LANDFILL LEACHATE TREATMENT

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Abstract

The application of membrane bioreactor technology for the treatment of landfill leachate is not new. This form of leachate treatment has been operating successfully within Germany and other European countries for nearly 15 years. From an environmental viewpoint, the application of MBR is perceived to be a superior process when compared to the alternative treatment techniques currently operating in the UK. This therefore begs the question, "Why have landfill operators in the UK not applied MBR technology for leachate treatment?"

The answer is not simple and therefore this paper will address the following issues:
- *What is landfill leachate?*
- *Current leachate disposal and treatment methods*
- *Comparison of MBR/SBR technology*
- *Comparison of using submerged and side stream MBR techniques*
- *The use of the low energy (airlift) side stream MBR*
- *What is the future for MBR in this sector?*

Keywords landfill, leachate, sidestream, submerged, membrane, MBR, SBR

Introduction

By definition, a landfill site is a large area of ground, normally lined, that is used for tipping/disposal of waste material. As long as the rainfall is greater than the rate of water evaporation then the liquid level (leachate) within the landfill area will tend to rise. Environmental regulations require that the leachate level be controlled, which means that excess leachate must be removed and disposed of.

The introduction of the Landfill Regulations, 2003 has had a dramatic effect on the waste industry. The prohibition of co-disposal of wastes, i.e. mixing of hazardous and non-hazardous waste is having a profound affect on the future of the waste industry. However, no amount of regulation is going to affect the consistency and quality of leachate currently being generated on existing landfill sites. The naturally bound biological process within a landfill will continue well after a landfill site is closed for fresh waste and is capped. Consequently, as long as there is significant rainfall, a landfill will continue to produce contaminated leachate, and this process could last for 30-40 years; the life span depending upon the composition of the landfill waste. Even with the various European initiatives requiring more recycling and alternative techniques for handling waste, landfill sites will continue to be in demand in many areas as the only cost effective disposal method.

Another very important reason for maintaining a low leachate level on a landfill is to maximise the production of landfill gas (LFG) during the methanogenic phase of the site. The collection and conversion of methane into electrical energy performs two important roles:

- The minimisation of gas dispersion within the immediate vicinity of the landfill, which reduces the environmental odour impact and explosion risk
- More importantly for a landfill site operator, the generation of electrical power.

It is the latter point that is receiving considerable attention, as LFG is a valuable commodity. Only about 60% of LFG is combustible methane, which results in a calorific value of 37 GJ/t compared to ~50 GJ/t for natural gas. However, if the site operator can link the electricity production potential to the Government's Non Fossil Fuel Obligation programme (NFFO) then considerable revenues can be guaranteed from selling kWhs to the electricity generating companies. In fact, it is estimated that electrical power generation from landfill sites in the UK is now ~450/500 MW and this will probably increase to ~600 MW. To put this into perspective UK landfill sites could be capable of generating up to 0.9% of the nation's electricity requirements.

Disposal of Leachate

Apart from recycling leachate between different cells on a landfill site, leachate can be disposed of in three ways,

(1) To sewer, where there is likely to be a restriction in the ammonia concentration, red listed substances, methane and compounds that might affect the sewer pipes

(2) To river/water course where, in addition to the items above, there will more than likely be limits for BOD, COD and suspended solids. In many cases, there will also be a limit on the chloride concentration level and perhaps nitrate.

(3) By road tanker to an alternative treatment site. This assumes that options (1) & (2) are not available. The limitation here is cost, as the charge for this disposal route is on average £12-18/m^3.

On-site Treatment

Generally, the lowest cost form of leachate disposal is to a local watercourse or sewer, although on site treatment is invariably a prerequisite. This can be performed in several ways depending upon the nature of the leachate,

Aerated lagoons are used for weak leachate. This is sometimes followed by passing leachate across a purpose planted reed bed before discharge to a watercourse.

High concentrations of ammonia can be removed by "stripping". The leachate pH is increased to 10.5+ and flashed off to atmosphere under vacuum conditions. Invariably, the leachate needs to be heated first. This disposal route has a very high operational cost but capital investment tends to be low.

The most cost effective form of treatment for high levels of BOD, COD and ammonia is intense biological oxidation, and in the UK the sequential batch reactor is the most common technology used. The sequence batch reactor (SBR) is a form of activated sludge treatment.

