Future Of Water Treatment: Membrane Bioreactor Technology

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ABSTRACT

In India an average of 70 - 75 m^3 of high quality ground water and around 22 - 25 GJ of energy is needed for the production of one ton of paper. As economic circumstances are changing and environmental legislation stiffens, paper mills are forced to minimize their energy- and water consumption. Due to increasing local taxes and regulations on energy and water consumption there is a need for further water system closure in paper industry. Purifying and recycling process water is a way to minimize the use of potable water and the production of wastewater in the industry. The use of well water as fresh water is attracting more and more attention because of environmental reasons like dry up in certain water sensitive areas. The degree of pollution of industrial effluent emissions on surface water areas is also becoming more important. These aspects make reduction of water consumption a major issue. The most important aspects for further water reuse for the paper production process are: a more stable process and product quality, a higher runnability, better energy efficiency, reduction in water demand and decrease of environmental pollution. This paper focuses on the upcoming membrane bioreactor technology and the applications in the paper industry for treatment and reuse of wastewater. An application in the paper industry is discussed: Pilot trial with a closed loop system at the paper mill.

Background of the membrane bioreactor technology

General description

Conventional aerobic wastewater treatment systems (activated sludge systems) are well-known and accepted as end of pipe technology in the paper industry. A technology that is based on the same concept is the membrane bioreactor technology. In both systems, dissolved organic components are converted by aerobic microorganisms in inorganic products like CO_2 and H_2O. After degradation, biomass and water are separated. In the conventional activated sludge systems, separation is based on settlement of biomass in large clarifiers. The concept of MBR systems consists of utilizing a bioreactor and micro- or ultrafiltration as one unit process for wastewater treatment thereby replacing the solids separation function of clarification and possibly effluent filtration. The membrane bioreactor is a key technology for water-system closure.

Membrane bioreactor vs conventional wastewater treatment

By using membranes some characteristic differences can be distinguished when comparing the membrane bioreactor with conventional biological treatment systems (table 1).

1. Footprint reduction

By using membranes for sludge/water separation, a much higher biomass concentration can be applied. Biomass concentrations of 25 g/l for cross flow MBR systems are feasible, making a high volumetric load possible. Conventional systems only operate at max. 6 g/l of biomass. Biomass concentrations higher than 25 g/l will lead to problems with viscosity, membrane fluxes and oxygen transfer. By applying an MBR, the total space requirement can be reduced by a factor 5 – 10.

2. Heat production

In membrane bioreactors, heat is produced in several ways:

Biological processes, like oxidation, nitrification and denitrification are exothermic reactions. Due to high biomass concentration and high bacterial activity the volumetric heat production due to biological processes is quite significant in a membrane bioreactor. Nearly 80 % of the energy input for membrane filtration is converted into heat, resulting in a heat production of 5 - 7 kWh/m^3 (cross flow ultrafiltration). Due to the heat production the bacterial processes can take place at relative high temperatures (ranging 30 - 70 °C).

3. High quality effluent: ready for reuse

Maintaining a high biomass concentration and the retention of high molecular-weight compounds by the membranes facilitates complete mineralization of organic components. Due to membrane separation, the solids retention time is independent of hydraulic retention time. Membrane separation in bioreactors is most suited for situations where long solid retention times are necessary to achieve the removal of pollutants. After passing an ultrafiltration membrane the effluent is also free of suspended solids and bacteria and viruses, which is necessary for reuse.

4. Reduced or even zero sludge production

Sludge production in membrane bioreactors is much smaller than in conventional aerobic systems due to the high temperatures and the relative low F/M ratio.

5. Higher capital and maintenance costs

Although recently membrane prices have dropped significantly and life expectancy of the membranes has increased, the investment and operational costs for the membrane unit still plays a dominant role. Prices for submerged membranes range from Rs. 3850 - 5200 / m^2, external membrane prices are in the range of Rs. 12800. Due to the fact that membranes need regular cleaning, also the costs for the

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Table 1: Advantages and disadvantages of MBR compared to conventional

Advantages	Disadvantages
• Small footprint • Complete solids removal from effluent • COD, solids and nutrient removal in a single unit • High loading rate capability • Low/zero sludge production • Possibility for water/energy reuse	• Membrane fouling • Costs

use of chemicals are higher.

