DESIGN AND OPERATION OF COST-EFFECTIVE LEACHATE TREATMENT SCHEMES AT UK LANDFILLS: RECENT CASE STUDIES

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ABSTRACT

Provision of simple and reliable on-site leachate treatment facilities is becoming a widespread requirement at many UK landfill sites. As applications for PPC permits have recently exposed site operations to increasing scrutiny, this trend will inevitably only continue. Although many on-site leachate treatment schemes have been procured, and are being operated successfully, there remain many instances of schemes where facilities have been installed, that have not been able to meet effluent discharge standards adequately.

Several recent papers have described leachate treatment case studies, where particularly difficult landfills have required relatively sophisticated solutions.

This paper, instead, summarises 6 case studies of installation of leachate treatment, at UK landfills where relatively straightforward systems have been applied successfully, to deal with leachate management situations that face many site operators. Operational data are presented from each of these plants, with the intention of demonstrating the degree of treatment which can be achieved consistently and reliably by such systems, treating leachates of various characteristics and strengths. This information provides valuable and realistic guidance to many landfill operators, who are required to install appropriate treatment systems at their sites.

Full-scale, on-site plants are now being designed and commissioned on a regular basis, and represent a generation of treatment systems applicable to many landfills. They are typically highly-automated, with modem links allowing remote interrogation of operation and performance, and with reliable and robust fail-safe and alarm systems installed, to provide control and security of effluent discharges. A separate paper at this conference (Novella et al 2004) describes how similar schemes have been applied to landfills in South Africa.

This paper addresses key issues such as presence of residual “hard” organic compounds in treated effluents, actual effluent standards being reliably maintained, and volumes of leachate being treated by the process adopted.

KEYWORDS

Leachate, Treatment, Case Studies, SBR, Reed beds, UK, ammoniacal-N, COD, trace organic compounds.

INTRODUCTION

Papers at recent CIWM conferences (eg Robinson et al, 2002; 2003) have described UK case studies, where particularly difficult landfills have required relatively sophisticated leachate treatment systems, which represent internationally state-of-the-art solutions.

Nevertheless, as these complex solutions have been implemented, at many more UK landfills, relatively straightforward biological leachate treatment systems have been installed successfully, to deal with leachate management problems which face many more site operators. More than half of these treatment systems result in effluents for which a consented discharge into surface watercourses, or into groundwater, is possible. Other schemes discharge treated effluents into the public sewer, achieving either financial savings in trade effluent charges, or sometimes enabling discharges to be made where release of untreated leachate would not have been possible.

In the UK, development of appropriate, reliable, and cost-effective leachate management schemes has for many years been based on:

- applied and experimental research data;
- site-specific risk assessment;
- Best Practical Environmental Option;
- Best Available Technique Not Entailing Excessive Cost;
- principles of sustainability.

In practice, therefore, only those options that are both practical and available have been possible – at some sites, specific options may be neither, and so other systems have been developed. Although the UK Environmental Agency is presently in the process of drafting guidance on Best Available Techniques (BAT) for leachate treatment (see Robinson, 2003), this will provide only general non-prescriptive guidelines. It will still leave the onus on the operator of an individual landfill and leachate treatment scheme, to demonstrate that an option being selected comprises BAT for that particular site. For many sites, more than one technology may comprise BAT, providing a choice of leachate treatment options.

This paper is intended, by providing real data from operation of actual leachate treatment plants operating in the UK over extended periods, to enable landfill operators to make informed decisions, about the standards to which simple SBR leachate treatment schemes can in practice treat a range of leachate types. A number of the case studies presented comprise combined treatment systems, where SBR treatment is enhanced by addition of a simple reed bed polishing system.

CASE STUDIES

In each case study presented, a brief potted history of the landfill site is followed by summary details of the type of leachate treatment scheme, method of procurement by the landfill operator, and operational results over a period of time. For reasons for expediency, (to prevent an excessively long paper), a range of data have been presented at each of the landfill sites. All leachate treatment plants included were designed and commissioned by Enviros Consulting Limited.

(1) Efford Landfill Site, Hampshire

The Efford Landfill Leachate Treatment Plant, that has been constructed and commissioned for Hampshire County Council, is a typical example of the sort of system being required by landfill operators. The plant is capable of treating up to 150 m^3/d of fairly strong leachate, using the

Sequencing Batch Reactor system at the heart of most Enviros plants, followed by polishing in a reed bed, before discharge of effluent to a small, rural STW. Mean operating data since the plant was commissioned in January 2003 are presented in Table 1 below, and the plant is shown in Plate 1.

Table 1. Mean values 2003, for performance of Effort LTP, Hampshire (mg/l except pH-value)

Determinand	Leachate	SBR effluent	Final effluent
COD	942	462	309
BOD_5	72	22	3
Ammoniacal-N	820	1.59	0.48
Alkalinity (as $CaCO_3$)	3830	1229	1138
Nitrate-N	0.21	423	384
Nitrite-N	0.04	0.56	0.87
Chloride	1502	1442	1507
Suspended solids	-	-	33
pH-value	7.6	8.2	8.4

Plate 1. Efford LTP, Hampshire

The plant is operated on behalf of Hampshire County Council by Onyx Limited, operating as Hampshire Waste Services Ltd. Figures 1, 2 and 3 below provide very detailed operational results for the extended period January 2003 to May 2004, and also provide data for volumes of leachate being treated – typically in the range 50-70 m^3/d Treated leachate is discharged into a small rural STW, discharging into the River Avon.

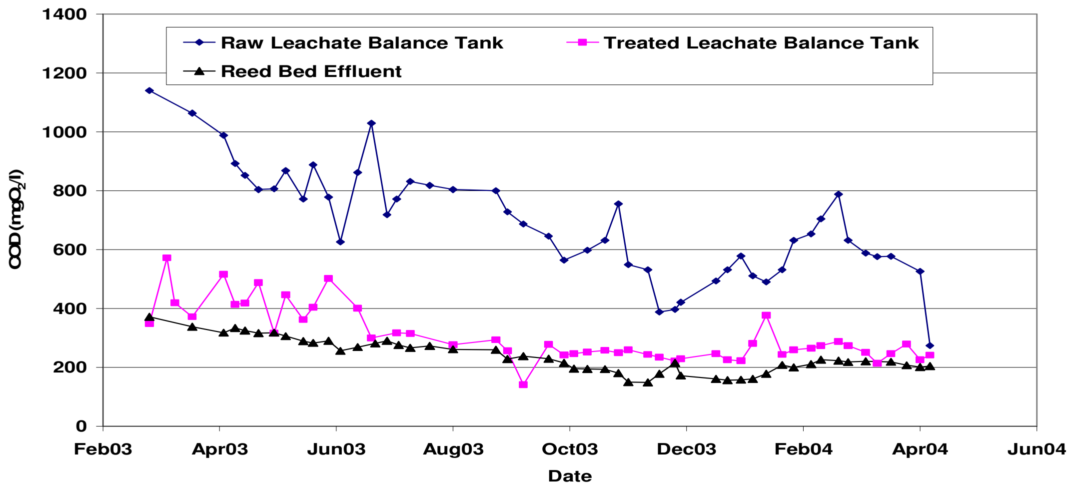

Figure 1. Removal of COD at Efford LTP, March 2003 – May 2004 (in mg/l)

