The Application of Low Energy MBR in Landfill Leachate Treatment

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Abstract

Cross-flow Membrane Bioreactor (MBR) is a leachate treatment technology that has seen widespread use throughout mainland Europe and has recently begun to make strong inroads into the UK leachate market. Recent developments in the design and operation of cross-flow MBR plants have remarkably improved the energy efficiency of the separation process to a point where the overall operating cost now compares favourably with conventional technologies such as Sequenced Batch Reactors (SBR). This paper will highlight the pioneering work carried out by the Wehrle Group and will explain why low-energy MBR will become a more attractive option for UK landfill operators.

Introduction

Onsite treatment of landfill leachate has become increasingly common over the past decade as operators try both to meet new regulations and reduce the operating burden associated with leachate disposal. A wide range of physical, chemical and biological processes are available that can help operators achieve these aims.

The biological treatment of leachate often uses activated sludge processes whereby bacteria, suspended in liquid and aerated by means of blowers or mechanical aerators, are fed with raw leachate. The bacteria utilise, as a source of food and nutrients, organic contaminants and nitrogenous compounds found in the leachate, converting these to new cellular material, CO_2 and NO_3. An additional denitrification step can even reduce NO_3 to nitrogen gas thereby enhancing environmental stability.

There are many forms of activated sludge treatment but the most commonly used for leachate treatment are cross-flow Membrane Bioreactor (MBR) and Sequenced Batch Reactor (SBR). The biological sides of both these technologies are similar. The difference lies in the technique used to separate the bacterial solution (commonly referred to as the mixed-liquor or sludge) from the treated leachate: SBR uses gravimetric separation whereas MBR uses membrane technology.

The MBR Process

Figure 1 is a schematic of an MBR plant. Sludge is intensively aerated in a bioreactor while being fed with leachate. It is then pumped to the ultrafiltration unit where separation of the sludge and treated leachate takes place.

Insert Figure 1

The ultrafiltration system is modular in design, being comprised of loops, each containing a recirculation pump and a number of membrane modules in series.

Insert Figure 2

The modules consist of small membrane tubes encased in a cylindrical housing (see figure 3). Biomass is pumped through these tubes, and the resulting pressures, push treated leachate, or permeate, across the porous membrane wall. All of the biomass is held back by the membrane and is returned to the bioreactor for reuse.

Insert Figure 3

The cross-flow stream, with a high flow velocity, induces a powerful mechanical scouring of the membrane wall (see figure 4) thereby reducing any fouling that might build up. Membrane cleaning, if required, is carried out automatically, in situ, with commercial chemical cleaners. The expected membrane lifetime is between 4 and 6 years.

Insert Figure 4

Gravity vs. Membrane Separation

The choice of separation technology has resulted in significant benefits for cross-flow MBR. Firstly, MBR is a far superior process from an environmental viewpoint. Lower concentrations of COD and zero suspended solids are characteristic of the treated leachate, meaning that direct river discharge is possible without tertiary treatment.

Higher operating temperatures allow ammonia-removing (nitrifying) bacteria to remain fully active even during winter months. The complete retention of all biomass within the system also guarantees that these valuable and slow-growing bacteria are not discharged with the treated leachate. In all, this guarantees a more stable process, but more importantly, the longer sludge age allows for more recalcitrant COD to be biodegraded.

In addition, a much smaller biological reactor is needed, as the use of membranes to separate bacteria from the treated leachate allows a much higher concentration of biomass in the system. The smaller footprint reduces the costs of any civil work and means a full-scale plant can occupy a fraction of the area required by a similar capacity SBR plant Another main advantage of the MBR process is its compact and modular design. This feature is very cost effective when converting an SBR into and MBR.

Insert Figure 5

However, the choice of separation technology has had, until now, a significant impact on operating cost. For MBR and SBR plants this can be divided into three broad categories: chemicals, personnel and energy. In comparison, the costs of chemicals and personnel are similar. Energy consumption, which can be within the total cost of operation, is higher with MBR than SBR. In both cases, the energy required to provide air for biodegradation is approximately the same at about 0.3-0.6 kWh/kg COD and 1.1-1.3 kWh/kg ammonia. The big difference is that membrane separation is a pressure driven process and as such requires a specific energy consumption of about 4.0 - 5.0 kWh/m^3 of treated leachate.