Membrane bioreactors are favorable in the following situations:

- In situations of limited availability of space
- For treatment of wastewater with difficult degradable components
- Where high effluent standards are required
- In-process treatment to realize further water system closure (savings for process water and energy)
- Where high costs for sludge treatment are considered.
- At special circumstances like high salinity or high temperature

In the submerged MBR system the key component is the microfiltration membrane that is immersed directly into the activated sludge reactor. The membranes are subjected to a vacuum (less than 50 kPa) that draws permeate through the membrane while retaining solids in the reactor. To clean the exterior of the membranes, compressed air is introduced through a distribution manifold at the base of the membrane module. As the air bubbles rise to the surface, scouring of the membrane surface occurs. For the cross flow MBR, activated sludge from the bioreactor is pumped to a pressure-driven tubular ultrafiltration membrane where solids are retained inside the membrane and water (permeate) passes through to the outside. The driving force is the pressure created by high cross flow velocity through the membrane.

An important difference between both systems is the mechanism of prevention of fouling. With submerged MBR, coarse air bubbles are used to prevent fouling of the outside of the immersed membranes. In cross flow systems, a high speed is used to create turbulence inside the tubes, which prevents fouling. Furthermore, pressures inside cross flow systems are higher when compared to submerged membranes. This results in a higher specific energy consumption for cross flow membranes. Due to the difference in fouling prevention, submerged membranes are more sensitive for fouling and production capacities are strongly influenced by the condition of the biomass. Specific membrane capacities for submerged membranes vary from 12 30 l/m^2.h, where cross flow systems operate at much higher specific production capacities (75 150 l/m^2/h). The membrane prices however are lower for submerged membranes. Maintenance like membrane cleaning

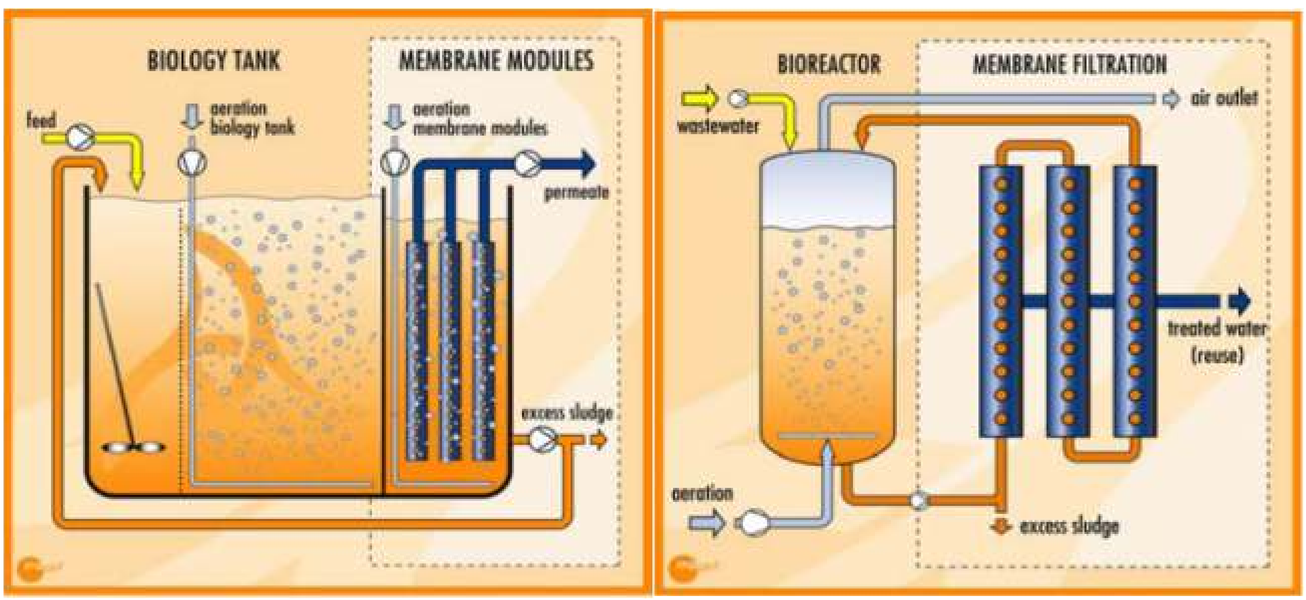

Figure 1: Process scheme of a membrane bioreactor (top submerged, bottom cross flow MBR)

Comparison between submerged and cross flow MBR

Membrane bioreactor systems have two basic configurations: (1) the submerged membrane bioreactor that uses membranes immersed in the bioreactor and (2) the cross flow MBR in which the mixed liquor circulates through a membrane module outside the reactor.

