Sector Guidance Note IPPC S5.03

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Guidance for the Treatment of Landfill Leachate

Integrated Pollution Prevention and Control (IPPC)

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Environment & Heritage Service www.ehsni.gov.uk
Environment Agency
SEPA Scottish Environment Protection Agency

Table 0.1: Record of Changes

Version	Date	Change	Template Version
Pre-Consultation		Draft for internal and external consultation	
External Consultation	January 2006	Amended following internal and external consultation	
Final Draft	February 2007	Amended following external consultation	

Note: Queries about the content of this document should be made to Jill Rooksby (0121 708 4655) or any member of the Waste Process Technical Services Team.

Written comments or suggested improvements should be sent to Waste Process Technical Services Team at the Environment Agency by e-mail to:

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Executive Summary

This guidance has been produced by the Environment Agency for England and Wales and the Northern Ireland Environment and Heritage Service (EHS) and the Scottish Environment Protection Agency (SEPA). Together these are referred to as "the regulator" throughout this document. Its publication follows consultation with industry, Government departments and non-governmental organisations.

This guidance and the BREF

This UK guidance for delivering the PPC (IPPC) Regulations for Leachate Treatment has considered BAT Reference document BREF (Reference Document on Best Available Techniques for Waste Treatment Industries dated August 2005) produced by the European Commission. The BREF is the result of an exchange of information between member states and industry. The quality, comprehensiveness and usefulness of the BREF is acknowledged. This guidance is designed to complement the BREF and concentrates specifically on Leachate Treatment. It takes into account the information contained in the BREF and lays down the indicative standards and expectations in the UK (England and Wales, Scotland and Northern Ireland).

The aims of this guidance

The aims of this guidance are to:

- provide a clear structure and methodology for operators to follow to ensure they address all aspects of the PPC Regulations and other relevant Regulations
- minimise the effort by both operator and regulator in the permitting of an installation by expressing the BAT techniques as clear indicative standards
- improve the consistency of applications by ensuring that all relevant issues are addressed
- increase the transparency and consistency of regulation by having a structure in which the operator's response to each issue, and any departures from the standards, can be seen clearly and which enables applications to be compared

To assist operators in making applications, separate, horizontal guidance is available on a range of topics such as waste minimisation, monitoring, calculating stack heights and so on. Most of this guidance is available free through the Environment Agency or EHS (Northern Ireland) and the Scottish Environment Protection Agency (SEPA) websites (see Reference).

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Key environmental issues

The key environmental issues for this sector are:

- **Emissions to sewer** – discharge to sewer and co-treatment at a Waste water Treatment Works (WwTW), is acceptable providing that such discharge and treatment guarantees an equivalent level of protection of the environment, taken as a whole, as would be achieved if dedicated treatment on-site had been employed.
- **Selection of appropriate technique** – techniques should be designed and operated to avoid deliberate or inadvertent production and/or displacement of substances that may be harmful to the environment and to prevent the transfer of such substances from one environmental medium to another.
- **Accident risk** – accident risks are increased through any failure in the management of leachate.
- **Odour associated with fugitive emissions** - the handling and treatment of leachate will potentially lead to odour noticeable beyond the installation boundary.
- **Site restoration (prevention of emissions to land)** – PPC in common with Waste Management Licensing requires that, on completion of activities, there should be no pollution risk from the site.

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1. Introduction

The status and aims of this guidance

This guidance has been produced by the; Environment Agency for England and Wales; Scottish Environment Protection Agency (SEPA) in Scotland; and the Environment and Heritage Service (EHS) in Northern Ireland - each referred to as "the regulator" in this document. Its publication follows consultation with industry, Government departments and non-governmental organisations.

It aims to:

- Provide operators and the regulator's officers with advice on indicative standards of operation and environmental performance relevant to the industrial sector concerned,
- Assist the former in the preparation of applications for PPC Permits, and to
- Assist the latter in the assessment of those applications (and the setting of a subsequent compliance regime).

The use of techniques quoted in the guidance and the setting of emission limit values at the benchmark values quoted in the guidance are not mandatory, except where there are statutory requirements from other legislation. However, the regulator will carefully consider the relevance and relative importance of the information in the guidance to the installation concerned when making technical judgements about the installation and when setting conditions in the permit, any departures from indicative standards being justified on a site-specific basis. The guidance also aims (through linkage with the application form or template) to provide a clear structure and methodology for operators to follow to ensure they address all aspects of the PPC Regulations and other relevant Regulations, that are in force at the time of writing. Also, by expressing the Best Available Techniques (BAT) as clear indicative standards wherever possible, it aims to minimise the effort required to permit an installation (by both operator and regulator).

SECTIONS 1.1 to 1.8 INCLUSIVE APPLY TO ENGLAND, WALES AND NORTHERN IRELAND ONLY. FOR INFORMATION ON THE LEGISLATION AND ITS INTERPRETATION IN SCOTLAND, PLEASE REFER TO SEPA'S WEBSITE.

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1.1 Understanding IPPC

IPPC and the Regulations

Integrated Pollution Prevention and Control (IPPC) is a regulatory system that employs an integrated approach to control the environmental impacts of certain listed industrial activities. It involves determination by the regulator of the appropriate controls for those industries to protect the environment, through a single permitting process. To gain a permit, operators have to demonstrate in their applications, in a systematic way, that the techniques they are using or are proposing to use, are the Best Available Techniques (BAT) for their installation and meet certain other requirements, taking account of relevant local factors.

The essence of BAT is that the techniques selected to protect the environment should achieve an appropriate balance between environmental benefits and the costs incurred by operators. However, whatever the costs involved, no installation may be permitted where its operation would cause significant pollution.

The three regional versions of the PPC Regulations implement in the UK the EC Directive on IPPC (96/61/EC). Further information on the application of IPPC/PPC, together with Government policy and advice on the interpretation of the English & Welsh Regulations, can be found in *IPPC: A Practical Guide* published by the Department for Environment, Food and Rural Affairs (Defra). The Department of the Environment, Northern Ireland has published equivalent guidance on the Northern Ireland Regulations.

Installation based, NOT national emission limits

The BAT approach of IPPC differs from regulatory approaches based on fixed national emissions limits (except where General Binding Rules or Standard Permits are issued). The legal instrument that ultimately defines BAT is the permit, and permits can only be issued at the installation level.

Indicative BAT Standards

Indicative BAT standards are laid out in national guidance (such as this) and, where relevant, should be applied unless a different standard can be justified for a particular installation. BAT includes the technical components, process control, and management of the installation given in Section 2 and the benchmark levels for emissions identified in Section 3. Departures from those benchmark levels can be justified at the installation level by taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. If any mandatory EU emission limits or conditions are applicable, they must be met, but BAT may go further (see "BAT and EQS" below).

Some industrial sectors for which national guidance is issued are narrow and tightly defined, whilst other sectors are wide and diffuse. This means that where the guidance covers a wide variety of processes, and individual techniques are not described in detail, the techniques (and their associated emission levels) which might constitute BAT for a particular operation, are more likely to differ, with justification, from the indicative BAT standards than would be the case for a narrow, tightly-defined sector.

BAT and EQS

The BAT approach complements, but differs fundamentally from, regulatory approaches based on Environmental Quality Standards (EQS). Essentially, BAT requires measures to be taken to prevent emissions - and measures that simply reduce emissions are acceptable only where prevention is not practicable. Thus, if it is economically and technically viable to reduce emissions further, or prevent them altogether, then this should be done irrespective of whether or not EQSs are already being met. The BAT approach requires us not to consider the environment as a recipient of pollutants and waste, which can be filled up to a given level, but to do all that is practicable to minimise emissions from industrial activities and their impact. The BAT approach first considers what emission prevention can

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reasonably be achieved (covered by Sections 2 and 3 of this Guidance) and then checks to ensure that the local environmental conditions are secure (see Section 4 of this Guidance and also Guidance Note IPPC Environmental Assessments for BAT). The BAT approach is therefore the more precautionary one because the release level achieved may be better than that simply required to meet an EQS.

Conversely, if the application of indicative BAT might lead to a situation in which an EQS is still threatened, a more effective technique is required to be BAT for that installation. The Regulations allow for expenditure beyond indicative BAT where necessary, and, ultimately, an installation will only be permitted to operate if it does not cause significant pollution.

Further advice on the relationship between BAT, EQSs and other related standards and obligations is given in *IPPC: A Practical Guide*.

Assessing BAT at the sector level

The assessment of indicative BAT takes place at a number of levels. At the European level, the European Commission issues a "BAT reference document" (BREF) for each main IPPC sector. It also issues "horizontal" BREFs for a number of general techniques which are relevant across a series of industrial sectors. The BREFs are the result of an exchange of information between regulators, industry and other interested parties in Member States. Member States should take them into account when determining BAT, but they are allowed flexibility in their application. UK Sector Guidance Notes like this one take account of information contained in relevant BREFs and set out current indicative standards and expectations in the UK. At national level, techniques that are considered to be BAT should represent an appropriate balance of costs and benefits for a typical, well-performing installation in the sector concerned. They should also be affordable without making the sector as a whole uncompetitive, either within Europe or world-wide.

Assessing BAT at the installation level

When assessing applicability of sectoral indicative BAT standards at the installation level, departures may be justified in either direction. Selection of the technique which is most appropriate may depend on local factors and, where the answer is not self-evident, an installation-specific assessment of the costs and benefits of the available options will be needed. The regulator's guidance IPPC Environmental Assessments for BAT and its associated software tool may help with the assessment. Individual installation or company profitability (as opposed to profitability of the relevant sector as a whole) is not a factor to be considered, however.

In the assessment of BAT at the installation level, the cost of improvements and the timing or phasing of that expenditure, are always factors to be taken into account. However, they should only be major or decisive factors in decisions about adopting indicative BAT where:

- the installation's technical characteristics or local environmental conditions can be shown to be so different from those assumed in the sectoral assessment of BAT described in this guidance, that the indicative BAT standards may not be appropriate; or
- the BAT cost/benefit balance of an improvement only becomes favourable when the relevant item of plant is due for renewal/renovation (e.g.. change to a different design of furnace when the existing furnace is due for a rebuild). In effect, these are cases where BAT for the sector can be expressed in terms of local investment cycles; or
- a number of expensive improvements are needed. In these cases, a phasing programme may be appropriate - as long as it is not so drawn out that it appears to be rewarding a poorly performing installation.

In summary, departures by an individual installation from indicative BAT for its sector may be justified on the grounds of the technical characteristics of the

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installation concerned, its geographical location and the local environmental conditions - but not on the basis of individual company profitability, or if significant pollution would result. Further information on this can be found in *IPPC: A Practical Guide*.

Innovation

The regulators encourage the development and introduction of innovative techniques that advance indicative BAT standards criteria, i.e.. techniques which have been developed on a scale which reasonably allows implementation in the relevant sector, which are technically and economically viable and which further reduce emissions and their impact on the environment as a whole. One of the main aims of the PPC legislation is continuous improvement in the overall environmental performance of installations as a part of progressive sustainable development. This Sector Guidance Note describes the indicative BAT standards at the time of writing but operators should keep up-to-date with improvements in technology - and this guidance note cannot be cited as a reason for not introducing better available techniques. The technical characteristics of a particular installation may also provide opportunities not foreseen in the guidance, and as BAT is determined at the installation level (except in the case of General Binding Rules (GBRs)), it is a requirement to consider these even where they go beyond the indicative standards.

New installations

Indicative BAT standards apply, where relevant, to both new and existing installations, but it will be more difficult to justify departures in the case of new installations (or new activities in existing installations) - and for new activities, techniques which meet or exceed indicative BAT requirements should normally be in place before operations start.

Existing installations – installation level

For an existing installation, it may not be reasonable to expect compliance with indicative BAT standards immediately if the cost of doing so is disproportionate to the environmental benefit to be achieved. In such circumstances, operating techniques that are not at the relevant indicative BAT standard may be acceptable, provided that they represent what is considered BAT for that installation and otherwise comply with the requirements of the Regulations. The determination of BAT for the installation will involve assessment of the technical characteristics of the installation and local environmental considerations, but where there is a significant difference between relevant indicative BAT and BAT for an installation, the permit may require further improvements on a reasonably short timescale.

Existing installations – upgrading timescales

Where there are departures from relevant indicative BAT standards, operators of existing installations will be expected to have upgrading plans and timetables. Formal timescales for upgrading will be set as improvement conditions in the permits. See Section 1.4.2 for more details.

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1.2 Making an application

A satisfactory application is made by:

- addressing the issues in Sections 2 and 3 of this guidance;
- assessing the environmental impact described in Section 4 (and in England and Wales Environmental Assessment and Appraisal of BAT (IPPC H1));
- demonstrating that the proposed techniques are BAT for the installation.
- providing a site report in accordance with *Environment Agency Guidance H7.*

In practice, some applicants have submitted far more information than was needed, yet without addressing the areas that are most important - and this has led to extensive requests for further information. In an attempt to focus application responses to the areas of concern to the regulator, Application forms (templates) have been produced by the Environment Agency, and by EHS in Northern Ireland. In addition, as the dates for application have approached, the operators in most industrial sectors in England and Wales have been provided with compact discs (CDs) which contain all relevant application forms, technical and administrative guidance, BREFs and assessment tools, hyper-linked together for ease of use.

For applicants with existing IPC Authorisations or Waste Management Licences, the previous applications may provide much of the information for the PPC application. However, where the submitted application refers to information supplied with a previous application the operator will need to send fresh copies – though for many issues where there is a tendency for frequent changes of detail (for example, information about the management systems), it will be more appropriate simply to refer to the information in the application and keep available for inspection on site, up-to-date versions of the documents.

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1.3 Installations covered

This guidance relates to installations containing the activities listed below, as described in Part A(1) of Schedule 1 to The Pollution Prevention and Control Regulations. The schedules of listed activities are slightly different in Northern Ireland so for their equivalent Regulations see Appendix 2. In Scotland the technical standards are applicable although the legislative differences will mean the scope of the guidance needs to be considered on a site-specific basis. Therefore the operator is advised to discuss the applicability of this guidance with SEPA for sites located in Scotland.

Section 5.3 – Disposal of Waste Other Than by Incineration or Landfill

Part A(1)
(a) The disposal of hazardous waste (other than by incineration or landfill) in a facility with a capacity of more than 10 tonnes per day.

(c) Disposal of non-hazardous waste in a facility with a capacity of more than 50 tonnes per day by –

(i) biological treatment, not being treatment specified in any paragraph other than paragraph D8 of Annex IIA to Council Directive 75/442/EEC, which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12 in that Annex (D8); or

(ii) physico-chemical treatment, not being treatment specified in any paragraph other than paragraph D9 in Annex IIA to Council Directive 75/442/EEC, which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12 in that Annex (for example, evaporation, drying, calcination, etc.) (D9).

The Environment Agency considers that disposal of the liquid effluent to sewer is either a D6 (release into a water body except seas/oceans) or a D7 (release into seas/oceans including sea-bed insertion) activity depending on the final point of release from the sewerage system.

This guidance also relates to **activities** forming a directly associated technical connection to the following activities, described in Schedule 1 Section 5.2 - Disposal of Waste by Landfill

Part A(1)
(a) The disposal of waste in a landfill receiving more than 10 tonnes of waste in any day or with a total capacity of more than 25,000 tonnes, excluding disposals in landfills taking only inert waste.

(b) The disposal of waste in any other landfill to which the 2002 Regulations apply.

Directly associated activities

Environment Agency advice on the composition of English or Welsh installations and which on-site activities are to be included within it (or them) is given in its guidance document *IPPC Regulatory Guidance Series No. 5 – Interpretation of "Installation" in the PPC Regulations*. Operators are advised to discuss the composition of their installations with the regulator before preparing their applications.

The installation will also include **associated activities** that have a technical connection with the main activities and which may have an effect on emissions and pollution, as well as the main activities described above. These may involve activities such as:

- the storage and handling of raw materials;

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- the management, handling and unloading of imported leachates;
- the storage and despatch of waste and other materials (primarily sludges from biological treatment processes);
- the control and abatement systems for emissions to all media;
- waste treatment or recycling.

For examples of some types of activities covered by this document see section 1.7.

Installation and sewer connection

The definition of sewer is given in Section 1.5 below. In considering whether a sewer is part of the installation the usual tests would apply and the decision will depend on the facts in any given case. The Environment Agency provides guidance on the definition of installation in *IPPC Regulatory Guidance Series No. 5 – Interpretation of "Installation" in the PPC Regulations*.

Any private sewer taking treated leachate from a leachate plant would normally remain part of the installation until it enters the public sewer or until other users connect to it. The length of the private sewer is one of the relevant factors when considering whether the private sewer is part of the same site as the leachate treatment plant. In cases where private sewers do not form part of the same site as the installation then appropriate off site conditions may be used to ensure the sewer's integrity.

Importation of leachate

In the UK, in some circumstances and at some locations, operators choose to transport leachate from one landfill to a leachate treatment plant located at another site.

This may be done for technical reasons such as:

- to enable an optimum disposal route to be used for treated leachate – e.g. a larger surface watercourse, or a more suitable location for discharge of effluent into the public sewer;
- to allow a single treatment system to be operated, supervised and monitored in an optimum manner. One example might be importation of leachate (by pipeline or tanker), from a small, closed landfill, to a leachate treatment plant on a large, operational landfill;
- to provide an optimum blend of leachate quality for the specific treatment process, to encourage most effective and consistent treatment of contaminants.