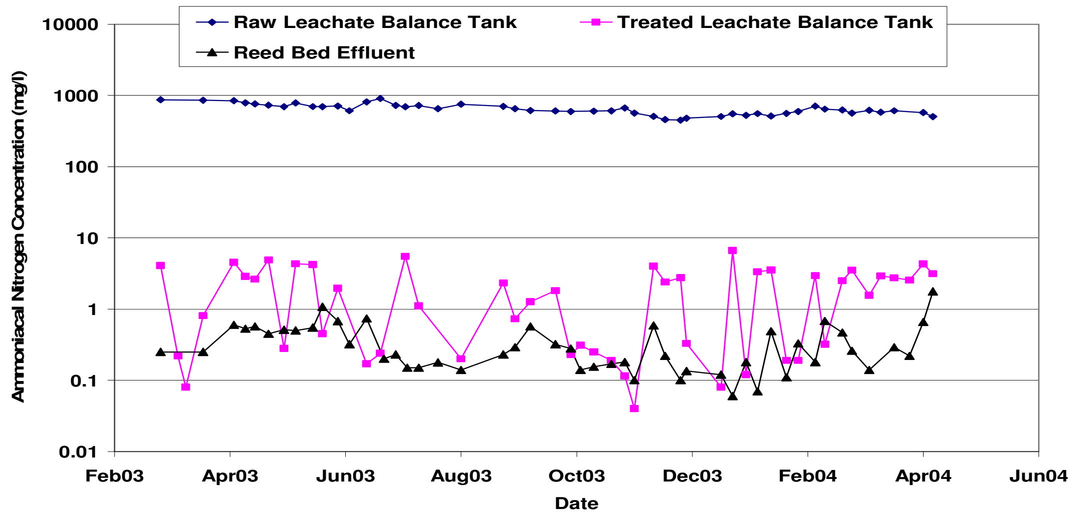

Figure 2. Removal of ammoniacal-N at Efford LTP, January 2003 – May 2004 (in mg/l as N)

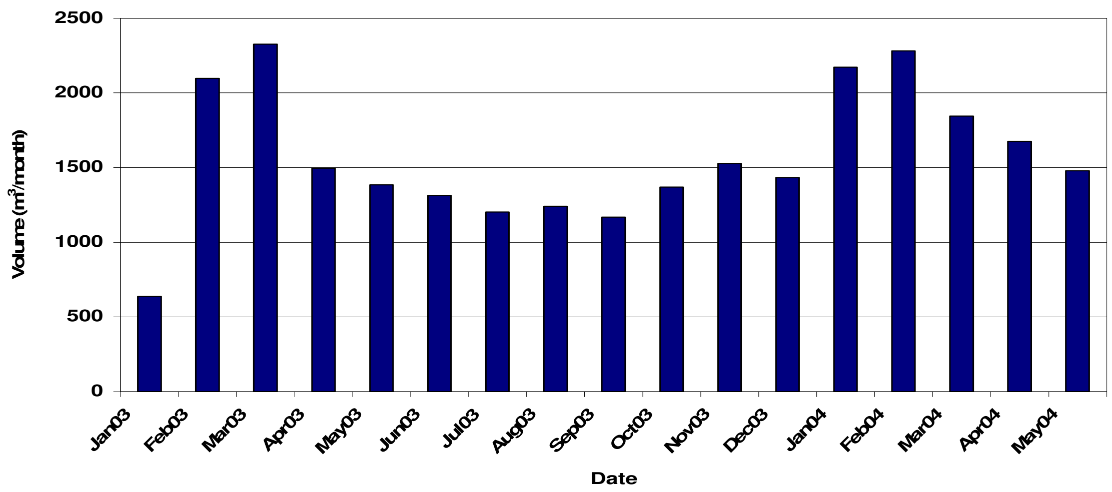

Figure 3. Monthly total volumes (m^3) of leachate treated by Efford LTP, January 2003 – May 2004

The plant was procured by Hampshire using a traditional consultancy route, Enviros preparing a very detailed design and specification, which was tendered to suitably-qualified contractors.

(2) Llanddulas Landfill, North Wales

Waste Recycling Group (WRG) adopted a different form of contract to procure a leachate treatment plant at its Llanddulas Landfill on the north coast of Wales. A partnering arrangement between contractor May Gurney, consultant Enviros, and staff of WRG has provided a state-of-the-art plant, commissioned during early 2003. The plant provides automated treatment of up to 150 m^3/d of leachate (see Figure 4) which is discharged into the public sewer about one mile from the site.

Plate 2. Llanddulas LTP, North Wales

Llanddulas is a very large limestone quarry within 500m of the North Wales coast, that is engineered to very high standards, and has received waste inputs since the early 1980s. The leachate treatment plant is part of extensive efforts made by WRG in recent years to gain full control of leachate at the site.

Figure 4 shows total monthly volumes of leachate treated by the plant since it was commissioned during the autumn of 2002 – typical treatment rates being in the order of 40 – 50 m^3/d. The plant is constructed on a bench of the original quarry, and can be operated cost-effectively at these lower flows, while still retaining capacity to treat higher leachate flows in later years, as the landfill extends.

