New Developments in the Application of Membrane BioReactors (MBR) for Industrial Wastewater Treatment

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PAPER SYNOPSIS

With the advent of IPPC and other environmental regulations there is an increased interest, amongst generators of industrial wastewater, to not only meet the new required standards, but do so at a reduced cost. One solution is MBR technology, which has been extensively applied in Germany for more than a decade and is only now being implemented within the UK industrial wastewater sector.

The combination of a very high rate biological treatment, and ultrafiltration, results in a compact plant, when compared to conventional treatment. The main advantage of MBR is that it offers the opportunity for process plant operators to easily install cost effective onsite effluent treatment, as an alternative to paying the ever-increasing trade effluent costs being charged by the Water companies, whilst meeting increasing standards being imposed by the environmental regulators.

This paper will describe how a MBR plant works, show examples of different applications, typical CAPEX and OPEX figures and the reasons why this technology will soon be the main choice in the UK for onsite treatment of ‘difficult’ industrial wastewater.

THE MBR

Although a relatively new wastewater treatment process in the UK, MBR has been well established in Western Europe and Japan. Kubota have an extensive track record with their submerged flat sheet membranes in Japan. Wehrle-Werk AG developed the first European MBR, in conjunction with the University of Stuttgart, during the late 80’s, and the first commercial plant started operations in 1991.

In many respects, the MBR is an extension of the activated sludge process. Conventional activated sludge processes suffer from several constraints, such as needing operate with a low MLSS (range 4 g/l to 7 g/l) and the use of gravimetric tanks to separate sludge from the clean supernatant effluent. The efficiency of separation is governed by the quality of the biological process, which affects the settlement of the sludge. Changes to the plant biology can easily cause the sludge to bulk, in effect making it float, thereby increasing the solids level in the final effluent.

The fundamental difference with an MBR is in the method of separating sludge from the clean effluent. The conventional use of settlement tanks is replaced by an Ultrafiltration (UF) membrane system.

In an MBR, the biological sludge is continuously circulated via an Ultrafiltration separation system. Many applications using membranes for wastewater treatment require UF to be used as a means of volume reduction. In the case of combining membranes with a biological treatment, solids concentration must be avoided. This is achieved by selecting the correct ratio between sludge circulation and final effluent (clean water) flow.

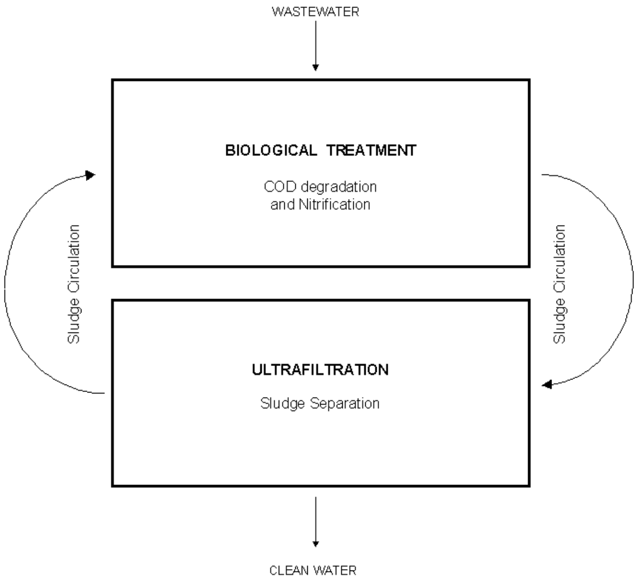


Fig. 1

Submerged and Cross-flow MBR

There are many types of MBR systems available on the market today but they tend to fall into two main UF system categories,

Submerged systems use membranes that are a hollow fibre or flat sheet construction and these are located within the bioreactor, or separate tank. The main feature is that the flow of effluent is from the 'outside to inside' of the membrane. The flux rate flow of the clean effluent is achieved by the trans-membrane pressure, which is created by the liquid head above the membrane surface. This is sometimes assisted by a vacuum pump.