Or, it may be done for economic reasons, for example, where it is more cost-effective to construct and operate a single large leachate treatment plant at one location, rather than to provide two smaller, similar plants at two separate landfill sites.

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1.4 Timescales

1.4.1 Permit review periods

Permits are likely to be reviewed as follows:

- for individual activities not previously subject to regulation under IPC or Waste Management Licensing, a review should be carried out within four years of the issue of the PPC Permit
- for individual activities previously subject to regulation under IPC or Waste Management Licensing, a review should be carried out within six years of the issue of the PPC Permit

However, where discharges of Groundwater List I or List II substances have been permitted, or where there is disposal of any matter that might lead to an indirect discharge of any Groundwater List I or II substance, a review must be carried out within four years as a requirement of the Groundwater Regulations.

These periods will be kept under review and may be shortened or extended.

1.4.2 Upgrading timescales for existing plant

Existing installation timescales

Unless subject to specific conditions elsewhere in the permit, upgrading timescales will be set in the improvement programme of the permit, having regard to the criteria for improvements in the following two categories:

1. *Standard "good-practice" requirements, such as, management systems, waste, water and energy audits, bunding, housekeeping measures to prevent fugitive or accidental emissions, good waste handling facilities, and adequate monitoring equipment.* Many of these require relatively modest capital expenditure and so, with studies aimed at improving environmental performance, they should be implemented as soon as possible and generally well within 3 years of issue of the permit.
2. *Larger, more capital-intensive improvements, such as major changes to reaction systems or the installation of significant abatement equipment.* Ideally these improvements should also be completed within 3 years of permit issue, particularly where there is considerable divergence from relevant indicative BAT standards, but where justified in objective terms, longer time-scales may be allowed by the regulator.

Local environmental impacts may require action to be taken more quickly than the indicative timescales above, and requirements still outstanding from any upgrading programme in a previous permit should be completed to the original time-scale or sooner. On the other hand, where an activity already operates to a standard that is close to an indicative requirement a more extended time-scale may be acceptable. Unless there are statutory deadlines for compliance with national or international requirements, the requirement by the regulator for capital expenditure on improvements and the rate at which those improvements have to be made, should be proportionate to the divergence of the installation from indicative standards and to the environmental benefits that will be gained.

The operator should include in the application a proposed programme in which all identified improvements (and rectification of clear deficiencies) are undertaken at the earliest practicable opportunities. The regulator will assess BAT for the installation and the improvements that need to be made, compare them with the operator's proposals, and then set appropriate improvement conditions in the permit

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1.5 Key issues

Relationship to BAT

Installations regulated under the PPC regime have to be operated so that "all the appropriate preventative measures are taken against pollution, in particular through the application of the best available techniques" (Regulation 11(2)(a)) and "no significant pollution is caused (Regulation 11(2)(b)). Best available techniques (BAT) provide in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions from the installation and the impact on the environment as a whole (Regulation 3). In addition, it is necessary to ensure that waste is avoided and where possible is disposed of "while avoiding or reducing any impact on the environment" (Regulation 11(3)(a)). These represent the key requirements within the PPC Regulations for controlling routine releases from PPC-regulated installations to the environment, including to water.

Leachate definition

Leachate is a generic term given to water that has come into contact with landfilled waste materials, and in doing so has dissolved contaminants from them. These contaminants may include organic and inorganic compounds and elements, many of which will have been released by biological degradation of the wastes. This report specifically considers leachates derived from hazardous and non-hazardous wastes, primarily when these are produced after these materials have been landfilled. Nevertheless, leachates generated during other waste treatment process – for example, in mechanical biological treatment of wastes – may often have similar characteristics.

The characteristics of a leachate will depend on the composition and nature of the waste materials, and where biodegradable wastes have been landfilled, on the stage of decomposition that these wastes have achieved. To this extent, leachate is an unusual wastewater stream, in that although day-to-day strength may be affected by dilution, (as are many other wastewaters), its overall quality will also change over timescales of decades, as wastes progressively decompose. Provision of appropriate leachate treatment facilities must take this into account. Treatment systems suitable for leachates from wastes in early stages of decomposition in a landfill, may not necessarily remain appropriate as wastes continue to decompose further.

Operator

Where the leachate plant is part of a larger installation, operated by a different operator to that of the landfill, each operator will each require their own permit. The Environment Agency provides guidance in the document *IPPC Regulatory Guidance Series No. 3 - Understanding the meaning of Operator under IPPC*.

Disposal to sewer

The IPPC Directive sets out at Article 2(6) how indirect releases to water (i.e. releases to sewer) are to be addressed when setting emission limit values from PPC installations. That provision is repeated within Regulation 12(5) of the PPC Regulations, which states:

"The effect of a waste water treatment plant may be taken into account when determining the emission limit values applying in relation to indirect releases into water from a Part A installation or Part A mobile plant provided that an equivalent level of protection of the environment as a whole is guaranteed and taking such treatment into account does not lead to higher levels of pollution."

The BAT approach complements, but differs fundamentally from, regulatory approaches based on Environmental Quality Standards (EQS). BAT requires measures to be taken to prevent emissions - and measures that simply reduce emissions are acceptable only where prevention is not practicable. Thus, if it is economically and technically viable to reduce emissions further, or prevent them altogether, then this should be done irrespective of whether or not EQSs are already being met. The BAT approach requires that the environment is not considered as a recipient of pollutants and waste, which can be filled up to a given

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level, but to do all that is practicable to minimise emissions from industrial activities and their impact. The BAT approach first considers what emission prevention can reasonably be achieved and then checks to ensure that the local environmental conditions are secure (see Guidance Note IPPC Environmental Assessments for BAT). The BAT approach is therefore the more precautionary one because the release level achieved may be better than that simply required to meet an EQS.

Conversely, if the application of BAT might lead to a situation in which an EQS is still threatened, a more effective technique will be required for that installation. The Regulations allow for expenditure beyond BAT where necessary, and, ultimately, an installation will only be permitted to operate if it does not cause significant pollution.

The approach to be taken, as far as is reasonably practicable, when considering the acceptability of a discharge to sewer from a PPC perspective, and what emission limit values are appropriate. It can be summarised as follows:

- The applicant will establish the volume of trade effluent discharged to sewer
- The applicant will chemically characterise the composition of the trade effluent, including BOD and COD
- The sewerage undertaker will provide information to the applicant about the integrity of the sewerage system between the PPC installation and the WwTW, and the frequency with which any storm or other overflow occurs.

If the frequency of overflow or the risk posed by overflow or leakage is acceptably low, discharge to sewer may be permissible under PPC. In these circumstances:

- The applicant will establish from the sewerage undertaker the degree of treatment that can be consistently provided and the environmental fate and impact of any substances finally released or disposed of.
- The applicant will establish what can be achieved by treatment of the trade effluent at the site of production, together with the environmental fate and impact of any substances finally released or disposed of. This is dependent on there being an acceptable disposal route for the treated effluent at the site.
- The applicant will compare the options against the requirements of Regulation 12(5) in order to determine whether the discharge to sewer meets the obligations of the PPC Regulations.
- Appropriate emission limit values for the discharge to sewer will be set either by the Environment Agency or the sewerage undertaker, or both.

It is important to note that the comparison between the treatment provided at a WwTW and that provided by on-site treatment must be based on the predicted reduction of mass release of each substance to the environment. A reduction in the concentration of a particular substance that is achieved simply by dilution of a trade effluent from a PPC installation with the high volumetric throughput of a WwTW does not constitute a reduction of mass release, and is therefore not relevant to this comparison. The assessment will also take account of any differences in the locations of the WwTW discharge and the direct discharge. For instance, a direct discharge to a small watercourse may cause a higher level of impact than a discharge to a larger watercourse via a WwTW, even if the mass load discharged via the WwTW were higher. In addition, the assessment may include a review of other matters associated with full or partial on-site treatment, These may include practical issues such as space limitations, noise and odour, water and power usage, sludge movement and the use of chemicals as neutralising agents, coagulants and nutrients.

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Definition of sewer

Regulation 2(3) of the PPC Regulations defines release into water as including a release into sewer within the meaning of section 219(1) of the Water Industry Act 1991. Sewer in the Water Industry Act 1991 includes all sewers (public and private) and drains which are used for the drainage of buildings and yards appurtenant to buildings.

Relationship with the sewerage undertaker

Sewerage undertakers, are privatised industries, but also conduct public functions and have public duties enforceable by OFWAT, the Secretary of State or the Welsh Assembly Government. Water U.K. is the representative body of the UK regulated water undertakers; its members include the ten statutory sewerage undertakers located in England and Wales. The Environment Agency and Water U.K. entered into a Memorandum of Understanding (MoU) in April 2005 that identifies the roles and responsibilities of both parties in issuing of PPC Permits and the setting of trade effluent consents in relation to discharges to sewer. The contents of this MoU are reflected in this guidance.

Selection of techniques

In assessing the leachate treatment options to determine BAT the effectiveness of the technique in destroying hazardous substances, reducing hazard and rendering substances suitable for release to other processes must be considered.

For the leachate treatment sector in particular, because of the variable and complex composition of leachates, not only primary hazards but also secondary hazards must be considered.

Techniques should be designed and operated to avoid deliberate or inadvertent production and/or displacement of substances that may be harmful to the environment and to prevent the transfer of such substances from one environmental medium to another.

However, it is also recognised that, to be viable over the lifetime of the landfill, and to cope with temporal changes in leachate quality and composition, leachate treatment facilities must take account of this variability in their design, although it is not always desirable or effective to over-complicate the design and operation of the treatment process. The selection of a treatment process can be informed by the use of treatability trials that help in deriving not only the treatment process but also the plant size and the predicted emissions and thus required abatement.

Merchant leachate treatment has to deal with a wide and variable range of leachates. This requires plant and equipment that is versatile and can be used for a number of wastes. This contrasts with treatment techniques used for "in-house" leachate treatment on landfill sites, where the leachate, although variable with time is well characterised. This may lend itself to the development of dedicated single-stream treatment techniques, although operators may wish to retain the flexibility to allow treatment of imported leachate, in the event that site yields fall to the extent that the plant provides excess capacity.

Leachate variation through time

Leachate quality and quantity varies throughout the life of a landfill site. It is important when considering the most appropriate treatment method to understand the changing nature of leachate through time. This is considered in more details in section 1.8 below.

Odour associated with fugitive emissions

The handling of any substance that is or may contain a VOC (or other odorous substances, for example, mercaptans or other sulphur-containing compounds) will potentially lead to odour noticeable beyond the installation boundary, even at concentrations that may be well below nominal emission limit values (ELV). Odours may arise from storage or treatment of leachate containing VOC or other odorous substances. Failure to adequately inspect and maintain plant and equipment is also a contributory cause to fugitive emissions, e.g. leaks from pumps.

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Site restoration (prevention of emissions to land)

PPC in common with Waste Management Licensing requires that, on completion of activities, there should be no pollution risk from the site. Like Waste Management Licensing, prevention of both short term and long term contamination of the site requires the provision and maintenance of surfacing, measures to prevent leaks and spillages, containment system that collect any spills or leaks, maintenance of containment systems.

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1.6 Summary of releases

The following list of potential releases is based on pollutants listed in Schedule 5 of the PPC Regulations. It is a requirement of the PPC Regulation that reporting is mandatory for the following releases.

Table 1.1: Potential pollutant releases

Releases → / Source ↓	Substances									
	Ozone	NH_3-N	H_2S	H_2O_2	Odours	COD	VOC's	Methane	Metals	Suspended Solids
KEY	To air (A) To water (W) To land (L)									
Acceptance (sampling/ vehicle waiting)			A		A		A	A		
Transfer (pipework/ pumps/valves)		W	A		A	W	A	A/W	W/L	
Physical treatment Air stripping		W			A	W	A	A/W	W/L	W
Physical treatment Solid removal		W	A		A	W	A	A/W	W/L	W
Chemical treatment	A	W		W	A	W	A	A/W	W/L	W
Biological aerobic treatment		W			A	W	A	A/W	W/L	W
Biological anaerobic Treatment		W	A		A	W	A	A/W	W/L	W
Engineered wetlands		W	A		A	W	A	A/W	W/L	W
Removal of solid residue from vessels					A		A	A	W/L	W

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1.7 Technical Overview

There are a number of widely adopted processes used for treatment of leachate, either alone or in combinations. These are specifically discussed later in this section, and the different roles which specific processes can play have been described under each individual process heading. The remainder of this technical overview presents a summary of the types of leachate treatment activities in use, and the broad categories of leachate for which they are appropriate.

Multi stage treatment processes

In many instances, BAT for the treatment of landfill leachates may well involve the adoption of more than one treatment process. A specific treatment requirement may involve the use of primary, secondary, and tertiary processes. Individually, specific processes may in one instance be used for primary treatment, but in other circumstances may comprise a secondary or tertiary stage of polishing for pre-treated effluent. An example might be the use of an engineered wetland/reed bed. At an older and closed landfill, such processes may be capable of providing complete treatment of diluted leachates, to achieve surface water discharge standards. At other sites, a reed bed may be used to remove residual organic matter, solids, and ammoniacal-N, after a leachate has first been treated using an aerobic biological process (e.g., see Robinson et al, 2003).

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Table 1.2 Examples of leachate treatment activities

Treatment activity	Process includes
Physical treatment processes	
Air stripping	Methane stripping – the use of diffused air to strip out or reduce the dissolved methane content of leachate is commonly used. Ammoniacal-N removal – is depended on pH and temperature, to be effective it may be necessary to raise the pH and heat the leachate. Stripping of other volatile contaminants – is dependent on the contaminants present and is unlikely to remove all contaminants completely
Reverse osmosis	Has been used to treat leachate in a number of European countries. The reverse osmosis process generates a high quality effluent.
Solids removal	Sedimentation and Settlement – this is currently the most common method of reducing the suspended solids content of leachate. If the particle sizes are colloidal it may be necessary to add a flocculent. Sand filtration – Occasionally used if the solids are very fine or colloidal. Sand filtration has a high initial capital cost and requires a high degree of control. Dissolved air flotation – This is sometimes used when available land does not allow the construction of settlement tanks. Leachate usually requires conditioning prior to treatment and there are high capital costs associated with this method of treatment.
Activated carbon adsorption	Powdered activated carbon (PAC) – Is sometimes used as an absorbent particularly for the removal of organic compounds in the final polishing after

	biological treatment, however the consumable costs can be high. Granular activated carbon – has the same uses but may be generated and although its use is associated with higher capital costs than PAC the operational costs may be lower than those for PAC.
Ion exchange	Resins typically made of synthetic organic material remove ions from solution by the exchange of anions or cations. The very high concentrations of anions and cations within leachate means that the use of this process is currently limited.
Evaporation/concentration	This process can be used to dispose of concentrates from the reverse osmosis process but is currently not commonly used in the U.K.
Chemical treatment processes	
Chemical oxidation processes	Ozonation – ozone is sometimes used to oxidise complex organic constituents that do not easily biodegrade. It is also used as a sterilising agent. Ozone is highly toxic and requires rigorous implementation of safety procedures. Hydrogen Peroxide – hydrogen peroxide has been principally used to oxidise sulphide. It can also be used to treat phenols, sulphite, cyanide and formaldehyde. As a strong oxidising agent it should be stored and handled with care.
Precipitation/coagulation/flocculation	Chemical precipitation of metals – Heavy metal concentrations in leachate from landfills accepting primarily domestic waste tend to be low when compared to raw sewage and can be reduced using oxidation and normal settlement processes. Consequently chemical precipitation is not widely used. Coagulation and flocculation – Flocculants can be used to remove particles that do not readily settle out. It is currently rarely applied in the UK to raw leachate treatment and only occasionally to biological retreated effluents.
Aerobic biological treatment processes	
Suspended growth systems	Aerated lagoons – These are generally effective for only relatively dilute leachate. Low water temperatures during the winter can reduce performance. Activated sludge – Is the most widely used aerobic biological process. It can provide a high degree of treatment for high strength leachate. Sequencing batch reactors (SBRs) – This uses the principles of activated sludge but with the biological treatment and final settlement all taking place within the same vessel. Tank based systems are less effected by seasonal temperature variations. Membrane bioreactors (MBRs) – This is an advanced form of the traditional activated sludge process that uses a membrane to capture the solids in preference to gravitational settlement.

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Attached growth systems	Percolating filters – This process is rarely used for leachate treatment. Rotating biological contactors – Have been used historically in the UK for leachate treatment. However they can suffer from the problems associated with percolating filters in that high concentrations of metals particularly iron can adhere to the media inhibiting biological activity. Biological aerated filters / submerged biological aerated filters – These are occasionally used for treating leachate but are susceptible to toxic materials adhering to the media inhibiting biological activity. Biofilm reactors – These are high rate reactors capable of high carbonaceous removal.
Anaerobic biological treatment processes	
Upflow anaerobic sludge blankets	Upflow Anaerobic Sludge Blankets (UASB) – This system is not known to be used in the UK.
Aerobic/anaerobic biological treatment processes	
Engineered wetlands	Horizontal flow reedbeds – Frequently used to provide tertiary treatment to reduce Biochemical Oxygen Demand and solids. Vertical flow reedbeds – These require less land area than horizontal flow reedbeds and are more efficient at reducing ammonia. Wetland ponds – Pond systems can combine gravitational settlement, gravel filters and marginal plants that can provide tertiary treatment.

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1.8 Economics

The economics concerning leachate treatment are dependent on site specific conditions. The nature of both quantity and quality of the leachate is landfill site specific. In addition the landfill site location will influence the practicalities of connection to foul sewer. This section considers these and other factors that influence the economic decisions taken when installing a leachate treatment plant.