Cross-flow MBR vs. Submerged Systems

Despite the obvious benefits of MBR, further advantages can be made if these strengths can be applied in a low energy process. In fact low energy MBRs do exist, which use the hydrostatic pressure exerted by the sludge on a submerged membrane to drive filtration, reducing filtration energy consumption to 0.6-1.5 kWh/m^3. However such submerged MBRs, while having found common use in the treatment of municipal wastewater, have yet to prove themselves with landfill leachate. The principal reason for this is membrane fouling.

The membranes used in submerged systems have a more open pore structure, more akin to microfiltration than the closed ultrafiltration of cross-flow MBR. While this is ideal for ‘easy’ waste streams such as municipal wastewater, the cocktail of chemicals found in landfill leachate pose a serious risk. This problem is illustrated in figure 6 which compares filterability of industrial, domestic and leachate activated sludge.

Insert Figure 6

Filterability is strongly affected by the degree of fouling present and as figure 6 demonstrates, is lowest in leachate activated sludge. Despite this, cross-flow MBR systems have been applied in leachate treatment for almost 20 years. In these applications the risk of fouling is reduced by the scouring effect created by the velocity of the sludge (see figure 4). Furthermore if fouling does occur, cross-flow tubular modules can be easily cleaned in situ (CIP). This is not the case with submerged systems where lifting membrane modules from the bioreactor results in long downtimes.

Perhaps of greatest importance is the issue of flux rate. The flux rate is the specific flow in relation to membrane area. For submerged systems this is as low as 10-15 l/(m^2h) in comparison to 80-120 l/(m^2h) seen with cross-flow MBR systems. This alone requires can require up to ten times the membrane area to be installed for submerged systems to match the flow of cross-flow MBRs. Not only does this create a higher initial capital investment, but as submerged membranes are more prone to fouling, their life spans tend to be reduced in comparison with cross flow tubular membranes, resulting in much higher replacement costs.

Development of a low energy MBR

With this in mind the challenge for Wehrle was to produce a system that could demonstrate starkly reduced energy consumption while inheriting the strength, durability and minimal membrane fouling effectiveness of cross-flow systems. The major consumers of energy in a cross-flow ultrafiltration system are the recirculation pumps that provide the pressure and velocity to drive the filtration process and prevent fouling (see figure 4).

The energy required to run the recirculation pumps is the product of the pressure head and the flow rate. As the equations below demonstrate, the pressure head is proportional to the square of the velocity.

$$energy_{Pump} = flow\ rate \cdot head$$

$$head = factor \cdot \frac{\rho}{2} \cdot v^2$$

Where v is the cross flow velocity.

This means that a small reduction in velocity will lead to a large reduction in the pressure head and consequently energy. To illustrate, a 50% reduction in velocity will lead to an 87.5% reduction in energy.

Of course, such an action would result in a reduction in the flux rate and an increase in the risk of fouling. To prevent fouling would require an engineered solution. For this, experience gained in operating a leachate treatment plant at Freiburg, Germany proved invaluable. Built in 1999, this plant followed a different design (see figures 4 and 5) where sludge is pumped through vertically mounted modules at a reduced velocity. Compressed air is periodically injected into specially designed distributor units mounted under the modules. As the air rises through the membrane tubes they expand and wipe clean the membrane wall (see figure 7).

To compensate a reduction in flux, larger membrane areas can be added, which thanks to advances in membrane and module design, and a general downward trend in membrane prices, do not present a significant cost increase.

Furthermore, by controlling the speed of recirculation pumps with a variable speed drive, it is possible to vary the flux rate to match the incoming flow. This provides a massive boost to energy reduction as it allows operators to run the ultrafiltration at extremely low velocities during dry periods or when flow drops off. This flexibility makes the Freiburg plant one of the most energy efficient of its kind in Germany.

Insert Figure 7

During 2005, Wehrle developed the Biomembrat Low Energy (LE) process incorporating various aspects of the Freiburg plant with new developments in plant operation. With these changes, good flux rates can be maintained at reduced flow velocities as low resulting in a specific energy consumption of 1.3 - 1.50 kWh/m^3.

These developments prevent the build up of a boundary layer, which if left unchecked would lead to complete plugging of the membrane tube. The effect of this is to create a more robust system that can operate at increasingly lower velocities.

Consequences for the UK market.