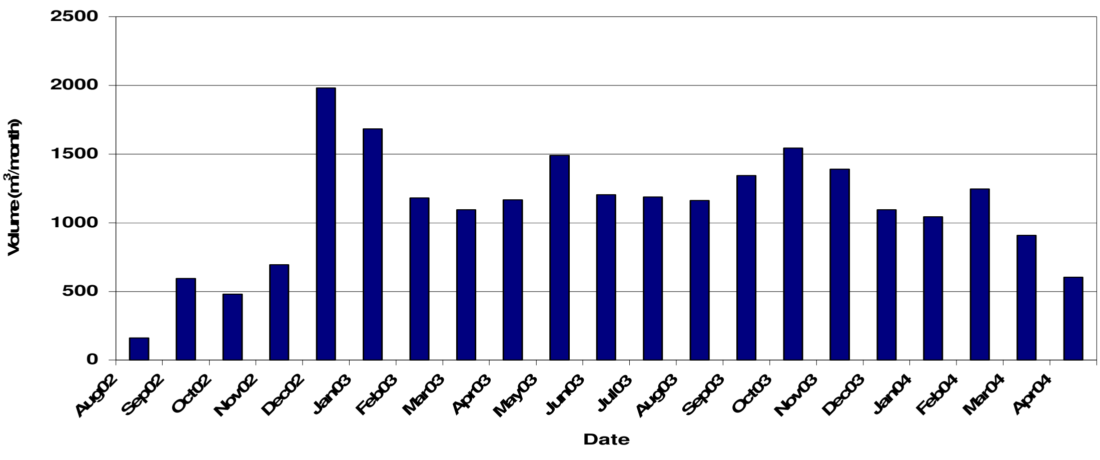

Figure 4. Monthly total volumes (m^3) of leachate treated by Llanddulas LTP, August 2002 – April 2004

Figures 5, 6 and 7 provide data for the treatment of COD, BOD_5 and ammoniacal-N over an extended period, and Table 2 provides very detailed analytical results for leachate and effluent quality during typical operations.

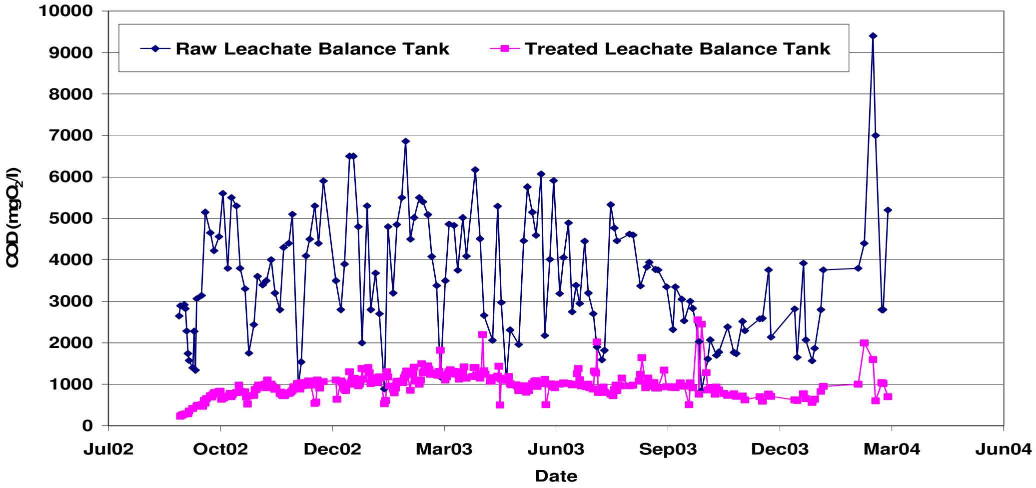

Figure 5. Removal of COD at Llanddulas LTP, August 2002 – May 2004 (in mg/l)

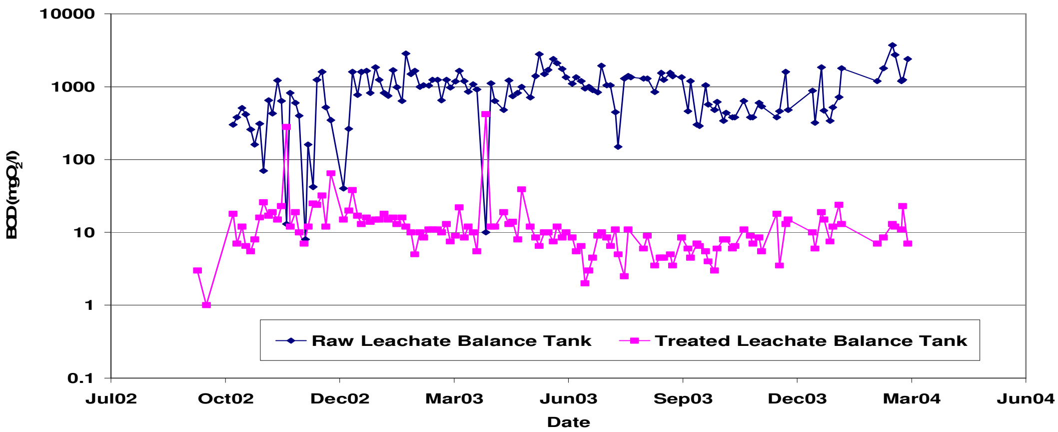

Figure 6. Removal of BOD_5 at Llanddulas LTP, August 2002 – May 2004 (in mg/l)

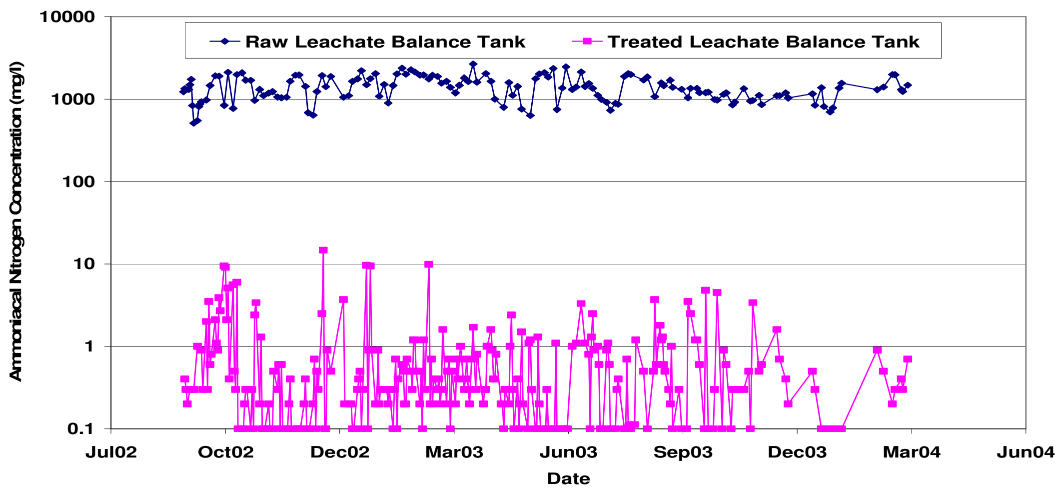

Figure 7. Removal of ammoniacal-N at Llanddulas LTP, August 02 – May 04 (in mg/l as N)

The plant provides a very high degree of treatment, and although residual levels of non-biodegradable COD in effluent are typically 800-1000 mg/l, these do not exceed consented values, and have been demonstrated to comprise very stable organic compounds, with no detectable toxicity (see later text).