Leachate production

When considering installing a leachate treatment plant at a landfill it is important to consider leachate production rates and changes in quality of the leachate when sizing the plant.

Leachate quality and quantity varies throughout the life of a landfill site. The design of the site and the type of waste deposited determine both. As waste changes with time so does the leachate quality. This is particularly evident in non-hazardous landfills that have received municipal waste. The initial aerobic condition of deposited waste lasts a few days or weeks and is generally not significant in determining leachate quality. However this is followed by anaerobic conditions, the early stages (the acidogenic/acetogenic phase) produces leachate with high concentrations of soluble degradable organic compounds and an acidic pH. Ammonium and metal concentrations increase during this phase. This phase can last several months or even years until methanogenic conditions are established. During this time leachate pH changes to slightly alkaline and of lower concentration (e.g. COD may reduce by 95% and the concentration of heavy metals by 50%), however some pollutants, like ammoniacal nitrogen, may remain relatively concentrated. In the final stage when biodegradation nears completion aerobic conditions may return and the leachate produced will eventually cease to pose an environmental hazard.

It is important to recognise that this process is illustrative of how leachate composition changes throughout the life of one type of landfill. The Landfill Directive (Council Directive 1999/31/EC) not only requires waste to deposited in one of three classifications of landfills (hazardous; non-hazardous and inert) but restricts the proportion of biodegradable waste going to landfill and requires the pre-treatment of certain wastes prior to landfilling. Consequently the composition of leachate is likely to alter significantly between landfill sites of different classifications and between older and newer sites of similar classification.

Leachate quantity can be determined by the overall water balance for each landfill site. A water balance calculation should assess likely leachate generation volumes considering waste volumes, input rates and absorptive capacity, effective and total rainfall, and infiltration. The leachate generation calculations will provide a likely predicted volume for design purposes of a leachate treatment facility. When looking at the design of a leachate treatment facility it is advisable to consider a worst case scenario i.e. examination of predicted peak production rather than average predicted production and make allowance for such an occurrence. It is also advisable to undertake a sensitivity analysis of the data used in predicting the leachate production rates, this should highlight how susceptible the proposed leachate treatment method will be to changes to variables such as waste input rates or precipitation.

Leachate disposal costs to sewer

Charges for trade effluent to sewer are based on the Mogden formula. This formula links charges to the characteristics (volume and strength) of the discharges which determine the level of treatment needed and therefore the costs involved. Sewerage companies calculate the average costs across their regions, so charges do not reflect the costs incurred at any one treatment works.

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Companies may reduce the collection charge if a discharger is connected directly to the treatment works.

Details of companies' trade tariffs for 2005-06 are shown table 1.3 below

Table 1.3 Trade effluent tariffs 2005-06
(OFWAT Tariff structure and charges 2005-06 report)

	Regional Strengths							
Water and sewerage companies	R p/m³	V p/m³	Bv p/m³	M p/m³	B[1] p/kg	S[1] p/kg	Os mg/l	Ss mg/l
Anglian – Green	17.45	27.30	5.25	14.61	54.11	48.09	423	403
Dwr Cymru	21.64	24.62	10.23	14.73	31.97	33.05	500	350
Northumbrian	23.06	11.27	6.26	-	24.50	46.01	360	182
Severn Trent	17.11	15.31	-	-	26.41	20.15	351	343
South West	45.85	42.23	-	7.69	99.95	90.85	744	489
Southern	32.70	23.87	3.90	20.72	69.71	42.10	425	512
Thames	7.67	9.42	-		27.14	34.43	445	336
United Utilities[1]	15.30	12.40	1.80	11.70	35.00	40.30	332	231
Wessex – Standard	42.37	19.50	-	-	41.20	49.90	802	313
Yorkshire	26.37	26.07		15.64	28.25	46.36	898	326

[1] United Utilities offers a trade effluent reservation tariff to customers who wish to be charged on that basis. The tariff has two components: reservation charge, which is based on maximum consent limits; and a volume charge, which is based on discharged volume.

Trade effluent bills are calculated according to the formula:

Bill = R + [(V + Bv) or M] + B(Ot/Os) + S(St/Ss).

Some companies apply the fixed charge for the foul sewerage in addition to the above, even if there is no domestic strength discharge. Charges for B and S are usually expressed in p/m^3 relative to standard strength (concentration: usually expressed in mg/litre), which vary from company to company. To maintain comparability, the charges shown here (B^1 and S^1) are corrected for standard strength and shown as p/kg.

Key to charges:

R – reception and conveyance

V – primary treatment (V for volumetric)

Bv – additional volume charge if there is biological treatment

M – treatment and disposal where effluent goes to a sea outfall

B – biological oxidation of settled sewage

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Leachate treatment and disposal costs

The cost of leachate treatment is dependent on the volume and composition of the leachate and the final disposal route. Table 1.4 below lists the range of costs associated with some of the of treatment process discussed later in this document.

The examples in Table 1.4 consider the possible capital and operational expenditure associated with different types of leachate treatment. Two example landfills have been considered:

Landfill 1 – has a large volume of leachate of 400 m^{-3} per day with high COD of 6000 mg/l and suspended solids of 250 mg/l.

Landfill 2 – has a low volume of leachate of 60 m^{-3} per day with low COD of 150mg/l and suspended solids of 90 mg/l.

Table 1.4 Leachate treatment costs

Treatment activity	Capital expenditure (£)		Operational expenditure (£ m^{-3}) (plant operation, maintenance and reagent or transport costs + discharge costs)	
	Landfill 1	Landfill 2	Landfill 1	Landfill 2
Removal by tanker and disposal at a WwTW	-	-	**17.50** (15+2.5)	**15.38**(15+0.38)
Air stripping – methane stripping Including sewer connection and disposal costs.[1]	300,000	100,000	**3 .10** (0.60+2.5)	**0.98**(0.60+0.38)
Sequencing Batch Reactor and disposal to sewer.[2]	1,000,000	250,000	**1.72** (0.80+0.92)	**1.15**(0.80+0.35)
Sequencing Batch Reactor, solids removal by dissolved air floatation and polished via a reed bed and discharged to surface water.[3]	1,500,000	400,000	**1.50** (there is no disposal cost associated with discharge to surface water as the PPC annual subsistence fee will apply to all treatment methods listed and does not distinguish significantly between the final disposal media)[4]	

[1] Methane stripping reduces methane concentrations sufficient to allow discharge to sewer but does not significantly reduce COD or suspended solids.

[2] Landfill 1 - COD is reduced to 1500 mg/l and suspended solids remain at 250 mg/l. Landfill 2 – COD is reduced to 42 mg/l and suspended solids remain at 90 mg/l

[3] COD is reduced to 650mg/l and suspended solids to 45 mg/l, BOD is reduced to 30mg/l (consents to surface water are more likely to limit BOD than COD).

[4] It is possible that the operational expenditure figure quoted could range from £0.75 - £ 5.50 m^{-3} depending on the concentration of ammonia in the leachate and how much of this requires removing.

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The examples given are purely illustrative and not representative of BAT for the given landfill. In some of the examples it is unlikely that the proposed leachate treatment technique would be used. Settlement tanks, for example, may well be employed in place of dissolved air flotation if available land is available.

Capital expenditure

Other material factors such as available land and proximity of the foul sewer or alternative disposal routes will inform the choice of treatment methods employed. Civil engineering costs can have a significant impact on the capital expenditure, an example being the requirement to construct piled foundations.

Operational expenditure

The concentration of Ammonia is typically the most crucial 'cost ' to consider when designing a plant as this requires some 4.5 times more oxygen to oxidise than COD/BOD. It is also important to note that operational costs may vary on identical treatment plants treating identical leachates if the consented discharge limit varies. A lower discharge limit of ammonia for example may require additional energy consumption to increase aeration within a sequencing batch reactor in order to reduce the ammonia concentrations.

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2. Techniques for pollution control

2.1 Introduction

To assist operators and the regulator's officers, in respectively making and determining applications for PPC permits, this section summarises the indicative BAT requirements (i.e. what is considered to represent BAT for a reasonably efficiently operating installation in the sector). The indicative BAT requirements may not always be absolutely relevant or applicable to an individual installation, when taking into account site-specific factors, but will always provide a benchmark against which individual applications can be assessed.

Summarised indicative BAT requirements are shown in the "BAT boxes", the heading of each BAT box indicating which BAT issues are being addressed. In addition, the sections immediately prior to the BAT boxes cover the background and detail on which those summary requirements have been based. Together these reflect the requirements for information laid out in the Regulations, **so issues raised in the BAT box or in the introductory section ahead of the BAT box both need to be addressed in any assessment of BAT.**

Although referred to as indicative BAT requirements, they also cover the other requirements of the PPC Regulations and those of other Regulations such as the Waste Management Licensing Regulations (see Appendix 2 for equivalent legislation in Scotland and Northern Ireland) and the Groundwater Regulations, insofar as they are relevant to PPC permitting.

For further information on the status of indicative BAT requirements, see Section 1.1 of this guidance.

It is intended that all of the requirements identified in the BAT sections, both the explicit ones in the BAT boxes and the less explicit ones in the descriptive sections, should be considered and addressed by the operator in the application. Where particular indicative standards are not relevant to the installation in question, a brief explanation should be given and alternative proposals provided. Where the required information is not available, the reason should be discussed with the regulator before the application is finalised. Where information is missing from the application, the regulator may, by formal notice, require its provision before the application is determined.

When making an application, the operator should address the indicative BAT requirements in this guidance note, but also use it to provide evidence that the following basic principles of PPC have been addressed:

- The possibility of preventing the release of harmful substances by changing materials or processes, preventing releases of water altogether (see Section 2.2.2), and preventing waste emissions by reuse or recovery, have all been considered, and
- Where prevention is not practicable, that emissions that may cause harm have been reduced and no significant pollution will result.

This approach should assist applicants to meet the requirements of the Regulations to describe in the applications techniques and measures to prevent and reduce waste arisings and emissions of substances and heat - including during periods of start-up or shut-down, momentary stoppage, leakage or malfunction.

In responding to the requirements, the operator should keep the following in mind.

- As a first principle, there should be evidence in the application that full consideration has been given to the possibility of PREVENTING the release of

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harmful substances, for example, by:

- Characterisation of the leachates
- Selection of appropriate treatment techniques.

2.1.1 Leachate acceptance, handling and storage

The first two parts of this section covers the acceptance of leachate generated off site. The remaining part concerning the storage and handling of leachate is applicable to all leachate.

Leachate pre-acceptance

Where the treatment plant is to accept leachate other than that directly pumped from the landfill on the same site a pre-acceptance procedure should be employed. This ensures that the leachate is suitable for the proposed treatment. These checks must be carried out before any decision is made to accept the leachate for treatment.

The operator must establish the composition of the leachate and confirm this by examining the results of representative samples.

This information must be recorded and referenced to the leachate being accepted. The information must be regularly reviewed and kept up to date with any changes in the leachate.

The producer of the leachate has obligations under the Duty of Care requirements to provide information on the composition of the leachate, its handling requirements and hazards and the appropriate EWC code. This information is required on transfer of the leachate between the producer and another party. However should the producer transport leachate to another one of their sites then the Duty of Care may not apply. Nevertheless the producer and operator of the receiving site must ensure that reliable and comprehensive information has been provided to determine the suitability of the leachate for the treatment process in question.

Adequate sampling and analysis must be carried out to characterise the leachate. In all cases the number of samples taken must be based on an assessment of the risks of potential problems.

Operators should ensure that technical appraisal is carried out by suitably qualified and experienced staff who understand the capabilities of the leachate treatment process.

Leachate acceptance

For leachate delivered to the site the majority of the characterisation work should have taken place at the pre-acceptance stage. This means that acceptance procedures when leachate arrives at the site should serve to confirm the characteristics of the leachate.

It is possible that automatic off loading facilities may be used for the delivery of leachate by tanker providing the issues identified in this section are adequately addressed.

The issues to be addressed by the operator in relation to waste acceptance procedures for the site include:

- tanker waiting, load inspection / checking, sampling and discharge areas
- traffic control
- procedures for checking paperwork arriving with the load

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- location of sampling point(s)
- infrastructure such as bunds
- sampling procedures
- verification and compliance testing
- assess consistency with pre-acceptance information
- rejection criteria
- sample retention system
- record keeping in relation to producer details, analysis results and treatment methods
- procedures for periodic review of pre-acceptance information
- identification of operators staff who have taken any decisions concerning acceptance or rejection of leachate.

Notwithstanding the legal requirements of the Duty of Care leachate should not be accepted without detailed written information identifying its source and composition.

Records should be made and kept up to date of all the information generated during pre-acceptance, acceptance, storage and treatment (i.e. the point the leachate entered the treatment plant).

Reception facilities must be provided. The design of the reception facilities and the operational practices should consider normal and abnormal events.

Reception areas need to be able to contain the spills. The size of the containment area should be based on a risk assessment that considers the potential for the largest uncontrolled release. This should consider the potential escape of the whole of the largest tanker delivering to the site. Containment is likely to include bunding with consideration being given to falls on the site and how a tanker can access the area when it is surrounded by bunding.

The surfacing and drainage provided for the reception area will have to be designed to prevent short-term discharges of contaminated water and longer term pollution of underlying ground.

The design process should also consider logic systems that can be employed to limit the potential for wrong connections or incorrect routing while discharges are being made.

Leachate storage

Leachate storage issues are of primary importance to the design and selection of leachate collection and treatment systems.

The manner in which leachate is generated from rainfall is in the short-term unpredictable, and during heavy rain takes place at potentially high flow rates. However, leachate storage that balances flow takes place in a landfill when rainfall percolates through the waste into collection systems. The degree to which this effect can be optimised by additional storage, as discussed below, is central to the design of leachate treatment processes.

It is unlikely that a biological treatment process can readily be designed, either robustly or cost effectively, with a minimum flow much below 20% of the design capacity. Although in certain circumstances a reduced flow may provide the came levels of contaminants and hence load to the treatment process. Any less than 20% flow and when the change from low to high flow occurs there may simply not be adequate biomass present to accomplish treatment at increased throughputs.

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The sizing and turndown ratio for a process design is critical to the amount of storage available to smooth (balance) the peak flows during storms. Even small adjustments in total site (landfill plus discrete storage/balancing vessel design) storage volume assumptions can potentially double or halve the design throughput rates for treatment facilities.

Short term leachate storage at landfill sites can range from, allowing excess leachate to accumulate in a developed area of the lined landfill within heads permissible within the permit, to purpose-built storage tanks.

Significant operational benefits arise for leachate storage, under circumstances such as:-

1. **Flow balancing prior to on-site treatment, tankerage off-site, or discharge to sewer;** resulting in a significant reduction in short term peak wet weather flows, which would otherwise result in a requirement for substantial additional treatment capacity which would be substantially under utilised for all but very short storm duration periods. (For biological systems it may not be possible to develop and maintain a viable biomass constantly available for such peaks, and therefore the importance of this form of storage to the viability of these processes should not be underestimated.)
2. **Flow balancing for one-off events during the life of a landfill**. All containment landfills will produce varying amounts of leachate through the life of the site. It is inevitable that there will be critical points during the development of any landfill when the generation of leachate will pose special problems. The most likely/frequently observed event is the scenario which occurs when a landfill is first developed, and large volumes of leachate may be generated before there is a significant quantity of waste within the site phase or cell to absorb rainfall incident on a large cell.
3. **Flow balancing winter/summer within the landfill**. Where landfills are reasonably shallow and base gradients not severe, the leachate storage volume which can be held within the permitted leachate head over the liner provides a storage capability for the well managed landfill. If an operator draws down the leachate head to almost zero during dry weather periods. In some instances this effect has been used to allow leachate treatment plants to be run at a constant flow rate for 9 months of the year avoiding operationally more difficult winter periods (e.g. for lagoon based leachate treatment plants).
4. **Leachate quality balancing to "blend" different strengths of leachate for optimum treatment.** Biological processes in particular require a reasonably constant feed quality as well as quantity, as the biomass available to provide treatment tends to develop/grow during periods of weeks to match the food source. Without balancing these changes can occur on a daily basis or more frequently. Therefore, blending leachates from different cells prior to treatment, where large variations in leachate quality exists between different leachate sources on a landfill, can be an important and appropriate use of leachate storage. It is anticipated that flow balancing for blending will become more important in future as mechanical biological pre-treatment technologies are implemented, and different landfill cells are developed for different waste types, resulting in greater variation in leachate qualities at individual sites.
5. **Leachate "storage" as part of a leachate collection/treatment system.** Some leachate collection systems require the storage of small quantities of leachate in header tanks at the pump location (eductor systems), and on some large landfills with significant perimeter pipeline runs, header and break-pressure tanks may provide storage for leachate in transit. Pre-treatment or post pre-treatment settlement of leachate may be appropriate under some circumstances, to allow solids to settle prior to discharge for

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example, or to allow contact time after chemical dosing.

6. **Leachate pumps:** Some leachate pump systems require the storage of small volumes of leachate as (for example pump priming and pressure surge (pipe hammer) reduction). These storage requirements are small and are justifiable/low potential impact, and are not discussed further here.

The diversity of uses of leachate storage is therefore very broad, and in many instances such storage may be essential to the provision of effective treatment.

It is therefore important for the operator to assess each form of leachate storage in the context of the risks that it entails, in terms of impacts on Health and Safety and environmental considerations. This document concentrates on the environmental considerations.

Within this document we have limited further discussion, the forms of storage afforded by mechanisms 2 & 3 above are not discussed further, as they fall under the general heading of landfill management.