Table 2: Comparison of submerged and cross flow MBR

	Cross flow MBR	Submerged flow MBR
Membrane capacity (flux) [l/m^2.h]	75 – 150	12.5 – 30
Max operational temp. [°C]	< 70	< 55
Trans Membrane Pressure [kPa]	400 – 700	20 – 50
Energy consumption filtration [kWh/m^3]	4 – 7	0.5 – 1.5
Estimated lifetime membranes	3 – 5	5 – 7
Max biomass concentration (g/l)	18 v 25	12 – 14
Maintenance (cleaning, exchange)	more easy	less easy
Membrane costs [Rs. /m^2]	12800	3850 – 5200

and replacement is easier with external membranes. Due to the specific differences between MBR systems with internal and external membranes, industries tend to use membranes with external membranes, whereas submerged membrane systems are favored for domestic applications, where usually huge flows are considered. In addition, submerged membranes are not suited at operational temperatures > 50 °C, making thermophilic operation difficult.

Water treatment and reuse in the paper Industry

In the processes of closing up water systems and reducing fresh water consumption, problems occur due to 'accumulates'. The following fractions can be distinguished:

1. Suspended solids: fibres
2. Suspended solids: fillers and fines
3. Colloidal material: starch, ligno sulfonates, hemi cellulose, anionic trash.
4. High molecular dissolved material: fatty acids, starch degradation products, wood sugars
5. Low Molecular dissolved material: (in) organic salts

The water quality can be described as a function of these 5 fractions, temperature (heat) and microbiological activities, i.e. slime forming, sulphur reducing and smell forming bacteria. To enable further closure of the water loop all 'accumulates' should be controlled and/or prevented. To overcome production problems and a reduced product quality (due to accumulation or increase of the five fractions) to realize further water system closure, a series of technologies can be applied which is part of the product based water treatment concept as presented in figure 2. The treatment concept is based on the five fractions present in process water. Fraction 1 and 2 will be removed by **pre-treatment** (settle plate clarifier; possibly in combination with dissolved air flotation), fraction 3 and 4 will be converted by a **membrane bioreactor** (MBR) and fraction 5 will be removed by use of **electrodialysis** (ED), **nanofiltration (**NF) or r**everse osmosis** (RO). In some cases, the salts can be up-graded to useful process chemicals (caustic and acid). Hereby a closed salt loop is created. However, this step is so far only conceptual and tested in experimental setup.

The membrane bioreactor technology offers specific advantages for papermaking industry. It is important to have an effective pre treatment step to remove solids from the wastewater, as solids can negatively influence the performance of the bioreactor. Furthermore, it is important to test the stability of the specific application and to perform tests with the treated water on the different production steps, as the treated water may influence the paper production. The MBR is ideal for in-process water treatment with temperatures of 40-65 °C. This way integration with the paper production process could be established.

- High effluent quality could be re-used on nozzles paper machine.
- Reuse of wastewater from bleaching plant
- Reuse of water from condensate / cooker

Pilot-scale realization of the membrane bioreactor

Because the construction of such a plant was new and very innovative and was both beneficial from environmental technological and economical point of view. A schematic drawing of the system is presented in figure 3. The dimensions of the system are presented in table 3.

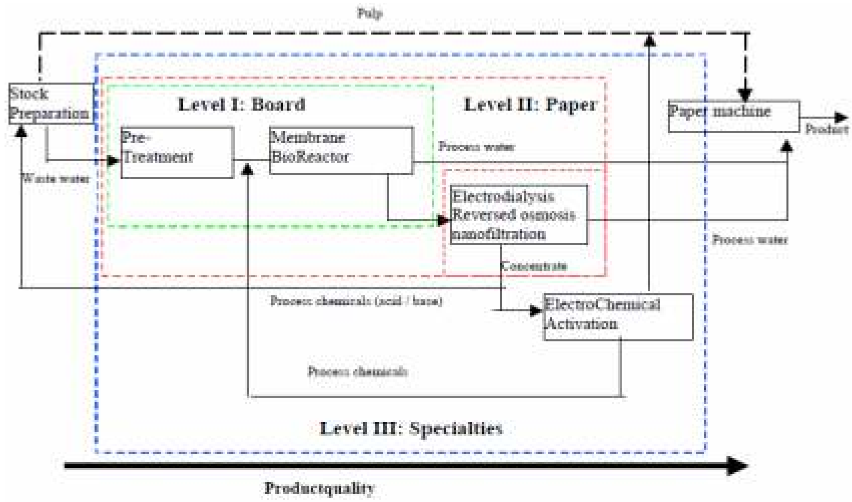

Figure 2: Product based concept on levels of technology input

Table 2: Comparison of submerged and cross flow MBR

	Value	Unit
Capacity (max)	12	m^3/hr
Volume DAF (Dissolved Air Floatation)	15	m^3
COD	1050	kg/d
Volume Bioreactor	250	m^3
Process temperature	60	^{0}C