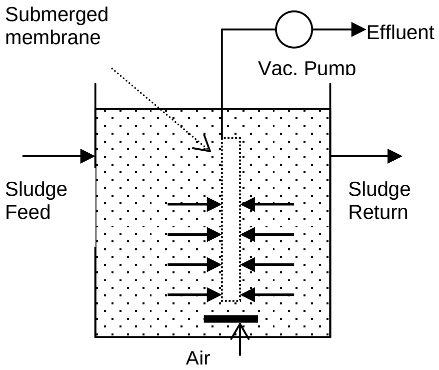


Fig. 2

Cross-flow systems, which use tubular or plate & frame membrane systems, are used where the biological sludge flows along the surface of the membrane. In this system, for example, tubular membranes are housed in modules through which sludge from the aeration tank is continuously pumped. (see fig. 3 and fig. 5)

Water and low molecular weight solids pass through the membrane wall as permeate, leaving all biological matter behind to return to the bioreactor. The rate of flow of permeate across the membrane wall (flux rate) is a function of the system pressure and sludge flow velocity.

(Photo by kind permission, Berghof GmbH)

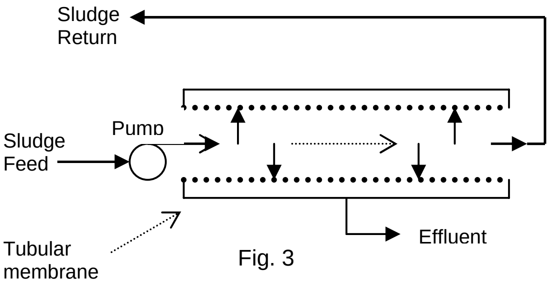


Fig. 3

Submerged MBR systems operate with a much lower flux rate (10-25 l/h.m^2) when compared to cross-flow systems (75-180 l/h.m^2). Consequently, submerged systems require more membrane area, which generally increases the required investment. On the other hand, the electrical energy demands for submerged systems are much lower.

Fig.4 highlights the filterability of three different types of MBR activated sludge. What is clear is that domestic sewage sludge is easier to filter than industrial sludge. Landfill leachate MBR sludge is the most difficult to filter. One of the factors affecting filterability is the fouling of sludge on the membrane wall.

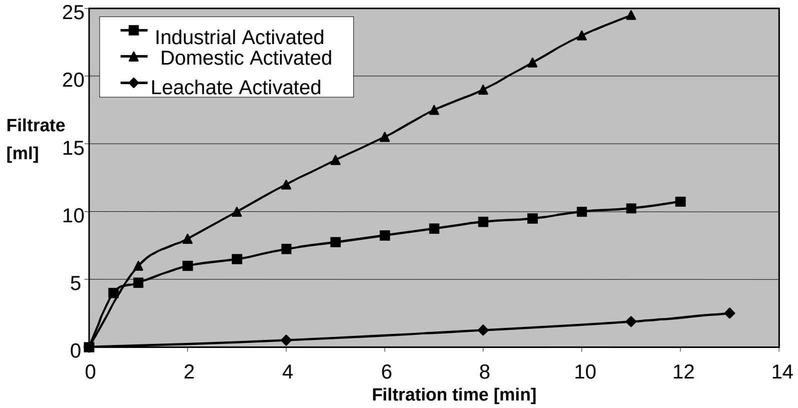


Fig. 4

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.

WHY MBR?

The main reasons why MBR has come into focus for the treatment of effluent are twofold,

- The final effluent is of a very high quality. The environmental agencies within Europe favour MBR because not only are discharges of biosolids completely avoided, but also specific chemical contaminants, such as pesticides, etc. are removed.
- An MBR is now a favoured wastewater treatment option for industrial processors faced with ever increasing environmental demands and costs. MBR not only occupies far less space than conventional treatment systems but it is also affordable.