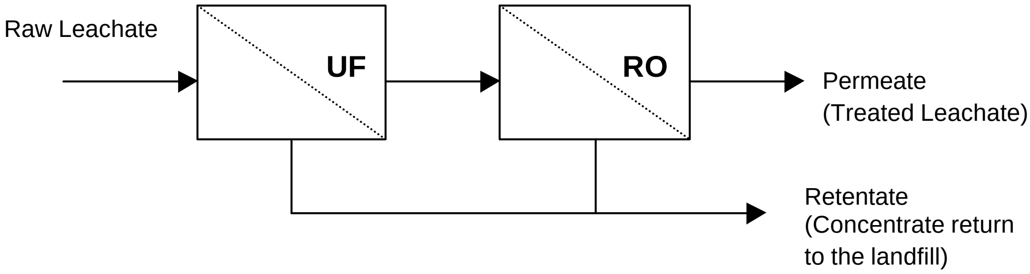
Traditional activated sludge plants utilise an aerobic/biological tank followed by a settlement chamber. Solids/sludge separation is carried out by gravimetric settlement, where solids are settled to the bottom of the vessel. The supernatant liquid is removed as clean/treated leachate and the remaining solids are recycled to the aerobic/biological tank for reuse.

The SBR combines this process into a single unit tank. Raw leachate is fed to the reactor and the aerated biological stage is timed to operate for a specified period. After this, the aeration system is shut down and the solids are allowed to settle to the bottom of the reactor. The supernatant (in equal volume to the initial raw leachate feed) is removed and discharged (to sewer or watercourse) and the cycle starts again with a new batch of raw leachate. When necessary a proportion of the suspended solids will be removed as excess sludge.

The fundamental difference between an SBR and a traditional activated sludge/settlement process is that biological degradation and solids settlement are carried out in the same tank. However, the SBR does have its negative aspects, which can be overcome with the incorporation of membrane technology.

Membrane Application

The application of membranes (MF, UF, NF and RO) did not start with the introduction of MBR in to Germany. In the late ‘80s UF and RO systems were being used to clean leachate by separating and concentrating the solids.



The UF plants at the time were using 12-25 mm tubular membranes. Spiral wound membranes were used for the RO systems. The UF plant had to be used to ‘pre-clean’ the leachate (removal of high molecular weight colloidal compounds and suspended solids in order to prevent blocking the RO membranes). This form of treatment was considered to be cost effective, but resulted in serious consequences for some landfill sites as can be seen from the example below.

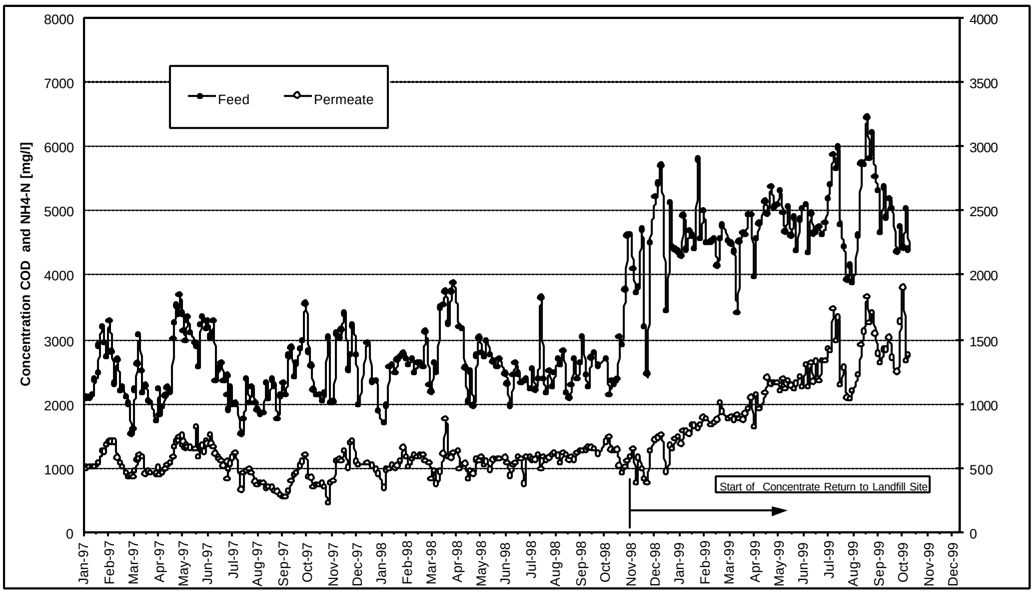
RO operation on the Wischhafen landfill site, Germany

The operating contract for the site was due to be renewed in the latter part of 1998. The landfill operator decided to replace the MBR process with a direct Reverse Osmosis system. The main reason for choosing the RO system was its lower operating costs in comparison to other treatment technologies, including the incumbent MBR process.

