AN INTRODUCTION TO LANDFILL GAS EXTRACTION SYSTEMS

IPPTS Associates

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INTRODUCTION

This ebook examines the design, and installation of active landfill gas extraction systems particularly with respect to best practice containment landfill sites.

This ebook has been written for a worldwide audience; however, we are based in the United Kingdom, and as this book is based upon our experience. So, we have concentrated on European Union standards and best practice, as these are also being adopted in many other nations worldwide.

There are various US and international standards for parts of landfill gas work, and where we are aware of these we have tried to add them.

The EU Landfill Directive requires that landfill gas be collected from all sites receiving biodegradable waste, and that this gas must be treated. Landfill Operators of all open permitted landfill sites also must comply with the principal of Best Available Technique (BAT) as required by the PPC Regulations (also known as “environmental permitting”).

Put simply - If the gas cannot be used to produce energy, it must be flared. Allowing the landfill gas to simply vent into the atmosphere is not acceptable within developed nations seeking to reduce carbon emissions.

Importantly, the Directive also stipulates that the collection, treatment and use of landfill gas must be carried out in a manner "which minimizes damage to or deterioration of the environment and risk to human health."

Gas extraction system designs can be split into two groups according to the legal requirement to collect landfill gas and flare it, as a minimum requirement in order to limit greenhouse gas emissions:

- Countries and states where the landfill operator is required by law to install a landfill cap of material which will have a low gas permeability and an active landfill gas extraction system for all landfills above a certain size
- Countries and states where there is no legal requirement for capping and limiting greenhouse gas emissions.

Most of the developed nations, and certainly the EU and states, fall into the first category. Under such circumstances the landfill is required to be capped, the gas extracted, and a flare installed as part of the landfilling operation. The cost of this has to be payable by the users of the landfill, and they are charged this, among other costs, in the landfill charges (or “gate fee”).

In the second “developing nations group” there is often no gate fee charged, or a very low gate fee for tipping on the landfill. Capping the landfill is seen as part of the cost of the landfill gas extraction system, and for such sites there is only one way to fund the extraction of the gas, that being the revenue from Energy from Waste Plant usually comprising a gas engine power generator and a connection to feed the electricity it produces into the local grid.

Even at today's high power revenues, financing EfW projects for developing nations, when the cost of capping collection system installation must be found, is very difficult.

CARBON CREDITS

In recent years many countries within the “developing nations group” have signed up to accept Carbon Credits for reducing greenhouse gas emissions and seek to finance their:

1. landfill gas extraction systems
2. the landfill capping needed to ensure good gas quality
3. the power generators and grid connections,
4. from the future Carbon Credit revenue, and income from the power produced.

There is a danger in thinking that because the landfill gas extraction systems owners in the developed and closely environmentally regulated nations are making big profits from Landfill Gas Energy from Waste (LFG EfW) schemes, the same will be the case for the developing nations.

However, the cost base for the two groups is completely different and much more onerous for the developing LFG EfW Scheme promoter in the developing nations than in the developed nations. The already apparent difficulty in implementing a landfill gas EfW scheme is compounded by CDM requirements.

There is usually a need for the capital for the project to be in-place well ahead of gaining the revenue which is hard enough to resource, but the delay between making the investment in landfill restoration capping and a LFG extraction system, and exporting the first power to gain revenue will normally be well in excess of one year, and may be many years.

Although, the developing nation LFG EfW scheme promoter has the benefit of the Carbon Credits, in order to avail himself of those credits, he will probably have to sell the rights to much of the future profit to the fanciers willing to take the risk that the value of the credits over something like a 10 year period will equal or exceed the amount they will pay for those future credits.

We will start where most landfill abstraction system designers begin their assessment. That is at the gas yield assessment stage. The factors which affect gas yield and the risks inherent in current landfill gas yield modelling applications as discussed.

Some pundits have spoken of LFG EfW schemes as “low hanging fruit” for profits from Kyoto Protocol Carbon Credits schemes, however, few of these schemes have so far turned out to be the very profitable ventures they set out to be. However, it is still early days yet for Carbon Trading and in areas other than purely financial benefits LFG EfW has undoubtedly provided social benefits already by providing:

- training of local operatives and maintenance skills for EfW plants
- improved reliability and benefits to local businesses from increased availability of electric power local to the landfill
- reduced pollution from reduced emissions from the capped landfills.

THE MOST IMPORTANT SUCCESS FACTORS FOR LFG EFW SCHEMES

For any successful LFG EfW scheme particular attention will need to be paid to three parameters that are easily forgotten, or not given the attention they need. These can have a major impact upon the success or failure of a gas abstraction system in operation, and are:

- condensate drainage from within the gas extraction pipework
- leachate extraction to ensure low levels
- avoidance of deterioration of the gas extraction system due to future waste settlement.

The principles which apply to good design will be described in this book in respect of the first and second of the above points. The third in the above list is a subject in its own right which we cannot hope to cover here, and is not covered this publication. (The extracted leachate will need responsible disposal and the author recommends his other web sites about leachate treatment at http://www.leachate.co.uk and http://leachate.eu.)

In this book the main LFG well designs types are also discussed and typical details are provided for a typical standard gas well type and a leachate extraction well.

High leachate levels can have a serious detrimental effect upon the gas generation rate and the efficiency and effectiveness of a gas abstraction system. One method for reducing leachate levels in combined gas and leachate extraction wells is described, based upon experience gained in developing practical techniques where pumping equipment has to be installed after filling has been completed.

Other aspects of gas extraction are also considered including connection of wells, dewatering, compressors and gas drying methods. These are discussed with the benefit of experience gained in the design and operation of numerous active gas abstraction systems.

The result should be that the reader obtains a good general understanding of landfill gas abstraction and operational requirements.

WHY DO MANY COUNTIES MAKE LANDFILL GAS EXTRACTION AND FLARING OR UTILIZATION A MANDATORY REQUIREMENT?

This is due to the need for all nations to reduce greenhouse gas emissions.

"Greenhouse Gases" (i.e., carbon dioxide (CO_2), methane (CH_4), the chlorofluorocarbons (CFCs), nitrous oxide (N_2O), water vapor, and non-methane hydrocarbons) in the atmosphere absorb heat that radiates from the Earth's surface.

Some of this heat is emitted downward, warming the Earth. Without this "greenhouse effect," the Earth would be about 30°C (60°F) colder than it is today (US EPA Report to Congress, February 1989).

Emissions resulting from human activities are generally recognized to be substantially increasing the atmospheric concentrations of the greenhouse gases.

These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

If steps were not taken to stabilize the concentration of greenhouse gases, an increase in the global mean temperature of at least about 1°C above the present value by 2025 and 3°C before the end of the next century has been predicted within scenarios using current modelling results. This rise is not expected to be steady because of the influence of other factors and this is based reports from Working Groups of the Intergovernmental Panel on Climate Change (IPCC).

In the EU, US and many other nations internationally, the growing concern about the potential for global climate change has become one of the key environmental issues.

Many nations throughout the EU particularly have focused on understanding how certain methane sources, amenable to cost-effective control, can be controlled to provide assistance toward achieving a near-term stabilization of atmospheric methane.

The understanding of major sources of anthropogenic (caused by humans) methane emissions including landfills, coal mines, and natural gas production and distribution has been studied. Researchers report a wide variety of levels of the contribution that landfill gas methane adds to the greenhouse gas effect at between 1.5% and almost 10%.

The Intergovernmental Panel on Climate Change (IPCC) recommends a fairly straightforward methodology whereby different greenhouse gases can be compared by using carbon dioxide as a datum for comparison. By definition 1 kilogram of carbon dioxide has a Global Warming Potential (GWP) of 1. Methane has a GWP of 21 so 1 kg of methane has the same heat trapping potential as 21 kg of carbon dioxide.

The statutory collection and flaring of landfill gas (as a minimum requirement) is within this context seen as a low cost means of ensuring that the small but significant greenhouse effect anticipated from landfill gas escape is minimised, and therefore this law is applied in many developed countries.

CDM AND CARBON CREDITS FOR LANDFILL GAS EXTRACTION AND FLARING/UTILIZATION

The Clean Development Mechanism (CDM) is one way in which LFG project developers can improve the economic viability of new landfill improvement projects and contribute to sustainable development in emerging economies

CDM brings developers in the developing nations who are signatories to the Kyoto Protocol the opportunity to realize financial value from Landfill Gas.

Due to the fact that the benefit in reducing methane emissions is 21 times greater than if the emission was carbon dioxide, the value of the credit which can be obtained is larger than other activities where carbon emissions savings result from carbon dioxide reductions alone.

This means that greenhouse gas emission reductions associated from LFG utilisation projects, are bigger than for many other CDM projects, and have sufficient financial value to make it worthwhile promoting their introduction in developing countries.

CDM was first established in 1997 during international negotiations on the Kyoto Protocol. Since that time, policymakers have been working to make CDM funding for clean and renewable energy projects a reality. The EU Emissions Trading Scheme has provided certainty that a long-term market for CDM carbon credits exists, and negotiations are proceeding toward agreement of the second phase of CDM. At the time of writing (Summer 2009) it is hoped that agreement will soon be achieved which will invigorate the Landfill Gas EfW project scene, by providing long term commitment to CDM.

The most significant buyers of CDM carbon credits are multilateral institutions (such as the World Bank Prototype Carbon Fund) and EU Member State Governments. However, private sector buyers in Japan, the EU and Canada are also active participants in the CDM market despite the slowdown caused by the global recession which started in 2008.

OTHER DEVELOPED NATION FISCAL ENCOURAGEMENTS FOR LANDFILL GAS UTILIZATION

The governments of the developed nations are increasingly providing assistance as incentives to those installing and operating landfill gas utilization schemes, these include:

- Classification of landfill gas generated energy as renewable energy
- Requirements on the privatized electric power industry to purchase minimum quantities of renewable energy including EfW power
- Favourable rates to be paid for approved schemes (eg the UK Renewables Obligation Certificates (ROCs) Scheme)
- Guaranteed minimum feed-out rates into the local electricity grid (eg Germany)
- Other grants often regionally based.

Many nations now have a policy which encourages the development or renewable energy projects such as EfW schemes. Wherever a landfill gas extraction scheme is located it is worthwhile seeking out renewable energy incentive funding available in the area.

Wherever you are planning to build a LFG EfW scheme we recommend that you contact local government officials responsible for these types of funding and incentives to ensure that you know about and can later claim these benefits for your scheme.

MODELLING LANDFILL GAS METHANE GENERATION

A number of workstation modelling software applications are in existence for predicting landfill gas production are available including the USEPA HELP Model, Golders/UK EA GasSim, and more.

These have some important applications, which take account of the sizing of landfill gas collection systems, evaluating the profits of gas recovery projects, and estimating gaseous emissions to the environment.