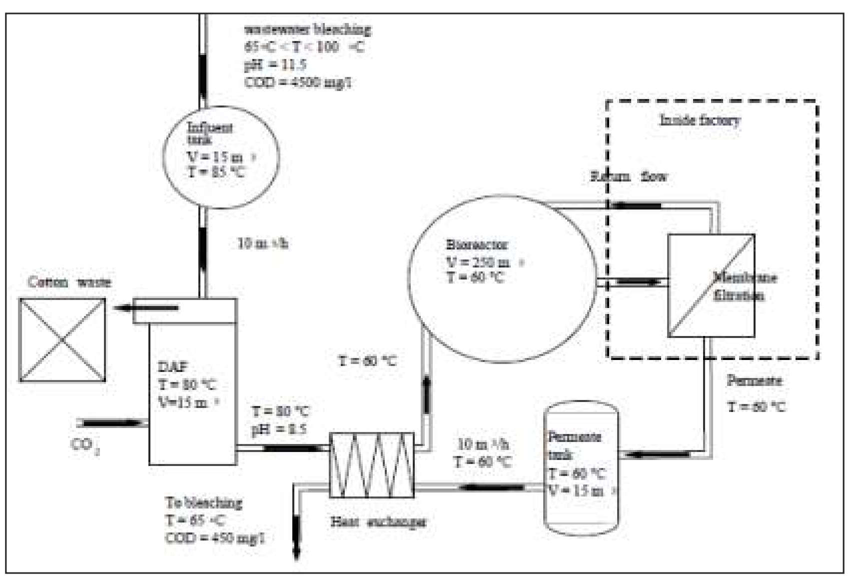

Figure 3: Schematic overview of treatment plant.

The reactor, DAF unit and wastewater buffertank are placed outside the factory (figure 4), the membrane unit is placed inside the factory and is shown in figure 5 and 6. The plant is constructed out of stainless steel, with the exception of the membranes, which are made out of synthetic material.

During the operation of the plant, all process parameters are intensively monitored. Furthermore, gradually the temperature is increased and the effects

Figure 4: Wastewater tank, DAF and reactor

Figure 5: Front view Membrane Unit

Figure 6: Side view Membrane Unit

on membrane filtration and COD removal efficiency have been investigated. The values for pH and temperature are presented in figure 7.

During the test it occurred that at a temperature > 50 °C at oxygen concentrations > 1 mg/l immediately foam formation occurs. Therefore the oxygen concentrations in the system were kept low. It is known that at higher temperatures the oxygen saturation levels in fluid are lower, however, this is compensated by higher oxygen diffusion. The oxygen uptake inside the system is relatively high because of the higher activity of the micro-organisms at high temperature (maintenance) and a high mineralization (low sludge production). Normally it should be avoided to use anti foam agents, as membrane capacities could be negatively influenced. However, it was decided to add 3 ppm of anti foam agent to the wastewater. The COD values for wastewater are presented in figure 8.