The RO system started operations in November 1998 and operated for one year, after which it was removed from the site and replaced by another biological system. The reasons for the short operating period for the RO plant are clearly evident on the attached two graphs overleaf.

One of the perceived “cost saving” factors of an RO plant is the recycling of the RO concentrate back onto the landfill site. However, the decision to recycle concentrate had an immediate effect on the landfill leachate, as can be seen from the enclosed graphs.

- graph #1 shows how the COD and Ammonia concentration levels increased
- graph #2 shows the sharp increase in leachate conductivity. This is directly related to increased concentrations of leachate salinity, which immediately affected the performance of the RO plant

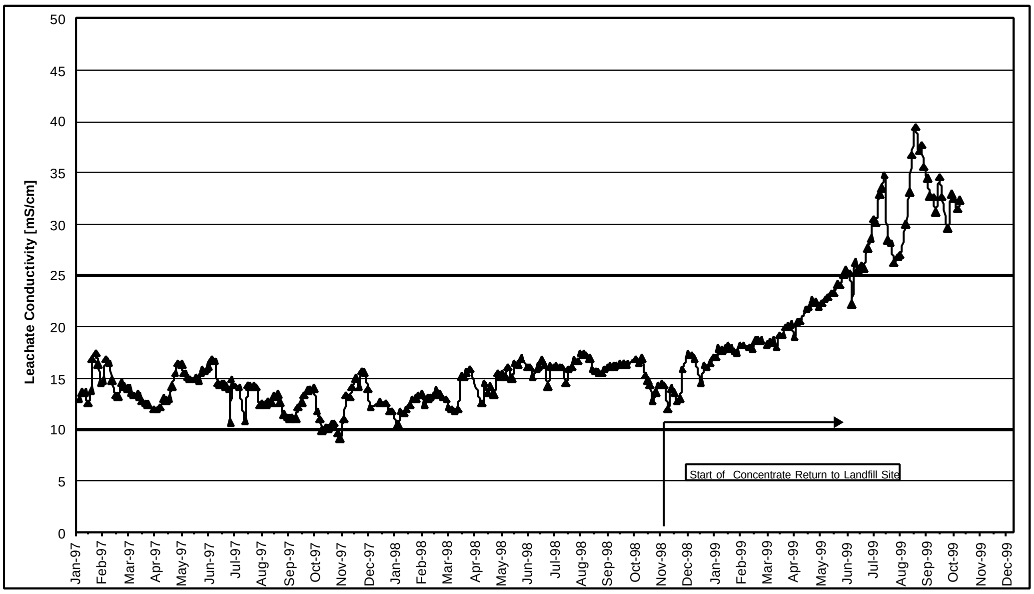


Graph 1

RO Osmotic Pressure

Reverse Osmosis plants, by definition have to operate at high pressures in order to overcome the osmotic pressure of the liquids being concentrated. For example, if a salt solution has an osmotic pressure of 18 bar and the system pressure is 30 bar, then the net filtration pressure for the process is 30-18 bar, i.e. 12 bar. However, the osmotic pressure is directly proportional to the liquid salinity. As the concentration of the combined “salts” increase, which is what happens when the RO concentrate is returned to the landfill, then the osmotic pressure will rise accordingly. If the RO process plant conditions remain constant, this will create an overall reduction in the net filtration pressure, which will result in a lower permeate flow rate.

Therefore, in order to achieve the same original flow rate the RO plant will need to operate at a higher pressure (more energy and investment, if a larger pump is required) or additional membrane surface needs to be installed.



Graph 2

However, the system process parameters do not reach a new “steady state”. A point will be reached where the addition of pressure or membrane surface area is not economically viable. This point was reached, after only one year of operation, and the RO plant was shut down in October 1999.

The only solution for the landfill owner was to reinstall a bio-oxidation process. However, the problem was exacerbated as follows:

- The replacement biological process had to cater with higher COD and ammonia loads.
- This meant that the plant investment and operating costs would be higher than the original biological process that had been in operation up to November 1998

In summary, reverse osmosis has a role to play in the treatment of leachate but not as the primary process. RO can be installed after an MBR process where there is a need to remove low MW compounds from the treated leachate.