Leachate at Llanddulas is strong and methanogenic, typically and consistently containing concentrations of ammoniacal-N just below 1000 mg/l. The treatment plant comprises a large above-ground concrete tank SBR, roofed for heat insulation. Like most of the other treatment plants being described, the system is fully automated, and makes use of modem links to reduce operator inputs to a matter of maybe an hour or so each day.

Table 2. Very detailed typical analyses for raw leachate and treated effluent at Llanddulas LTP, November 2002

Determinand	LEACHATE	EFFLUENT
COD	3410	762
BOD (20-day)	1520	27
BOD (5-day)	1160	9
TOC	1210	212
ammoniacal-N	965	12.3
chloride	2210	1830
pH-value	7.9	8.2
alkalinity (as $CaCO_3$)	5380	865
nitrite-N	<0.1	<0.1
nitrate-N	<0.3	668
sulphate (SO_4)	<5	180
fatty acids (as C)	280	<10
conductivity (µS/cm)	9780	13100
sodium	1550	2180
magnesium	60	35
potassium	672	480
calcium	242	72
chromium	0.145	0.084
manganese	4.68	0.12
iron	45.9	1.09
nickel	0.113	0.147
copper	<0.02	0.08
zinc	0.16	0.09
cadmium	0.001	0.002
lead	0.04	0.02
arsenic	0.017	0.055
mercury	<0.0001	<0.0001
Notes: • Results in mg/l except pH-value, and conductivity (µS/cm)		

(3) Ardley Landfill, Oxfordshire

The leachate plant at Ardley in Oxfordshire was procured by Viridor Waste Management, using a Design and Build contract arrangement, which was tendered and won by a team of Enviros and Hytech Water. The plant can treat up to 150 m^3/d of leachate, which typically contains about 8,000 mg/l of COD (although this varies from 2,500 to above 15,000 mg/l across the site), and ammoniacal-N in the range 300-700 mg/l. Treatment comfortably achieves limits for discharge of effluent to sewer, and in doing so minimises the trade effluent charges being levied. Since being commissioned by Enviros during late 2002, the plant has typically treated about 100 m^3/d, in a single concrete SBR tank, again roofed for thermal insulation. The plant is shown in Plate 3 below, and detailed data for removal of COD and ammoniacal-N are presented in Figures 8 and 9.

Plate 3. Ardley LTP, Oxfordshire

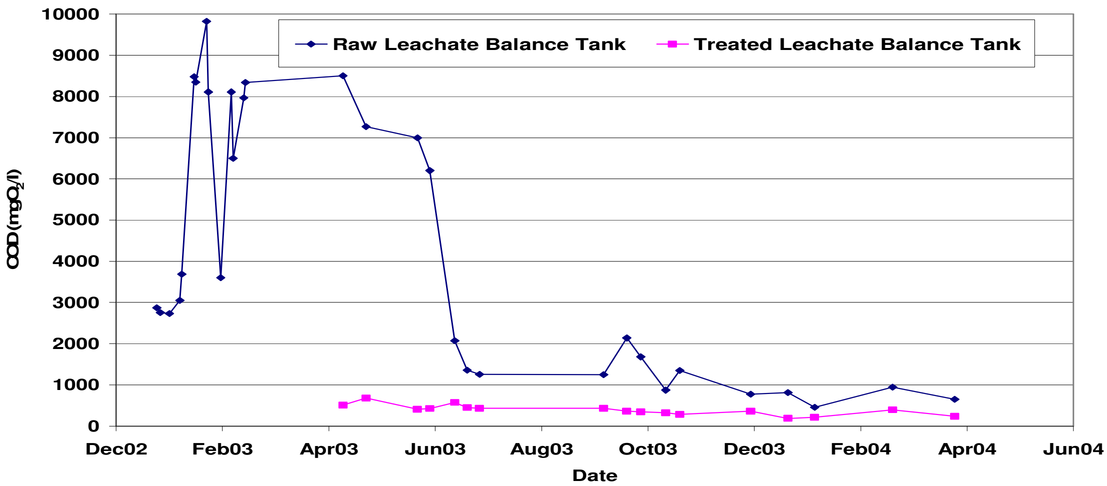

Figure 8. Removal of COD at Ardley LTP, January 2003 – April 2004 (in mg/l)

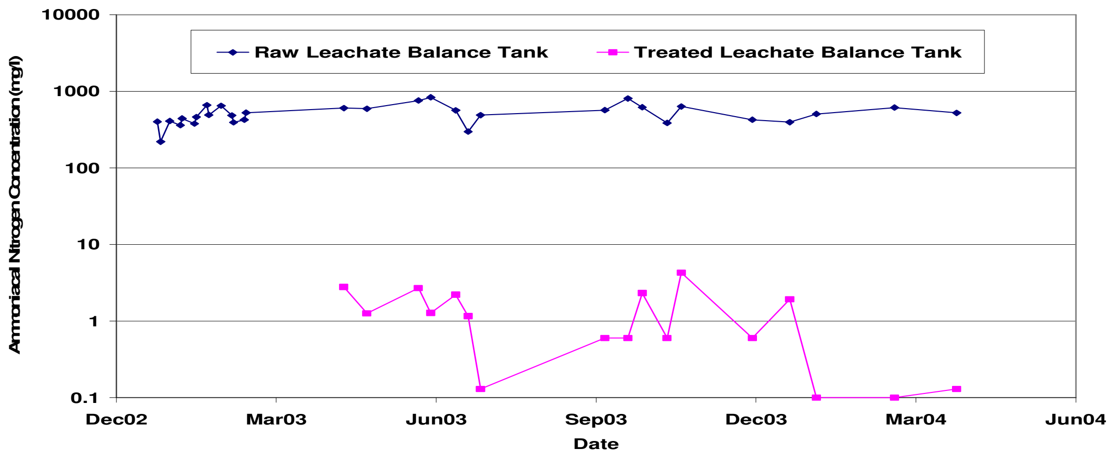

Figure 9. Removal of ammoniacal-N at Ardley LTP, September 2002 – March 2004 (in mg/l as N)

(4) Granish Landfill, Aviemore, Scotland

Traditional consultancy was also used by Highland Council to obtain a leachate plant at its Granish site in Aviemore, which was commissioned during April 2003. This plant is designed to treat up to 80 m^3/d of leachate to a standard suitable for discharge of effluent directly into groundwater, and is the fourth by Enviros for this client.