Concerning the latter point, consider a typical food/dairy application treating 100 m^3/h of effluent. The aeration tank volume requirement for an MBR can be four to six times less than required for a conventional biological activate sludge treatment plant. In addition, the latter plant would require two, 16 Mt. Diameter settlement tanks, whereas the MBR cross-flow UF system space requirement would only be 8x4 Mts. Overall, an MBR would require 12 to 15 times less space and the investment would also be lower.

Industrial Wastewater

Although MBR technology for wastewater treatment is now well established it is important to select the system most suitable for the task.

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 process. However, for high strength-low volume wastewater, the capital and operating costs for ultrafiltration are low relative to the total COD load, and cross flow MBR is often the best choice.

Most industrial wastewater falls into the second category. For the treatment of this wastewater, cross-flow MBR has been found to have many advantages.

The biological treatment of higher strength industrial wastewater is a far more complex matter. Generally, the levels of COD and ammonia to be treated are much greater but, more importantly, the membrane surface can foul very quickly if the wastewater contains a high amount of dissolved solids, which precipitate as organic salts during biological treatment. The self-scouring action of tubular systems allows the membrane surfaces to remain clear of fouling materiel. In any case, if the membranes require a chemical wash then this can easily be achieved by standard *in situ* cleaning, using well established CIP techniques. (See fig. 12)

EXAMPLES OF MBR SYSTEMS

The simplest form of MBR is shown in fig.5 and is applied to COD degradation and nitrification.

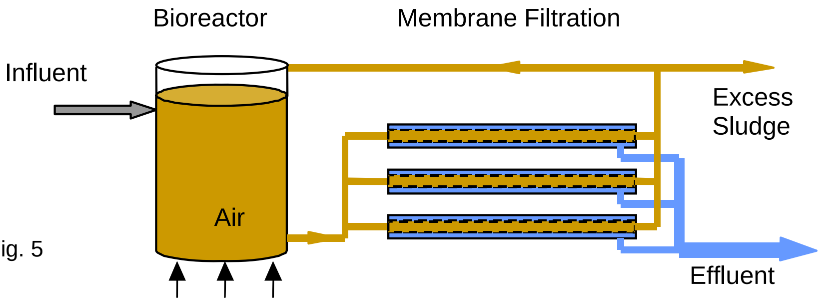


Fig. 5

If the wastewater contains ‘hard’ COD or, for example a textile waste where residual dyes need to be removed, then a post activated carbon step is recommended (fig. 6). This particularly applies to landfill leachate, which normally contain an array of organic substances, which are difficult to biodegrade.

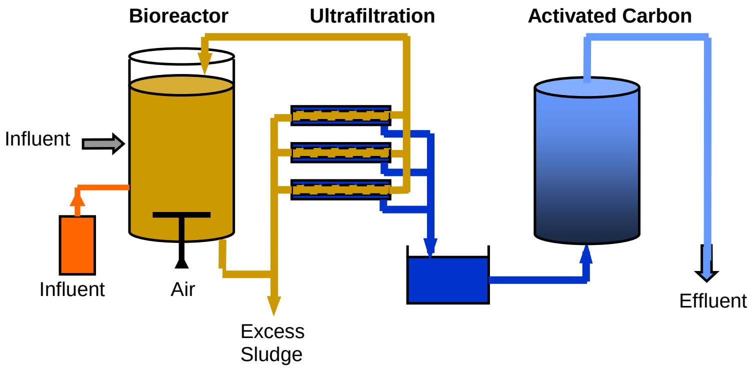


Fig. 6

If the final effluent is being discharged to a watercourse where the local environmental authority is placing a nitrate or total-N consent, the solution is to include denitrification as a feature of the process. This can easily be achieved with a pre-denitrification step as shown in the fig. 7.