For similar reasons leachate recirculation, which results in leachate storage by merit of the fact that a volume of leachate will be held "in-transit" as it percolates through the waste, before the portion which is not absorbed emanates again from the drainage system, is not classified as storage within this discussion.

Environmental issues and concerns

The source-term for leachate quality has been well documented. Leachate stored may comprise any leachate across the full range identified in the source term.

The manner in which leachate changes in nature from fresh "acetogenic" to old "methanogenic" is also well documented. In general terms it is clear that the risk of impacts from leachate storage will be greatest from the youngest and strongest leachates, and can reduce with leachate age. Young leachates will contain the greatest concentrations of odorous chemicals (e.g. volatile organic chemicals (VOCs), mercaptans, and hydrogen sulphide (H_2S)).

Any assessment of potential impacts must allow for chemical changes that may take place during storage and the effects of these on potential impacts. For example, a freshly generated leachate from newly deposited, waste may undergo decomposition after storage commences, which results in the generation of anaerobic conditions, and as a result generates significant odours.

Clearly, storage incurs risks, which encompass all the normal Health and Safety risks that arise from the presence of any body of water, but these are assumed to be included automatically in any assessment, and are not discussed here.

However, stored leachates will impose special Health and Safety risks related to the generation of methane while stored (if stored under anaerobic conditions without mixing or any aeration) and also from dissolved methane which is likely to be present in all leachate emanating form methanogenic landfill cells/phases.

The principal environmental risks posed by leachate storage are:-

- Odours
- Leakage from storage vessels into surface or groundwater
- Release of dissolved methane from solution

A site specific risk assessment is necessary for each of the above, before such risks and suitable ameliorative measures can be identified, that are appropriate to the specific circumstances of type of storage, nature of leachate stored, nature of any chemical or biochemical change which might occur during treatment.

The risk of an impact from odour should be considered in respect of the nature and location of the receptor, which during the active life of the site may be located at

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the site perimeter, but may be otherwise after site closure depending upon after-use.

Leachate storage facilities may be roofed in order to prevent the escape of odours. Under such circumstances, consideration should be given to venting which will occur as a storage vessel fills and displaces air from the air-space above the liquid. If odour generation from the raw leachate is likely to be a particular problem, or there is a history of odour concerns, or the site is in close proximity to sensitive receptors, aeration air should be drawn from headspace in raw leachate tanks and maintained under negative pressure and thus reduce the potential for fugitive emissions.

The prediction of impacts from odours emanating from storage vessels may be assessed using:-

- Evidence of experience elsewhere with similar installations;
- Assessing the results of from trials;
- Reports from odour panels which can provide a rating for the "odour potential" of the leachate if a characteristic and fresh air sample of the relevant off-gas is dispatched when a panel is sitting;
- In some cases it may be necessary to run air dispersion models to predict the effect of an odour, if the sensitive receptor is remote from the source.

Odour treatment can be carried out to most leachates. Depending on the nature of the leachate and odour produced, biological methods and physical/chemical methods may be appropriate. Again each method proposed will need to be assessed on a site specific basis.

There will be a predisposition, wherever possible and for most biologically-treatable leachates, to use biological odour treatment techniques, whereby the odorous air is passed through a medium which is maintained at an optimum moisture content (e.g. heather, peat. seaweed, shells etc) and a biomass is allowed to build-up which will bio-chemically oxidise and remove the odours. Activated carbon and resin adsorption based techniques may also be appropriate, subject to consideration of the efficacy and environmental impacts of the creation and disposal of these materials.

To assess the potential impact of leachate storage on a groundwater or surface water at any specific site, the following should be considered:-

- Leachate quality;
- Likely modes of failure/possible rates of leakage under a worst case tank failure scenario (i.e. concrete tanks fail gradually by developing cracks, steel tanks may fail by penetration by corrosion and thus typically results in a greater leakage rate before emergency action can be taken);
- Emergency ameliorative measures and response time after any leak was to develop;
- The source and receptor relationship (i.e. distance and dilution available in the event of leakage, which would provide further protection from a groundwater impact under the worst case scenario.

Satisfactory ameliorative measures can be utilised, under circumstances where bunding would otherwise be necessary, subject to compliance with the requirements of the risk assessment, such as:-

For entirely above ground vessels;

- Regular inspection and maintenance, provided that any leakage is adequately contained (this may include the return of leachate to the landfill of its origin via

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an appropriate engineered mechanism provided that this landfill has adequate containment and any leachate return is justified in the groundwater risk assessment);

for part or fully buried vessels

- Providing gravity under-drainage to storage vessels with a form of active leakage detection, which would alarm in the event of any leakage (e.g. electrical conductivity meter). This, combined with suitable method statements which would ensure satisfactory maintenance of such a system, and suitable short response times in the event of an incident, may provide adequate protection;
- Installing a low permeability clay and/or membrane liner below the tank to provide the equivalent of 110% capacity equivalent to a bund:
- Installing into clay backfill.

(NB: Care should be taken by the design to avoid flotation when the vessels are occasionally drained.)

Leachate storage in any location subject to flooding, should also be risk assessed for the effects of flooding. The principal requirement will be the avoidance of escape of leachate to the environment from any storage provisions, during a worst case flood scenario.

Overtopping of the rim of a vessel during floods must at all times be avoided. However, other forms of flood damage may require assessment, but due to the downtime potentially arising from lesser flood damage (e.g. to monitoring systems), the longer term effects on the ability of a landfill site operator to continue leachate disposal from the site.

On some sites where the risk of impacts from leachate leakage or spillage is significant, a risk assessment may be necessary on the effect of any failure of mechanisms in place to prevent the overfilling by pumping or gravity flow, of the storage vessel.

Storage vessels which generate a sludge (e.g. due to incidental settlement of high suspended solids content) may require additional risk assessments.

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Indicative standards for leachate acceptance, handling and storage
Leachate pre-acceptance
1. Prior to acceptance of leachate the operator should obtain information in writing relating to its: • Quantity; • Chemical analysis • Hazards; and • Sample storage and preservation techniques 2. The operator should ensure that the sample is representative of the leachate and has been obtained by a person who is technically competent to undertake the sampling process. 3. Samples should be clearly labelled and any hazard identified. 4. Sample tracking systems within the installation should be established and be auditable.

5. Analysis should be carried out by a laboratory with robust quality assurance and quality control methods and record keeping.
6. Leachate should not be accepted at the installation unless it has been established that:
   - The leachate treatment plant has available capacity;
   - The leachate treatment plant is capable of treating the leachate; and
   - The leachate will not cause the plant to fail to comply with any prescribed emission limits.

Leachate acceptance

1. On arrival loads should:
   - be weighed or quantified based on a volumetric system
   - not be accepted unless sufficient storage capacity exists and the leachate treatment plant is adequately manned; and
   - have all documents checked and approved.
2. On site sampling, verification and compliance testing should take place to confirm:
   - the description of the leachate
   - consistency with pre-acceptance information
   - compliance with permit
3. The operator should have a clear and unambiguous criteria for rejection of the leachate together with a written procedure for tracking and reporting such non-conformance. This should include notification to the customer/producer and the regulator. Written/computerised records should form part of the waste tracking system.
4. Documentation provided by the driver, written results of acceptance analysis and details of the offloading point should be added to the tacking system documentation.
5. A permanent impervious and suitably bunded hardstanding area must be provided for the reception of tankers. The location need not be roofed but bunding must fully enclose any area in which spillage may occur during offloading, and this includes suitably protecting pipe runs between the off loading point and the delivery point into the treatment plant vessel.
6. The bund shall be constructed in a manner that will permit any spillage to be immediately intercepted and held safely until measures are implemented in accordance with emergency planning provisions.
7. The bunded area should be kept free of accumulations of rainwater to avoid compromising the storage volume available, and render the bunding protection ineffective.
8. Where concrete surfaces are used, care shall be taken to ensure that the corrosion-resistance properties of the facility are suitable for long term exposure to the leachate. All other items in contact with the leachate shall be similarly protected against corrosion.
9. Any valves, pipework, temporary hoses etc, installed as part of the system shall be regularly inspected and maintained.
10. Procedures must be in place to ensure that leachate spillages are cleared in order to prevent odour.

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11. Deliveries in bulk road tankers should be accompanied by a "wash-out" certificate or a declaration of the previous load so that contamination by this route can be prevented. 12. Wheel cleaning facilities should be provided if required.
Leachate handling and storage
1. Storage and treatment vessels to be specified for a suitable "design life" that takes account of the proposed operational life of the plant, to suitable BSS, and Eurocodes. Vessels should not be used beyond the specified design life. Vessels should be inspected at regular intervals, with written records kept to prove that they remain fit for purpose. 2. Particular attention is needed to corrosion protection in leachate. Parts in contact with leachate shall not include unsuitable materials such as zinc, or galvanising (i.e. as these impart metals to the leachate, and are not long lasting). Aluminium is not considered suitable in most instances. 3. Storage and treatment vessel design must take into account the following: • the physical-chemical properties of the leachate being stored • how the storage is operated, what level of instrumentation is needed, how many operatives are required, and what their workload will be • how the operatives are informed of deviations from normal process conditions (alarms) how the storage is protected against deviations from normal process conditions (safety instructions, interlock systems, pressure relief devices, etc.) • what equipment has to be installed, largely taking account of past experience of the product (construction materials, valves quality, etc.) • which maintenance and inspection plan needs to be implemented and how to ease the maintenance and inspection work (access, layout, etc.) • how to deal with emergency situations (distances to other tanks, facilities and to the boundary, fire protection, access for emergency services such as the fire brigade, etc.). 4. Storage and treatment vessels should be secondary contained or be located above ground on an impervious surface that is resistant to the leachate being stored, with sealed construction joints within a bunded area. The bunded area shall have a capacity at least 110% of the largest vessel or 25% of the total tankage volume, which ever is the greater. Bunds shall be regularly inspected to ensure that bunds filled by rainwater are regularly emptied – otherwise the purpose of the bunding provided is lost. Connections and fill points should be within the bunded area and no pipework should penetrate the bund wall. 5. Tanks and vessels should be equipped with suitable abatement systems and level meters with either remote telemetry communication systems or both audible and visual alarms. These should be sufficiently robust and regularly maintained to prevent foaming and sludge build-up affecting the reliability of the gauges. 6. Pipework outside of the landfill area should preferably be routed above ground; if below ground it should be contained within suitable inspection channels. *7.* Underground or partially underground vessels without secondary containment should be scheduled for replacement with aboveground structures or secondary contained vessels.

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> 8. Where possible tanks and vessels should be located on virgin ground rather than areas of landfilled waste, where this is not possible the bearing capacity and likely settlement of the waste must be considered in the design of the tanks and vessels.
>
> Enclosing or covering tanks and vessels in order to control odour emissions is discussed in Section 2.2.6.

2.1.2 Acceptance procedures when process materials arrive at the installation

Written information

An internal tracking system and stock control procedure should be in place this will enable the operator to:

- prevent unwanted or unexpected reactions
- ensure that the emissions are either prevented or reduced
- manage the throughput of materials incompatibility with incoming wastes.

Records should be made and kept up to date on an ongoing basis to reflect

Labelling and segregation

Materials arriving at the installation will be labelled for transport according to the Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996, as amended.

For COMAH installations, calculation of the hazard inventory requires hazard identification using the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994, as amended (CHIP).

There are examples of substances having one hazard class under the Regulations relating to transport and quite another under the CHIP Regulations.

Segregated storage is necessary to prevent incidents from incompatible substances and as a means of preventing escalation should an incident occur. Best practice on segregation is provided within HSE Guidance Note HSG71. This guidance is also based on CHIP classifications. The individual storage requirement on a particular installation will be dependent on a full assessment of risk (see **Section 2.8**). Further guidance on storage and segregation is available from, HSG51, HSG716 and CS21.

Delivered by tanker; precautions required as for leachate, plus compliance with the special hazard requirements for the chemicals handled. All vessels containing incompatible materials should be separately bunded.

All delivery nozzles and pipework to be designed for safe connection and removal of fittings. Specific caution is required where the possibility exists that a hose connection may accidentally be removed while still under pressure.

Overfilling precautions shall be considered and suitable provision for overfilling prevention provided by method statement or installation of suitable protection devices.

Delivered in a container which is offloaded and the contents used on site; as above. Overfilling is not a problem, but with additional care in this instance that at all times the containers stored shall be placed in the bunded areas provided, and the volume stored shall not at any time exceed bunding requirements.

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Indicative BAT requirements for acceptance procedures when treatment chemicals arrive at the installation
1. On arrival loads should: ▪ not be accepted into site unless sufficient storage capacity exists ▪ have all documents checked and approved, and any discrepancies resolved before the material is accepted, and ▪ have any labelling that does not relate to the contents of the drum removed. 2. Appropriate designated storage must be provided, ensuring that all drums and containers are correctly labelled and that non-compatible materials are segregated. 3. Vessels/tanks should be secondary contained or be located aboveground on an impervious surface that is resistant to the chemical being stored, with sealed construction joints within a bunded area. 4. Drums should be stored in separate bunded areas that ensure non-compatible materials cannot come into contact. 5. All bunds shall: ▪ Have a capacity at least 110% of the largest vessel or drum or 25% of the total tankage volume, which ever is the greater. ▪ Be regularly inspected to ensure that bunds filled by rainwater are regularly emptied – otherwise the purpose of the bunding provided is lost. ▪ Have connections and fill points within the bunded area and no pipework should penetrate the bund wall. 6. Appropriate training should be provided to operatives on the safe handling, use and disposal of process chemicals. 7. Spill kits should be provided in areas of chemical handling and storage and operatives should be trained in their use. This training should include appropriate measures e.g. dilution adsorption neutralisation etc.

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2.1.3 Physical treatment processes

2.1.3.1 Air stripping

2.1.3.1.1 Methane stripping

General information

Methane is more soluble in water than oxygen. At 20°C, about 25mg of methane will dissolve in a litre of water, from a pure methane atmosphere. Leachates from within a biologically active landfill will generally be extracted from a gaseous environment comprising typically 60 percent methane, and 40 percent carbon dioxide (by volume). In these circumstances, at temperatures of between 40 and 20 degrees centigrade, methane can dissolve to concentrations of between 10 and 15 mg/l. Such dissolved methane concentrations are routinely measured in landfill leachates (e.g. Robinson et. al., 1999). Even at landfills where relatively diluted leachates are collected from surface seepages, perimeter ditches etc, concentrations of methane in the order of 2 – 5 mg/l are often determined, and values can vary widely on a day-to-day basis. Significant methane levels can even be measured in pools of surface water on capped landfill areas, where landfill gas is escaping by bubbling through them.

A concentration of dissolved methane as low as 1.4 mg/l is known to be capable of giving rise to an explosive level of methane gas, in confined atmospheres in contact with such liquid (Buswell and Larson 1937; Larson, 1938). Although there has not been any reported incident of such an explosion within any UK sewer, and actual (as opposed to potential) risks have not been established, there is now a presumption that measures should be applied to control levels of dissolved methane in discharges of leachate into the public sewerage system. Therefore, in accordance with mine safety procedures, a factor of safety of ten times is increasingly being applied by regulators to discharges of leachate into the public sewerage system, and a consent limit of 0.14 mg/l of dissolved methane is widely applied by receiving sewerage authorities.

In order to meet this consent limit, therefore, from initial dissolved methane levels of 15 mg/l in leachates, more than 99 percent removal must be achieved, reliably and consistently.

Process overview

The partition of methane between dissolved and gaseous phases is governed by Henry's Law. Therefore, removal of methane gas from solution using the passage of air bubbles through the leachate will operate on a half-life principle. That is, passage of a given volume of air through a given volume of leachate, will reduce concentrations of dissolved methane by a fixed proportion. As such, it will prove very difficult, or very expensive, to achieve required overall percentage removal of methane within a single stripping reactor, especially if this is operated on a continuous flow basis. Detailed trials reported using a number of leachates from throughout the UK and Ireland (Robinson et. al., 1999) have demonstrated that 3 or 4 reactors, operating in series, will provide optimum performance (see Figure 2.1 below). A small, non-aerated, final vessel can provide additional methane removal, by allowing release of micro-bubbles of methane, prior to release of effluent to sewer. Plate 2.1 shows a typical methane stripping system in operation on a landfill site, capable of treating up to 300 m^3/d of leachate.

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Alternative process designs using packed towers or trickling filters with forced aeration have often suffered from organic and inorganic fouling, and because of the simplicity and efficiency of alternative aerated reactors, are not recommended.

