CONFERENCE PROCEEDINGS
HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 2. pp. 71 - 75 (2000)

APPLICATIONS OF MEMBRANE TECHNOLOGIES IN WATER REUSE FIELDS

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This paper was presented at the Second International Conference on Environmental Engineering,
University of Veszprém, Veszprém, Hungary, May 29 – June 5, 1999

This paper presents the application of microfiltration and reverse osmosis membrane technologies in water reuse and recycle projects within the power industry, through one pilot scale and two full-scale case studies.
The paper also describes a relatively new microfiltration technology, based on ZeeWeed®, a shell-less, outside-in hollow fibre membrane immersed into a process tank and operated by applying a small suction to the membrane's lumen. Operating at differential pressures of -7 to -55 kPa, the immersed membrane is an energy efficient membrane. In addition to its low energy consumption, offers a number of advantages e.g. chlorine and oxidant resistance, exceptional durability, small footprint, low infrastructure costs and allowance to high suspended solids. These features provide flexibility to a membrane plant, which in turn allows for treatment of a variety of streams.

Keywords: prefiltration; pre-treatment; membrane technology; microfiltration; reverse osmosis; hollow fibre; ZeeWeed® membrane; wafer reuse and recycle

Introduction

The increased public concern over health and the environment, the increasingly stringent effluent discharge criteria, the limited water supplies for meeting prevailing and projected water demand at a specific location along with the increasing fresh water costs strongly affect the large industrial water consumers, such as the power industry.

To extend existing water supplies, to limit the discharge of pollutants as well as to recover useful materials where is possible, industrial firms are looking for technical solutions which enable them to reuse treated wastewaters (e.g. from sewage treatment plant) or to recycle internally their own technological wastewater. In the context of technology advances, the answer to this obvious challenge is the combination of two membrane separation techniques, namely: microfiltration (MF) and reverse osmosis (RO).

Reverse Osmosis is a membrane desalination process, commercialised during the 1960s especially in arid regions of the Middle East. Since its introduction, due to ever decreasing membrane prices and accumulating process knowledge through experience, the RO technology is successfully implemented on large and diverse scale. For successful application in the treatment train of troublesome waters, which contain some combination of high and variable suspended solids, organics, inorganics (e.g. iron and manganese) and bio-contaminants (microorganisms: bacteria, algae etc.)[1], the pre-treatment of the feed water to the RO system should be reliably and well established. In the past, the pre-treatment was entirely solved through conventional technologies e.g. clarification and multimedia filtration or multimedia filtration alone. The success of this pre-treatment depended largely on the control and monitoring of the coagulant addition. This control was extremely difficult with variable raw water supply, which rendered an unreliable, unstable and unpredictable property to this conventional pre-treatment process. An insufficient amount of coagulant could contribute to process fouling due to contamination, whereas an excess of coagulants could lead to RO membrane fouling by the coagulants themselves. Therefore the elaboration and further development of the microfiltration membrane process presented a breakthrough in the field of RO pre-treatment as well.

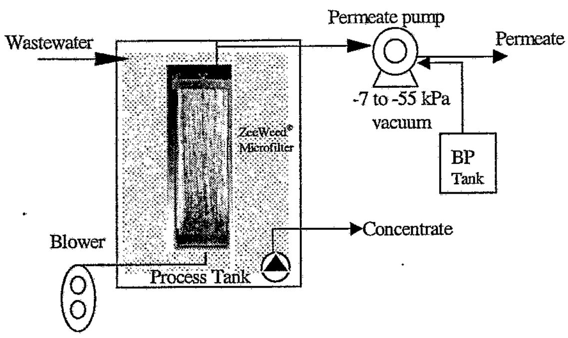

Fig.1 Operational Concept of ZeeWeed® Membrane Filtration

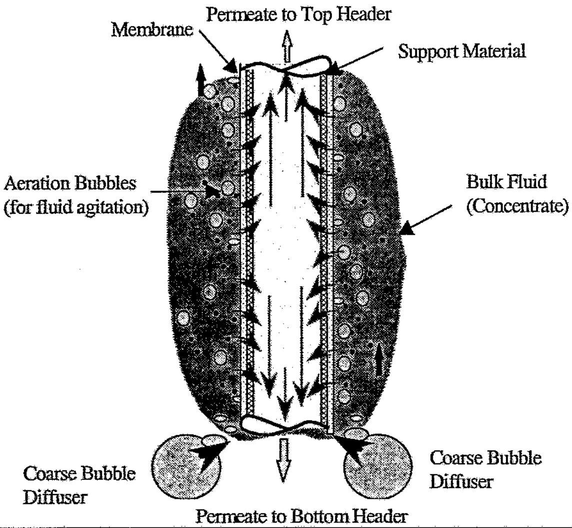

Fig.2 ZeeWeed® Membrane Fiber Schematic

Microfiltration Membranes

Microfiltration membranes operate on the principle of particle separation based on pore size and pore size distribution. Microfilters have pore sizes that vary from 0.075 micron to 3 microns. Depending on the membrane selected, it will allow separation of suspended solids, bacteria, cysts etc., which have a diameter larger than the largest pore size of the membrane. This allows for production of microorganism and suspended solids free water without the need of chemicals.