Methane, which constitutes in the region of 40 to 60 percent (55 percent on average) of landfill gas, is on the whole the component of most of the interest.

The two most important components of model predictions are the amount of gas that can ultimately be generated from with a given amount of land-filled refuse, as reflected by means of eventual yield, plus the velocity of generation through time, as reflected by means of parameters describing rate plus the profile of the output curve.

Landfill refuse varies greatly in its gas producing potential.

Theoretical forward projections have been based on assumed fractional conversions of the organic component of the landfilled waste. Evidence from laboratory reports, as well as inferences from stoichiometric calculations in addition to field outcomes, suggests that eventual yields from for example United States landfills will range between 1 and 2 cubic feet of methane per pound (62 to 125 l/kg) of dry wastes. (Ref; J. Pacey and D. Augenstein EMCON Associates, Landfill Gas Energy and Environment '90, DoE, Modelling Landfill Gas Methane Generation, San Jose, California, USA)

The lessons of gas extraction over a period of time has shown that landfill gas yield, is influenced as a result of a number of variables and can change extensively over time.

Numerous factors (as a rule most significantly moisture content) can influence gas generation, however the understanding of their power is for the most part qualitative and a long way from ideal. Obstacles on the way to model improvement have included complexity in defining the level of dependency on the plentiful variables, and difficulties of significant gaps in measurement of both the variables along with generation commencement times.

As a consequence, the models up to now are estimates and no more than that. Furthermore the results confirm unpredictable reliability and are inevitably virtually every time founded on incomplete and flawed data.

Despite all these difficulties, models are useful and are widely used. It is also likely that existing empirical models will be considerably improved by being fine-tuned against appropriate production data obtained in defined situations with good compliance with measurement protocols.

Further improvement in projecting methane production is continuing as the landfill gas industry gains theoretical and practical knowledge of the various influencing factors in landfills such as liquid permeation, and nutrient and bacterial distribution and mobility.

INTRODUCTION TO MODELLING LANDFILL GAS METHANE GENERATION

A landfill gas or methane generation model is a tool that allows estimation of methane or total landfill gas generation over time from a mass of waste. Such models in their simplest form foretell gas generation over time from a single unit weight or volume of landfilled waste. Total output from a landfill or other waste mass (like a cell of a landfill) is the total of single-batch outputs computed over time by trying the model to all unit groups of waste in the deposit in question.

The requirement for landfill gas models became apparent with larger implementation of sanitary landfilling beginning the 1970s. This, mixed with the rise in energy costs that began in 1973 with the first global energy crisis, made a high level of interest in landfill gas as a power source.

Around this time, there were also a number of unfortunate accidents relating to the migration of gas from landfills in many countries including the United Kingdom. As awareness rose of the chance that an explosion may take place, it also became critical to develop generation models for gauging the impact of methane gas from landfills on the environment due to concerns about greenhouse gases and the amount of methane from landfills which was and still is contributing to global warming.

In addition, the necessity for convincing models has grown through a concern per methane and other organic landfill gas emissions as they would affect the local air quality, and public health for those living close to landfills.

In this book we have limited our dialogue to the prediction of landfill gas yield for the capture and utilization of as much of the landfill gas as practicable. We have not covered migration or air quality monitoring aspects though there have been techniques available which now make possible the monitoring of air quality, including the presence of emitted methane in the airspace above a landfill.

The sections which follow will address the bases for models, their parts, their sensitivities, and extremely importantly, their inaccuracies. We cannot stress to much the fact that methane generation modeling is presently an imperfect art, but still worth doing, and will get better in time as improvements occur through a mix of better field measurements and basic research.

If you are landfilling now, and not collecting basic data about the types of waste disposed in your site, its location, and date of deposition throughout, then we recommend that you start.

This information will be very valuable when it comes to assessing the suitability of the site for a LFG EfW scheme and pay for itself many times over when funding is sought for such schemes.

MODELING LANDFILL GAS GENERATION AND FACTORS WHICH INFLUENCE GAS YIELD

The basic biological processes leading to the generation of methane from landfills have been well known for many years, and are shown in Figure 1.

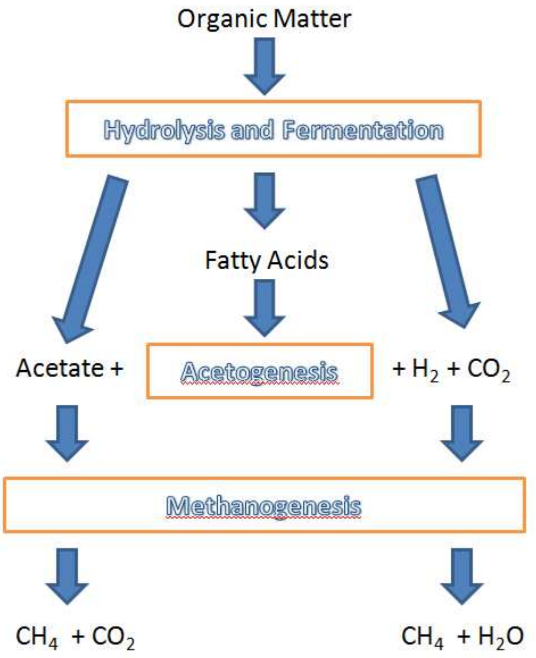
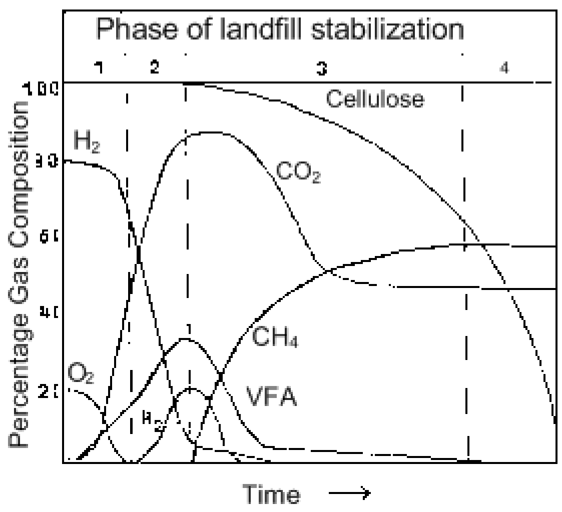


Figure 1: Microbial Processes in Landfill Gas Production

Bacterial action leads to the generation of methane from organic substrates by reactions such as the following (simplified) of cellulose to methane.

$nC_6H_{10}O_5 + nH_20$ ------------—> $3nCH_4 + 3nCO_2$ (1)



Note: CH_4 production will always trend downwards after peaking. This idealized table does not show this.

Figure 2: Idealised Landfill Gas (CH4) Production in a Landfill

Stages in the decomposition of wastes in landfills have been defined. Figure 2 shows events or stages in landfill decomposition, as described by Farquhar and Rovers and modified by Rees (Farquhar GJ, and Rovers FA. Water, Air and Soil Poll. 2. 483 (1973)).

The occurrence of these stages is well established. The crux of the methane generation modelling problem is not to predict what will happen (since the above reactions and methane generation are known to occur), but to predict the rate and extent of reactions.

In principle, with enough data, we would think that landfill methane production may be precisely modeled. As an example, the basic rate equations that describe microbial processes can be quantified re nutrient availability, temperature, and substrate level; by relations such as that for rate vs temperature; and the classical relations like the Monod curve that describes reliance on nutrient level. In practice landfill conditions are far outside of the controlled conditions where correlations have been developed in the theory.

Landfill conditions are variable; the unknowns and variables are enough, at least at the moment, to confound efforts to apply the correlations developed under more controlled conditions. Many variations on models can be invented. One possible adaptation is to vary lag times. Another is to subdivide the waste into fragments, each having its own lag time, decomposition time, and yield to reflect the reasonable expectancy the waste will be made of variably decomposable fragments characterized such as:

- rapidly decomposable (eg. Food),
- less easily decomposable fragments (eg. paper products);
- other slowly decomposable fragments (eg wood).

Inherent doubts in model prophecies could be reflected by projecting a possible range for output over time instead of a single outcome. (The frequently used models as an example, take these approaches subdividing the waste into types to account for variations in methane generation from each fragment, and projects output across a band between a likely lower and upper limit).

While many models are possible, all have main elements in common that most significantly influence their outputs. Models are broken down conceptually (realizing that this as a simplification) into 3 basic elements. These are (a) the final yield, (b) generation time, and (c) an assumed shape of (or parameters describing features of) the output curve.

The yield determines how much gas will be created, regardless of the rate, and the generation time is a guesstimate of how long it will take to generate almost all of the gas. The output profile provides details on the profile of gas generation over a period of time set in the model, within confidence bands.

MOISTURE CONTENT AND MODEL SENSITIVITY

It is most likely that for your modeling the most serious variable to be quantified both re its measurement and its effect on generation is moisture content. Given moisture's significance to generation, careful consideration should be given per the best strategies to gauge it at existing sites and guesstimate it at proposed new landfill sites. (Core moisture sampling and analysis is one way to obtain moisture content, but definitely not the sole or easiest way to get such information.).

WASTE TRANSPORT AND PROCESSING ACTIVITIES WHICH AFFECT LANDFILL GAS YIELD

Before refuse arrives at a disposal facility, there may be changes in the waste that can influence the generation cycle. Baling to high density can significantly change the decomposition cycle since permeation of moisture into such bales is generally limited.

Shredding, on the other hand, changes refuse particle size and breaks down bundles, packets, and containers. This produces refuse which has a maximum particle surface exposure to bacteria and can most readily take up moisture. Refuse may also vary in that it may be temporarily stored at a transfer station where some material is removed for recycling, or where the refuse is pushed to transfer trucks by special equipment that breaks open bags and breaks down containers (crushing/ flailing activity).

Source separation and other removal of waste components also affect the waste composition at the landfill. These activities can have a significant impact on refuse composition, particle size, and refuse homogeneity.

All these variables are best tested by sampling your anticipated waste.

WASTE COMPOSITION

This variable ranks high in importance in its influence on ultimate yield and generation rate.

Refuse composition varies among countries and regionally within countries. Honolulu, New York City, Rome, and Manila should all be expected to have different refuse compositions. The variations are attributable to the mix of industrial, commercial, and residential refuse; local regulations; local customs; local weather conditions; and so on. Once the composition is determined, the modeller can determine the amount of organic material and subdivide it into subcomponents in order to assess their relative ultimate yield and generation rate. This is a necessary step in site-specific model data generation, and the inputs vary from landfill to landfill.

In addition to refuse, many landfills accept organic material in the form of sludge, agricultural and forest wastes, tires, and other special wastes. Each of these waste types can be assigned a generation yield and generation rate, which can be added into the refuse model estimate.