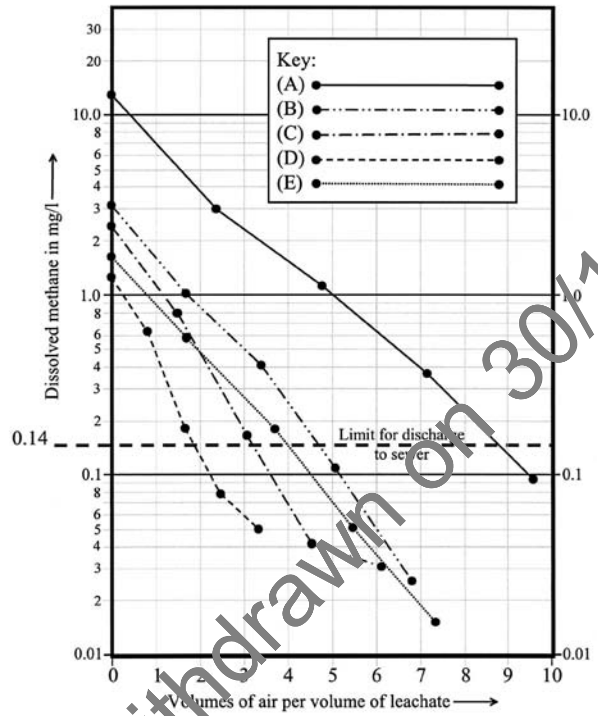

Figure 2.1: Reduction in concentrations of dissolved methane in five samples of landfill leachate, in a four reactor continuous flow air stripping system, as a function of air volume used (after Robinson et. al., 1999) (bullet points represent treatment achieved within a specific reactor)

Plate 2.1: Typical methane stripping plant, treating up to 300 m^3/d of landfill leachate, at Kendal Fell Landfill, Cumbria, 2002

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Environmental issues and concerns

Provided that adequate volumes of air are used during the stripping process, concentrations of methane present in exhaust gases will be well below explosive levels. Of greater concern, especially in leachates from relatively-recently emplaced wastes, may be potential for release of odorous gases during the stripping process. The significance of such releases can rapidly be assessed by use of pilot-scale stripping trials, involving collection of gas samples for formal testing using odour panels (where members of the public determine at what dilution such odours are detectable, in controlled trials).

Although at the great majority of full-scale methane stripping installations in the UK, such odour effects have been minimal and have not required specific treatment, at some sites gas biofilters (e.g. brushwood or heather filters) have been successfully installed.

Additional impacts/concerns at leachate methane stripping plants relate closely to the composition of specific leachates. Foaming may sometimes be an issue, particularly in treatment of leachates from more recent wastes, and can require routine addition of small quantities of antifoam agents.

A further potentially serious issue to be addressed is the precipitation of inorganic scale within the stripping reactors, or downstream pipework, as the stripping process also removes dissolved carbon dioxide, and oxidises metals such as iron. This has been addressed successfully using a variety of systems, including electromagnetic inhibitors, acid addition/pH control, and simple routine de-scaling programmes.

Because reactors used are relatively vulnerable, and contain untreated raw leachate, good practice should generally incorporate secondary containment by bunding in sensitive locations. Simple telemetry and alarm systems are widely available and used.

Continuous monitoring of levels of dissolved methane in final effluents using membrane probes has proved unreliable at present. Alternative, indirect measurements, (such as PPM methane values in off-gases from the final stripping reactor) could be incorporated as could continual monitoring of dissolved oxygen, but simpler systems such as fail-safe shutdown and alarm systems when blowers fail to operate/ draw current are likely to be more reliable at present.

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2.1.3.1.2 Ammoniacal-N removal by air stripping

General information

Ammonia can be removed from leachates as a gas, using air stripping, as an alternative to biological nitrification. Ammonia dissolves in water to form the ammonium ion in the following manner:

$$NH_3 + H_2O = NH_4^+ + OH^-$$

Ammonia gas — *ammonium*

The relative proportions of dissolved ammonia gas, and of ammonium ions, depend on the pH-value and the temperature of the water. Only the ammonia form is removed (as ammonia gas) by air stripping, and at normal temperatures and neutral pH-values in leachates or other waters, only a small proportion (<2 percent) of the total ammoniacal-N will be in the gaseous ammonia form.

At raised pH-values or temperatures, concentrations of dissolved ammonia gas adjust to an equilibrium between liquid and gaseous phases, and ammonia can be stripped from the liquid within the gas stream (usually air). The efficiency of the process is increased significantly by increasing values of pH or temperature, and with increasing efficiency the quantity of air required will decrease, and the concentration of ammonia gas in the exhaust air increases. Typically, either pH-values in excess of 10.0, or temperatures in the order of 60-70°C, are needed to achieve greater than 80 percent of ammoniacal-N in the gaseous ammonia phase, to provide an efficient removal process.

Unlike many other treatment processes, the required air volume removes a constant percentage of the incoming ammonia, regardless of influent concentrations in leachate, the progressive removal of ammoniacal-N therefore operating in a "half-life" manner. This has two consequences – first, at very high concentrations of ammoniacal-N, the stripping process is increasingly cost-effective; and second, it becomes difficult or costly to achieve low effluent concentrations of ammoniacal-N, such as below 50 or 100 mg/l. On this basis, ammonia stripping will generally only prove to be cost-effective, where partial pre-treatment is required, for example, prior to discharge into the public sewer, or before further removal of ammoniacal-N in a subsequent stage of biological treatment.

In achieving relatively low effluent values of ammoniacal-N (e.g. <50 mg/l), very large volumes of air will be required and this generally makes air stripping uncompetitive in cost terms for such applications.

Process overview

Ammonia stripping can be carried out in tanks or lagoons, packed towers, or in counter-current, multi-stage reactors. A consequence of optimisation of the process, to achieve reduced aeration requirements, is that air containing high concentrations of ammonia gas (to tens of grammes per cubic metre, equivalent to 10 percent by volume), can be released. This is likely to cause unacceptable health hazards at most sites, and must therefore be controlled. One option would be absorption of the ammonia in sulphuric acid, to produce ammonium sulphate, which may have potential for use as an agricultural fertiliser. Another possible solution is thermal destruction of the ammonia to nitrogen gas, ideally within a high efficiency landfill gas flare.

Few full-scale ammonia stripping systems have been installed for treatment of leachates at UK landfill sites. A few based on alkali dosing have failed, or rapidly been abandoned, as a result of environmental impact, operational difficulties or excessive cost of reagents. At least one plant in the UK plant uses leachate heating to enhance the stripping of ammonia. In recent years this technology has become established as a pre-treatment step for leachates in Hong Kong, from some of the largest landfill sites in the World (e.g. see Eden, 2001).

At three initial sites where such systems were installed in Hong Kong, leachate flows were typically in the range 720-1800 m^3/d, and concentrations of ammoniacal-N of 6700 mg/l in leachate were used for design purposes. The plants could efficiently remove these high concentrations of ammoniacal-N down to below 100 mg/l, before subsequent biological treatment of effluent in sequencing batch reactor (SBR) plants. Landfill gas was used to raise leachate temperatures to 70°C before passage to the stripping tower, and effective thermal destruction of ammonia gas (>99.99 percent) has been achieved within the landfill gas flare.

Environmental issues and concerns

Although ammonia stripping can be an effective and cost-effective treatment process for large volumes of very strong landfill leachate, application for use on a smaller scale at UK landfills is limited.

This document was withdrawn on 30/1/2020

The control and destruction of ammonia gas is of primary concern. When considering the utilisation of landfill gas flares for thermal destruction the consideration must be given to the impact on the emissions from the flare.

2.1.3.1.3 Stripping of other volatile contaminants

Significant removal of a number of trace organic components, often present in landfill leachates, can be achieved during air stripping treatment processes. Recent work carried out for the Environment Agency has provided guidance to landfill operators making reports of emissions under the Pollution Inventory (see Robinson and Knox; 2001; 2003) and has provided the following examples of such compounds:

Table 2.1 Trace organic components found in leachate

Compound	LOD (µg/l)	Presence (%)	median value (µg/l)	% removal
Ethylbenzene	10	15	10	40
Mecoprop (MCPP)	0.1	98	11	50
Naphthalene	0.1	70	0.46	40
Toluene	10	54	21	25
Xylenes	10	35	35	40
(**Notes:** LOD = limit of detection achievable routinely in leachate samples; presence (%) represents percent of samples in which compound was above the limit of detection).				

For several other substances, some present in only a small proportion of leachate samples, air stripping may also provide significant removal, but in the study above, no data were obtained.

It is unlikely that an air stripping treatment system would be employed specifically to reduce concentrations of such trace components in landfill leachates. To achieve this would be expensive, and require specific detailed process design information. Nevertheless, such compounds may well be present in exhaust air from other stripping processes, albeit at extremely low concentrations.

2.1.3.2 Reverse osmosis

General information

The reverse osmosis (RO) technique aims to extract clean water from the aqueous solution of organic and inorganic contaminants that constitute the landfill leachate.

The process exploits the natural phenomenon of osmosis where by, if two aqueous solutions, with different degree of concentration, are separated by a semi-permeable membrane, water from the weakest solution will pass through the membrane to dilute the higher concentration solution on the other side. The process will continue till solutions on both side of the membrane display the same degree of concentration.

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With reverse osmosis the process is reversed. Pressure is applied to a water solution, (leachate), against a semipermeable membrane forcing the water molecules to pass through the membrane, thus forming the clean “permeate”.

The majority of the solutes or contaminants will be left behind forming the “concentrate”.

Reverse osmosis is the finest physical separation method known. In contrast to normal filtration where solids are eliminated from a liquid, reverse osmosis succeeds in removing solutes from a solvent.

As a technology, RO is well established in wastewater treatment applications.

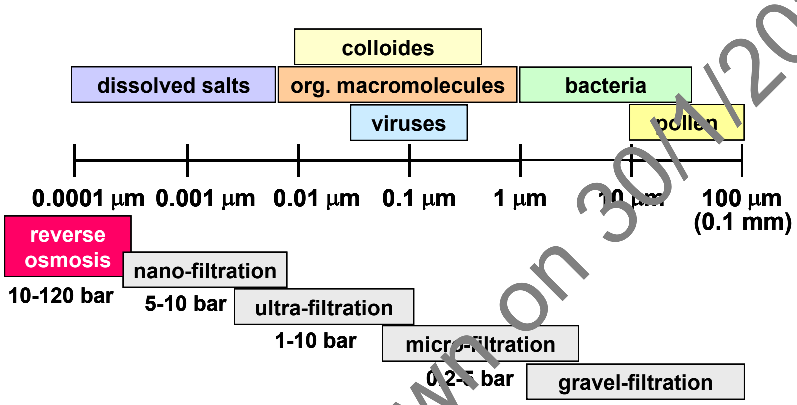

Figure 2.2: Filtration range comparison

Advances in membrane technology, in particular in the last 15 years, have allowed the development of RO systems designed specifically for the treatment of leachate.

The retention efficiency is primarily depended upon the molecular weight and polarity of contaminants.

Reverse osmosis membranes can result in the retention of more than 98% of large molecules dissolved in leachate. Ions of valance 1 such as Na^+, Cl^- can also be retained.

Most commercially available plants are constructed as two stage plants with contaminant removal rates better than 99.6%. Where unusually high strength leachate is treated or very stringent discharge consents apply, three stage plants can be employed and achieve contaminant removal rates better than 99.98%.

Reverse osmosis leachate treatment plants are widely used on landfill sites throughout Europe including Germany, France, Holland, Belgium, Italy, Switzerland, Spain, Portugal and Greece. More than 100 plants are currently operational some of them for longer than ten years.

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Table 2.2: Retention effect [%] against number of stages (see Packheuser 2002)

Parameter	Average retention effect (%)		
	Number of stages		
	1	2	3
COD	91.5	99.89	99.999
BOD_5	88.5	99.78	99.996
TOC	91.5	99.90	99.999
AOX	87.5	99.81	99.998
NH_4-N	85.0	99.65	99.987
PO_4-P	96.5	99.90	99.998

Modern 2-stages RO plants do reliably and consistently separate 75% - 85% of leachate volume into a high quality water stream. Plants specially configured can increase yield to 90%, (yield refers to production of "permeate" as a percentage of the treated leachate volume).

The main advantage of the RO process, in treating leachate, is the high quality of permeate produced. More than 99.9% of the contaminants can be retained and their release to the environment avoided.

As a non-biological process, RO is quite insensitive to changes in leachate strength. Though changes in leachate composition will effect the quality of permeate, well designed plants will sense this and adjust automatically either the throughput or/and yield ratio to compensate.

RO plants can operate intermittently; indeed RO plants do require frequent stoppages to "wash" the membranes. Washing of the membranes is done with a solution of membrane detergent and permeate produced by the plant. There is no requirement for a fresh water supply permanently connected to the plant though a supply should be made available close to the plant for use during maintenance and in cases were the permeate store is exhausted. "Wash" cycles are generally managed automatically and their frequency is governed by the level of contaminants in the leachate and in particular those of Calcium, BOD_5, COD etc.

Most plants able to reach steady state and full production within 10 to 15 minutes from re-starting. However switching the plant off frequently increases detergent usage, as most plant will go though a membrane wash cycle before shutting down.

The ability of RO plants to operate intermittently as well as their ability to adjust to leachate composition changes minimises the requirement of large balancing tanks/lagoons. However, care needs to be taken in designing such installation to provide adequate leachate storage capacity to allow for planed and unplanned maintenance of the equipment. Typically an RO installation will display better that 90% plant availability. The availability of the plant should be taken into account in designing the storage requirement as well as selecting the maximum capacity of the plant.

Commercial plants are generally containerised modular plants that are fully automated and capable of been monitored and controlled remotely. Standard modules are available with leachate throughput capacities from 30 m³/day up to 200 m³/day housed in single 40" ISO containers.

This modular approach requires very little infrastructure to be in place other than a suitably engineered hard-standing area for the plant and chemical storage tank. Installation and commissioning of such a plant will normally take 3 - 4 days. This allows the addition and removal of plant from site.

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Process overview

Most commercial RO plants, designed for the treatment of leachate, are of multi-permeate stage configuration, (typically two and rarely three stage). The first stage provides the majority of the leachate cleaning while subsequent stages "polish" the permeate further.

The plants use artificial, semi-permeable membranes of thin film composite construction. Such membranes have high salt rejection and display very high physical and chemical durability. Membrane manufacturers and in particular those of spiral wound type have optimised the construction of these membranes for use with leachate.

The membrane modules are mounted inside pressure tubes on racks, complete with interconnecting pipework and re-circulation pumps which circulates leachate in each membrane block in order to provide constant conditions on the membrane surface. The feed to a membrane must be of a sufficiently high velocity in order to provide an effectual overflow of the membrane surface to avoid concentration polarisation and fouling effects that would decrease their efficiency.

RO plants are designed to provide as large a surface area of membrane as possible for a given treatment unit, based on calculated flux rates of permeate through the membranes. Peters (1999) has stated that flux rates achieved depend on many parameters, and has reported typical values of between 13 and 15 litres of permeate per square metre of membrane per hour.

Flux rates gradually reduce during periods between cleaning of membranes, and over the life of membrane components, which is typically 1.5 to 2 years.

A variety of membrane module systems are available including; proprietary tubular modules, spiral wound modules, hollow fibre modules and disc tube modules. Standard spiral wound modules, hollow fibre modules and disc tube modules are sensitive to the presence of solids in the leachate. For this reason RO plants incorporate a pre-filtration stage by sand-filters and fine filters.

Continuously working reverse osmosis plants operate fully automatic. Operation parameters are permanently recorded and displayed. Start and shutdown procedures occur automatically. In most cases remote control is possible

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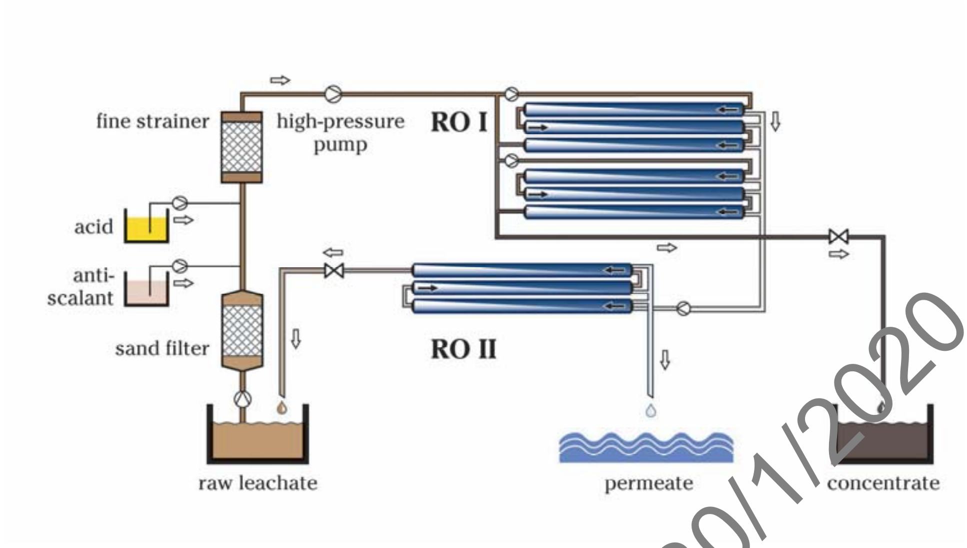

Figure 2.3: Typical process scheme of a 2-stage RO plant

The quantitative cleaning efficiency of reverse osmosis plant can vary between 50% and 90% clean permeate effluent. Experiences on European landfills treating "strong" leachate (e.g. ammoniacal-N >1000 mg/l) show, that values of 75% permeate yield are typical.

Permeate is normally suitably clean to be allowed direct discharge without any further treatment. The concentrate is in normally re-infiltrated in the landfill body.

In some cases, the RO concentrate has to be treated or disposed off site. In such cases an additional high pressure 2-stages concentrate stage (High Pressure RO, HPRO) can be included, after the standard plant, to further reduce the volume of concentrate. The total quantitative efficiency can be increased to nearly 90% permeate.

Table 2.3: Typical performance data from a 2-stages RO with 2-stages HPRO for concentrate treatment. (see Kolboom 2005).

