
ii) The pumps will only operate when there is liquid in the location of the pump. Pneumatic pumps operate with a level sensor that shuts them down when there is no liquid around them.
iii) The motive power is pneumatic, resulting in no electrical cables around a site and fewer pressurises liquid pipes.

The disadvantages are:

i) The individual pumps are considerably more expensive than electric pumps or eductors.
ii) A system with only one or two pneumatic pumps is very expensive, and difficult to justify as a compressor is required to deliver the air supply

3.1.3 Combined gas and leachate wellheads

Within the system described above, wellheads are adapted to accept both gas control valves and pump or eductor hoses. These require relatively straightforward attachments which for the leachate comprise flow and return hoses, control valves assemblies and air release valves for use during surging (which may happen if the pumps stop for any reason) within the pipelines, and for priming the system. For gas extraction, wellheads are equipped with control valves, either ball, gate, butterfly or sleeve type valves are acceptable, although should a fine control of the gas flow be required, it is recommended that ball or sleeve valves are used as these allow fine adjustments to be made. All valves should be made of non-corrosive material. On newly completed sites wellheads should be constructed to allow for settlement of the landfill site.

The basic unit is relatively simple although optional attachments include devices for measuring flow rates both of gas and leachate. Ports to measure gas concentration, pressure and to dip the leachate level can also be included in the construction.

3.1.4 Pipeline and collection networks

The design of the combined gas extraction system will not be discussed here as there is a large body of literature dealing with the physical attributes of both gas and leachate collection systems[5,6,7].

Essential in the design stage of the collection pipeline are hydraulic calculations, surge analysis and, in the case of gas carrier mains, pressure drop calculations. The object of these investigations is firstly, within the leachate collection lines, to calculate head losses contributed by the various components within the system. These are calculated depending on the number of bends, branches and junctions within the system, which are totalled to arrive at a suitable head requirement for the main pump. Secondly, to ascertain whether or not appropriate pressure surge control devices are required in order to counteract the formation of sub-atmospheric pressure should pumping stop for any reason.

Within the gas extraction system pressure drop calculations are designed to ensure that the design diameter of the pipeline is adequate and that sufficient pressure will be exerted over the whole of the system to ensure that all extraction wells are effective in gas removal.

4.0 Disposal of gas and leachate

Within the system described above the method of collection and transport of gas and leachate to the point of disposal is effected via common collection points and pipes laid within common trenches. At the point of disposal, however, the method of disposal obviously differs markedly and installations have to be constructed to ensure safe, effective disposal. The actual method of disposal will have been decided upon at the desk study and field investigation stages.

Landfill gas is basically disposed of by two methods: either by incineration in a flare stack or by use in a utilisation plant. The suitability of the gas for utilisation will depend on the following factors:

a) quality of the gas stream in terms of methane concentration and other gases
b) size and potential gas reservoir of the site
c) final use of the electricity produced, either local use or sale to the national grid
d) viability of the scheme in terms of capital expenditure versus royalty returns

The technology involved in landfill gas disposal is well understood and 'guidelines are in place to aid in the construction of schemes that will meet both current and future legislation[8,9,10]

The situation is not so clear cut for leachate disposal. There remains confusion as to what is and what is not acceptable in terms of leachate strength and environmental polluting potential, and the short term effects are not so apparent as are those for landfill gas. Consequently, many operators do not treat leachate on-site, preferring to allow the water companies to dispose of their effluent. There are, however, many methods of treatment and disposal of leachate[11]. These are briefly listed below, with the qualifying criteria added. It is emphasised that in order to properly design a leachate treatment and disposal system, the specifier must be aware of all the site specific facts including the variability of leachate composition with time.

a) <u>Recirculation:</u> * Reduces leachate volume by pervading unused absorptive

capacity.
* promotes rapid breakdown of wastes.
* Uses the landfill as storage.

b) Spray irri~ation: * Combines evapotranspiration with physical, chemical and biological mechanisms. Not known what the long-term effects on the soil horizon are.

c) Chemical treatment:

Precipitants and flocculants:	Mainly to remove suspended solids that may block pipeline or result in scale formation.
Chemical oxidants:	Used to destroy odour forming compounds ~ hydrogen peroxide to remove sulphides.