BIOLOGICAL FACTORS

Once refuse is placed within a landfill, moisture content becomes by far the most important variable influencing biological activity. Projection of moisture influence on generation is difficult because moisture content itself changes during landfill operation and in the years following landfill closure. The amount of water infiltration management at landfills varies widely throughout the world. The United States and EU approach focuses on restricting infiltration of liquids, either naturally induced (precipitation), or artificially induced (irrigation, recycling, and semi-liquid and liquid) waste additions.

Most other countries adopt a limited version of this approach. For many years now, the U.S. and the EU regulators have required the use of intermediate covers and drainage controls to minimize water infiltration into the refuse, and both have adopted a policies encouraging the use of final landfill covers that incorporate natural clay barriers or synthetic membranes.

The U.S. Environmental Protection Agency and European regulations also require the use of leachate collection and extraction systems in new landfills. Most of these are recent requirements that will only affect future gas generation at sites where they are implemented. It can be seen, however, that moisture content control is a common practice in new and older landfills.

Where a landfill is situated in a temperate to hot climate with an annual rainfall of less than 20 inches (50 cm) spread fairly evenly through the year, and run-on drainage is precluded from infiltrating the refuse, and where the ground water will not infiltrate the refuse, and then the moisture content will probably change little throughout the methane generation cycle. However, rainfall averaging 30 inches (76 cm) or more can cause moisture content to increase significantly before capping.

As a general rule the greater the rainfall, the higher the ultimate gas yield, and the faster the gas generation.

This correlation can be lessened to the degree that liquid infiltration is restricted at the landfill. The authors believe that a dry and wet landfill will produce respectively, about 1 and 1.8 cubic feet of methane per dry pound of U.S. refuse over the generation cycle; refuse will produce about 90 percent of its gas in the 10 to 20 years and 20 to 40 years following its placement for the wet and dry landfill, respectively.

The benefit of higher moisture content lies in the ability of water to redistribute nutrients and bacterial seed from one location to another within the landfill. The implementation of leachate recycling maximizes this redistribution and provides the highest yields and shortest generation times. Limiting changes in the moisture content by moisture control management has the effect of limiting such bacterial and moisture redistribution; that is why dry landfills produce less gas than wet landfills and the gas and generation cycle lasts much longer.

Nutrient and bacterial availability are clearly important. The nutrient and bacterial contents of refuse are almost invariably sufficient to allow methanogenic activity. Their poor distribution can be limiting but distribution can be improved by the means noted above including increasing moisture content and shredding.

A satisfactory pH environment is important; however, most landfills tend to develop this without management assistance. Some cases of highly acid environments have been reported in central Europe, but the authors have not encountered such conditions in their experience. Particle size is important but not subject to change after the refuse is placed.

The author believes that it is desirable to break open containers during placement to expose all waste to the same biological environment and increase surface area, thereby encouraging decomposition. This can increase gas production to a degree depending upon the nature and prominence of containers in the refuse.

Density is an important variable, but difficult to quantify. The authors believe that there is relatively little variation in the generation yield, or rate, attributable to different compaction densities in the normal landfills of the world. The exception occurs in the case of baled refuse, which is so dense that it retards the mobility of moisture and possibly bacteria into the interior of the bales.

LANDFILL DESIGN

The areal and depth configuration of the landfill may affect the gas generation cycle.

A shallow landfill with a permeable cover may permit infiltration of enough oxygen to inhibit methane generation in layers near the surface. However, the refuse thickness, in conjunction with effects such as oxygen consumption by the refuse and oxygen displacement by the generated gas, is sufficient in most landfills to support the anaerobic environment necessary for methane production.

In addition, the increasing use of more impervious final cover material encourages the anaerobic environment, and enhances methane yield.

The gas generated in a landfill escapes by migration through the base, sides and top.

A landfill design that restricts, or precludes, migration from these perimeter areas enhances gas management and recovery efficiency. Such design will have less effect on gas yield and generation rate since they depend principally on moisture content.

Intermediate cover material design and use can be significant in managing moisture content change. A program designed and operated to restrict, or minimize, moisture change, will not enhance gas yield or generation rate and it may adversely affect these factors.

However, normal landfill operational practice is to do just that as the operator and regulatory bodies usually view the requirement to reduce leachate generation as paramount. It would be preferable for landfill gas yield optimization that the moisture content be allowed to rise from exposure of the surface to the weather, and that the increased volumes of leachate simply be treated before discharge.

OTHER EFFECTS OF LANDFILL OPERATIONAL ACTIVITIES ON LANDFILL GAS

As formerly debated, moisture content in the refuse is the most vital factor influencing methane yield and generation rate. It should be expected the moisture content of wet landfills is some way from uniform. The lower portion of the landfill usually has the highest moisture content due to the downward infiltration of water and moisture additions. As the liquid moves downward by gravity, it may cause an absolutely saturated condition to develop in the lower portions of the landfill.

Local areas of the refuse can also possess a particularly high moisture content caused by locally deposited liquid additions, or rainfall infiltration may be uneven in an active landfill area. This non uniformity of moisture content is tough to consider comprehensively when modeling landfill gas generation. Spreading and compressing refuse can have a significant effect on particle size, and local permeability of the waste, as bundles of refuse are opened up, bags and boxes are broken open due to action of surface compaction equipment, and semi-liquid and liquid additions to the landfill may have been unevenly mixed into the refuse.

The opening up of the refuse subcomponents by compaction, or other methods, exposes more refuse surface area to the gas generation environment, while the addition of semi-liquids and liquids (sludges and some animal wastes) raises the moisture content.

Another operational factor affecting methane yield occurs when wastes different to the ordinary city wastes are be segregated. Segregated wastes generally contribute less to methane generation than normal municipal solid waste. Their contribution to yield is explicitly related to their organic content and their decomposition rate. For example, tires and lumber might be placed in special cell areas of a landfill and they will contribute little or much less to the gas generation.

The model user may separate such wastes from the other wastes in the information that is input to the model. Certain rural wastes, and sludges, if disposed at landfills may make a contribution to the gas generation model and dairy waste and some sewage sludges are examples.

Wet weather areas are used at certain landfills to help placement of refuse in wet weather. Such areas, by their very nature, should be anticipated to have a higher generation rate than non-wet-weather areas.

Gas Yield Modeling Conclusions

Some important specific conclusions of landfill methane generation modelling are:

Landfill Gas Generation model uncertainties arise from a number of sources, and be quite large. These uncertainties are most readily reflected by expressing likely gas output in terms of a probable range, rather than a single value, at any given time over the generation interval.

The landfilling situation most often encountered is one where waste placement occurs at a slowly changing or constant rate for periods of many years. In such cases the gas generation profile is affected to the greatest extent by the yield, and the rate parameters which in turn determine generation time; the profile assumed for unit batch output tends to become less important as the interval of placement increases.

Due to the uncertainties of modelling landfill gas generation it is essential that calibration of the model for each site where the model is applied and then refined against data of actual gas yield from a test pumping trial carried out over a number of boreholes and extending for more than one month in duration.

To sum up, the modelling of methane generation is a topic of major interest, not only to make that first essential decision to develop the field for landfill gas extraction but also for deciding whether a business case can be made for a profitable investment in landfill gas energy from waste scheme by (for example) installing generator sets coupled into the local power grid for the sale of the electricity produced including for its significance to gas migration hazard potential, health and safety concerns and the "greenhouse effect."

Numerous natural and artificial variables influence gas generation and recovery, and can critically influence methane generation within a landfill. The variables can differ between landfills and can change significantly during landfilling and post-closure.

In addition, the extraction system and its management protocol can have a significant impact on the gas yield and generation rate. The large matrix of variables, in conjunction with our current inability to quantify many of their effects, clearly illustrates the difficulties of predicting landfill gas yield and generation rate. The modeler and user of the outputs from modelling must recognize the likely uncertainties in the output estimates, and the future system owner must appreciate risk inherent in these uncertainties which could result in lower gas yields than forecast.

All these concerns regarding yield are normally addressed by the LFG operator's use of easily adaptable and modular landfill gas extraction and EfW systems. The operator who runs a number of LFG extraction and EfW systems has the advantage of being able to move pumps and gas engines around between landfills as production at each site demands.

HOW A GAS EXTRACTION SYSTEM ITSELF WILL AFFECT GAS QUALITY AND THE USES FOR WHICH LANDFILL GAS IS USUALLY WELL SUITED

The gas extraction system design and management system installed and the way it is used can have a crucial effect on the gas generation cycle. There are 2 main project drivers for the management of landfill gas:

- Gas migration prevention where risk of explosion might otherwise occur when the gas reached and entered a property
- Gas recovery, where extraction is provided for the production of Energy from Waste.

Both may have Energy from Waste (EfW) power generation facilities installed. In the developed nations gas control (flaring) projects predominated up to about 10 years ago, but power generation projects now prevail.

GAS MIGRATION PREVENTION PROJECTS

Their purpose is to govern migration of the gas from the base and sides of the landfill onto nearby properties and to regulate emissions through the top cover system into the atmosphere. The potential for gas migration will only normally occur at older un-engineered landfills.

This is a specialized subject in its own right, in which many operators have developed expertise and is not covered here.

GAS RECOVERY (ENERGY FROM WASTE) PROJECTS

Gas recovery projects produce energy from waste (EfW). They supply a gaseous fuel (landfill gas comprising methane as the combustible content) for energy use, usually by generating electricity delivered into the power distribution grid.

In either project type, the gas is picked up by engendering a vacuum inside a pipe and well collection system that encompasses a number of collection points (wells or horizontal ditches). The picked up gas is either combusted in flares such as in a migration control project for a small landfill where the gas yield), or delivered to energy conversion units like electric generator sets, gas turbines, gas boilers, or pipeline quality process facilities (biomethane recovery projects).

The vacuum at which the extraction system will be run for migration control purposes will be set by experience to draw gas at a rate just sufficient to prevent migration, as monitored in wells outside the site.

A gas migration control project generally prompts a higher vacuum and higher extraction stress in the refuse, vs a gas recovery program.

As a result, in a gas migration control project more air is introduced into the fringe sections around landfill and this leads directly to a retardation of gas generation in the area. Gas yield and generation rate are lowered. The size of this part of the landfill not producing landfill gas and its effect on generation yield and rate are a direct function of the system design and operation.

Care must be taken with all migration control extraction not to draw air into the landfill sufficiently to cause a landfill fire, and the most difficult to control are usually deep-seated within the waste.

LANDFILL GAS RECOVERY (EFW)

Recovery projects for commercial use fall into many classes per their effect on methane yield and generation rate. There's now also a new and skyrocketing interest in developing LFG Energy from Waste (EfW) systems for direct delivery into the local natural gas distribution network. This is described by many in the landfill gas industry as producing a pipeline quality product.

A pipeline quality gas distribution implementation project will be needed to provide gas to the gas distributors design quality requirements. Pipeline quality product in most situations can't effectively be achieved if much nitrogen is present, so that the extraction system must collect only the highest quality landfill gas. It must also limit air infiltration into the landfill.