Parameter	unit	Raw leachate	Permeate	Concentrate
Yield	mg/l	100	89	11
COD	mg/l	835	15.0	7300
Ammoniacal-N	mg/l	406	6.11	2480
Nitrate-N	mg/l	0.2	<0.1	-
Conductivity	mS/cm	11.25	0.2	51.1
pH	-	7.45	6.8	7.36

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Plate 2.2: Typical configuration of two 2-stage RO plant with leachate tanks, direct permeate discharge and concentrate re-infiltration (350 m³/d, Niemark landfill, Luebeck Germany, commissioned 1999).

Plate 2.3: Typical configuration of a 2-stage RO plant with leachate lagoon, direct permeate discharge and concentrate re-infiltration (72 m³/d, landfill CSDU Pays des Graves, district Hautes-Pyrenees, Commune de Lourdes, France, commissioned 2004) (see Wachter 2005)

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Plate 2.4: Typical configuration of a 2-stage RO plant with permeate lagoon (140 m³/d, Tondela landfill, district of Tondela, Portugal, commissioned 2004) (see Loeblich 2005)

During the late 1990s a lot of RO leachate treatment systems where designed with an aerated lagoon in front of a 2-stages RO plant. The advantage of this configuration is that an aerated lagoon reduces the NH_4-N, BOD_5 and COD level by its biologic activity.

Plate 2.5: Typical configuration of a 2-stage RO plant with aerated leachate lagoon, direct permeate discharge and concentrate re-infiltration (120 m³/d, Rebat landfill, district of Amarante, Portugal, commissioned 2001) (see Loeblich 2005)

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Table 2.4: Performance data from 2-stages RO plants

	Neimark Landfill, Luebeck, Germany (Kolboom 2005)		ZMD-Rastorf Landfill, Rastorf, Germany (Becker 2003)	
Parameter	**Leachate**	**Permeate**	**Leachate**	**Permeate**
COD (mg/l)	1024	15	2500	22
BOD_5 (mg/l)	40	0.6	-	-
Ammoniacal-N (mg/l)	388	6.1	2100	4
Nitrate-N (mg/l)	3.44	0.1	-	-
Conductivity (μS/cm)	8310	48	1810	78
pH	7.44	6.5	6.4	4.33
	Suldoro Landfill, Portugal, (Loeblich 2002)		**Lamego Landfill Lamego, Portugal (Loeblich 2002)**	
Parameter	**Leachate**	**Permeate**	**Leachate**	**Permeate**
COD (mg/l)	17780	28	17029	23
BOD_5 (mg/l)	10000	8	11350	15
Ammoniacal-N (mg/l)	3140	9	891	1.01
Nitrate-N (mg/l)	101	0.8	-	-
Conductivity (μS/cm)	20000	80	15400	18
pH	8.9	5.4	6.9	5.7

Environmental issues and concerns

The production of a high quality effluent (permeate) is a significant advantage of the RO process. In particular the removal of non-degradable components of leachate such as chloride, or residual COD and heavy metals. However, all these contaminants are present within the concentrate, which can be 10%-25% of the leachate volume. In the majority of cases concentrate is returned to the landfill, in other instances the concentrate is disposed of off site. In addition, all chemicals required for effective operation of an RO plant are contained in the concentrate. This amounts to about 0.3% of each cubic metre of leachate treated. Chemicals including citric acid, membrane cleaner and anti-scaling detergents. Modern designed membrane modules do not require treatment with biocides.

Disposal of concentrate is a key factor to be addressed. To date, concentrates have widely been recirculated back into landfilled wastes. The sustainability of this practice would have to be assessed on a site by site basis. Some data indicates that the return of concentrate to the landfill coincides with an increase in concentration in the leachate of COD and NH_4-N as well as an increase in conductivity. However, other data (Loeblich 2005 and Blumenthal 2005) shows that on some European sites there is no significant increase in diluted contaminants in landfill leachate following the commencement of concentrate return.

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When considering the sustainability of the return of concentrate to the landfill:
- any predicted change in leachate concentration should be assessed;
- it must be shown that the landfill is adequately engineered so that the concentrate does not cause pollution (particular attention should be given to the impact on groundwater);
- it must be shown that the leachate treatment system can adequately treat any predicted change in leachate quality resulting from the return of the concentrate; and
- chemicals essential to the effective operation of the plant should be selected so as not to compromise the disposal of the concentrate.

Secondary concentrate treatment processes, such as evaporation and dryers, have been used to reduce volumes further in countries such as Germany, the Netherlands, Belgium, France, Portugal, Spain (where RO plants are most widely used for leachate treatment), the residues from these processes have been stored in barrels within old mines. Since most of the solid material is readily soluble, highly engineered containment is required indefinitely. Most of the leachate dryers are out of operation now.
Reverse osmosis systems have also been used to treat leachates from landfills that have received residues from MSW incinerators. Hanashima et. al. (1999) reported RO tests using disc tube modules at one such site. Although leachates contained concentrations of chloride above 6000 mg/l, 95 percent permeate recovery was reported, and concentrations of dioxins were also reduced by up to 99.8 percent.

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2.1.3.3 Solids removal

It may be necessary to remove solids from either raw leachates or from pre–treated leachates prior to disposal. Processes most commonly used include sedimentation/settlement, sand filtration, dissolved air flotation or membrane filtration.

2.1.3.3.1 Sedimentation and settlement

Provision of sedimentation or solids settlement stages for pre-treatment for raw leachates is rarely appropriate, and there are very few situations in the UK where such facilities have been used.

Use of coagulation and flocculation processes, not only to reduce levels of suspended solids in leachates, but to provide additional removal of colloidal and other contaminants, is discussed separately below.

An efficient sedimentation/settlement stage of treatment is essential to achieve adequate clarification of effluents following biological treatment of leachates, and these issues are considered separately within that section.

2.1.3.3.2 Sand filtration

General information

Sand filtration involves the passage of the effluent through a high quality sand media with a specific particle size range between 0.8-1.7mm. The application of sand filtration processes of any sort to raw leachates will rarely be appropriate. Operational difficulties such as generation of biological sludges, or of uncontrolled partial biological processes, might potentially cause great difficulties.

Nevertheless, the use of tertiary sand filtration processes can make a significant improvement to the quality of effluents from biological stages of treatment, not only in terms of concentrations of suspended solids, but also of other associated contaminants (e.g. BOD_5, COD, iron).

Although continuous backwash sand filters are in use world wide, they have to date only occasionally been applied to treatment of leachate. There have been a few applications in the UK, where they have been specified for polishing of biologically pre-treated leachates, and in appropriate circumstances they have great potential for this purpose

Units have the advantage that they are generally transportable, and can readily be trialled or used on a temporary basis. They are relatively simple in operation, and lend themselves well to automation and telemetry/failsafe programming. On the other hand, they can be relatively expensive per kg of solids removed basis, and their height (typically 8m or more) may sometimes cause planning difficulties.

Process overview

Fixed bed sand filters, where a media (usually graded sand) traps and removes suspended solids from water passing through the media, may operate using gravity to drive water downwards, or by means of pressure applied from a pump. For both types of filter, the bed builds up head loss over time, as solids accumulate within it. When this pressure head loss becomes unacceptable, as solids are progressively entrained within the sand media, the filter needs to be backwashed, by reversing the flow of water to an upward direction. Backwash water (generally, treated effluent is used), sometimes using air to agitate the sand media, with addition of chemicals and released particles are usually discharged into a balancing tank, or may be returned into the original biological treatment process. Backwashing is automatically controlled either by adjustable timers, or by sensors which detect when the pressure differential exceeds a pre-set value. During the period of backwashing, no effluent can be treated by the bed.

The volume of backwash water produced will be determined by the concentrations of suspended solids in the feed, to some extent by their nature, and by the concentration of suspended solids required in the effluent. Many proprietary systems for fixed bed filtration are available, but few have been used in the UK for either raw leachate pre-treatment, or for final polishing of biologically treated effluents.

The resultant final effluent from a sand filtration system can have low levels of residual solids, and the application is particularly useful for discharge to river. The interception of solids can also be a useful technique for the removal of substances capable of bioaccumulation, which may be present in biological solids, or in some colloids.

Recently, tertiary treatment of biologically treated leachate has been carried out using a recovered media made from waste glass, with a particle size range of 0.5-1.0mm. The much smoother surface of the recovered glass has enabled the media to be cleaned more effectively using simple backflushing, and the removed solids have been returned to the treatment process. This has been particularly useful for maintaining nitrifying bacteria in the treatment process, and for the elimination of list 1 substances from the discharge.

An alternative type of sand filter is the moving bed, or continuous backwash filter, which has been developed into several forms, the most well-known being the proprietary "DynaSand®" system, which is currently in use in tens of thousands of applications Worldwide, since its introduction 2 or 3 decades ago.

The moving bed sand filter operates continuously, avoiding the need for periodic shutdowns to allow the sand to be backwashed, as sand is cleaned continuously by means of an internal washing system. The process is based on the countercurrent principle (see Figure 2.4), with dirty water entering the unit at the bottom, and travelling upwards, through the downward-moving fluidised sand bed. Suspended solids are strained from the rising water, by filtration and adsorption.

An airlift pump and draft tube, in the centre of the unit, recirculate sand and filtered particles from the bottom of the filter to the top of the vessel, which is usually open, into a separation box at the top of the unit. Here sand is separated from the removed suspended particles by turbulent action, the heavier grains of cleaned sand falling back into the top of the filter, and the lighter solid particles flowing over a weir to waste. As a result, the sand bed is in slow, constant downward motion through the unit, water purification and sand washing take place continuously, and no moving parts are involved in the system. Chemical flocculants (e.g. $FeCl_3$) can sometimes be added to water being treated, to improve the performance of the process.

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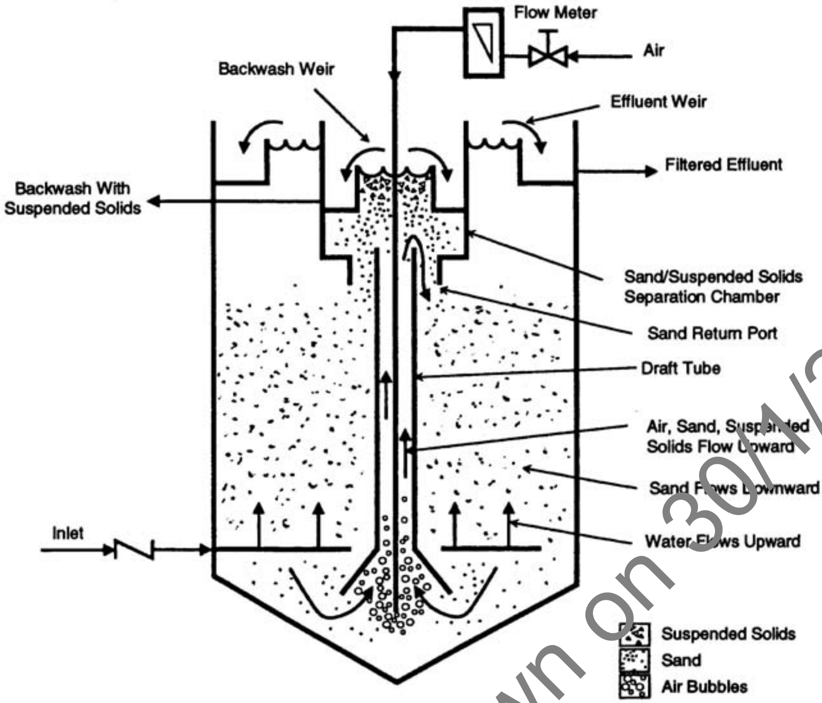
Figure 2.4 The moving bed sand filter process



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2.1.3.3.3 Dissolved air flotation (DAF)

General information

Although few full-scale DAF units have yet been applied to treatment of leachates at UK landfills, the process has an extensive track record in many industries, and has shown great promise in some projects for polishing of effluents from biological treatment of leachates. An extremely successful DAF system polishes effluent at the biggest leachate treatment plant in the UK, at Arpley Landfill in Warrington. Another unit has been recently installed at a leachate treatment plant constructed at Marston Vale in Bedfordshire. A number of other systems are planned for commissioning and operation in the near future.

Optimisation of the coagulation process prior to DAF treatment is key to increasing the efficiency of treatment, and is readily effected by specialists using experimental trials. The relatively short hydraulic retention time of the process can make DAF more sensitive to non-optimum or inconsistent coagulation control, however, biological leachate treatment processes such as SBRs, that give rise to intermittent discharges of consistent effluent, are ideal, as this can then be treated gradually over an extended period.

Process overview

Dissolved Air Flotation (DAF) is a process for the removal of fine suspended material from an aqueous suspension, in which solid particles are attached to small air bubbles, causing them to float to the surface. Attraction between the air bubbles and the particles results from adsorption forces, or physical entrapment of bubbles within the particle, colloid or floc. Chemical conditioning is generally used to increase the effectiveness of the DAF process, and optimisation of coagulation processes prior to DAF is key to improving effluent quality and minimising unit costs.

The most commonly adopted method of producing micro-bubbles of the optimum size (20-70 µm) is by recycling a proportion of the treated water through a pressurised (typically 2-5 bar) air saturation system, where it is saturated with air at the high pressure. Water then passes through a pressure relief nozzle in the base of the DAF tank within which air precipitates as tiny bubbles, with an enormous surface area.

A key benefit of this process of producing bubbles is that it produces a very positive attachment between air bubbles and the particles it is required to remove. Particles, colloids or flocs act as nucleation sites for the bubbles to precipitate on, which is a much more effective process than relying on contact between particles and larger bubbles introduced by some other means.

The rising particles float to the surface of the water, forming a scum/sludge layer which is removed, usually by means of mechanical scrapers or scoops. Treated water flows out from a lower level.

The first UK application of DAF to a leachate treatment system was at Arpley Landfill in Warrington, during 2001/2002. Effluent from biological treatment of very strong leachate (ammoniacal-N 2,500 mg/l, COD to 10,000 mg/l, conductivity 20,000 µS/cm) within an SBR, is treated using DAF, before receiving final polishing in a reed bed, and being discharged into the River Mersey to meet a strict discharge consent (see Robinson et. al. 2003). A relatively small DAF unit (see Plate 2.6) is able to treat effluent at the required rate of up to 20 m^3 per hour (450 m^3/d) and incorporates initial polyelectrolyte dosing.

Environmental issues and concerns

Providing that the process is well-specified, installed and operated, it should give rise to few environmental impacts or concerns. The DAF process uses limited energy, and few chemicals, sludge production representing less than about 1 percent of volumetric throughout, which can readily be disposed of either back to landfill, or via occasional road tanker to a sewage treatment works.

The Arpley unit has demonstrated not only the effective reduction in concentrations of suspended solids, typically from 250 mg/l to <40 mg/l, but also the associated reductions in levels of organic materials in non-degradable COD, many of these being present within colloidal materials which are effectively removed by the DAF process.

Table 2.5 provides typical operating data for the DAF unit.

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Table 2.5 Treatment of SBR effluent in a DAF unit at Arpley Landfill Site, Warrington, UK (after Robinson et. al., 2003)

Determinand	Leachate	SBR effluent	DAF effluent
COD	5990	1470	1060
BOD_{20}	1720	67	6
BOD_5	688	20	<1
TOC	1240	356	281
Ammoniacal-N	1460	3.7	3.2
Nitrate-N	1.9	1490	1238
Iron	13.0	5.51	0.72
Sodium	2560	3490*	3770*
Chloride	2710	2300	2650
Notes: results in mg/l, * = related to dosing of NaOH as alkalinity			

Plate 2.6. The main DAF treatment tank at Arpley Landfill

2.1.3.4 Activated carbon adsorption

General Information

Adsorption is the transfer of (generally) organic compounds from a liquid phase onto the surface of a solid material, and its extent is related to chemical and physical properties of each. Several adsorbent materials may be used, but for removal of organic compounds from leachates, to date only activated carbon has been found to be cost-effective.

Activated carbon is a highly porous and crude form of graphite, with a wide range of pore sizes, and very large surface area of hundreds of m^2 per gramme. It can be made from coal, wood, peat, coke or coconuts, and adsorption capacities of greater than 10 percent by weight are possible. In the field of drinking water or groundwater treatment, activated carbon is widely used to remove trace levels of organic substances that can impart flavours to water.

The performance of activated carbon for removal of organic compounds is

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influenced by the:

- capacity of a specific carbon to adsorb a specific organic compound;
- concentration of the organic compound in the feed;
- contact time between water and carbon;
- loading rate applied to the carbon; and
- presence of other organic compounds which may compete for adsorption sites.

Activated carbon is normally used in either a powdered form (PAC), or in a granular form (GAC). When the adsorption capacity of the carbon becomes exhausted, it may be possible to regenerate GAC using specialised equipment (at 2 or 3 locations in the UK). The accumulated organic compounds (often concentrated to hazardous levels) are removed from the carbon and thermally destructed, with less than 10 percent mass loss of the GAC, (resulting from general attrition processes). In contrast, PAC is normally used only once, and then disposed of rather than regenerated.

Activated carbon is capable of removing significant quantities of BOD and COD, however due to the relatively high costs of activated carbons, in many cases it is more economical to utilise the synergies between biological treatment and activated carbon. In leachate treatment it is generally restricted to polishing of effluents that have previous been treated using biological, or rarely other, processes. Occasionally activated carbon has been used in biological treatment plants to provide a buffering effect and reduce toxic shock when highly contaminated leachate enters the system.

The effectiveness of a carbon adsorption process is described by a function known as an adsorption isotherm. The adsorption capacity of carbon is the mass of adsorbed contaminant per mass of activated carbon (e.g. mg COD/g AC). This value is measured at several effluent values of COD (in mg/l) to provide the isotherm curve, which can be determined by simple and small-scale laboratory experiments. Because of variability between specific AC materials, and in the many compounds which comprise residual COD values, generic data are unhelpful, and site-specific tests using several different AC sources are an essential part of a design process.