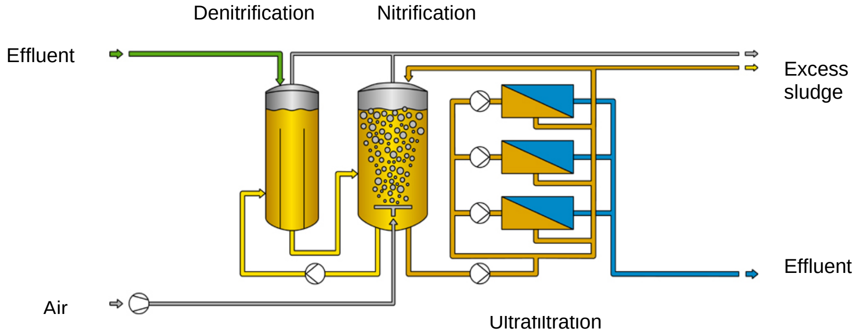


Fig. 7

EXAMPLES OF MBR SYSTEMS (cont.)

Table 1 demonstrates examples of tubular cross-flow MBR systems within some industrial sectors. The membrane flux rates shown is the average for the time period between two CIP cleaning operations. The average period between cleaning varies, but is generally between four and eight weeks.

Table 1

Industry		**Wool Scour**	**Tannery**	**Rendering**	**Pharma.**
Flow	m^3/d	240	300	200	1,050
COD	mg/l	25,000	16,000	17,500	9,900
BOD	mg/l	14,000	5,000	8,800	5,000
Ammonia	mg/l	-	450	2,500	-
Denitrification	%	-	-	60	-
Aerated bioreactor	m^3	400	600	630	1,300
Anoxic bioreactor	m^3	-	-	270	-
Membrane flux rate	$l/h.m^2$	60	105	70	100
Specific energy absorbed (biology)	kWh/m^3	18	6.8	15.2	6
Specific energy absorbed (membranes)	kWh/m^3	7	3.2	7.2	4

Industry		**Dairy**	**Beverage**	**Leachate 1**	**Leachate 2**
Flow	m^3/d	2,000	720	200	50
COD	mg/l	3,500	1,750	1,000	10,300
BOD	mg/l	2,200	1,000	145	4,500
Ammonia	mg/l	120	-	415	2,400
Denitrification	%	91	-	60	55
Aerated bioreactor	m^3	2,000	280	75	50
Anoxic bioreactor	m^3	700	-	22	22
Membrane flux rate	$l/h.m^2$	160	150	90	70
Specific energy absorbed (biology)	kWh/m^3	2.3	2.1	4.2	15.1
Specific energy absorbed (membranes)	kWh/m^3	2	2.5	6.3	6.1

The figures should be used with caution as each industrial sector covers a wide range of primary process applications. For example, the dairy figures in table 1 are typical for treating wastewater from whey processing plant. The flux rate is quite high although fouling caused by precipitation of calcium compounds is a major factor. However, the flux rates of MBR systems on some dairy/food wastewater can be much lower- generally, because of too many fatty compounds being present within the effluent. As for any biological treatment system, adequate primary treatment and flow balancing must precede an MBR process.

The photo on the left shows an example of a dairy MBR plant. The cross-flow UF plant is in the foreground and the Bioreactor is the tall tank. The aeration basin on the right forms part of an activated sludge plant, which is not linked with the MBR.

Portable Containerised Plants

One of the advantages of tubular cross flow membranes is they do not require much space. Consequently, these membrane systems can easily be pre-assembled into 30' of 40' containers and shipped to site.