d) Aerobic biological treatment:

Effective, economical means of reducing BOD and ammonia.
Aerated lagoons have been used successfully to remove BOD and nitrify ammonia. Can be adversely affected by low values of BOD.

e) Rotating biological contactor:

Bacteria grow on a plastic surface and are rotated through the incoming leachate. Useful for treating low BOD and for nitrification of ammonia. Short retention time. Can be adversely affected by variations in leachate quality.

f) Anaerobic biolo~ical treatment:

Used extensively in sewage sludge treatment. Particularly effective for acetogenic leachates, although may become inoperative once methanogenesis commences. Ammonia removal not always achieved.

f) Reed beds:

This method has the potential to remove COD, ammonia, nitrate and suspended solids, although research has yet to establish optimum conditions of operation.

g) Reverse osmosis:

Used to remove non-degradable organic compounds, although often used after some prior form of treatment to 'polish' effluent. The technique is, however, expensive and can produce a high-strength concentrate which must in turn be disposed of.

h) Activated carbon adsorbtion:

This can potentially (a) remove toxic organic constituents, (b) treat trace levels of adsorbable halogencompounds (AOXs) and (c) treat colour and low levels of COD and

TOC after leachate treatment. Exhausted carbon must be disposed of or thermally regenerated.

5.0 CONCLUSIONS

The installation of a combined landfill gas and leachate extraction system can have the following advantages: (a) there is only one set of contractors working on the site, ensuring that any disturbance due to trenching operations and drilling of boreholes is kept to a minimum, (b) all restoration work is completed as part of a single combined project, (c) the system can be easily adapted and added to if required, ensuring minimum additional disturbance to the site, (d) the system uses the same set of extraction boreholes and trench lines. In short, the headaches of two tender proposals and submissions, two requests for financial approval, two sets of mobilisation and attendant difficulties are distilled into one.

Any combined landfill gas and leachate system has to be thoroughly investigated prior to installation. This type of investigation includes desk studies, pumping trials and design recommendations. Once a system has been decided upon it is essential that adequate mathematical investigation as to the physical characteristics of the design is undertaken. This exercise will ensure that the pumps, both for landfill gas and for leachate, are correctly sized. Too often, it is the case that these stages are dispensed with in order to keep the cost of the installation down. It is stressed that this is false economy. Comprehensive investigation as to the sizing of the intended works should be included as a major part of the works in any project and should not be optional.

References

1. *Department of Environment (1991). Waste Management Paper No* 27, *Second Edition. ISBN No 0-11-752488-3.*

2. *Department of Environment report CWMO67F/92 (1992). Guidelines for the Safe Control and Utilisation of Landfill Gas, Parts 1 to 6.*

3. *Eden, R. (1991). Flare specification to meet European standards. In: Methane - Facing "lie Problem. University of Nottingham, 1991.*

4. *Eden, R. (1993). Toxic Emissions from driferent types of LFG burners. In: Proceedings of the Fourth International Landfill Symposium, Sardinia 1993.*

5. *Good, A. (1991). "The Allsops Hill Landfill Gas Extraction Scheme, Rowley Regis." Proceedings of the Discharge Your Obligations Conference on Cost Effective Compliance with Landfill Legislation, University of Warwick, 1991.*

6. *North West Waste Disposal Officers (1991). Leachate Management Report.*

7. *Pacey, J. (1986). The factors influencing landfill gas production. Energy From Landfill Gas, Solihull, October 1986.*

8. *Pacey, J. & Augenstein, D. (1991). Modelling Landfill Methane Generation. hi: 3rd International Conference on Landfill Gas, Energy and Environment 90, Bournemouth, October 1990.*

9. *Robinson, H.D. & Mans, P.J. (1979). Leachate from domestic waste: generation, composition and treatment, A review, Technical Report No TR 108, Water Research Centre, Medmenham, UK*

10. *Robinson, H.D. (1987). Design and operation of leachate control measures at Compton Bassett Landfill site, Wiltshire UK, Waste Management and Research 5, 107-122.*

11. *Young, C.P. (1991). Options for the Management and Treatment of Leachate.: Proceedings of the Discharge Your Obligations Conference on Cost Effective Compliance with Landfill Legislation, University of Warwick, 1991.*