Granish Landfill is situated about 2km north of Aviemore, and just off the old A9 trunk road. Earlier unlined phases of the site infilled sand and gravel excavations in the flood plain of the River Spey, and operated on a dilute and attenuate basis. Later (post 1990) phases of infilling took place on a containment basis, and presently the plant treats relatively small volumes of leachate from these areas (<20 m^3/d). Leachate is treated to very high standards, following commissioning during April 2003, by the SBR and reed bed polishing system. Effluent quality is suitable to allow a consented discharge into groundwater beside the site, into the sands and gravels of the flood plain of the River Spey.

The Granish LTP is shown in Plate 4, and operational data for removal of COD and ammoniacal-N during the first 12 months operation of the plant are provided in Figures 10 and 11, including an initial period when primarily acetogenic leachate was being treated. The benefits of the reed bed polishing scheme will increase as the reed plants establish.

Plate 4. Granish LTP, Aviemore, Scotland

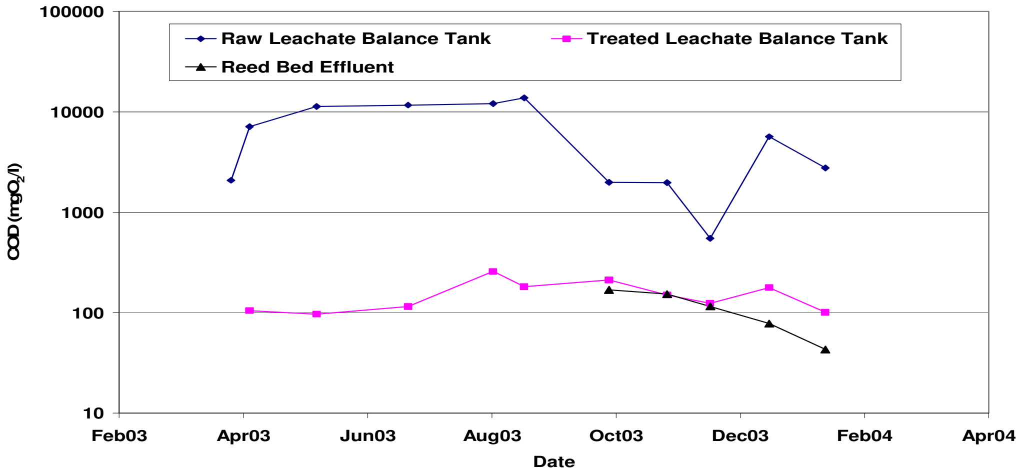

Figure 10. Removal of COD at Granish LTP, April 2003 – February 2004 (in mg/l)

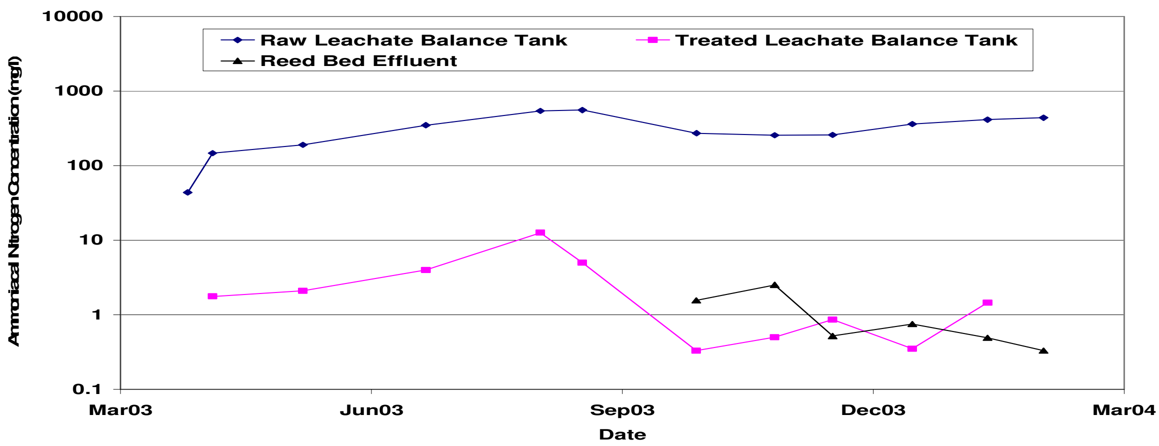

Figure 11. Removal of ammoniacal-N at Granish LTP, April 2003 – February 2004 (in mg/l as N)

(5) Ballymacvea Landfill, Ballymena, Northern Ireland

Ballymacvea Landfill is located about 10 miles south of Ballymena Town, and is an unlined site occupying a former shallow peat extraction site. Landfilling activities are due to cease shortly after 2007, and restoration and capping has already been completed for parts of the site. Ballymacvea is operated by Ballymena Borough Council, and has been accepting controlled wastes for about 25 years. About 30,000 tonnes of waste has been accepted each year at the site, which now contains about 0.75 million cubic metres of waste, across an area of 17 ha, to depths typically between 4 – 7 metres. The site has recently been the subject of a detailed study into the performance of passive biofilter landfill gas vents (see Kelly et. al., 2003).

The leachate treatment plant comprises a buried and roofed SBR tank, an effluent balance tank, and a horizontal flow reed bed polishing system has been incorporated to provide a very high quality final effluent. This effluent is pumped several kilometres in a dedicated pipeline, to enable a consented discharge to be made into a very high quality salmon river.

The plant was again procured on a traditional consultancy basis, using a modified ICE 6th Edition contract, and has operated extremely successfully, typically treating between 50-80 m^3/d of relatively diluted leachate (ammoniacal-N typically 100 – 500 mg/l). The plant has been designed to be capable of treating up to 120 m^3/d at the stronger end of this range, but again, flexibility in operation allows lower volumes to be treated cost-effectively.

Plate 5 shows the Ballymacvea plant, and performance data over a 2 year period to the end of 2003 are included in Figures 12 and 13. Table 3 provides very detailed analytical data for leachate and effluent, (obtained as part of UK Environment Agency research studies), obtained during February 2001, when more diluted leachate was being treated during very cold weather.