This gas recovery design criterion normally ends with the agreement of an extraction pumping installation program which will balance the gas well field to optimum methane.

Care is required in doing this as in the event the extraction system is needed to also limit migration the two needs might not be compatible. Gas use as a boiler feed fuel is least impaired by the presence of air elements especially the presence of oxygen in the extracted biogas.

Sitting between the two for gas pureness are the Gas Engine generator projects (where landfill gas powers a reciprocating gas engine or in rare examples a turbine) are nearer to the boiler fuel projects than they are to the pipeline quality projects per air part contamination.

In summary, the extraction management process requested different gas end users will have different impacts on gas generation.

These impacts result from differing degrees of air entry, which suppresses gas generation in those sectors where the air enters. The recovery potency of an extraction system will change seriously relying on the system design and its operational management. Well spacing, well depth interval over that the gas is picked up, vacuum applied, vicinity to fringe, and so on, are but some of the management variables that have an effect on the potency of gas recovery.

These in turn are without delay related to the kind of project debated above. The writers think the collection potency of gas extraction systems is 40 to 90 %.

The lower potency is for the pipeline quality recovery projects, the higher potency is for the gas control and electric generation projects, and where the cover system is comparatively impervious.

POST-CLOSURE MOISTURE CHANGES PERCHED LEACHATE AND THE EFFECTS OF RECIRCULATION OF LEACHATE TO RAISE MOISTURE CONTENT AND LFG YIELD

After landfill closure the moisture content will not vary rapidly. Free water will continue to be created within the landfill as part of the decomposition reactions taking place, but the effect is gradual and tends to balance the water loss through the vapor in the gas extracted.

Though a landfill is finished and closed, the landfill gas generation yield may be affected by post closure events, but predominantly only by moisture content increases. Some landfills may not be provided with adequate leachate extraction. This can cause a direct loss of landfill gas yield if the waste becomes flooded, but even at lesser rates of leachate build-up short of full saturation; high rates of percolation into landfills can lead to perched water tables.

These comprise large areas of the landfill in which there is water (leachate) sitting in the waste at a level well above the base of the landfill where for example there has been a low permeability temporary cover used which has not been scraped off before the next lift of waste. Perched leachate tables can be remarkably persistent and they may form a barrier to landfill gas movement which can reduce gas yields.

At a number of landfills attempts have been made to raise moisture content after operation and after closure. There's no doubt that if the general moisture content across the body of the waste is raised the landfill gas generation rate will be increased, but actually achieving that is notoriously difficult.

Leachate can be pumped into distribution soakaway drains constructed just under the landfill surface. If the water introduced does not freely drain downward, perched water tables in the waste build up quite possibly reducing quantity of gas able to get to the extraction well.

For this reason recirculation should be approached with caution only, and experimenting with the landfill first by trying out the idea in just one limited area is advisable. Monitor the experiment carefully, as gas yield might be reduced, and any areas which become saturated with water will suffer seriously reduced landfill gas production.

In addition the quantity of water in the landfill may rise where the landfill capping is permeable over many years, and such a slowly rising leachate level may present on many old landfills. Perimeter water running onto the landfill may start to soak into the landfill on the edges if differential settlement opens up cracks into the waste around the landfill perimeter.

This surface water entering the landfill may also increase the moisture content. Such changes could lead to major changes that is the result of intended or inadvertent moisture increases in the generation cycle and should be good for gas generation rates. The important rule about this is that regular monitoring of the landfill leachate levels is continued after closure, and when levels rise extraction is carried out to reduce leachate levels.

If, for example, a closed landfill is converted to a park or golfing course, the irrigation water mandatory for supporting grass and vegetation could be applied too freely, or drainage pipes laid within the capping layer may leak, raising the refuse moisture content. This can lead to a major increase in gas generation yield and generation rate if consistently achieved throughout the landfill, but perched water tables and saturation of waste would tend to limit the benefit, or may cause a net reduction in gas yield in some circumstances..

If the area is flooded, or the ground-water table rises, the moisture content could also rise, leading to increased gas generation if the effect is short-lived and ends up in general moisture content elevation. However, if the waste becomes waterlogged (effectively crammed with water / leachate) and/or significantly cooled in the act, gas generation rates may plunge.

CONCLUSION

The foregoing discussion has provided some practical examples of how landfill and the gas extraction system field balancing and pumping operational factors can influence gas generation. These illustrate the complexity and also the inherent uncertainties of typical situations facing those promoting and operating landfill gas generation energy from waste (EfW) schemes.

The prudent landfill gas engineer designs wherever possible on a modular basis and will plan to move pumps and power generation sets around between landfills as gas yield changes.

TESTING THE LANDFILL GAS BEFORE SPECIFYING GAS UTILIZATION EQUIPMENT

Landfill gas is not a pure gas only comprising the main elements of atmospheric air to a varying extent plus methane. It will contain a varying mix of other elements and compounds at low concentrations. These are often referred to as trace gases.

Before investing in landfill gas EfW utilisation equipment such as a Gas Engine or the Gas Scrubbing and Cleaning equipment needed for pipeline gas projects, it is essential to carry out a full gas analysis on a set of representative samples.

It is recommended that discussions be opened at an early stage with potential suppliers of

It will be important to obtain details of the full range trace chemicals including trace organics. For example, the presence of even low concentrations of silicon may build-up

GAS SAMPLING AND ANALYTICAL METHODS

Trace components are analysed by GC-MS after direct Thermal Desorption from a product such as “Tenax™”. Alternatively, adsorbent materials such as Tenaxª, Carbowax¨, Porapak¨ or Carbotrap¨ may possibly be used for high moisture containing samples using the Thermal Desorption Technique. The technique of Thermal Desorption has been developed to permit the analysis of organic compounds present in air or compounds which can be easily purged from solid and liquid samples.

More information is available at http://www.sisweb.com/sptd/sptddesc.htm .

GAS SAMPLING PROCEDURE

Landfill regulatory bodies will often specify gas sampling procedures, and for all landfills in the developing economies the site data collection methods adopted must comply with the requirements of the funding bodies so that accreditation is obtained once the system is operational.

Thus, local requirements will override the following which is provided as an example.

For all projects on existing landfills and as soon as new landfills become established as methane generators gas quality sampling becomes a requirement.

Gas bomb samples are taken for analysis of major components to establish both the mian components and small trace levels of other contaimants.

K Knox in his paper describes the use of Tenax™ for landfill gas trace analysis. It was selected after consideration of techniques reported in the literature for trace components, and initial comparison trials with Tenax and solvent desorption from activated carbon. While the limitations of Tenax™ were recognised for some specific groups of compounds, it was felt to give the best combination of general coverage, consistency of results and convenience in the field.

The Tenax™ can be contained in glass injection-port liners from Philips PTV (Programmed Temperature Vaporisation) chromatographic injector. These tubes measure 64mm x 3mm and are much smaller than conventional Tenax tubes. Samples taken on them are amenable to thermal desorption directly on to the chromatographic column without any intermediate nitrogen trap.

Methane concentration in the gas is first checked using an FID (Flame Ionisation Detector such as the Gascoseeker; a sample volume roughly equivalent to 50ml of gas at 60% CH_4 is then calculated; a Tenax™- filled PTV tube is then fitted to a 100ml syringe by a short length of silicone tubing, when sampling from a gas sampling valve.

The open end of the tube is inserted several centimetres into the opened sampling valve, to minimise the risk that air will be drawn into the tube. The required volume of gas is then drawn slowly through the Tenax™at less than 50ml/minute so as to ensure efficient adsorption of trace components. At sites where only open boreholes were available, a length of at least 1m should used between the Tenax™ tube and the syringe. After sampling, the tube is then tightly re-wrapped eight times in aluminium foil and stored away from heat and light for transit without delay to the analytical laboratory.

GC-MS analysis was undertaken by SAC Scientific, Bedford, using a Philips PU 4550 gas chromatograph and Finnegan Mat mass spectrometer with ion trap detector or equivalent.

Care should be taken to minimize the amount of time that the Tenax™ tube is unwrapped; at sites where composite samples are to be taken from several boreholes the Tenax™ tube should be carefully re-wrapped between each borehole.

Assuming that the model shows that landfill gas generation rates will be high enough for extraction to be economically viable ,and even if they will not be, in those countries where landfill gas capture and flaring are required by law (such as throughout the EU), for carbon emission (greenhouse discharge) reduction reasons landfill gas extraction will be needed. This is discussed in the sections which follow.

LANDFILL GAS EXTRACTION SYSTEM DESIGN

INTRODUCTION TO LANDFILL GAS EXTRACTION SYSTEMS

I am indebted to Andrew Leach upon who's initial paper this section has been based. Andrew was at the time working for Shanks and McEwan (Southern) Ltd., Bedfordshire and thus this section is inspired by some of the leading work done by that organisation in the 1980s in the United Kingdom.

Andrew's paper presented at Landfill Gas Energy and Environment '90, DoE, Modelling Landfill and Gas Methane Generation Symposium, was written at a time when the UK waste management industry in general was very doubtful that EfW from landfills would ever reliably achieved, due to high rates of corrosion experienced in the only generation sets available at the time, or would be profitable.

Nowadays, of course, the reality is completely the opposite and it is often said that in the United Kingdom the only reliably profitable activity connected with landfilling is LFG power generation.

A wide variation in the design of gas abstraction systems is found throughout the U.K., US, and Europe however, as the current landfills have been nowadays almost wholly set up in compliance with the EU Landfill Directive and are similar in design, so the variability of the landfill gas systems has reduced.

In this document we have concentrated on the most standard well types and systems.

The older sites in Europe and the current largely unmanaged landfill sites around the world where regulation is poor and which are more appropriately called "dumps" may require more site specific installations to unique designs.

Nevertheless, as the world treads a path toward better regulation of landfills and the demise of the "dilute and disperse" sites with the move towards fewer and larger well engineered containment sites the key design parameters can be expected to converge and a more standardized approach to develop as it has done in the developed nations.

This paper examines the design and operation of active gas abstraction systems particularly with respect to contemporary containment sites and attempts to assist in the move towards standardization.

Particular attention is paid to three parameters that can have a major impact upon the success of gas abstraction system operation, namely, leachate level, condensate and settlement. The advantages and disadvantages of various designs are outlined and some methods of overcoming problems are proposed.

CRITICAL PARAMETERS

Three parameters are critical to the success of the design and operation of any active landfill gas abstraction system. These are:-

a. Leachate Level

b. Condensate

c. Settlement

A description of each follows:

LEACHATE LEVEL

In a modern landfill site the required level of control of leachate is probably going to have dictated that the site be built to contain leachate. The site license is also certain to contain a maximum leachate level that is allowed in the site measured either above the site base to minimize infiltration from the landfill into the strata below, or below the edge to stop an overflow of leachate at the rim of the landfill.