Interestingly, the author is aware of the installation of only one UK based reverse osmosis plant for handling leachate. According to information received, the RO plant never functioned correctly. In fact, this single example of failure is considered within some quarters of the waste disposal industry to be the main reason why membrane plants, including those associated with MBR, have not been widely installed for treating leachate in the UK. This is interesting because it is in complete contrast to the vast number of submerged MBR plants operating on municipal effluent and the large industrial sidestream MBR plants, for example, operating at Dairy Crest and Kellogg’s - two well known household names.

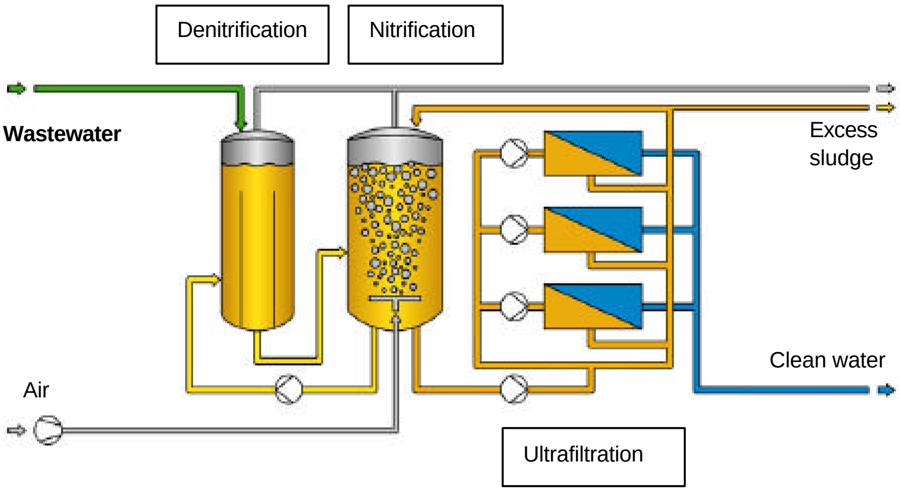
MBR for Leachate: The Wehrle Experience

The waste industry would reply that viewing the treatments of municipal effluent with leachate is not a fair comparison. They would be quite correct in pointing out that leachate is a collection of very difficult chemical compounds and its treatment can be troublesome. However, Wehrle have installed 85 sidestream MBR plants to date of which 58 are dedicated to treating landfill leachate.

For low strength-high volume wastewater, for example sewage, low ultrafiltration energy costs per cubic metre are important. This requirement is usually best met by a submerged membrane MBR process where high fouling factors are not a major issue. However, for high strength-low volume wastewater, the tubular sidestream MBR is more often the best choice. Most industrial wastewater and leachate fall into the second category.

On paper, the most important issue is the cost of energy and it would appear that submerged membranes are perceived to be the best choice in comparison to the sidestream design. This matter will be reviewed in more detail later in this paper. However, for those that are operating MBR plants the single most important issue that affects plant performance is membrane fouling

The Wehrle BIOMEMBRAT^{R} process addresses the above issue head on and is an optimal solution for the treatment of many industrial wastewaters and landfill leachate. Both atmospheric and pressurised bioreactors are used depending upon the process circumstances. The bioreactors can be operated at up to 25 kg/m^3 MLSS, which minimises reactor volume for a given sludge loading. However, membrane flux performance deteriorates with an increase in MLSS and the optimal sludge concentration is on average 17-20 kg/m^3.



Sludge foaming is often a problem associated with treating leachate, which results in choosing the use of a pressurised bioreactor for the MBR process. The smaller aeration tanks can be pressurised at up to 3 bar to facilitate the provision of optimum dissolved oxygen concentration even at a high organic loading. The pressurised tanks also minimise the airflow, reducing the risk of stripping out volatile compounds, and reducing the size of air scrubbers when these are required.

A further effect of using a smaller aeration tank is that the energy from the exothermic bio-process, aeration blowers and pumps is used to heat a relatively small volume of liquid. This enables the Biomembrat process to operate at an elevated temperature, usually 30 to 35°C, providing the following advantages:

Biology

- Increased rate of bio-oxidation of pollutants.
- Improved performance of 'hard' COD removal.
- Higher rate of nitrification.
- Lower sludge production.

Ultrafiltration

- Increased flux rates with increased temperature.

For leachate, where complex organic substances often occur, it can be necessary to operate in a low F/M (sludge loading) – long sludge age mode. The high MLSS in the BIOMEMBRAT facilitates this mode of operation, which together with the retention of bacteria by the membranes maximises the biodegradation. This is reflected in the observed improvement in 'hard' COD reduction when the treatment of leachate by BIOMEMBRAT was compared with a conventional activated sludge process.
A low F/M loading is also necessary for nitrification, and in turn minimises the production of surplus sludge.