2.1.3.4.1 Powdered activated carbon (PAC)

Process overview

PAC may in certain circumstances be cheaper than GAC, but cannot be reactivated, and so must be disposed of after a single use. PAC is dosed as a slurry, to achieve a desired concentration of PAC in mg/l, and a contact period in the order of 30 minutes to an hour, within an aerated or fully-mixed reactor (see Plate 2.7 below).

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Plate 2.7: Typical reactor (35 m^3) for contact with PAC in treatment of landfill leachate

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The mixed liquor must then be treated to remove the PAC, by subsequent processes, such as coagulation, flocculation, or filtration.

During the 1980s and early-mid 1990s, PAC was widely used in Germany as a final polishing step after biological treatment of leachates, primarily as a means of achieving nationally-applied standards for COD and AOX (adsorbable organic halogens) in all discharges, and waste PAC was landfilled locally. However, later legislation limiting the disposal of waste products from water treatment processes, meant that GAC systems are now generally preferred.

Data from the PAC systems (e.g. Albers and Kruckeberg, 1988) did demonstrate the ability of the process to achieve significant removal of residual COD in biologically pre-treated leachates. Typically, when treating effluent COD values in the range 200-800 mg/l, adsorption rates in the order of 250-450 mg COD per g of PAC were maintained, and final effluent COD values of <100 mg/l could be consistently achieved.

Table 2.6 below presents data obtained from sampling of a PAC polishing system at Minden Heisterholz, near Hannover, as part of a UK Government research project during 1990.

Table 2.6: Minden Heisterholz leachate treatment plant, with PAC 1990

Determinand	Leachate	Biological effluent	PAC effluent*
COD	2320	376	75
BOD_{20}	627	15.0	<0.5
BOD_5	370	<0.5	<0.5
TOC	1940	171	33
Ammoniacal-N	712	0.2	<0.2
Chloride	1440	1120	1020
Notes: all results in mg/l; PAC removal by $FeClSO_4$ coagulation, with polymer addition and settlement/clarification			

Although operationally the process is relatively simple (for example, levels of suspended solids in final biological effluent do not affect process efficiency) generally at larger leachate treatment plants the reduced operational costs of a GAC plant more than offset the extra capital costs of equipment required, and GAC systems are preferred. The costs of disposal of spent PAC to landfill, and environmental considerations regarding this, reinforce this decision in most circumstances.

The main operational consideration in the use of PAC is the appropriate dose required to achieve a desired level of treatment. This can be determined readily on a site-specific basis by a simple batch equilibrium isotherm tests in a laboratory. Performance may vary considerably between different carbon materials, and different leachates. Table 2.7 below compares data from the Minden site with results for polishing of biologically treated leachates at a range of UK and other landfills.

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Table 2.7: Data for removal of residual organic compounds in biologically treated leachate effluents, using PAC

Leachate Origin	Parameter	Influent (mg/l)	Effluent (mg/l)	Reduction (%)	C. dose (kg/m³)	Ref (#)
Pitsea, UK	TOC	407	130	68	5	a
Compton Bassett, UK	TOC	89	3.7	95	8	b
	COD	249	30	88	8	b
Greengairs, UK	TOC	88	6.1	93	8	b
	COD	238	45	81	8	b
Summerston, UK	TOC	248	12	95	8	b
	COD	623	33	94	8	b
Harewood Whin, UK	TOC	54	4	92	8	b
	COD	159	16	90	8	b
MSW, USA	COD	184	18.4	90	4	c
Minden, Germany	TOC	171	33	81	~1	b
	COD	376	75	80	~1	b
References: (a) Knox (1983) (b) Robinson (1990) (c) Pohland (1975)						

2.1.3.4.2 Granular activated carbon

Process overview

GAC is normally used in fixed beds or tanks, through which effluent is passed in a controlled manner, at a controlled rate. Because such filter systems generally use two or three identical tanks, operated in series, they provide several benefits:

- higher effluent quality can be achieved more cost-effectively, as a result of relatively fresh GAC always being available to contact effluent at the end of the final tank;
- higher overall contaminant loading rates can be achieved, per kg of carbon consumed.

As an example, a typical GAC polishing installation for COD removal might comprise four treatment tanks. At any time, three units would be receiving passage of effluent in series (say, numbers 1, 2 and 3), and a 4th would be empty. Effluent quality from GAC tank 1 would be monitored for COD on a regular basis, and as COD rose to a predetermined trigger level at this point, the GAC could prepare to be replaced. Because the downstream tanks 2 and 3 continue to provide further treatment, with fresher carbon, maximum use could be obtained from GAC in tank 1, until effluent COD from it approached COD values in influent.

At this stage, a tanker would fill tank 4 with fresh GAC, then removing the spent GAC from tank 1 to be regenerated. The new order of treatment would now be tanks 2, 3 and 4 ensuring that, again, the freshest carbon is treating the final effluent before discharge.

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Plates 2.8 and 2.9 below show a simple and typical GAC installation.

In general, a 3-tank system (plus one spare) provides optimum operation, minimising overall usage of GAC. The service life of each tank of GAC depends on the specific carbon being used, the volume of the tank, the flow rate, the strength of the liquid being treated, and final effluent quality limits required. As with PAC, sizing can be determined very accurately using small scale laboratory isotherm tests. Appropriate flexible pipework layouts and valves are essential, to allow efficient operation of the overall scheme, and reduce down-time to a matter of minutes each time GAC is replaced (generally one tank every four months or less).

Plate 2.8: Typical internal sequential GAC tank installation for polishing of biologically-pre-treated landfill leachate

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Plate 2.9: Typical external sequential GAC tank installation for polishing of biologically-pre-treated landfill leachate

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Hydraulic retention times in the order of 15 to 30 minutes are typical within each tank. In order to maximise carbon usage there should be a total empty bed contact time of between 2 to 4 hours. In some cases when discharge limits are very tight (or flows are very small) this figure can be as high as 6 to 8 hours.

A parameter termed the "effective carbon dose" (ECD) is often used to compare performance of different GACs, when treating different pre-treated leachates, and is defined as:

$$ECD = \frac{\text{weight of GAC in the bed (grammes)}}{\text{Volume of water treated during service run}}$$

Because concentrations of contaminants in treated water normally increase gradually over a period of several weeks or months, sampling and analysis frequency must be determined accordingly.

Environmental issues and concerns PAC and GAC

For either powdered or granulated activated carbon treatment systems, the main environmental concerns relate to the disposal or regeneration of the activated carbon itself.

During treatment, powdered activated carbon is readily and safely dosed as a slurry, but used PAC cannot be reactivated, and so must be removed as a sludge by processes such as coagulation, flocculation or filtration. The used PAC is then disposed of, generally to landfill or by incineration.

GAC is delivered and used contained within reaction vessels. The spent GAC must then be removed for regeneration, which must be undertaken at specialist facilities.

The presence of persistent organic pollutants that have been adsorbed onto either form of activated carbon will limit locations where they can be regenerated or disposed of safely.

2.1.3.5 Ion exchange

Ion exchange removes ions from an aqueous solution by the exchange of anions or cations between contaminants and the exchange medium. Ion exchange materials typically consist of resins made from synthetic organic materials, which contain ionic functional groups to which exchangeable ions are attached. They may also be inorganic or natural polymeric materials.

Ion exchange processes are most widely used in potable water treatment, and have been successfully applied to nitrate removal, or to water softening (see Hall and Hyde, 1992). For nitrate removal, water is passed through a bed of synthetic resin beads, which remove anions including nitrate from the water, exchanging them for equivalent amounts of chloride. When the capacity for exchange is saturated, the bed is taken out of operation and the resin regenerated with sodium chloride brine (~10 percent w/v), which returns the resin to the chloride form. The bed is then rinsed with clean water and returned to service. Used regenerant contains high concentrations of sodium chloride, as well as nitrate (and sulphate) removed from the bed, and must be disposed of, often to sewer.

For water softening, cationic resin is instead used, which can be regenerated either using NaCl, or acid, but the process is essentially similar.

Application of ion exchange processes to the treatment or polishing of landfill leachates has to date been limited by the very high concentrations of anions (e.g. chloride, nitrate-N to 2000+ mg/l) and cations (e.g. sodium, calcium to 1000+ mg/l) present in raw or biologically pre-treated leachates. This continues to restrict any cost-effective applications for leachate treatment.

The complexity and variability in composition of leachate, including the presence of multiple contaminants makes it unlikely that naturally occurring ion exchange materials will be suitable for treating leachate. The presence of hydrocarbons may also cause the media to be blinded. Zeolite has been used for ammonia removal but regeneration has not proven cost effective and therefore the technology may be more applicable to sites where the flow rates and ammonia concentrations are small.

That is not to say that ion exchange processes may not be developed in future, which may find useful applications. If suitable systems can be developed, operated in contact with leachates to provide cost-effective treatment of specific ions, and demonstrated in pilot-scale tests, they should be considered seriously at that stage.

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2.1.3.6 Evaporation/concentration

Table 2.8: Operating results from a MSF evaporation plant treating leachate at Uttigen, Switzerland

Determinand	Leachate	Effluent	
		Range of values	Mean value
COD (mg/l)	4060	40 – 116	61
BOD_5 (mg/l)	305	32	17
Ammoniacal-N (mg/l)	2000	4 – 17	9
Conductivity (µS/cm)	12000	42 – 302	140
pH-value	-	4 - 7.8	6.5
AOX (µg/l)	4500	2 9- 67	54
Phenols (µg/l)	-	208 – 450	320
<u>Notes:</u> Units as shown; - = no data; from Hofstetter, 1990			

Environmental issues and concerns

As with reverse osmosis, the process is a concentration step, and identical considerations apply to the disposal of the concentrate that is produced, involving considerable cost.

Electricity consumption, for production of vacuums etc, is typically about 10 KWh per m^3 treated. Costs of heat energy will vary, depending on availability of local waste heat sources. The plant itself is very expensive – treatment of 250 m^3/d will involve a plant costing in excess of £2.5M.

Very large quantities of acid and other chemicals are involved, for example, about 1 percent by volume of 32 percent w/v hydrochloric acid (i.e. 10 litres of acid per m^3 of leachate treated). This is not only expensive, but if leachate is concentrated by a factor of 20 times, will <u>in itself</u> result in concentrations of chloride in excess of 60,000 mg/l of chloride in the concentrate sludge. Typical chloride levels of 2,000 mg/l in leachate would raise total concentrations of chloride in sludge to greater than 10 percent by weight.

Operation is relatively labour-intensive, estimated at 2 hours per day for a skilled operator.

A further key issue is the control of air emissions from the process.

Indicative standards for physical treatment processes
General
1. The standards for storage and treatment vessels are detailed section 2.1.1
2. The standards for storage of raw materials are detailed in section 2.1.2
3. Leachate of some composition, particularly those from more recent wastes will cause foaming in stripping plants. Foaming should be countered by routine addition of antifoam agents.
4. Odour and ventilation is addressed in section 2.2.6.

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5. Fugitive emissions to air are addressed in section 2.2.4

Methane stripping

1. Adequate volumes of air shall be used during the stripping process to keep concentrations of methane present in the exhaust gas well below explosive levels.
2. Close control of the air input during the operation of the plant can be used to reduce the precipitation of inorganic scale within the stripping reactors, or downstream pipework. Provision of additional flow capacity in the downstream pipework increases the period between pipe cleaning operations.

Removal of Ammoniacal-N by Air Stripping

1. If raising pH-value is used to increase the process efficiency, high dosages of alkali (typically in the range 3-8 kg of $Ca(OH)_2$ per m^3 treated) will be required, and effluent may subsequently require acid neutralisation before discharge, such dosing should be undertaken using automatic calibrated in-line dosing pumps.
2. Operation at elevated temperatures will reduce alkalinity requirements, use can be made of landfill gas, or of waste heat from landfill gas power generation schemes an option. In the event that the operator proposes to use energy other than waste heat to raise the process temperature consideration should be give to alternative uses of this energy to determine which represents BAT.
3. Precipitation of inorganic and organic materials may cause scaling and clogging problems if packed towers are used for the stripping operation, and may result in a requirement for removal and disposal of sludges. Procedures must be in place that ensures that the identification of any scaling or clogging within the pack tower and for subsequent management and disposal of sludge arising.
4. Where relatively high effluent concentrations of ammoniacal-N are accepted (e.g. 100-200 mg/l), greatly reduced aeration rates can be achieved. Leachate will require secondary biological treatment if effluent discharge to watercourses is an option, the removal of ammoniacal-N to very low levels during stripping can result in nitrogen deficiency in secondary stages of treatment
5. Release of ammonia gas in exhaust air may be controlled by thermal destruction in a landfill gas flare. When considering the utilisation of landfill gas flares for thermal destruction the impact on the emissions from the flare have to be considered.

Reverse osmosis

1. The return of retenate to the landfill shall only take place if:
   - Any predicted change in leachate concentration has been assessed;
   - it must be shown that the landfill is adequately engineered so that the concentrate does not cause pollution (particular attention should be given to the impact on groundwater, an appropriate source term should be modelled in the landfill site's hydrogeological risk assessment);
   - it must be shown that the leachate treatment system can adequately treat any predicted change in leachate quality resulting from the return of the concentrate;
   - chemicals essential to the effective operation of the plant should be selected so as not to compromise the disposal of the concentrate; and
   - the leachate originated from the landfill site (i.e. no imported leachate).

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2. Ideally the soluble contaminants should be stabilised before disposal. 3. The chemicals used in membrane backwashing should be selected to ensure they will not cause damage to the RO membrane.
Sand filtration
1. The application of sand filters to raw leachate is rarely appropriate and is more applicable as tertiary treatment. 2. The optimum application is to reduce levels of solids from up to 200 or 300 mg/l, down to below about 30 or 50 mg/l. They are likely to represent BAT for such applications at landfills which are relatively large, fully-manned and treat consistent and relatively high flows (>100 m^3/d) of leachate. 3. Efficiency is directly related to levels of suspended solids in water being treated, although they can deal well with variable influent quality. Volumes of backwash water generated are also related to solids being removed. Backwash water should be reused by returning it directly into the biological treatment reactor.
Dissolved air flotation
1. Optimisation of coagulation processed is key to improving effluent quality. Therefore automated on-line dosing of chemical equipment should be used. Manual dosing should be avoided as it reduces the accuracy of addition rates and can lead to overdosing.
Activated carbon – general
1. Activated carbon should be regenerated.
Activated carbon – powdered
1. In the event that the PAC may be contaminated with persistent organic pollutants and no suitable regeneration facility is available incineration preferably with energy recovery should be used.
Activated carbon – granular
1. GAC filtration systems generally demand a relatively low level of suspended solids in incoming effluent, which may require a specific additional treatment stage (e.g. DAF, reed bed, etc), following initial biological treatment processes. 2. The presence of multiple contaminants can impact overall performance. For example (hypothetical), if the GAC is required to reduce overall COD in effluent to a specific level, and also to remove a specific contaminant completely, such as a relatively non-biodegradable pesticide (e.g. isoproturon), then it cannot be presumed that removal efficiencies for each contaminant will necessarily decline in a similar manner. Bench tests are therefore essential to estimate carbon usage for mixtures. 3. Treatment costs can be high if used on effluents with high COD values, following biological treatment, or if very low final effluent values are required. Since biological effluents from treatment of leachates containing high (>1500 mg/l) concentrations of ammoniacal-N can contain up to or greater than 1000 mg/l of soluble, intractable COD, (e.g. see Robinson et al, 2003), this can make polishing of such effluents relatively expensive. 4. In general, smaller molecules are adsorbed less well, as are highly water-soluble compounds.

5. Spent carbon, possibly containing some hazardous compounds which, have been concentrated within it (e.g. chlorinated compounds and pesticides), will require regeneration (and safe destruction of these compounds) at one of only 2 or 3 locations in the UK. Proximity of the treatment plant to such a location may impact on costs for carbon, and overall unit costs of treatment.

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2.1.4 Chemical treatment processes

2.1.4.1 Chemical oxidation processes

Chemical oxidation processes are potential treatment options for the removal of specific organic and inorganic pollutants from landfill leachates, but are unlikely to provide full treatment of the wide range of contaminants present in typical samples. Oxidation involves the loss of one or more electrons from the element being oxidised – the electron acceptor being another element, including an oxygen molecule, or a chemical species containing oxygen, such as hydrogen peroxide, ozone, or some other electron acceptor.

In practice, the application of such processes will be restricted by cost, by the rate of reaction possible (oxidation rates for some organic compounds may be too slow), and by the availability of alternative treatment processes for specific contaminants.

In a complex wastewater such as leachate, the amount of chemical oxidant required in practice, is generally greater than the theoretical mass calculated from first principles. This results from a number of reasons, including incomplete oxidant consumption, and lack of specificity of the desired process – oxidant also being consumed by other chemical reactions. Oxidation reactions are often pH-dependent, and control of pH-values may be an important consideration.

For treatment of landfill leachates, a limited range of oxidants have found successful application to date, primarily ozone or hydrogen peroxide. Use of others has been limited by concerns about formation of toxic reaction by-products – for example, chlorine and chlorine compounds giving rise to trihalomethanes, or other halogenated compounds.