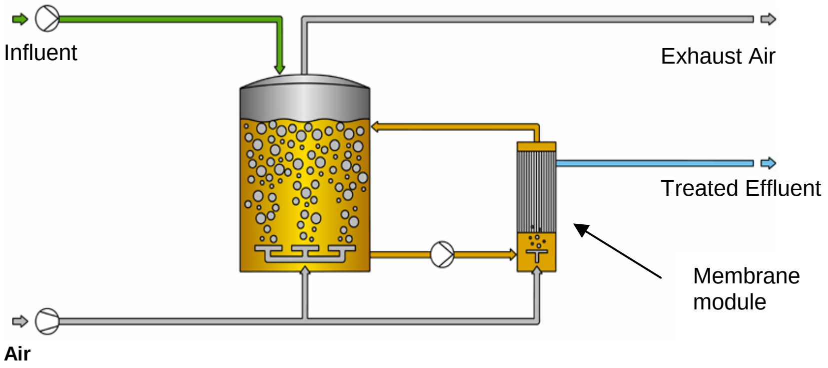
This method of assembly is particularly useful in two application areas,

- Retrofit onto an existing activated sludge plant. This is an ideal solution for sites where there is a requirement to meet an increased effluent load, normally as a result of a factory expansion, or the local environmental authority is requiring an improved final effluent quality.
- Portable MBR systems (PMBR) where the plant will move from site to site. This concept fits in well where a site cannot economically justify its own permanent effluent treatment facility. For example, a tank farm operator wishing to discharge a specific volume of effluent, or small landfill sites

TECHNOLOGICAL DEVELOPMENTS

One of the discussion points within the MBR industry is the on going argument concerning energy costs. There is no doubt that submerged MBR systems absorb less energy, but this only applies when membrane fouling is not a factor. For example, studies on the application of a submerged MBR treating landfill leachate have shown that as much as 2 kWh/m^3 is being used solely to blow compressed air onto the underside of the membrane pack. This is in order to create sufficient bubbles to keep the membranes free of fouling deposits.[1]

However, considerable progress is being made in the development of ‘low energy’ cross-flow MBR systems. One approach is the, so-called, “airlift” technique, which is shown in the diagram below.



BIOMEMBRAT– *Loop* ®

Fig. 8

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.

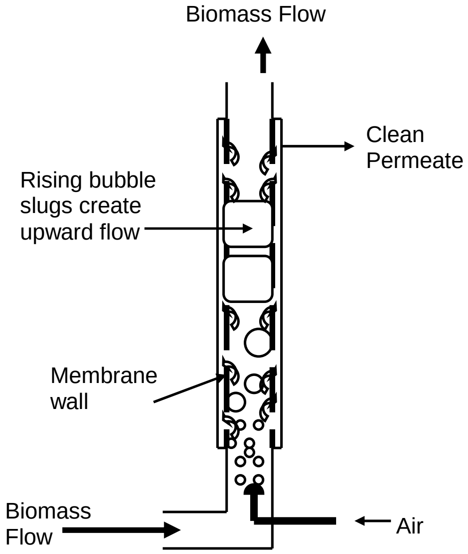


Fig. 9

Bio-*loop MBR*

This MBR ‘airlift’ system design has been in operation on a landfill site in the southern part of Germany for 18 months. The results, so far, have been excellent. The flux rate is reduced by 40%, due to the lower biomass flow velocity along the membrane tube, but the specific energy consumption is only 1.0 kWh/$m^{3.}$

This is a considerable saving in electrical power when compared to conventional cross-flow data shown in Table 1.

Further development is also taking place using horizontal tubular membranes with low velocity sludge flows.

Although, the rate of precipitation on the membrane wall increases with lower velocities, the fouling layer is removed by short term, periodic bursts of sludge flowing at higher speeds. Again, this work is based upon the fact that the power consumption drops, roughly, as the square of the sludge flow velocity. For example, a conventional cross-flow system operating at 4 m/s might consume 4 kWh/m^3, whereas a reduction in velocity to 2 m/s would result in the power consumption dropping to a value near 1 kWh/m^3.

The ‘air lift’ and the ‘ low flow’ techniques are called ‘semi cross-flow’. The main point to note is that the standard, *in situ* CIP capability for membrane cleaning is still available, as required.