Plants can be designed to incorporate a denitrification stage if required. Denitrification takes place in an anoxic tank, which precedes the aeration tank, and receives both the flow of incoming wastewater and the recycled thickened sludge from the ultrafiltration unit. Methanol is dosed to this tank as necessary to ensure an adequate carbon source.

Membrane Choice and Application

It has always been a matter of principle for Wehrle to use readily available, off the shelf membranes for its MBR designs and the Company regularly uses three nominated suppliers. All the membranes used for sidestream MBRs are based upon the shell & tube concept. Initially 1" tubes were used, and these were replaced by 11.5 mm and 10.5 mm units. Within the past five years, all the high flow MBR plants have been designed and built using the standard 8" x 3m module incorporating 8 mm tubes.

Two of the suppliers have integrated their respective designs and now offer a standard interchangeable module, which means that the end user is not tied to a specific supplier-unlike the situation that exists with some other membrane designs.

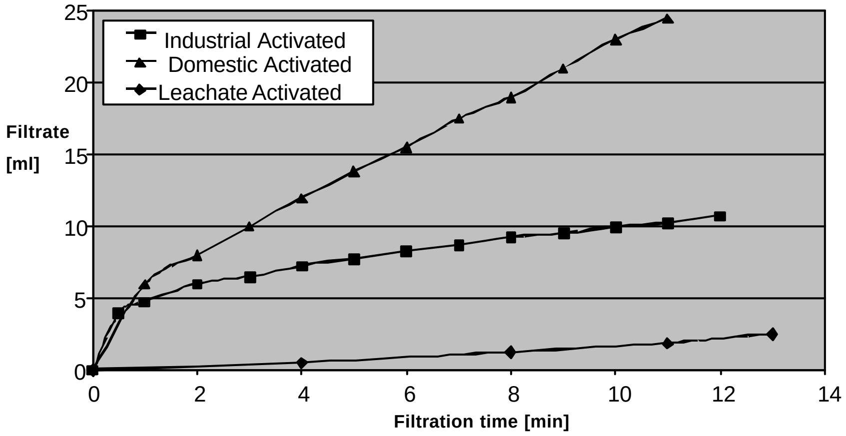
Although the 8 mm tubular membrane is readily available, its design was originally conceived in a co-operation between Stork Friesland and Wehrle. The 8-mm tube was found to be the best compromise hydraulic diameter that offered the advantages as highlighted below.

1. The membranes are separate from the bioreactor and cannot affect the efficiency of the aeration
2. The *'self scouring'* action created by the velocity of the sludge along the surface of a tubular membrane, in fact, considerably reduces the rate of fouling.
3. The membranes can also be easily chemically cleaned '*in situ'* (CIP).
4. Reduced maintenance and plant downtime costs. Module replacement takes about 5 minutes to accomplish
5. Some wastewater including leachate can contain high levels of inorganic dissolved solids, which tend to precipitate salts during biotreatment. These most certainly will cause scaling problems for membranes that are not subject to high levels of agitation. This problem is greatly reduced with tubular membranes as described in (2) above and any precipitate layers formed are easily removed with the CIP as highlighted in (3) above.
6. Ability to operate the plant at a higher MLSS than is possible with alternative systems
7. It is not necessary to use additional aeration for cleaning the membranes in situ

Membrane Fouling

Membrane Fouling is a topical issue amongst MBR operators. There is no doubt that the application and performance of membranes is an empirical science and the success in this field is very much dependent upon 'In-house' knowledge gleaned from designing and building a multitude of MBR plants.

The graph below highlights the filterability of three different types of activated sludge in an agitation cell at constant temperature and shear rate. One of the factors affecting filterability is the fouling of sludge on the membrane wall.



The absolute figures are not important. What is critical is the relationship between the three filterability lines. What is clear is that domestic sewage sludge is easier to filter than industrial sludge. Landfill leachate MBR sludge is clearly the most difficult to filter.

Domestic or municipal sludge has a relatively low fouling factor and hence its suitability to be treated by submerged MBR systems. Unfortunately, the same does not apply to MBR systems treating industrial effluent or landfill leachate. The graph highlights the fact that membrane flux rates for leachate treatment plants will always tend to be lower.