In both cases it should be recognized that a landfill site is a bioreactor and the presence of water (leachate) in carefully controlled quantities is a required part of the landfill process for any gassing landfill. The presence of leachate in carefully controlled volumes enhances the waste degradation process and enables a higher yield of landfill gas to be extracted.

With tough needs on the control of leachate the landfill operator should try carefully control of his operational area to minimize the working area (area exposed to rainfall) and maximize the capped area, therefore reducing incident rainfall volume and the capability of the landfill to generate leachate.

LEACHATE BUILD-UP

At first, following capping of a rapidly filled waste cell - almost no leachate may be there. However, a leachate level is probably going to build with time as an effect of the following mechanisms:

A. The degradation and breakdown of waste releases the basic moisture.

B. Surface water infiltration thru the cap or ground water infiltration thru the sides and base.

C. As a derivative of the methanogenic process.

D. Through settlement and compaction of waste reducing holding capacity (i.e. Sponge effect).

The effects of these actions are to extend leachate levels immediately following capping of the waste at unexpected and alarming rates. To give some guideline figures for these effects:

- infiltration of 30mm of incident rainfall across a cap (a volume of 30mm/m^2 of cap/yr) might be not untypical of real life for a clay cap of 1x10^{-9} m / s permeability – at the base of a well (densely) compacted landfill this can cause leachate levels to rise 1m / year.

- settlement of one metre as measured at the landfill surface, has given rise to leachate level rises of four metres.

This serves to point out the importance of monitoring for leachate levels, otherwise serious and rapid landfill gas reductions may occur without warning which impact severely on the reliability of your system and usually also on the price the receiver of the electricity will be willing to pay for the power produced.

The effect of (a) and (c) above are less easy to quantify, however, their effect should not be ignored.

CONDENSATE

Condensate is the name given to the liquid which condenses within LFG extraction system pipework. It is essential that condensate never builds up within the gas extraction pipework, otherwise blockage to gas flow occurs.

Landfill gas is typically produced within the body of the waste at a temperature of 30-45°. The atmosphere within the waste is normally completely saturated with water vapour (100% humidity) and as the gas is drawn to the exterior or surface of the site the gas will cool causing condensate to form.

Within the vertical shaft of a well this will flow back down into the well, however, in a horizontal gas well condensate is more likely to be drawn through with the gas and out into the suction system pipework.

As the gas travels along gas collection pipes further cooling will occur particularly where collection pipes are exposed to close to the surface or ambient conditions around the flare or gas engine. The gas temperature can easily drop from 30°C at the well head to 20°C at the entrance to a gas flaring compound.

Such a drop in temperature would theoretically release approximately 20ml of condensate per m^3 of landfill gas or 500 l/day on a system flowing 1,000m^3/hour of landfill gas.

Where semi-anaerobic conditions are allowed to prevail or where a particularly deep site allows higher temperature methanogenic activity (thermophilic) to take place, then as a study of a psychometric chart will show, significantly greater volumes of condensate can be carried over in the form of water vapour.

For this reason an essential part of any landfill gas extraction system is the condensate removal capability which must be built into the system.

A general rule adopted by many designers is that interconnecting landfill gas pipework must be laid to a minimum gradient of 1 in 50 (however, this must be judged site by site by the designer and pipe bore, future predicted localised and differential settlement and the design life also have a bearing on this and must be considered), and steeper falls not less than 1 in 20 are preferred. This or another minimum slope requirement decided upon must be rigorously adhered during construction, to prevent pipe blockage due to the build-up of condensate in low areas.

At each low point there must be a means of removing condensate liquid at what are known as "Knock-Out Pots", and these must be trapped and incorporate soakaways or pumped sumps.

SETTLEMENT

The operator of a modern landfill site in responding to the requirements for minimising leachate generation is likely to fill the site rapidly within small constrained areas (cells) within the landfill, to reduce rainfall ingress.

When each operational cell is complete to restoration levels it is normal good practice to cap it to stop further ingress of rainwater.

Even the oldest and first waste to be tipped at the bottom is thus sure to be in only the initial stages of degradation.

Subsequent settlement can then be anticipated because of the following mechanisms:

i. The load on waste in the lower levels imposed by waste above it, especially for deep sites, will be many times larger than that imposed in the initial compaction process using mechanical compactors. This will have the effect of continued, graded compaction through the waste depth, causing surface settlement. This mechanism for settlement is probably going to be predominant during filling and straight away following capping, but further and far less rapid settlement will continue for many years to come.

ii. The degradation process will break down waste into a denser foundation.

iii. The production of gas will mean a net mass loss of most likely 15% to 20% presuming 150m^3 / hr of landfill gas at 1.15kg / m^3 is preoccupied from each tonne of waste

iv. Removal of leachate from lower levels of waste over a period of time may also cause further settlement as pore pressures are reduced.

Settlement is thus unavoidable and must be catered for in the planning of the gas extraction pipework layout and falls, the condensate removal system, and within pipework located in the flare and any power generation compound. (For further information on Settlement of Landfils go to http://blog.landfillcqa.co.uk/downloads .)

It's the job of the landfill gas Engineer to consider the landfill site "condition" and establish the aptitude for further settlement so that he will be able to be satisfied an appropriate design is suggested. Resolution of settlement rates and possible leachate levels is very important to new sites and are vital design parameters for the landfill gas Engineer to identify before he starts his system design.

However, there are still many sites where filling has taken place slowly over many years with a high % "inert" input and where gas control is revealed to be required following capping and restoration of the site. The site might also be a "dilute and disperse" site and so no leachate level might have established. In this example the design parameters of settlement and leachate level will be not nearly as vital as for the "new" site.

Other concerns are probably going to predominate like poor containment leading to air ingress and low quality gas.

ACTIVE GAS EXTRACTION FIELD DESIGN CONSIDERATIONS

It is important that all landfill gas extraction wells (also often referred to as boreholes) are designed carefully in accordance with best practice, and in this section we have tried to identify the most important aspects of design. We also recommend the United Kingdom reader to consult the Environment Agency Publication, "Guidance on the Management of Landfill Gas".

All landfill gas field system layouts must be designed individually for the specific requirements of the site, taking into account the depth, shape and topography of the site, plus the data from the gas production flow rate modelling and the gas yield assessment pumping trial.

It will be necessary to obtain an up to date site survey of the landfill, and to be in possession of the fullest possible information on the size, location, and likely dates of infilling of any remaining landfill cells or phases to be developed.

The landfill gas systems installed all around the world rely on suction however the field must be "balanced" and regularly re-balanced by the operator, throughout its use so that the system does not cause excessive amounts of air to enter the landfill gas due to excessive suction at any location.

To "balance" the field the quality of gas in each well is monitored and the high yielding wells are drawn for as much gas as possible while lesser quality wells are throttled back using the valves at each wellhead to extract just as much gas as they can produce.

Such adjustments will improve gas yield and quality, but great care must be taken to ensure that gas migration control (particularly near the site perimeter) is not jeopardized (by reducing suction at the perimeter for optimum quality) by either allowing gas to escape, or drawing-in air and causing fires in the waste by sucking excessive amounts of air into the waste mass.

If gas migration is a potential problem on the site, the first requirement of the landfill gas collection system will be to encircle the site perimeter 40 m inside the perimeter with wells spaced at 40 metre centres, and these will be drilled to within a reasonable allowance for tolerance on accuracy depth measurement to the base of the landfill, without penetrating the bottom liner. (40 metres is a dimension often selected – check your local requirements with your regulating (environmental permitting) authority before applying this dimension.)

The intention is that these wells will intercept any landfill gas which would otherwise migrate out of the site. If there is no man-made or natural site development lining then a large amount of air will tend to enter this ring, making the gas extracted a low quality.

So for old gassing landfill sites without clay lining it is usually best to run separate pipework routes for the outer and inner landfill gas extraction systems, and balance the migration system separately to the EfW system. It may also be necessary to design the system so that the perimeter migration prevention system is flared as low quality gas, and only the inner wells deliver gas to the EfW system.

In central areas of the landfill the wells may be set out at a wider spacing, and it is often preferred to space them at 50 metre centres. (Again, check with your regulator first).

Each well/borehole is drilled to its full depth at approximately 325mm diameter and is then fitted with a high Density Polyethylene (known as HDPE or PE) pipe. The actual pipe diameter chosen will depend upon the depth, as usually the pipe used will be smaller at the base so that the lower pipe lengths can be lowered through the larger diameter upper pipes.

All well pipes are perforated at regular intervals, to allow leachate and landfill gas to pass through, except at the top where the pipe will pass through the landfill restoration capping material where they are of “hole free” construction.

Leachate well pipework is not usually wrapped with a filter geotextile, which if used, tends to blind up with fine material and the flow into the well then reduces or ceases. (However, discuss this with your local regulator before acting as opinions and practice vary.)

Twin wall pipe construction systems are commonly used, the inner wall smooth and the outer wall convoluted and with a maximum outer diameter of 160mm has been used by some. However, concern exists that this type of pipe is so flexible that there is a tendency for the wells made in this material to bend after installation more than for the solid HDPE pipe equivalent. The problem after gradual well pipe bending is that the pump may become stuck at the bend.

Although there are differences in views and practice adopted by LFG well drilling contractors, it is normal practice adopted by many driller/installers that no gravel or any other material is placed in the annulus between the well rising pipe and the ground/landfill waste. Gravel packs tend to prevent differential settlement between the liner and the well head which is a thing to be avoided. Furthermore it has been observed that where a gravel pack has been used with certain types of liner the entire well pipe structure has sheared, as a consequence of being too rigid.

Rigid pipework in wells will appear to rise at the wellhead as settlement takes place, and this needs careful consideration at the design stage.

The top of the landfill restoration cap (or liner) is usually set at approximately 2.5m below ground, or as deep as the capping layers plus the extra depth needed to accommodate the thickness of covering soils materials.

The use of a well head with a sleeved top pipe junction provides some flexibility for settlement and is considered good practice by many, as when settlement takes place the wellhead slides over the liner and no stresses build up which otherwise will usually bring problems at a later date.

However, other installers contest his and consider that fixed wellheads are best, as long as the owner/operator cuts the wellhead pipework down whenever necessary after settlement. This remedial work will be needed every few years anyway and should be considered to be normal maintenance for a landfill capping system.

When finally installed with the lateral flange connections are placed on the floor of the pipe trench, and they and all well pipe penetrations through the low permeability capping are sealed around with bentonite slurry.

The Landfill Gas Engineer having determined the design requirements must decide on the sort of well system that will best serve the specific needs of the site.