As mentioned above, energy is the largest operating cost on a biological leachate treatment plant. The two biggest user of energy are aeration, and in the case of MBR, membrane separation. As the strength of the leachate rises, the relative proportion of energy required for aeration increases in relation to the energy required for ultrafiltration. This, in effect, reduces the disparity in energy consumption between SBR and MBR at for higher strength leachate. The table below illustrates how the gap between SBR and MBR narrows as COD and ammonia increases. It assumes a constant flow of 4 m3/h, a specific aeration energy consumption of 0.6 kWh/kg COD and 1.2 kWh/kg ammonia, and a specific filtration energy consumption of 1.5 kWh/m3.

COD (mg/l)	NH_4 (mg/l)	Process	Energy for aeration (kWh)	Energy for UF (kWh)	Total (kWh)
3000	1000	SBR	12	-	12
		MBR	12	6	18
5000	2000	SBR	21.6	-	21.6
		MBR	21.6	6	27.6
7000	3000	SBR	31.2	-	31.2
		MBR	31.2	6	37.2

This bodes well for the future of low energy MBR in the UK leachate treatment market, where leachate is generally of a higher strength than in mainland Europe.

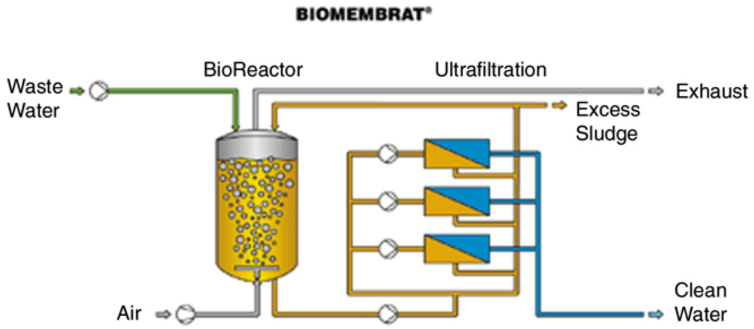

Figure 1 MBR Schematic

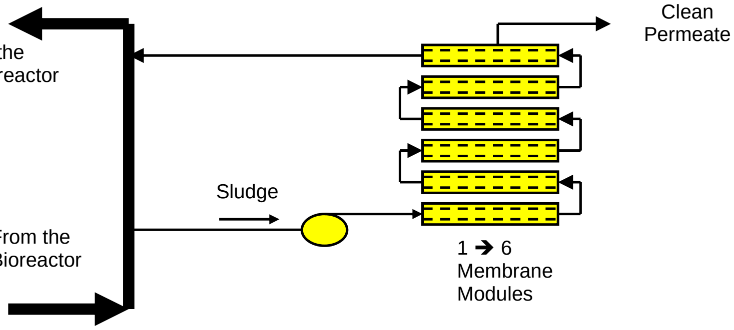

Figure 2 MBR Loop Arrangement

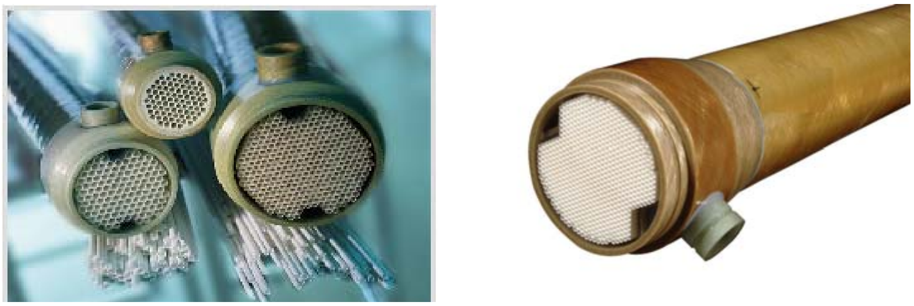