Nevertheless, in specific situations, chemical oxidation processes can provide particular benefits – for example, at elevated pH-values, cyanide can be oxidised to carbon dioxide and nitrogen using sodium hypochlorite (e.g. see Patterson, 1985). It is likely, therefore, that chemical oxidation processes will find only occasional application in leachate treatment, and then to deal with individual and site-specific circumstances. Ozonation and use of hydrogen peroxide will probably account for most applications.

For all reagent-based chemical oxidation processes, the storage and handling of potentially hazardous chemicals must be addressed and considered, and appropriate standards of design and care applied. If extreme conditions are required within a treatment reactor, then high standards of control and containment become even more important safety considerations.

Because of their nature, advanced chemical oxidation processes continue to be developed experimentally. Examples include wet air oxidation, and electrochemical oxidation systems. At the time of drafting, these have not been successfully applied to leachate treatment, but over coming decades it is possible that novel processes may be developed and need to be considered.

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2.1.4.1.1. Ozonation

General information

Ozonation is well established as a treatment technology for drinking waters, or in swimming pools, for which it is used as a disinfectant, to degrade substances of concern, and to enhance the performance of other treatment processes. Although not so widely employed for the treatment of sewage or industrial wastewaters, ozonation has much to offer in specific circumstances.

Ozone is the strongest practical oxidant available for waste water treatment, and is used for:

- Oxidation of organic materials, especially recalcitrant organic compounds, to enhance their removal by subsequent treatment – especially in biological processes;
- Disinfection;
- Taste, odour, and colour removal;
- As a pre-oxidant stage to enhance removal of turbidity and algae within subsequent treatment processes; and
- Precipitation of iron and manganese.

Capital costs of ozone treatment are relatively high (typically £250K to £350K to dose 150 mg/l into 200 m^3 of effluent per day), due to the high cost of equipment for ozone generation. Electricity comprises the majority of operational costs, which can also be high, especially for stronger leachates.

Ozonation should be seen as an expensive polishing option, appropriate only in specific circumstances for leachate treatment, such as complete destruction of less biologically-degradable pesticides in final effluents. Nevertheless, case studies in the UK and overseas have demonstrated that such systems can operate reliably on landfill sites.

Process overview

Ozone itself (O_3) is an allotrope of oxygen, and is a gas at normal temperatures and pressures. It is relatively unstable, having a half-life of less than 30 minutes in distilled water at 30°C (Reynolds, 1982). Because of this instability, ozone must therefore be generated at the point of use, by passing air or pure oxygen between oppositely charged plates. The gases having been pre-dried to a dew point lower than about -40°C. Pure oxygen feed is generally only more cost-effective than air for ozonation systems that are required to generate more than 1 tonne of ozone per day. For smaller systems (typical leachate applications will require less than 50 kg of ozone per day) then air is generally used.

Once produced, air containing enhanced concentrations of ozone gas is bubbled through the water to be treated in a column, using a bubble diffuser system. Generally, a batch system of treatment is preferred, with a contact time of between 15 minutes and an hour.

Ozone transfer occurs as fine bubbles containing ozone and air (or oxygen) that rise slowly inside the column, contacting the contaminated water phase. Correct ozone dosage to achieve required oxidation of specific compounds is generally determined using small-scale treatability studies. Pesticides, aromatics, alkanes and alkenes are examples of compounds readily and successfully treatable by ozonation.

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Ozone treatment is generally only appropriate as a polishing step in the treatment of landfill leachates, following extensive biological pre-treatment to remove degradable organic compounds that might otherwise result in excessive consumption of ozone. Removal of suspended solids from water being treated is also essential for efficient treatment. In addition, ozonation is best applied to well nitrified or low ammonia containing effluents, since to some extent ammonia also competes for ozone with the organic compounds being targeted.

Environmental issues and concerns

Unlike chlorine, the use of ozone for effluent polishing does not result in excessive formation of trihalomethanes. However, as well as directly degrading some organic compounds, ozone can increase the degradability of organic compounds, resulting in increased levels of BOD in effluents. These can then readily be degraded efficiently, using passive processes such as reed bed polishing. Particularly during treatment of landfill leachates, ozonation can result in generation of very reactive brominated intermediate compounds (e.g. bromal, = tribromoacetaldehyde). Experience has demonstrated that although such compounds exhibit significant toxicity, they are readily and completely degraded within an appropriately designed reed bed polishing system.

There is only one example of a full-scale leachate treatment plant in the UK where ozonation has been applied as a polishing stage for leachate treatment. In that instance, ozonation was applied to meet extremely stringent effluent toxicity criteria, before discharge into a very sensitive receiving watercourse. The plant has operated successfully since 1994, particularly for the complete removal of a number of pesticides, such as mecoprop and isoproturon, in biologically pre-treated leachate. Experience has been that ozonation generally only provides between 10-15 percent removal of residual hard COD, and that if COD levels in final effluent are a major issue, then alternative polishing processes, such as activated carbon, may be more appropriate.

Where removal of adsorbable organic halogens (AOX) is an issue, ozonation has been shown to be capable of reducing values of AOX from up to 3 mg/l, to below 0.5 mg/l (e.g. see Kaulbach, 1993). Costs of such treatment, where required, must be compared with those of alternative processes, such as activated carbon adsorption.

Although variants of ozonation, involving combined treatment with hydrogen peroxide (H_2O_2), and/or Ultra Violet irradiation, are capable of providing increased oxidation potential by the enhanced generation of hydroxyl radicals, such processes have rarely been applied to treatment of landfill leachates.

2.1.4.1.2 Hydrogen Peroxide

General information

Hydrogen peroxide (H_2O_2) is a strong oxidising agent generally supplied as a 35% w/v solution. Use of hydrogen peroxide has found many applications to oxidise contaminants in industrial wastewaters. In the presence of a catalyst, such as iron, hydrogen peroxide (H_2O_2) generates hydroxyl radicals (*OH), which can react with reduced compounds and specific organics.

For leachate treatment, peroxide treatment systems have ranged from very simple drip feed dosing into open leachate lagoons, through pumped dosing into the inlet of large recirculation pumps, to fully engineered dosing systems into mixed reactors. Dosing of hydrogen peroxide has sometimes also been incorporated within simple methane stripping systems for leachate (see earlier), in order to meet discharge consents for entry of leachate into the public sewer. Hydrogen peroxide and potassium permanganate have also been used successfully to treat odorous

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leachates for short periods by turning the leachates aerobic and reducing the potential to cause odour.

Process overview

In leachate treatment, hydrogen peroxide oxidation has been applied principally to oxidise sulphide, although experience from other industries has shown that many other contaminants which might be found in leachates can also potentially be treated (eg phenols, sulphite, cyanide, formaldehyde, etc).

For oxidation of sulphide, reactions depend on pH-value as below:

(a) acidic or neutral pH

$$H_2O_2 + H_2S \rightarrow 2H_2O + S$$

Reaction time 15-45 minutes (much quicker if catalysed by Fe^{2+})

(b) Basic pH

$$4H_2O_2 + S^{2-} \rightarrow SO_4^{2-} + 4H_2O$$

Reaction time 15 minutes

Sulphide levels have been successfully managed at between 10 – 20 UK landfill sites, either to control odours, or to comply with limits for discharges of leachates into sewers. Under the optimum pH-value conditions of neutral or slightly acid, the reaction of peroxide and sulphide is relatively specific, and chemical requirements of about 25 percent greater than those predicted in equation (a) have generally proved to be appropriate, with a reaction time of about 30 minutes. Laboratory trials may be valuable in optimising chemical dosing rates.

Environmental issues and concerns

Principle concerns over Hydrogen Peroxide relate to storage and handling issues and ensuring that in the event of a spillage adequate controlls are in place (spill kits, bunding and training) to protect sensitive environmental receptors.

Hydrogen Peroxide is a strong oxidising agent and as such must not be allowed to come into contact with incompatable materials.

2.1.4.2 Precipitation/coagulation/flocculation

2.1.4.2.1 Chemical precipitation of metals

General information

It has been widely demonstrated that, with the exception of levels of zinc in acetogenic leachate samples, concentrations of heavy metals in leachates from landfills containing primarily household wastes are relatively low. Typical values are generally lower than those measured in samples of domestic sewage, and far lower than levels of metals being treated at sewage treatment works, where inputs of industrial effluent have also been received. Median values for key metals in leachates from modern large landfills, with high waste input rates (including co-disposal sites and sites receiving industrial and commercial wastes) are reported below, and are compared with values for non-industrial crude sewage (in mg/l, after Robinson, 1995).

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Table 2.9 Median values for key metals in leachate

Metal	Acetogenic leachate	Methanogenic leachate	Domestic sewage (range of values)
Chromium	0.12	0.07	0.01 - 0.17
Nickel	0.23	0.14	0.01 - 0.19
copper	0.07	0.07	0.06 - 0.50
zinc	6.85	0.78	0.10 - 1.65
cadmium	0.01	<0.01	0.001 - 0.03
lead	0.30	0.13	0.03 - 0.395

Additionally, significant removal of some of these metals in leachate (e.g. zinc, chromium, copper) has been reported during aerobic biological treatment (see Robinson and Knox, 2001).

On this basis, chemical treatment to reduce concentrations of metals is unlikely to be widely required, in particular at landfills which, receive significant inputs of household wastes, or where leachates are treated biologically before discharge. Precipitation and other reactions within an anaerobic landfill will generally reduce the mobility of heavy metals significantly.

Nevertheless, if specific circumstances require such metal removal, chemical precipitation processes are widely employed for this purpose, for effluents in a wide variety of industries, and could readily be adopted.

Although specific treatment processes for removal of heavy metals from landfill leachates will only occasionally be necessary, and have rarely been provided at UK landfill sites, on occasions when specific features of landfills require such treatment, there is a wealth of experience and data to allow appropriate systems to be designed (e.g. see Eckenfelder, 1989).

Difficulties may arise from the relatively low concentrations of heavy metals present in leachates, reducing the cost-effectiveness of the process, and also where there is a need to remove mixtures of metals, and these have different optimum pH values for precipitation.

Process overview

Precipitation is widely employed for the removal of concentrations of heavy metals from industrial wastewaters, and although many chemicals have been used (e.g. hydrated lime, quicklime, magnesium hydroxide, sodium hydroxide), hydrated lime, Ca $(OH)_2$, has been most widely used, and is generally the cheapest. Heavy metals are usually precipitated as the hydroxide through the addition of alkali, to a pH-value at which solubility of the metal of interest is minimised. Several metals are amphoteric, and exhibit a point of minimum solubility, below or above which solubility will increase and removal will reduce. Examples are chromium (pH value 7.5), and zinc (pH value 10.2).

Although many leachates have been shown to contain organic complexing agents, which have potential to interfere with metal removal (especially at relatively low concentrations in leachate), excellent removal of metals has nevertheless been reported by many authors (e.g. Knox, 1983; Bjorkman and Mavinic, 1977; Chian and DeWalle, 1977).

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All precipitation processes are very strongly influenced by the pollution matrix of specific leachates, and as a consequence, laboratory and pilot-scale trials are essential if the process is to be optimised, and efficient treatment systems are to be developed, and operated to achieve effluent limits reliable and cost-effectively.

The wastewater treatment industry has extensive experience which enables it to provide appropriate precipitation processes, which take advantage of a range of chemical phenomena including co-precipitation and adsorptive co-precipitation, so that residual metal solubility levels far below theoretical solubility limits for simple metal salts can commonly be achieved. Similarly, appropriate subsequent treatment stages of flocculation, sedimentation and clarification; can be optimised based on experience. Volumes and handling characteristics of precipitated sludges are frequently at least as important as economic factors, in final selection or optimisation of precipitation processes.

Environmental issues and concerns

Principal environmental issues relate to the correct storage of chemicals, correct dosing to prevent excessive use of reagents and sludge disposal. Sludge may be dewatered to facilitate handling transportation and disposal. Typically, disposal will by landfill depending on Landfill Regulations limitations.

2.1.4.2.2 Coagulation and flocculation

General information

Chemical coagulation and flocculation are used for the removal of waste materials present in suspended or colloidal form. Colloids represent particles typically within a size range from 1.0nm to 0.1nm (10^{-7} to 10^{-8} cm). These particles do not settle out on standing, and are not readily removed by conventional physical treatment processes.

Coagulants, usually salts of iron or aluminium, are added at controlled pH-values to form solid precipitates termed floc, which contain the colloidal particles, and can then be separated out using conventional solid, liquid separation processes. The process of flocculation encourages floc growth by gentle mixing, to suite the subsequent separation process being used.

Process overview

In leachate treatment at UK landfills, full-scale coagulation/flocculation systems have rarely, if ever, been applied to the raw leachates, and only occasionally to biologically pre-treated effluents.

Nevertheless, in other countries such as Germany, coagulation and flocculation processes are more widely applied to both raw and treated leachates, and extensive experience is available. Common applications have included:

- Removal of turbidity and colour from biological treatment effluents;
- Reduction in COD values associated with colloidal materials;
- Removal of powdered activated carbon (PAC) in effluent polishing (see separate section);
- Reduction in suspended solids concentrations, to protect subsequent treatment stages – e.g. in activated carbon columns.

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Coagulant aids, often polyelectrolyte compounds, may be added to enhance coagulation by promoting the development of large, rapid-setting flocs. Polyelectrolytes are high-molecular-weight polymers that form bridges between particles or charged flocs, when added at low concentrations (1-5 mg/l) in conjunction with alum or ferric chloride.

The key to successful coagulation and flocculation is detailed jar-scale, laboratory testing, to establish the optimum pH-value and coagulant dosing for treatment of a specific leachate or effluent. Good mixing at the point of chemical dosing, and tight control of coagulant dose and pH-value are essential, as is optimisation of the physical process of floc formation. In large-scale wastewater treatment processes, sophisticated feedback controls are routinely used, which may be more difficult to apply to smaller leachate treatment applications.

Environmental issues and concerns

Principal environmental issues relate to the correct storage of chemicals, correct dosing to prevent excessive use of reagents and sludge disposal. Sludge may be dewatered to facilitate handling transportation and disposal. Typically, disposal will by landfill depending on Landfill Regulations limitations.

2.1.4.2.3 Electrochemical Processes

General information

The future use of electrochemical processes in the treatment of leachate has been suggested. This section provides a brief overview of the processes involved for information purposes and does not make any recommendations or specify standards.

Three electrochemical processes may be applicable to the treatment of wastewater, electro-coagulation/electro-flocculation, and electro-oxidation.

Electrodes placed in the leachate can be aluminium or iron. On the application of an electric current coagulants are formed by the dissolution of the anode. Hydrogen gas is generated at the cathode and oxygen at the anode. Aluminium and iron precipitates that form can be removed by sedimentation or by flotation. Flotation of low density flocculated particles is aided by the generation of hydrogen and oxygen. The oxidation of organic substances and ammoniacal-N can occur directly at the anode or indirectly from the degradable content of the solution.

Indicative BAT requirements for chemical treatment processes
General
1. Storage and handling of chemicals is covered in section 2.1.2. 2. The use of automated on-line dosing of chemical equipment. Manual dosing should be avoided as it reduces the accuracy of addition rates and can lead to overdosing.
Ozonation
1. The ozone contactor should be designed for efficient adsorption that minimises ozone in the off-gas. Any ozone remaining in the off-gas from the diffusion system must be destroyed before release into the atmosphere. Destruction of excess ozone is accomplished readily using thermal, catalytic, or other processes. (Threshold limit value (TLV) for repeated exposure of workers to

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ozone is 0.21 mg/m^3 in air.)
2. By decomposing to oxygen as it reacts, ozone provides an environmentally preferable alternative to halogenated oxidants (e.g. chlorine), adsorption (e.g. activated carbon) or even reverse osmosis in some circumstances. 3. Typical power consumption for generation of ozone from air or oxygen is 16 kWh and 8 kWh respectively, per kg of ozone produced. Process design must take into account the additional costs involved in purchase and safe handling of liquid oxygen, and also the significant costs of pumping liquids and dosing these with the ozone-enhanced air.
Hydrogen Peroxide treatment
1. Hydrogen Peroxide has several key advantages over alternative chemical oxidising agents for leachate treatment applications. It does not produce toxic chlorinated by-products, nor any increase in AOX, as does chlorine and hypochlorite, nor does it increase salinity. 2. Hydrogen Peroxide can provide a temporary buffer against septicity, in the form of dissolved oxygen, because it readily decomposes to water and oxygen within the environment.
Chemical precipitation of metals
1. Lime or other chemicals used as part of the process must be selected on the basis of a high purity to avoid introducing other potential contaminants into the process, or reducing the reactivity of the reagents. 2. Equipment used to prepare and dose slurries is critical to operation of the process and must be subject to a preventative maintenance programme. 3. Certain chemicals e.g. lime are susceptible to the effects of moisture and must be stored in dry conditions. 4. Treated water will be of much higher pH-value than the feed water, and may require addition of acids to reduce pH-values to suitable levels for discharge or subsequent treatment. 5. The precipitated metals will be settled out of the water stream, and will be contained within the waste sludges generated by the process, which will also exhibit high pH-values. Handling and disposal of waste sludges must be appropriate to the nature and hazard of the metals present. These sludges may be designated as a hazardous waste.
Precipitation /coagulation/flocculation
1. Chemical coagulants, flocculants, and pH-control chemicals may be hazardous and require appropriate precautions in use and storage. Cationic and anionic flocculants can be very toxic to fish and their storage and use should ensure appropriate containment and dosing. 2. The main risk to the process is lack of appropriate control, resulting in failure to meet treatment objectives. A high degree of process control should be maintained at all times. 3. The optimum pH-value and coagulant dosing should be established by detailed laboratory testing prior to operation.

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