These different designs available can be classified as follows:-

STANDARD VERTICAL WELLS

The well design is as shown in figure 1 and includes a 6" nominal bore polypropylene well surrounding inserted within a 12" or 14" bore hole in the waste, with the outer annulus between the well pipe and the waste usually full of pea gravel, however some installers may leave out the pea gravel. The top 2-4m of the annulus are sealed using or a bentonite based clay with low permeability and high expansion when it becomes hydrolyzed after taking up water from the surroundings when it is placed. The casing is slotted (3mm) for the length below the bottom of the bentonite seal.

A wellhead made from UPVC fittings enables the installation of a 4" Durafelton valve for adjusting the suction on each well. A sampling point is provided to enable the well to be dipped for leachate and a manometer to be inserted to permit the well head suction pressure to be measured. A length of flexible pipe is used to connect the well head to the collection pipework to make allowance for a different settlement rate between the each.

LARGE DIAMETER VERTICAL WELL

A normal well design is where the landfill operator has installed a big circular precast concrete shaft that has gradually been raised with each lift of the waste as infilling advances. These are composed of large diameter punctured concrete rings which often alter in diameter but are usually six hundred mm to 1600 mm diameter.

To guard against the possible degradation of the concrete rings in an aggressive leachate environment a well surrounding is placed in the concrete rings.

Sealing the well can be done by either terminating the concrete rings below the final waste level or extending the well surrounding to the surface or extending the concrete rings to the surface and sealing the top 2-4m with polyurethane foam or bentonite clay.

A well head is needed for control and monitoring purposes including a length of flexible pipe to attach the well to the collection pipework.

SMALL BORE HORIZONTAL WELLS

These are usually comprised of 2" N.B. Slotted drainage pipes placed in a total surround inside an excavated ditch. The ditch is generally between half a metre and one metre deep in the refuse. Refuse and cover is then backfilled over the pipe and total to try to achieve an air tight seal.

Un-slotted 2" N.B. flexible pipe joins the gas picking up pipe to a central well head. The final connections to this central manifold are sealed with closed cell polyurethane foam.

GABION WELL

These consist of a metre diameter cylinder of gas and leachate porous material within the landfill held in place by an open-work gabion shell. A length of M.D.P.E. pipe is connected through the centre to a well head. Installation of these wells is either undertaken by either:

- excavation of a pit within the refuse, placing the gabion shell at the required depth and back filling with the excavated material
- progressively raising the structure with each lift of waste, as infilling progresses.

HYBRID WELL

As the name implies, the hybrid well mixes both vertical and horizontal forms of gas abstraction. 2" N.B. slotted pipe was placed vertically into the refuse. 6 vertical wells are then attached to a central well take-off point using un-slotted connecting pipe. Installation of the half-breed wells concerned excavation from the current refuse level, positioning the slotted pipe and porous fill, then backfilling.

RESULTS OF PERFORMANCE TESTING ON WELL TYPES

Although each well type has its own merits in particular landfill applications, not unexpectedly, by far the most efficient landfill gas well is a full depth large diameter vertical well. Thus, this type of well is nowadays the workhorse of LFG extraction

The following is an extract from the paper previously referred to by A Leach:

“To make comparisons between different gas wells the quotient of the flow rate against well head suction was determined for the range of flows where the gas quality is steady. This constant is obtained using the units of m^3/hr and mm Hg for flow rate and well head suction respectively. This method enabled a quick and easy comparison of different gas wells and gas well types to be made.

The higher the constant the more prolific the gas well and likewise the lower the constant the lower the gas yield for an equivalent well head suction.

Using this method to test wells of different designs in similar sites or areas they were able to rate the performance of different well types as follows:

WELL TYPE	**GAS WELL PERFORMANCE CONSTANT (m^3/hr.mm H_2O)**	
Large Diameter Vertical	5.0	Low Leachate Level
Standard Horizontal	1.5	
Standard Vertical	1.0-3.0	
Small Bore Horizontal	1.0	High Leachate Level
Gabion	0.7	
Hybrid	0.6	
Standard Vertical	0.3	
Large Diameter Vertical	0.3	

(Ref: LANDFILL GAS ABSTRACTION; A. Leach Shanks and McEwan (Southern) Ltd., Bedfordshire, landfill Gas Energy and Environment 1990.)

Obviously these results will only be repeatable in a site of similar waste inputs, waste age, depth etc.

However, the comparisons that can be made are useful and some conclusions can be drawn from them, namely:-

i. High leachate levels have a disastrous effect on vertical gas wells.

ii. The productivity of a well is in part related to the area of interface it has with the waste.

iii. Vertical wells perform better than horizontal wells in relation to the "area of interface" with the waste.

These conclusions can be explained as follows: Firstly the effect of a high leachate level on a vertical well is to greatly reduce the length of perforated well casing through which gas can be drawn as gas cannot be sucked through saturated waste.

If the leachate level rises too close to the top of the perforated section then a leachate "foam" is often produced in the well as gas is drawn into the well with leachate.

Secondly the increase in well productivity with a greater surface area exposed to the waste is as expected, unfortunately generally the greater the surface area the greater the cost of the well and its installation.

Finally the better performance of the vertical well with respect to the horizontal well can be explained by consideration of the lateral and vertical permeabilities of waste. Waste is put down in layers and sandwiched every day between further layers of daily cover material. As a consequence the lateral permeability is greater than the vertical permeability by up to as much as 40:1.

The vertical well penetrates all layers and is able to take full advantage of the higher lateral permeabilities."

PRACTICAL GAS WELL DESIGN

The choice of gas well for a particular site depends as much upon the practicalities of installation as much as it does on the design. Some of the advantages and disadvantages of the main well designs are summarised as follows:

STANDARD VERTICAL WELL

This is the most simply installed well especially if the waste is at last restoration levels. A good seal can be acquired around the apex of the well permitting high suctions to be applied.

Vertical wells are fitted with valves at each wellhead which permit the operator to blance the field of wells and to finely control gas quality and easily identify and isolate rogue wells. When used for gas migration control they permit variations of spacing from a normal 40m spacing within sites with 10m or deeper waste to cover areas of extra depth or unusual waste types in that area within the landfill.

Vertical well installation simplifies filling and avoids obstructing the tipping area with wells of the type that are raised with the waste as they are retrofitted after the waste has been brought to the surface. They cannot, be used due to their not being present at the start of infilling in a cell, earlier for leachate extraction during filling, so at least one concrete well may be needed to be raised simultaneously with the waste for leachate extraction during filling.

However, it is common that vertical wells will be combined leachate and landfill gas extraction wells with a leachate extraction pump inserted, which may be either an (in Europe) ATEX zone certified electric pump and a similarly certified pneumatic pump.

Vertical wells which are of rigid construction will have a tendency to settle at a lower rate to than the waste surrounding them causing a "floatation" effect, where the top of the wellhead appears to rise from the ground. Of course, what is actually happening is that it is the ground that is settling downward.

As a result the installation must permit the well surrounding to "rise" above the encircling ground level without damaging pipework and fittings or the end result will be well damage from loading the casing. A well surrounding too highly loaded due to settlement, differential or otherwise, will buckle and fail generally in its mid-section.

Proprietary well pipework is available which has joints which are designed to telescope together inside the bore of the well casing. In theory this offers a solution to the settlement problem, if not for always, for a long while. However, within the landfill gas installation industry not all of the specialist well installers are convinced this solution works in practice.

For this same reason solid connections from vertical wells installed to add horizontal branches in the waste and increase the influence of a well may fail when employed in sites subject to significant settlement, as are all sites taking a high proportion of domestic waste.

LARGE DIAMETER VERTICAL WELL

These wells are typically used primarily for leachate monitoring purposes.

The installation is comparatively straightforward provided care is taken by the site operators. Uniform compaction of waste around large diameter wells is tough to get right, and this can cause increased settlement round the well, poor sealing of the well or distortion and collapse of the well. In some locations during construction the odours from the plume of the well during its passive venting stage may prove unsuitable, so in many instances they are avoided.

If the well is sited on the base of the site then the settlement of the waste surface relative to the well will be larger than that experienced by the standard vertical well.

Provided a good seal can be done around the head of the well, and with good compaction, it can be an extremely effective gas well.

HORIZONTAL WELLS

This well type is quite rare and presents the site operator with a quandary in picking a methodology of installation.

Horizontal wells should ideally be installed to a depth of four metres or bigger to stop increased air ingress through the cap. This is capable of being achieved by trenching from last restoration levels, but only at the cost of a substantial odour nuisance during installation and with a loss of waste density immediately above the installed pipes at the risk of permitting accentuated air ingress during operation.

Or, alternatively horizontal wells can be installed with the filling operation this presumes extremely careful machine operators are employed to avoid pipe damage during installation, and even then there's no straightforward way of checking the pipe hasn't been crushed. A compromise solution is to shallow ditch the horizontal gas well into the waste before the placing of the last layers of waste.

The use of land drainage machinery has been attempted but generally ends up in pricey machine breakages. Horizontal gas wells might be surrounded by a gravel pack but for the degree of unavoidable over-break in the waste, which means that this may prove more costly than the pipe. Of course, without the gravel pack the pipe is very susceptible to point loading damage when under any plant loading from above.

Horizontal wells must always run uphill to permit the gas to be drawn from the highest point thus leaving the condensate to drain back to the site. To install them otherwise may lead to an efficient land drainage system that swamps the gas plant. Also excessively long runs need to be steered clear of obstacles especially where corrugated "drainage" pipe is employed as the corrugations severely cut back the effective diameter of the pipe. Settlement damage is most also possible and indeed likely to happen at the transition point where the horizontal well is attached to a vertical riser due to pressures caused by different settlement rates between the horizontal and vertical.

The control of horizontal wells is hard as often badly performing sections can't be isolated, also squashed or blocked pipe runs can't easily or simply be located. Gas extraction systems based on horizontal wells usually produce gas of a lower quality than their vertical well equivalents.

Many operators as a consequence of problems of reliability of this well type no longer use them.

LEACHATE EXTRACTION

Where leachate levels are too high for correct gas condensation to be exercised and sumps installed originally as dedicated leachate pumping wells and boreholes don't exist or have collapsed and failed it is feasible to reduce leachate levels by pumping from vertical gas wells.

In fact, increasingly, landfill operators are seeking to fill cells rapidly before leachate builds up and before they need to extract leachate, and then rely entirely on retrofitted wells.

Three pumping techniques are available for leachate removal, but only two are commonly used, these being c. and d. in the list which follows:

a. Ejector Pumps

b. Shaft Driven Sump Pumps

c. Submersible Electric Pumps

d. Pneumatic (Compressed Air Driven) Pumps

Both Ejector and Shaft Driven Pumps have been used with a low level of success, and neither are supported in the UK by specialist contractors specifically offering suitable products for use in the corrosive and high organic fouling conditions found in landfill leachate applications.