Plate 5. Ballymacvea LTP, Northern Ireland

Table 3. Very detailed typical analyses for raw leachate and treated effluent at Ballymacvea LTP, February 2001

determinand	LEACHATE	EFFLUENT
COD	183	45
BOD (20-day)	44	6
BOD (5-day)	6	<2
TOC	61	163
ammoniacal-N	181	<0.3
chloride	279	225
suspended solids	112	14
pH-value	7.0	7.7
alkalinity (as $CaCO_3$)	1430	230
nitrite-N	<1	0.1
nitrate-N	<0.3	96.1
sulphate (SO_4)	<5	22
fatty acids (as C)	<10	<10
conductivity (µS/cm)	3180	1460
sodium	196	207
magnesium	98	31
potassium	95	29
calcium	160	90
chromium	<0.02	<0.02
manganese	0.87	<0.04
iron	25.3	<0.6
nickel	0.03	<0.03
copper	0.02	0.03
zinc	<0.03	1.25*
cadmium	<0.01	<0.01
lead	<0.04	<0.04
arsenic	<0.001	<0.001
mercury	<0.0001	<0.0001
Notes:	• Results in mg/l except pH-value, and conductivity (µS/cm)	

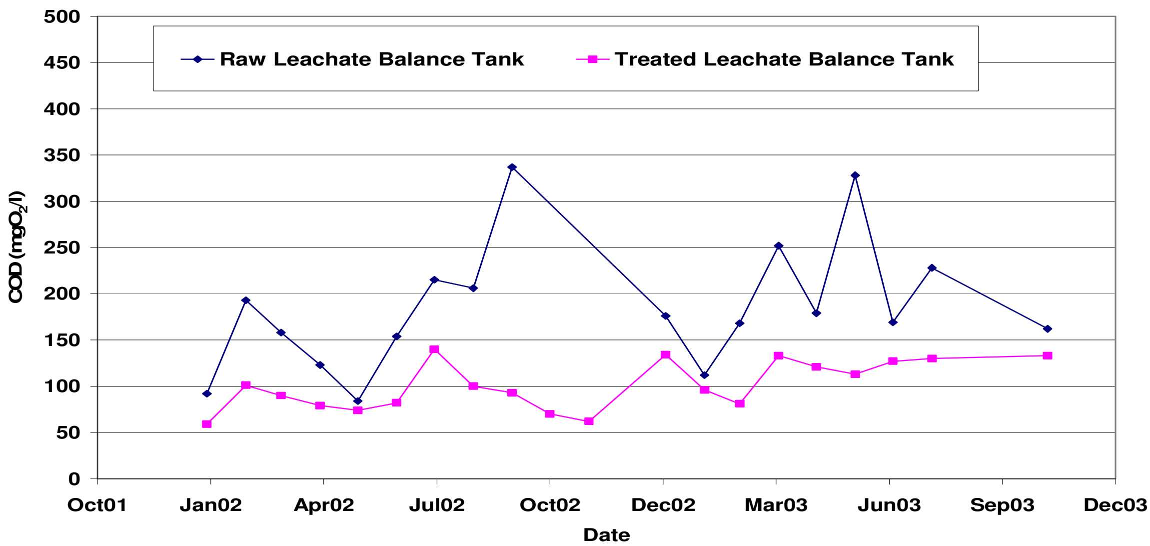

Figure 12. Removal of COD at Ballymacvea LTP (in mg/l)

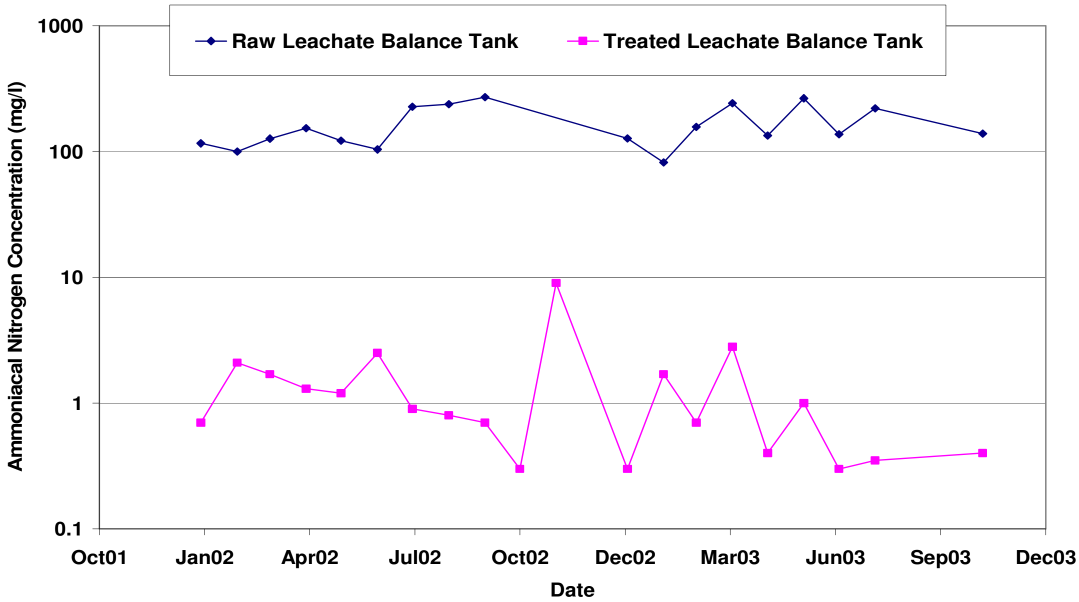

Figure 13. Removal of ammoniacal-N at Ballymacvea LTP (in mg/l as N)

(6) Deerplay Landfill, Burnley

Deerplay Landfill comprises a large hardrock quarry in the Lancashire Pennines above Burnley. The site was taken over by Caird Ltd and turned into a highly-engineered modern containment landfill, and part of this work involved the design, construction and commissioning of a state-of-the-art SBR leachate treatment plant during early 1999.

The plant comprises an above-ground, roofed SBR tank, designed to treat up to 130 m^3/d of strong methanogenic leachate. Effluent is discharged from a balance tank, down a long dedicated gravity pipeline into the sewerage system of the nearest urban area. The plant was again procured by Caird (now part of the Shanks Group) on a traditional consultancy basis.