Figure 3 MBR UF Membranes

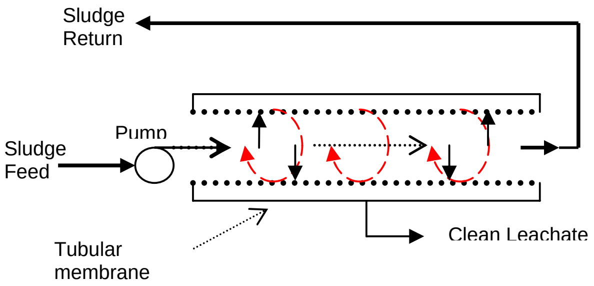

Figure 4 Cross Flow & self scouring membrane

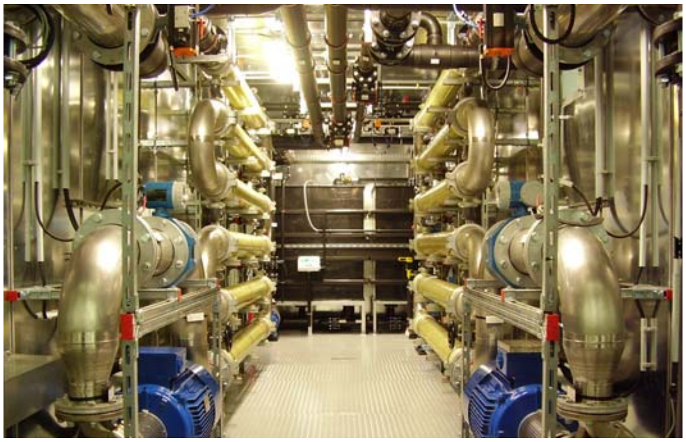

Figure 5 ***Compact MBR Container***

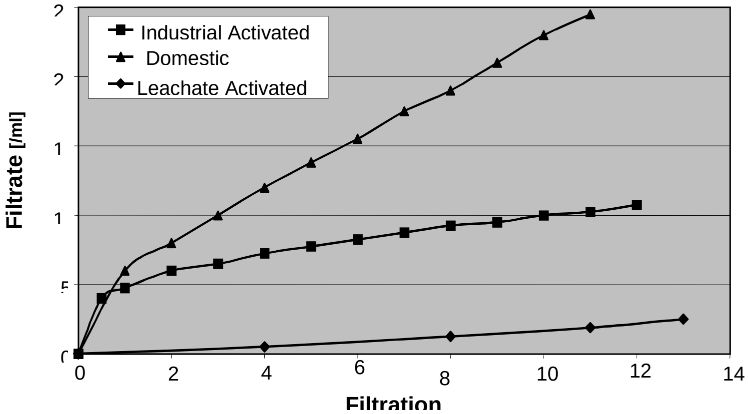

Figure 6 ***Filterability Comparison***

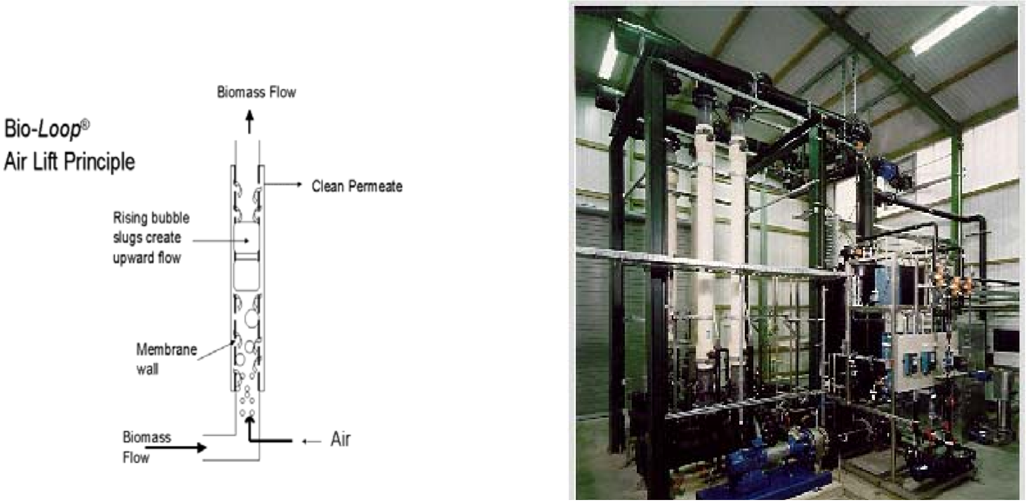

Figure 7 Air Lift MBR at Freiburg

Antony Robinson - Author Biography

Antony Robinson is a mechanical engineer by profession. Following his original specialisation in the field of process design and control, Antony worked several years in Brazil developing the introduction of advanced process automation systems for the fast growing food and beverage industries. He then moved to Ireland with the Stork Group and then to the UK.

In the ‘90s, Antony was involved in the development of transferring Stork’s technical expertise in the field evaporation and drying for the dairy/food industry to water and waste applications. In 98/99 Stork and Wehrle set up a joint venture, which was managed by Antony. Wehrle had been extremely successful in the design and installation of Membrane BioReactor systems for the industrial wastewater and landfill leachate sectors.

Antony moved to Wehrle as General Manager of the newly formed Wehrle Environmental in 2000.