There may be some limited potential for their use in very weak leachates, but in those cases simultaneous landfill gas extraction would be unlikely, and their interest to those involved in landfill gas systems would be very low.

Ejector Pumps use the venturi principle to provide a low cost and very simple pump head which is lowered to the bottom of the well, and with no moving parts required in the landfill the idea seems to be very sound. Unfortunately, corrosion at the pump head/venturi is high and add to that the fact that a lot of high pressure water has to be pumped out to bring back a small additional quantity of leachate at lower pressure, the use of energy is high so the system has been largely ignored. With rising power costs this is hardly a selling point for the technology.

Shaft driven pumps, are easy to maintain at ground level, but they are limited in shaft length and thus in the depth from which they can draw leachate. Removal of the heavy rigid shaft is also a costly exercise.

Electric submersible pumps were the most popular leachate extraction work-horses for the industry for many years.

The 316SS, 4" Grundfos submersible pumps, and equivalent FLYGT equivalents were placed in big numbers in large wells and still are some of the most common used, and as fitted with special high temperature motors and connected with a flexible riser, they do allow easy removal of the pump for servicing. Plus, they can be used for a lift of no more than say 4 metres, but when fitted with a high head impeller they can pump to almost 40 metres head.

These pumps have a high solids passing tolerance making them robust in operation, and not subject to blocking. Unfortunately, their high torque on start up tends to disturb and draw silt through collection systems more rapidly than a gentler system such as pneumatic systems, however, the big stumbling block for most when considering electric submersible pumps for new installations was in the EU the introduction of the ATEX Directive.

Recently in the United Kingdom various specialist electric down-well pumps to suitable ATEX certification levels, have become available for use in 6” bore wells.

The problem for the large Grundfos type electric submersible pumps arises for the designer who in accordance with the ATEX Directive and in the UK DSEA Regulations is required to select the safest system. When a design engineer is confronted with the air driven largely intrinsically safe alternative, and electric submersible pumps which are not inherently intrinsically safe, will usually choose the pneumatic alternative.

This is a case of the regulations having a perverse effect, as the actual additional risk inherent in the electrically driven system are tiny, and both can be purchased with the appropriate ATEX (explosion protection rating) certification.

Pumps are installed in 6" diameter gas wells drilled to the maximum depth possible without affecting the integrity of the base seal, and were waste and leachate depths permit, fitted with a length of plain casing at the bottom to provide a sump in which the pump can be located.

The location of the pump within a plain casing sump minimises the ingress of gas drawn in at the pump suction which can otherwise seriously affect the pumps performance.

Control of electrical pumping is achieved by a digital timer mounted in a control box located four metres from the gas well and by so doing is outside the explosion zone. (See the ATEX section for more information about zoning.)

The sundry and antagonistic environment inside a gas well isn't conducive to trustworthy operation of sensors, so if you are required to install them by regulatory or other requirements seek out the most rugged and if possible devices intended for use in landfills.

The performance of these sensors was further irritated by the capability of gas wells between the completely flooded and dewatered stages to foam copiously.

LANDFILL GAS WELL FIELD INTERCONNECTION PIPEWORK

Gas wells should be connected using PE, MDPE or HDPE pipe laid to maximise falls to stop condensate build-up at low points, and of a generous size to minimise gas flow friction losses. The highest level consideration should be given to the consequences of settlement and then designing out these effects.

Landfill gas extraction systems operate at fairly low suction pressures. If the extraction pipework becomes filled a blockage ensues. The air suction pressure is quite simply unable to pull gas through a water (condensate) filled pipe.

Care is needed especially on the link between the well and the collection pipe where some tolerance of movement must be allowed and also on the effects of settlement on collection pipeline falls.

The necessity to profile the site with satisfactory pre-settlement surcharge is typically an imperative for the success of the gas condensation system. Flat pipeline runs on fill material must be ruled out and this may for example mean the main collection pipes are moved to virgin ground at the fringe of the site, just to avoid subsequent settlement which would cause loss of free draining gradients.

To stop condensate build-up and slugging, pipe sizing should permit lower gas velocities where condensate and gas are contra-flowing than for pipes where gas and condensate flow in the same direction.

May landfill site gas extraction systems have failed prematurely at great cost to the landfill operator, due to lack of attention to detail within the gas pipework layout and design.

Smaller diameter pipes manifestly are far more simply blocked by condensate than bigger pipes and so what seems to be excessively generous sizing at the design stage could in reality be money wisely spent though it could be tough to prove.

Black P.E. pipe is sometimes used as it is less expensive than the standard yellow gas main pipe utilized by the gas utilities, and is not an inferior material as some salesmen may have the novice buyer suspect. Black P.E. is often more immune to degradation from ultra violet (UV) light than yellow P.E. so always check UV tolerance and permissible storage times before use to avoid such damage. Tracer wires can be laid with pipes, but may be of little use where metal objects in underlying waste may trigger the tracing device and make future pipe tracing impossible.

PVC pipe shouldn't be used as it is a brittle material and does not have the inherent plastic deformation capability of PE, MDPE and HDPE. Due to its brittle nature PVC will become highly stressed if put through settlement. PVC and solvents used to joint PVC are also susceptible to material degradation when in contact with condensate.

DEWATERING

As stated previously, landfill gas at the wellhead is usually at the saturation moisture point and at a temperature of 25-45^{o}C. Therefore a big quantity of liquid is being carried by the gas that may be expected to keep on dropping out as the gas cools on its way to the gas condensation compound.

All potential water traps must be identified and eliminated in the design of the collection system and the landfill gas design Engineer must make sure that future settlement does not affect the capability of the system to continually empty itself of condensate.

Where syphons are used for condensate removal the Engineer must be satisfied that future rises in leachate level won't stop the condensate soaking away. Also the planning of a syphon should enable its performance to be checked for future system fault diagnosis. Knock-out pots found at the fringe of the site on undisturbed ground (not waste) or before the fan or compressor has the benefit of that faults can be simply diagnosed and condensate can be removed from the site for treatment with leachate.

This is especially beneficial where leachate levels are being reduced by pumping. The condensate will contain the volatile elements of leachate in much higher concentrations than seen in leachate, and often has a pH less than five and so is even more highly corrosive to some materials than leachate. Corrosion steels and plastics should be used throughout in the construction of knock-out pots and all parts in contact with condensate.

COMPRESSORS (BLOWERS)

The kind of machine to be used for developing negative pressures for landfill gas extraction is called a "blower" and the choice of a blower type depends on a number of factors. The diameter and run length of the pipeline and the quantity of gas to be extracted, establish the suction needs, while the means of disposal sets the discharge pressure, whether by flaring or EfW power generation use.

Where environmental control by flaring is necessary rugged and heavily corrosion protected centrifugal fans are usually the most low cost and trustworthy way of abstracting gas. If elevated discharge pressures are required as for instance with low pressure spark ignition engines higher pressure fans, two stage fans or regenerative fans could be used.

For pressures up to one bar gauge as is typically needed by industrial burner installations Rootes-type blowers generally prove the most cost effective. The Rootes type blower has lobe shaped impellers which rotate within a casing and entrain fluid as they do so.

Above one bar gauge and up to pressures of roughly three bar gauge, oil lubricated sliding vane compressors have been used successfully.

Above this pressure the choice is reported as being limited to reciprocating economic gas compressors. It is also reported that liquid ring compressors can present the operator with a heavy upkeep load as the sealing liquid is in contact with the gas and becomes poisoned leading to increased corrosion rates and biomass build up.

Screw compressors should also reportedly be avoided due to contamination of the sealing liquid (oil) with landfill gas and condensate.

GAS DRYING

The need for and extent of gas drying before onward delivery of the landfill gas to the gas engine, turbine, factory, or biomethane upgrade step, needs to be determined by the landfill gas Engineer at the system design stage.

Where gas is being supplied to a commercial buyer the inability to supply gas due to a build-up of condensate in pipework, valves and meters leads to unwanted spending in lost production and man hours and would do great damage to client / provider relationships.

Where pipework is exposed to freezing temperatures even larger gas supply failures are possible unless drying I provided. Also the presence of condensate in the gas stream would probably be expected to increase the corrosion and upkeep of downstream elements especially for items like regulators and positive displacement gas meters.

Where gas is supplied immediately to engines for power generation then the choice to dry or not to dry is less clear cut. The removal of condensate from the gas stream does remove some soluble trace contaminants from the gas stream. Also the condensate itself is sufficiently aggressive if permitted to form in the engine to cause corrosion damage.

The removal of condensate may so be considered a worthwhile step targeted at increasing oil life and reducing corrosion though inadequate research has been done to quantify the advantages.

Gas drying can be achieved reportedly by any one of number of strategies some of which are described below:

A. Radiator (pre-cooler) and refrigerant chiller with 2 heat exchangers to warm up the outgoing gas. A relative humidity of 50% and dew point of 3C are generally achieved across all ambient temperatures.

B. Radiator (pre-cooler) and deliquescent drier. Needs the radiator to achieve an approach temperature of less than 10C above ambient for relative humidities of 48-55% and dew points from -8C upwards, dependent on ambient temperatures are generally achieved.

C. Buried pipeline (pre-cooler) and deliquescent drier. This needs a buried pipeline of enough length, and laid to a fall, to permit condensate formation down to a temperature less than 10C above ground temperature. The deliquescent drier then decreases the gas dew point at least 10C. This strategy is successfully employed in Sweden to dispose of the need for pipeline dewatering to below surrounding ground temperature.

D. Gas heating or trace heating of pipelines and elements. The dew point achieved will be that of the compressor package outlet gas and the relative humidity will depend on the quantity of heating applied.

On some engine installations the jacket water heat can be used to cut back the relative humidly of the supplied gas.

FLAME ARRESTORS

Flame arrestors or automatic emergency slam shut valves with suitable automatic closure mechanisms must be provided between the pump and the flare stack.

HEALTH AND SAFETY

We can only touch on a few of the special risks encountered by those involved landfill gas and EfW schemes in this book. It is essential to treat landfill gas and its associated gases found from time to time on landfills with a very great deal of respect and always remain vigilant to avoid accidents.

There have been a number of deaths worldwide from landfill gas.

Landfill sites which are gassing present a risk of explosion, which means that the EU ATEX Directive applies. Each EU state applies the Directive locally. In England for example the directive is regulated under the DSEAR (Dangerous Substances and Explosive Atmospheres Regulations).

All confined spaces must also be risk assessed and require compliance with the HSE (UK) Confined Spaces Regulations as well.

Guidance is available for England and Wales, on how to install and operate landfill gas systems safely in the form of the Waste Industry ICoPs (Industry Codes of practice).

Visit the Environmental Services Association www.esauk.org and go to their publications page where you will find a link from which all 5 of the codes can be downloaded completely free of charge.