CAPEX AND OPEX

Capital and operational costs of MBR systems can be split into two main areas.

- Plant biology, including bioreactor tanks, aerators and blowers. The CAPEX and OPEX costs are a function of daily flow and biological load to be removed. There might be differences in the type of aeration system used and the design MLSS within the bioreactor, but this will not have a major bearing on the plant costs.
- However, the same cannot be said for the membrane system employed. This element can have a considerable effect on the CAPEX and OPEX of an MBR.

Three main elements affect membrane plant costs.

1. Membrane replacement costs, i.e. the cost per m^2 of membrane area
2. Membrane flux rate, expressed in l/h.m^2
3. Membrane life

A recent study[2] into separation of biomass has been carried out, combining the three elements. The results, comparing submerged, semi cross-flow and cross-flow systems, are illustrated in the following graphs.

Fig. 10 shows a typical relationship between flux rate and power for the three systems.

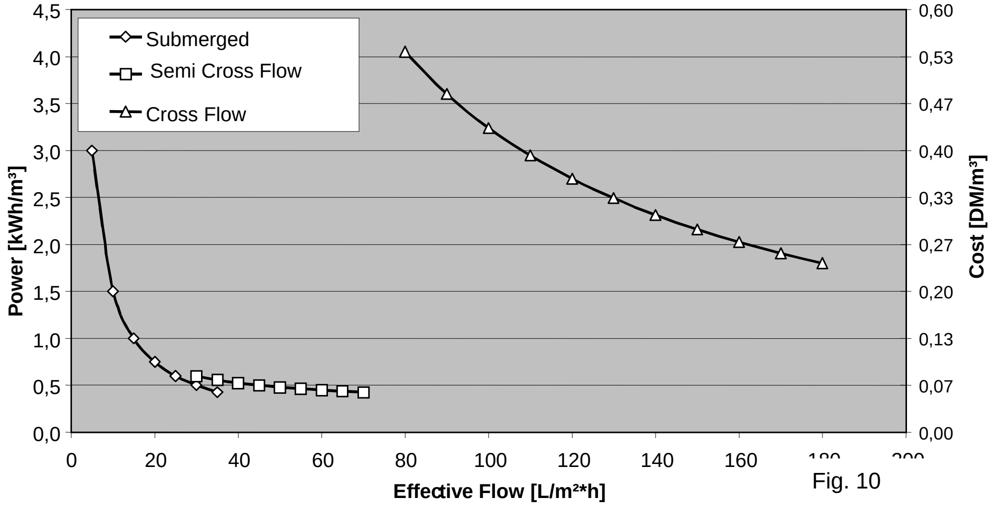


Fig. 10

The results combining the costs for membrane replacement, life span and power are snown in fig. 11. The data is based upon the following specific membrane costs:

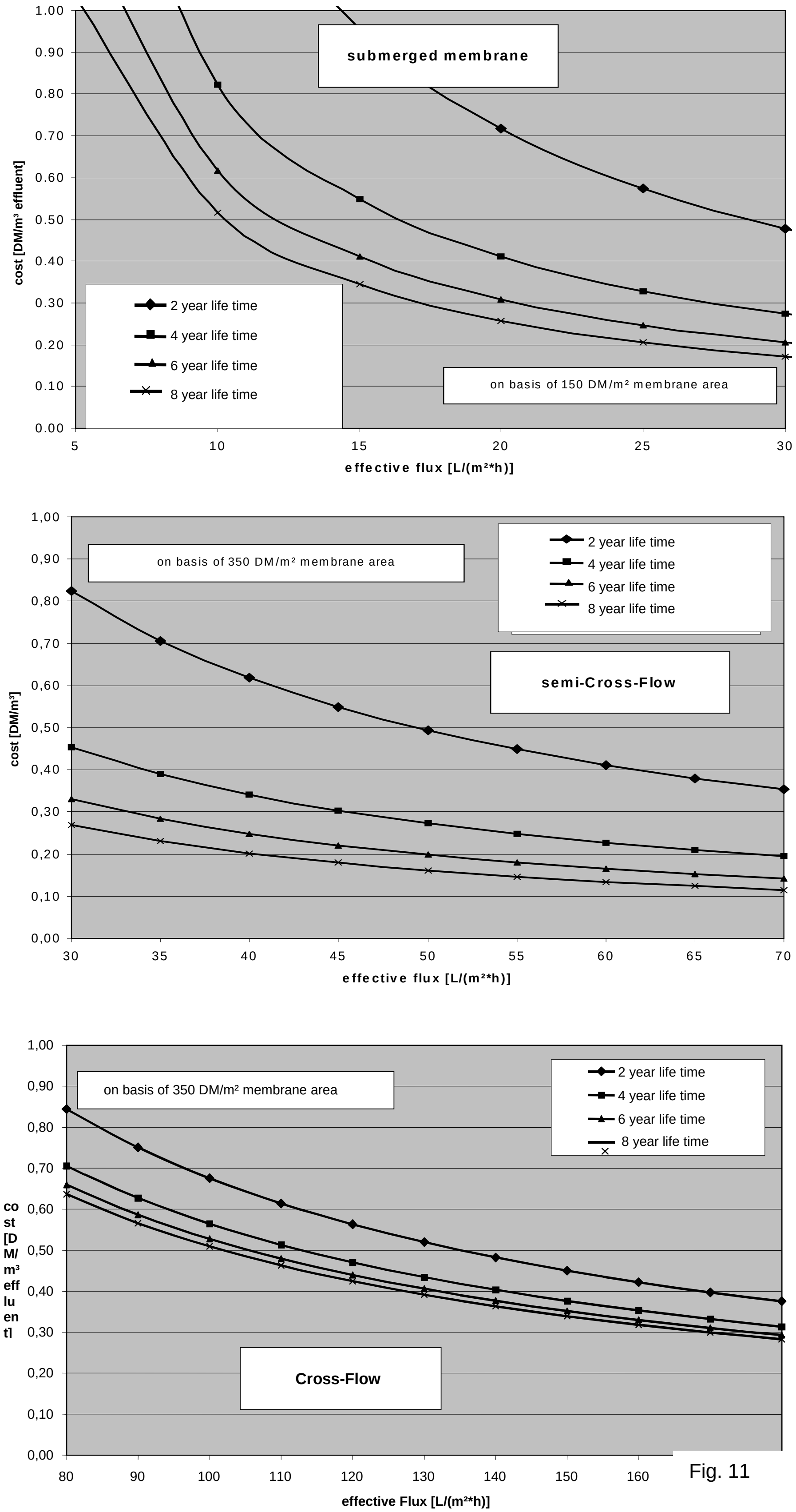
- Cross-flow membranes DM 350/m^2 or GBP 115/m^2
- Submerged membranes DM 150/m^2 or GBP 50/m^2

(exchange rate DM 3.00 = GBP) 1.00.

For example, in fig. 11 select submerged membranes operating with a flux rate of 20 l/h.m2 and having a life span of 4 years. According to the graphs, the total costs per m^3 of effluent treated are approx., DM 0.40/m^3. A comparison with semi and fill cross-flow membranes, on a ‘like-for-like’ basis where the costs of membrane usage are equal, would require the following flux rates,

Submerged system	20 l/h.m^2	Assuming, life span 4 years and DM 0.40/m^3 of effluent
Semi cross-flow system	38 l/h.m^2	
Cross-flow system	135 l/h.m^2	

In effect, the semi and cross-flow systems would have lower combined CAPEX/OPEX costs if their respective flux rates exceed 38 and 135 l/h.m^2. In fact, this is the case for many industrial wastewater treatment applications.