The effects of proteins, carbohydrates, fats, etc, on the performance of the membranes is reasonably well documented. However, leachate will vary from one landfill site to another. The co-disposal of waste until the implementation of the Landfill Regulations means that each site has its own ‘mix’ of chemical compounds, which is dependent upon the type of waste being deposited since the set up of the individual cells. Therefore, on site trials are recommended before initiating an MBR design.

The ‘biological health’ of the process also plays a major role at establishing membrane performance. MBR is often referred to as a modification, or advancement of the activated sludge (AS) process. Theoretically this might be true except for one point – The AS process is based upon creating flocs, which imposes limitations upon the operating conditions, whereas the MBR system creates the complete opposite. It does not need to create a settleable sludge and this removes some of the restrictions upon the operating conditions that are required for the AS process. But, some factors – for example organic load and low DO – can adversely affect membrane performance.

Flux rates - Submerged .v. Sidestream Membranes

The table in the Appendix 1 shows a performance comparison between various MBR applications. It is unfortunate that there does not appear to be any published data on the application of submerged MBR systems, specifically for treating landfill leachate. Most of the published data for the latter mainly reflects experience within the municipal effluent sector. However, the data presented in Appendix 1 is interesting because it highlights a performance comparison across a wider application range.

Therefore, it can be safely assumed that the flux rate for a submerged membrane MBR treating leachate will be less than average daily flux rate from the three municipal plants, which is ~12 $l/h.m^2$. Based upon data collected from visiting a variety of sites the flux rate for a submerged MBR treating leachate will be in the range 5-10 $l/h.m^2$, but this figure is only an estimate. However, this is in line with data from other MBR plants where the flux rate ratio between sidestream and submerged membranes is between 7:1 and 8:1.

Energy

No doubt, energy cost is one of the primary issues when considering the installation of an MBR system to treat leachate, or for that matter, any other application. The success of MBR systems in the municipal sector highlights the success of the submerged membrane concept. But, is this really the case?

If energy is the only reference point then the submerged MBR approach must be the logical choice. However, if the overall operating costs (including membrane life span and replacement) are considered then we have a completely different assessment, as highlighted in the comparison table, Appendix 1. When membrane life span and replacement costs are entered in to the equation the overall specific operating cost changes in favour of the sidestream membrane MBR design. For example, the overall operating cost for the sidestream MBR at Bilbao is 0.38 €/m^3 (£0.27/m^3), and 0.43 €/m^3 (£0.30/m^3) for the submerged MBR at Nordkanal. In fact, the latter cost would be expected to be higher if the plant were treating leachate, and not municipal effluent.

The fact remains that energy cost is the main reason why the application of sidestream MBR plants in to the UK leachate treatment sector has not followed its success in Germany and other European countries. Energy is not the only reason for UK landfill operators not to adopt the MBR, as the SBR has a good track record in this country. However, the SBR design and operation does have its faults as highlighted in Appendix 2.

The Low Energy Sidestream MBR

The optimum solution would be to combine the benefits of submerged and sidestream membranes in to one system. The results from the MBR treatment plant at Freiburg prove this compromise is possible to achieve for low/medium strength leachate. This plant, originally reported at the MBR 3 conference, is designed around the Bio-Loop (airlift) system.

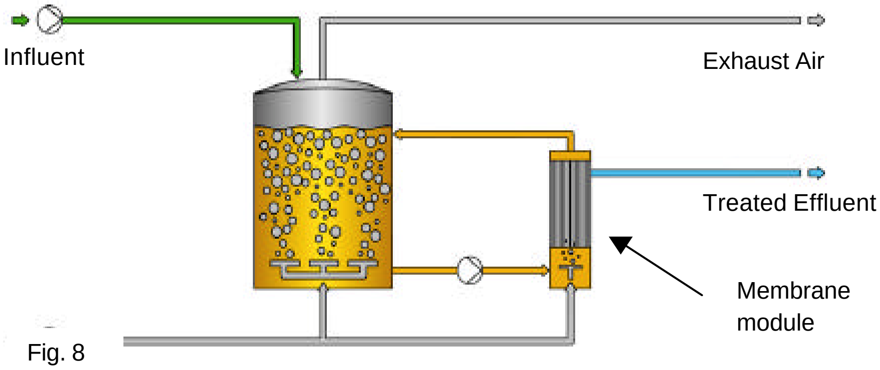
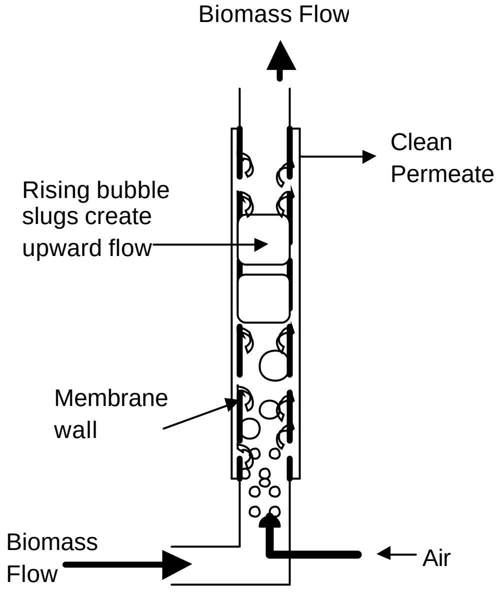