A useful web site for assessing the tasks needed to be completed before the operator/owner of a landfill gas extraction system/EfW scheme can achieve DSEAR compliance is www.atexanddsear.co.uk

RESOURCES SECTION

LANDFILL AND LANDFILL GAS SYSTEMS DESIGN CONSULTANT

Enviros Consulting www.enviros.com (also CDM "Carbon Credit" Applications and Advice)

SPECIALIST LANDFILL GAS EQUIPMENT SUPPLIERS:

Gem/Geotech	www.geotech.co.uk
MGS	www.mgs.co.uk
QED	www.qedenv.com
Fernco	www.fernco.com
Flexseal	www.flexseal.co.uk

SPECIALIST LANDFILL GAS EXTRACTION SYSTEM INSTALLERS AND OPERATORS

B9 Energy	www.b9energy.co.uk
Biogas	www.biogas.com
EDL	www.energydevelopments.com.au
EnerG	http://www.energ.co.uk/landfill_gas_generations
Organics	www.organics.com
RPS	www.renewablepower.co.uk
Viridian Systems	www.viridiansystems.co.uk (also act as suppliers)

WASTE AND RESOURCE MANAGEMENT WEB SITES

Landfill Site Information	www.landfill-site.com
Landfill Gas Information	www.landfill-gas.com
Wastersblog	www.wastersblog.com (UK Based Waste Management Blog)
Landfill Construction Quality Assurance Blog	www.blog.landfillcqa.co.uk
Leachate Web Site	www.leachate.co.uk
Environmental Services Organisation (ATEX & DSEAR)	www.esauk.org
ATEX & DSEAR Complianc	www.atexanddsear.co.uk

USEFUL GENERAL WEB SITES (UK)

Environment Agency (England & Wales) www.environment-agency.gov.uk

UK Health & Safety Executive www.hse.gov.uk

NEED FURTHER ASSISTANCE?

Further professional design assistance and UK waste regulations advice from Expert Consultants in Landfill Gas and Landfill Design based in the United Kingdom, Ireland and South Africa, **is available**.

Just **email steve@ippts.com with your query** and we will provide a fee price quotation for solving your problem.

Funding Queries:

Please only approach us for funding assistance if the project is well defined

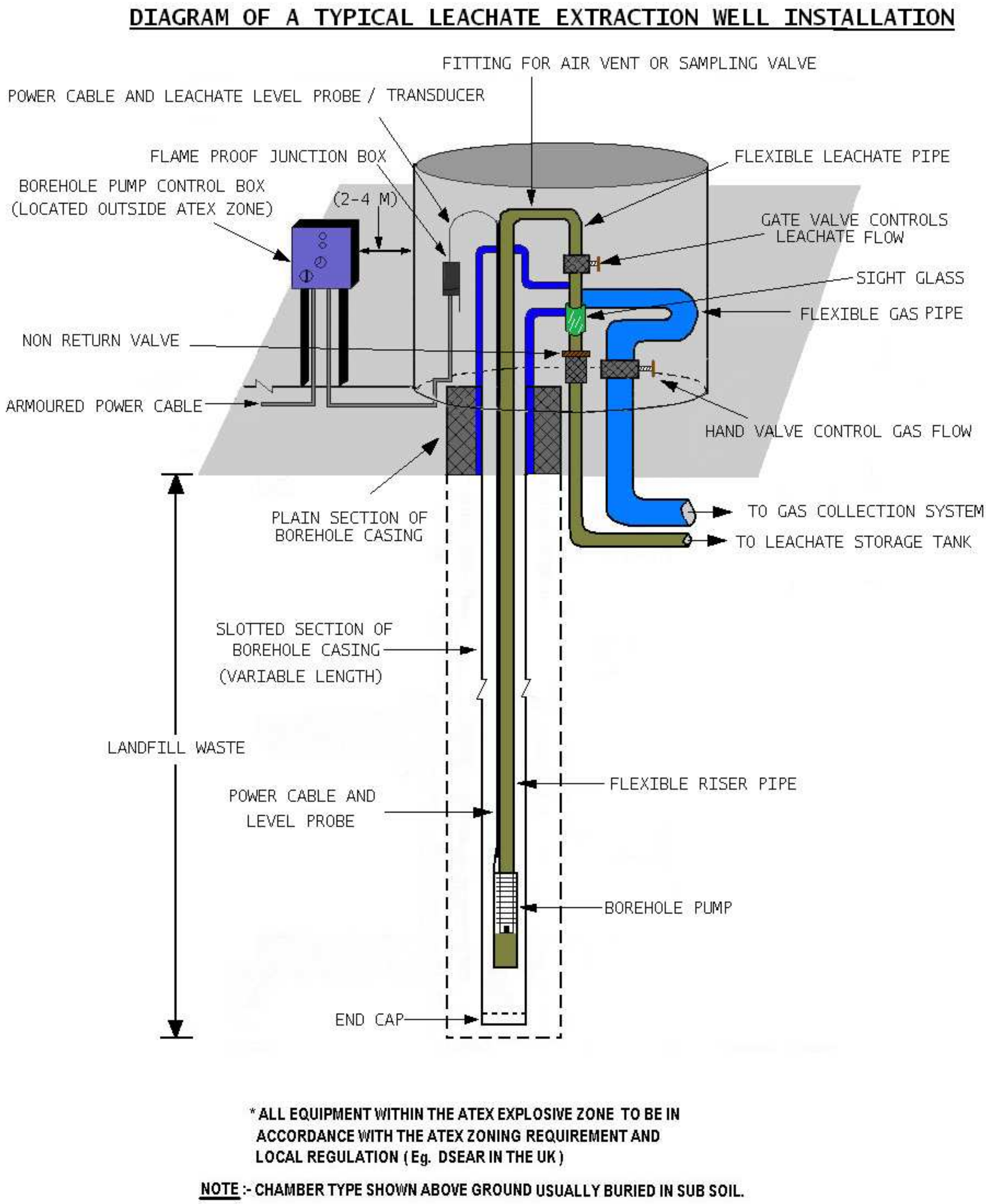
Although **consultancy work can be carried out at any stage of an EfW project** on the basis of a fee proposal and agreed payment, the same is not true for projects where we are asked to waive payment for a stake in the venture.

Funding through a partner whom we may introduce may be possible. However, we regularly receive funding assistance queries for projects at a stage which is too early for the project to be "bankable". **We do know various organisations and some individuals, who will consider funding this type of scheme, but only if approached at the right stage.**

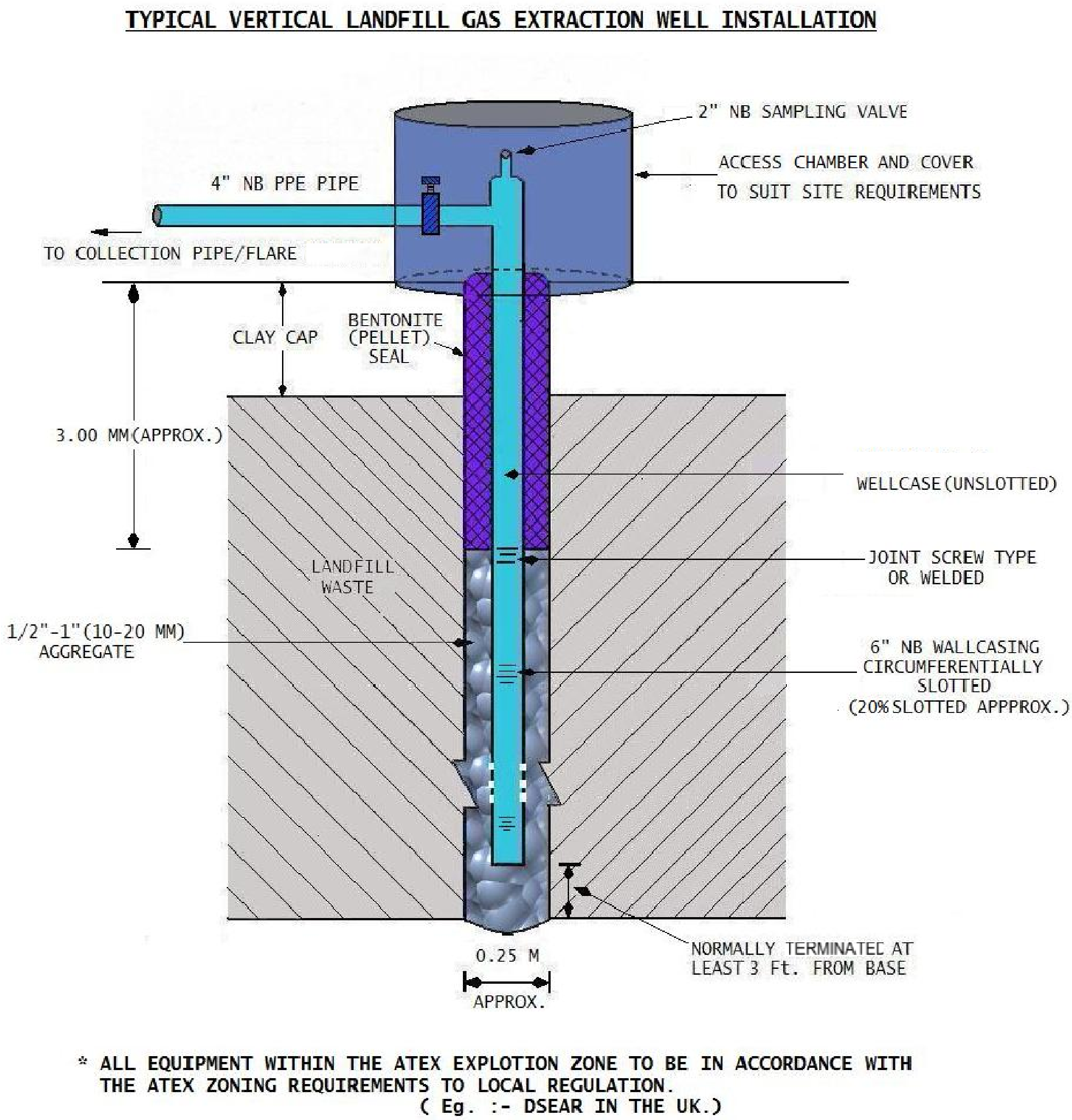
It is very rare that we can take schemes forward, until a stage is reached where evidence can be provided that the proposer holds **ownership rights to the landfill gas, and regulatory provisions** have been **complied with** (such as planning consent), or are well known and very close to being resolved.

DRAWINGS

1. Typical Vertical Borehole Detail – Diagram of a Typical Leachate and Gas Extraction Well Installation
2. Typical Vertical Borehole Detail – Diagram of a Typical Gas Extraction Well



This type of well extracts both landfill gas and leachate, while the second diagram shows a landfill gas only well.



If you require paid landfill gas system design and/or CDM consultancy advice this is available. Email steve@ippts.com for a free quote.