submerged membrane
on basis of 150 DM/m² membrane area
2 year life time
4 year life time
6 year life time
8 year life time
cost [DM/m³ effluent]
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5
10
15
20
25
30
effective flux [L/(m²*h)]
on basis of 350 DM/m² membrane area
2 year life time
4 year life time
6 year life time
8 year life time
semi-Cross-Flow
cost [DM/m³]
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
30
35
40
45
50
55
60
65
70
effective flux [L/(m²*h)]
on basis of 350 DM/m² membrane area
2 year life time
4 year life time
6 year life time
8 year life time
Cross-Flow
cost [DM/m³ effluent]
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
80
90
100
110
120
130
140
150
160
effective Flux [L/(m²*h)]

Fig. 11

SUMMARY

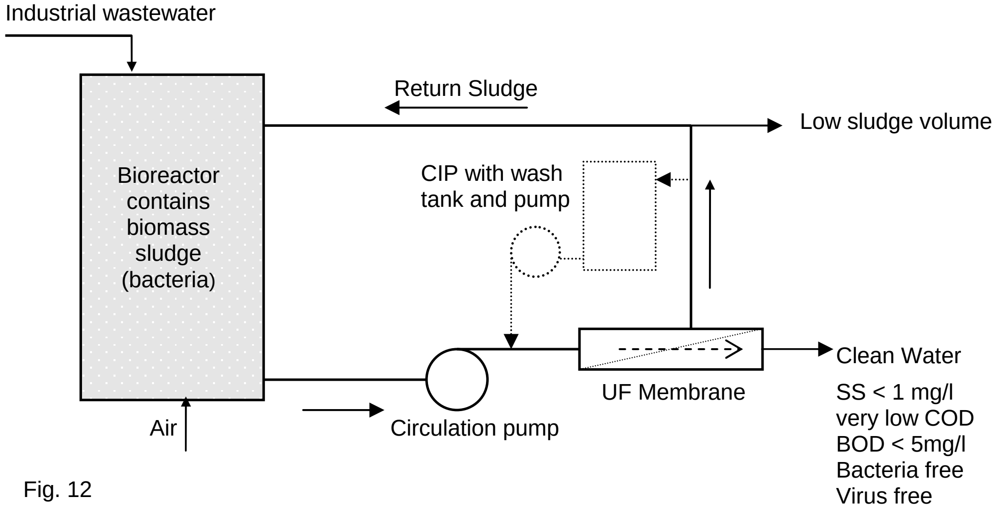


Fig. 12

In summary, the advantages of cross-flow MBR are as follows:

- Virtual zero solids discharge in the final effluent.
- The application of a very high MLSS (mixed liquor suspended solids) within the bioreactor which equates to smaller tanks and lower investment cost
- The ability to handle wastewater in which salts will tend to precipitate.
- The membranes can be easily cleaned *in situ* (CIP)
- Flux rates ranging up to 170 l/h.m^2 are achievable. Less membrane area means a lower investment cost
- The use of low sludge loading (F/M ratio) results in extended sludge age and, by definition, less generation of excess biological matter.
- Very small foot print required when compared to conventional biological treatment plants
- Cross-flow membranes can be retrofitted onto existing activated sludge plants
- The availability of portable containerised systems
- The membranes are separate from the biological aerated tank (bioreactor) and will not affect the aeration efficiency. They can be easily removed for inspection.
- The development of the semi-cross flow MBR will result in even lower operating costs.

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[1] W.Firk Dipl. Eng. Dr., K.Densla. *Perspectives with the Membrane Activation System in the treatment of Municipal Sewage.* (ATV-DVWK Conference, Germany. 2000)

[2] J. Laubach, Dipl. Eng. *A Comparison of Various Membrane Systems for the Separation of Biomass.* Water & Waste Treatment Conference, Aachen, Germany. 2001