Fig. 8

BIOMEMBRAT– ***Loop*** ®

This plant has been operating for four years and a summary of its operating parameters is shown in the MBR Comparison Data table in Appendix 1.
The membrane modules are mounted in the vertical plane. Compressed air is injected into a specially designed air bubble distributor, located under the module tube plate. The bubbles rise inside the membrane tubes creating an upward flow of sludge. However, the main advantage is the scouring action created by



the rising bubbles – these expand as they rise, wiping clean the membrane wall.

Bio-*loop MBR*

The biomass (sludge) flow is controlled by the variable speed circulation pump where the optimum tubular flow velocity is 2 m/s.

The membrane plant is being operated at lower pressures with a wide range of flow velocities, ranging from 2 – 4 m/s. Therefore, typical operating parameters are as follows:

4 m/s >>> 80-90 $l/h.m^2$ >>> 5-6 kW/m^3
2 m/s >>> 50-60 $l/h.m^2$ >>> 2-3 kW/m^3

The variable speed pump offers the following flexibility:

- During summer months of low rainfall the volumetric demand on the MBR is low and the circulation pump was either switched off or operating at low flow. Sometimes the forward flow provided by the rising air bubbles alone is sufficient to provide the necessary membrane flux rate.
- Under conditions of excessive rainfall the circulation pump speed was increased to its maximum – resulting in the permeate flow rate being raised to 90 $l/h.m^2$.
- The pump was used to provide the high flow velocities required for highly turbulent CIP conditions.

It is worth noting that the Freiburg plant is operating under the following biological conditions:

	Inlet	Outlet (Consent to Sewer)
COD:	1,500 mg/l	400 mg/l
Ammonia:	900 mg/l	100 mg/l

These conditions are not excessive and the leachate from the Freiburg landfill site could be considered as weak. This allows the bioreactor to operate with an MLSS of ~ 12-15 g/l, which helps to facilitate the measured flux rates.

Although the low energy BioLoop design at Freiburg has been successful there are three reasons why this approach has not yet been proposed for the UK landfill sector.

- Generally, leachates from UK landfill sites are ‘stronger ‘ in COD and Ammonia.
- The prices of side stream tubular membranes are still too high.
- Vertically mounted membranes do not lend themselves to containerised plants

The way Forward

In situations where fouling and membrane life span are an issue, and this is particularly applicable to landfill leachate treatment, there is no doubt that the sidestream MBR is far more suited to operate in these adverse conditions, when compared its submerged membrane counterpart.

The prediction is that price for sidestream tubular membranes will reduce quite rapidly. Currently, sidestream tubular (Ø 8mm) membrane modules are priced at ~ €200-230/m^2. Over the next two years, the price is predicted to drop to €170/m^3 for the following reasons:

- Operating the plants at lower pressure means that special module housings will not be required.
- Module diameters are likely to increase to 10”, which means a membrane area increase per module of ~50%. This will considerably reduce the manufacturing costs per m^2.
- The higher usage of membrane area will also increase the economies of scale thereby reducing the specific membrane price.

The above will result in much lower capital and operating costs for the low energy sidestream MBR (BioLoop) because the membrane area requirement will continue to be three/four times less when compared to submerged plants. However, the membranes will only cost twice as much.

Hence, the BioLoop approach is expected to feature as the best practice solution for treating weak to average strength leachate. Interestingly, this technology could also make inroads into the municipal effluent sector and compete head on with the submerged membrane MBR.

The conventional sidestream MBR will continue as the main stay for treatment of strong leachate. The predicted membrane price reduction will have a positive effect on the operating costs of this mode of MBR. However, the sidestream MBR will gradually become a more dominant leachate treatment process for the reasons as highlighted in Appendix 2.