Treatment has typically taken place at rates between 60-90 m^3/d, and a high quality effluent has been produced reliably and consistently. The plant is shown in Plate 6, and typical and detailed analyses of raw leachate and treated leachate are presented in Table 4.

Plate 6. Deerplay LTP, Burnley

Table 4. Very detailed typical analyses for raw leachate and treated effluent at Deerplay LTP, January 2000

determinand	LEACHATE	EFFLUENT
COD	3470	426
BOD (20-day)	422	23
BOD (5-day)	107	2
TOC	No data	147
ammoniacal-N	1060	0.5
chloride	1380	1360
suspended solids	100	212
pH-value	8.0	7.3
alkalinity (as $CaCO_3$)	5500	280
nitrite-N	<0.1	<0.1
nitrate-N	0.7	940
sulphate (SO_4)	6	88
fatty acids (as C)	<10	<10
conductivity (µS/cm)	11300	9990
sodium	890	1120
magnesium	111	119
potassium	341	352
calcium	164	1070 (?)
chromium	0.05	<0.02
manganese	1.75	0.50
iron	3.8	0.9
nickel	0.12	0.11
copper	0.03	0.03
zinc	<0.03	<0.03
cadmium	<0.01	<0.01
lead	<0.04	<0.04
arsenic	0.025	0.022
mercury	<0.0001	<0.0001

Notes:
- Results in mg/l except pH-value, and conductivity (µS/cm)
- (?) = dubious result

DISCUSSION

It is only 20 years since Aspinwall (now Enviros) designed and commissioned the first fully-engineered Sequencing Batch Reactor (SBR) leachate treatment plant at a landfill site high on a mountain in mid-Wales. That plant is still pre-treating leachate before discharge to sewer, but has been joined by more than 50 other UK plants using the same process, nearly half of which are required to meet stringent standards, which allow them to discharge treated effluent safely into surface watercourses.

Some of these plants are extremely sophisticated, treating strong and difficult leachates (e.g. Robinson et al, 2002; 2003). However, the most common requirement at UK landfills is the reliable, robust, automated and cost-effective treatment of everyday leachates, where the main contaminants are ammoniacal-N, and organic compounds measured in total as COD and BOD_5. State-of-the-art technology has moved on significantly, even since 1999 when a detailed review paper was published (Robinson, 1999), and demand for simple, automated and reliable leachate treatment systems, suitable for operation on remote, rural sites, has grown rapidly during even the last 3 years. An increasing number of plants is now being required to discharge high quality effluents, directly into surface watercourses. This trend is certain to continue –

primarily driven by the requirements of Integrated Pollution Prevention and Control (IPPC), for the application of Best Available Techniques of treatment.

At some sites where local sewerage networks are able to accept raw leachate for co-treatment with domestic sewage in Water plc works, often the only pre-treatment required is removal of dissolved methane from the leachate, to avoid generation of explosive atmospheres within the sewer system itself. This involves careful process design – reliable removal of 99% dissolved methane can often be needed to achieve the widely-adopted discharge standard of 0.14 mg/l. Detailed design guidance has been published to allow adequate systems to be provided (see Robinson, 2001 and Robinson et. al., 1999).

The largest growth, however, is in demand for medium-sized (typically to treat 100-200 m^3 of leachate per day) aerobic biological treatment systems, often with reed bed effluent polishing systems to allow discharge of high quality effluents into surface watercourses. Although other biological processes are entering the field (eg Biological Aerated Filters (BAFs), or Membrane Bioreactors (MBRs), the SBR process probably accounts for more than 90 percent of biological treatment schemes designed for leachate, during the last ten years in the UK.

A number of forms of contract have been used to procure leachate treatment plants, but a significant proportion of plants that have been built have failed to provide an adequate solution. In some situations, plants have been constructed that have simply not worked.

The commonest form of contractual arrangement being adopted remains a traditional consultancy approach, and this retains many advantages. In particular, the consultant selected for expertise in leachate treatment, works directly for the landfill operator, providing safeguards through the process. By preparing a detailed design and specification for tendering, the landfill operator can be sure that when tenders are received, they are directly comparable with each other, rather than offering a wide range of different levels of specification and even treatment processes, as is often the case when a design and build approach is adopted. Nevertheless, several plants have also been successfully procured on a design and build basis.

The most important aspect in the selection of leachate treatment facilities is that an appropriate, reliable, and cost-effective solution is adopted. Increasingly, high standards of effluent quality are being required, and where effluent discharges into surface waters are being made, consistent compliance with effluent discharge standards is vital.

During the last 10 years, great advantages have been made in both aeration technology (most systems now using submerged venturi aerators), and in SCADA (Systems Control And Data Acquisition) control systems for operation and control of plants. This is invariably achieved using Programmable Logic Controllers (PLCs), being far more reliable than Personal Computers (PCs), although the latter provide a valuable means of interfacing with the PLC, and storing and interrogating operational data.

Many simple and reliable programmes have been developed to automate the operation of SBR leachate treatment plants, and to minimise requirements for operator attendance. Modem links allowing remote interrogation of the plant operation, and a host of simple alarms and fail-safe logic systems, can make for extremely reliable operation.

The case study data provided in this paper represent the first broad survey of what full-scale SBR leachate treatment plants can reliably achieve, and of the consistency with which they can achieve it. There are 3 key issues in the treatment which they provide.

(i) Removal of ammoniacal-N

Most well-designed SBR plants can very consistently maintain concentrations of ammoniacal-N in effluent below 10 mg/l at all times, as demonstrated by data presented, and usually below 1 mg/l. Standards being applied for discharge of treated effluents into surface watercourses are often as low as 5 or 10 mg/l. Reed bed polishing systems provide removal of any remaining low levels of ammoniacal-N in a simple manner. It is starting to become a requirement that not only is ammoniacal-N removed by biological oxidation to nitrate, but often denitrification to nitrogen gas is required, which can be achieved by minor modification of the SBR process.

(ii) Supply of alkalinity

Nitrification of ammoniacal-N in all wastewaters requires an adequate supply of alkalinity, in order to buffer reductions in pH-value that take place during the process. Requirements can be calculated by simple chemical stoichiometry, and demonstrate that for most strong methanogenic leachates, alkalinity present in the leachate itself will be inadequate. Addition of sodium hydroxide (NaOH) solution is the preferred option, alternative compounds of calcium (eg hydrated lime) being far less readily dosed by automated systems, and far more prone to encourage scale formation within an aerobic system. Use of fully automated NaOH dosing systems to achieve pH values within an SBR reactor is common good practice, and can be noted in data from the case studies presented, by increases in concentrations of sodium as leachates are treated.