During the first period of operation (as well as during the pilot test) the COD

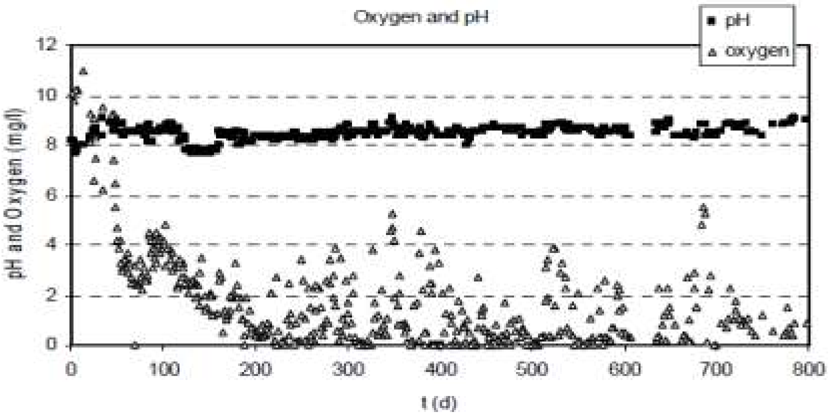

Figure 7: pH and oxygen in Bioreactor

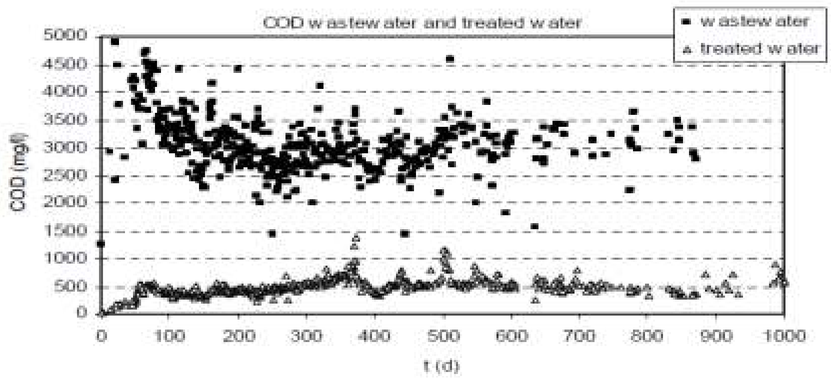

Figure 8: COD in wastewater & treated water

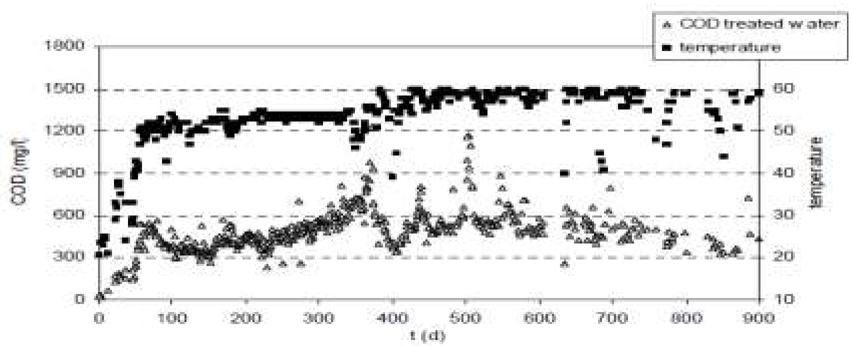

Figure 9: Relation between COD in treated water & temperature.

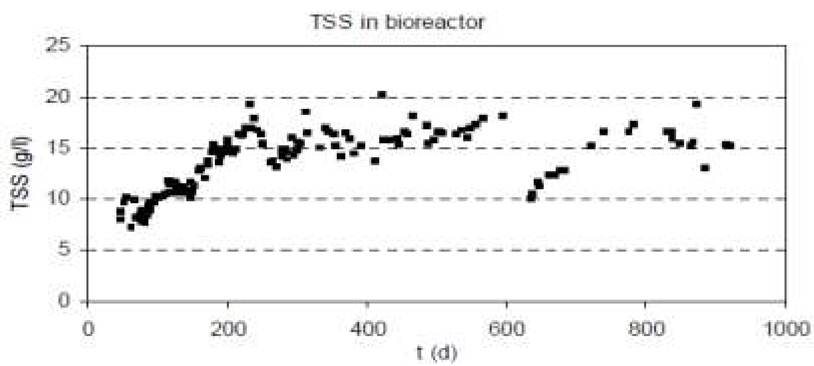

Figure 10: Biomass concentration in the Bioreactor

concentration of the wastewater was around 4000 – 4500 mg/l. The temperature of this stream however was too high (> 85 °C) and hindered the DAF operation. Therefore it was decided to mix the water with flush water with lower temperature and COD load. Therefore also the COD of the wastewater decreased. During operation occasionally peaks occurred in COD of treated water, which were caused by oxygen limitations. The relation of the COD concentration in the treated water and the temperature in the bioreactor is presented in figure 9.

The peaks to 1000 mg/l can be explained by insufficient oxygen supply. After increase of the temperature to 60 °C COD values even decreased to values from 350 - 500 mg/l. Both adaptation and the dilution effect of the wastewater could be an explanation for this occurrence. A very important factor is the biomass production, as many times these costs contribute significantly to the total operational costs. The biomass concentration in the bioreactor is presented in figure 20. The biomass concentration (TSS) increases and stabilizes around 15-18 g/l. At this concentration, no net sludge yield is found, so no sludge discharge is needed. This means that the gross biomass yield is fully compensated by the biomass decay.

Conclusions

Overall it can be concluded that the use of a thermophilic MBR, possibly in combination with other techniques can lead to savings for raw material, water intake, wastewater discharge and energy for heating. The membrane bioreactor produces high quality treated water that can be reused for many applications. These economical and environmental advantages make full-scale application feasible. The first full scale thermophilic membrane bioreactor in the Netherlands is in operation since 2010 and so far results have been very satisfying. In this concept, wastewater from a bleaching plant is treated and reused for the same application. The quality of the treated water is even better that found during pilot tests. Because of the thermophilic conditions zero sludge production has been found, which is a major advantage for this treatment technology. The membrane performance is high (> 100 $l/m^2.h$) and proved to be suited for these kind of applications

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