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Appendix 1

MBR Comparison Data

Customer/End User		**Freiburg**	**Bilbao**	**Kellogg**	**Dairy Crest**	**Dairy Gold**	**Rothaus**	**Markranstädt**	**Rödigen**	**Nordkanal**	
Application		Leachate	Leachate	Food	Dairy	Dairy	Brewery	Municipal	Municipal	Municipal	
Type of installation		MBR	MBR	MBR	MBR	MBR	SBR + Membrane	MBR	MBR	MBR	
Membrane Type		lo-flo sidestream	Sidestream	Sidestream	Sidestream	Sidestream	Submerged	Submerged	Submerged	Submerged	
Flow Rate 1	m^3/a	41610	624150	540,200	416,100	710,000	414,343	657,000	164,250	3,200,000	m^3/a
Flow Rate 2	m^3/d	120	1800	1,800	1,200	2,000	1,250	2,700	675	24,576	m^3/d
membrane area	m2	88	700	864	486	648	6,000	8,800	2,500	84,480	m2
Flux (year average)	l/m^2h	54	102	71	98	125	8	9	7.5	4.3	l/m^2h
Flux (day average)	l/m^2h	57	107	87	103	129	8.7	12.8	11.3	12.1	l/m^2h
Specific Membrane price	€/m2	220	270	230	230	252	80	80	80	70	€/m2
Membrane price total	€	19,360	189,000	198,400	111,600	163,200	480,000	704,000	200,000	5,913,600	€
Membrane Life Span	yrs	6	4	4.50	5.00	6.00	5.00	2.00	3.00	4.00	a
Membrane replacement	€/a	3,227	47,250	44,089	22,320	27,200	96,000	352,000	66,667	1,478,400	€/a
Specific Energy consumption	kWh/m3	3	5	3.75	3.18	2.14	1.00	1.00	0.86	1.00	kWh/m3
Specific Energy Price	€/kWh	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	€/kWh
Total Energy Cost	€/a	7,490	187,245	121,564	79,347	91,264	24,861	39,420	8,475	192,000	€/a
Total Operating cost	€/a	10,716	234,495	165,653	101,667	118,464	120,861	391,420	75,142	1,374,000	€/a
Total specific operating cost	$€/m^3$	0.26	0.38	0.31	0.24	0.17	0.29	0.60	0.46	0.43	$€/m^3$
Total Investment, Membrane + Biology + Civils	€	510,000	3,100,000	2,964,537	1,857,143	2,250,000	8,500,000			21,000,000	€
Reference Source		a	a	a	a	a	b	e	c/d	f	

Reference Literature

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Appendix 2

MBR v SBR COMPARISON

	MBR	SBR
ADVANTAGES	**Final effluent Quality** ❑ Better ‘hard COD’ removal ❑ No suspended solids in the final effluent ❑ Reed beds not required for biological polishing ❑ Good nitrification ❑ Easier control of de-nitrification **Security** ❑ More secure process with physical membrane barrier ❑ More security against discharge of toxic organics ❑ Easy to control and automate ❑ Ideal for river discharge. Tertiary treatment not required ❑ Low risk odour emission due to lack of settlement phase ❑ More adaptable for remote operation and control ❑ Good leachate treatment track record in Germany and other environmentally conscious European countries ❑ The Wehrle MBR has a good (non-leachate) track record in the UK **Design** ❑ Operates at higher temperature/better metabolic rate ❑ Small footprint ❑ Design flexibility - ability to use very high sludge MLSS ❑ Easy to expand for flow and load ❑ Portability. Modular design/installation. ❑ Same plant can be moved from site to site. **Cost** ❑ Phased CAPEX implementation ❑ Plant portability favours rental options	**Final effluent Quality** ❑ Good nitrification ❑ Natural de-nitrification capability ❑ Excellent de-nitrification **Security** ❑ Longer hydraulic retention time ❑ Dilution of shock loads ❑ Simple to operate ❑ Good UK track record **Design** ❑ Simple design **Cost** ❑ Low energy costs ❑ Low maintenance costs
DISADVANTAGES	❑ Higher energy cost ❑ Membrane replacement cost ❑ No UK track record with leachate treatment ❑ Potential membrane fouling	❑ Poor settlement when there are problems with the process biology ❑ Risk of solids carry over in to the final effluent ❑ Tertiary treatment often required before discharge to river ❑ Higher risk of odour emission due to sludge settlement stage ❑ Much larger footprint required ❑ Not portable ❑ MLSS limitation reduces expandability