(iii) Removal of organic compounds

All of the case study treatment plants presented show pretty much complete removal of biodegradable organic materials – always far in excess of levels measured by either the 5-day or 20-day BOD test in raw leachate. This is testimony to the value of an acclimatised bacterial population within the reactor, and the long hydraulic residence period that is provided within an SBR system (10-15 days typically). Relatively high levels of non-degradable COD in treated effluents comprise harmless long chain molecules such as humic or fulvic acids, and tests at many full-scale SBR treatment plants have demonstrated that they cause no detectable toxicity to sensitive analytical procedures such as the Microtox® test, or even to species such as rainbow trout (see Robinson, 2002). Likely levels of residual COD in treated effluents can be accurately predicted by knowledge of the composition of leachate being treated. A recent paper by Carville et. al. (2003) demonstrated that residual COD levels were not closely correlated with COD values in raw leachate, but rather with concentrations of ammoniacal-N in leachates being treated (see Figure 14). Whether this is because initial release of hard COD from decomposing wastes is related to release of ammoniacal-N, or that nitrification of this ammoniacal-N itself releases hard COD, is yet to be determined.

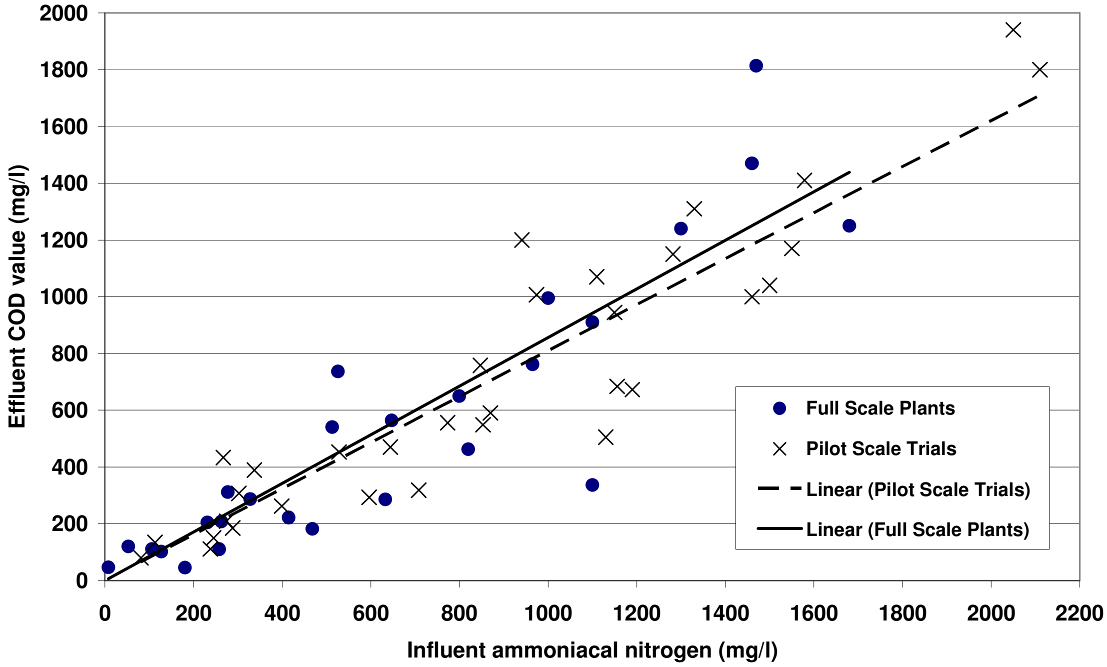

Figure 14. Correlation between concentrations of ammoniacal-N in leachates, and residual "hard" COD levels in treated effluents, for full scale treatment plants and detailed pilot-scale studies (in mg/l)

Removal of this residual COD is possible – processes such as Dissolved Air Flotation can significantly reduce levels of colloidal material, and have been applied at a number of sites – or much more expensive processes such as activated carbon (AC) filtration can be applied to achieve very high removal rates. Although AC systems are widespread in countries such as Germany, to our knowledge none have yet been constructed in the UK for polishing of treated leachates. We have no doubt that this is because informed decisions have been taken based on risk assessment and knowledge of the nature of the residual COD.

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REFERENCES

Carville, M S, Last, S D, Olufsen, J S and Robinson, H D (2003). Characterisation of contaminant removal achieved by biological leachate treatment systems. Paper presented to Sardinia 2003, the Ninth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 6-10 October 2003, Proceedings on CD, 11pp.

Kelly, M, Latham, B and Ramsay, J (2003). The performance of passive biofilter landfill gas vents at Ballymacvea Landfill Site, Ballymena, Northern Ireland. Paper presented to Sardinia 2003, the Ninth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 6-10 October 2003, Proceedings (on CD ROM), 10pp.

Novella, P, Haider, S, Strachan, L, Robinson, H, Last, H (1984). Full scale landfill leachate treatment in South Africa: The use of aerobic SBR processes and reed bed systems. Proceedings of WasteCon 2004, The Biennial International Waste Congress and Exhibition of the IWM (SA), 11- 5 October 2004, Sun City, South Africa, 11pp.

Robinson, H (2003). BAT guidance for leachate treatment. Wastes Management, CIWM, November 2003, pp 16-17.

Robinson, H, Farrow, S, Last, S and Jones, D (2003). Remediation of leachate problems at Arpley Landfill Site. Paper presented to the 2003 CIWM Conference and Exhibition, "Environment, Economy, Equality", 10-13 June 2003, Paignton, Torbay, UK. Presented to Workshop Session J, In: Proceedings, Subsequently published in CIWM Scientific and Technical Review, December 2003, pp 18-26.

Robinson, H, Walsh, T, Last, S and Carville, M (2002). Advanced leachate treatment at Buckden Landfill, Huntingdon, UK. Paper presented to Waste Con 2002, 30 September – 4 October 2002, Durban International Conference Centre, Durban, South Africa, Volume 2, 252-265.

Robinson, H (2001). Managing dissolved methane in leachates. Wastes Management, CIWM, March 2001, pp 36-37.

Robinson, H, Harris, G R and Last, S D (1999). The stripping of dissolved methane from landfill leachates prior to their discharge into sewers. Paper presented to Sardinia 1999, the Seventh International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 4-8 October 1999. In Proceedings, Volume II, pp 285-293.