The first microfilters were of the depth filter type, where particles and microorganisms are entrapped within the internal structure of the filter [2]. Due to the need for regular replacement, depth microfilters have had limited application in the pre-treatment process. Among the membrane module geometries, spiral wound configurations were the first commercially available. Due to their flat-sheet nature, these membranes could not tolerate very well solids, which prevented their widespread use. Therefore, the most commonly employed configurations are the tubular and hollow fibre MF membranes. However, the higher packing density and lower energy consumption of the membrane systems with hollow fibre modules will favour their use over the tubular modules especially in larger plants.

Based on the flow regimes, two types of hollow fibre membranes are distinguished:

- inside-out membranes, where the influent is fed inside the membrane's lumen and the clean water travels from the inside of the fibre to the outside.
- outside-in membranes where the influent is fed from the outside of the membrane and the clean water travels from the outside to the inside of the membrane fibre.

The common pressure driven hollow fibre membranes, known to the market, are installed within pressure vessels, necessary to apply the pressure for proper fluid transfer. Typical operational pressure for these membranes is 103 to 207 kPa.

The introduction of vacuum driven hollow fibre membrane process, the ZeeWeed® membrane process, by ZENON Environmental Inc. further revolutionised the microfiltration market.

The ZeeWeed® Membrane - Process Description

The ZeeWeed® based water filtration is a novel, low energy membrane process that employs outside-in, shell-less hollow fibre microfiltration modules immersed in raw feed-water. The ZeeWeed® microfilter has a 0.085 micron nominal and a 0.1 micron absolute pore size, ensuring that particles with diameter exceeding 0.1 microns do not escape to the treated water stream.

The membranes operate under a small vacuum created within the hollow fibres by the operation of a centrifugal pump. The treated water passes through the membrane, enters the hollow fibres and is pumped out to distribution by the permeate pumps. *Fig.1* illustrates the operational concept of ZeeWeed® membrane filtration.

A low-pressure airflow is introduced at the bottom of the membrane module to create turbulence, which scours and cleans the outside of the membrane fibres allowing them to function at a high flux. This air will also oxidise iron and other organic compounds, generating better quality water than provided by microfiltration alone. *Fig.2* shows a schematic of a ZeeWeed® membrane fibre in operation.

In order to remove fouling material from the surface of the membrane, in addition to air scouring, at regular intervals, collected permeate is pumped in the reverse direction, forcing flow through the membrane from the inside of the hollow fibre to the outside, cleaning the membrane pores and fibre surface. This in-situ cleaning process is termed backpulse. Due to the high permeability of the ZeeWeed® membrane, the backpressure during backpulsing is low. The small variations in operating pressure that the membrane is subject to occur smoothly over relatively long periods so that at no time is the membrane stressed. This in turn, results in a microfiltered permeate with the lowest, sustainable particle count on the market. The reject water called concentrate is discharged directly from the process tank intermittently or continuously depending on system operating parameters and design. Intermittent discharge (no concentrate removal during backpulse) offers the advantage of decoupling the hydraulic recovery from the backpulsing operation [4]. The hydraulic recovery is simply controlled by setting a bleed rate from the process tank.

To prevent pump cavitation and the development of water hammers in the distribution system, the ZeeWeed® process is equipped with air separator columns, which remove the entrained air from the permeate. Accumulated membrane foulants are removed when a limiting suction is reached by on-line or off-line chemical cleaning. Several procedures and cleaning agents may be employed, depending on the application. Off-line chemical cleaning interval is typically one to several months, and takes 2 to 4 hours, depending on the number of steps required.

The ZeeWeed® membrane modules consist of many hollow fibres, which are coated on the outside with the membrane and run vertically between top and bottom permeate headers on the membrane module. Individual modules are assembled to cassettes, which in turn are attached to frames. Therefore, the resulting systems are extremely compact. The system does not need elaborate pre-treatment, even if the feed water contains clays and fine particles, only coarse screening. Therefore, in a single process, it replaces the coagulation, flocculation, clarification and sand filtration steps of conventional plants and also eliminates the pre-treatment required by spiral and inside-out membranes.

Applications of MF & RO in Water Reuse Projects within the Power Industry

Driven by unsatisfied user needs due to unreliable operation of the conventional pre-treatment, technological development in the field of microfiltration and membrane manufacturing cost reductions due to increasing application of microfiltration membranes throughout the water and wastewater industry, microfiltration is being increasingly applied to replace conventional boiler feed water pre-treatment processes. Moreover, as discussed, due to the application of MF in the pre-treatment step of a RO system, "difficult to treat" waters could also be considered as primary feed source, which represents considerable savings and contributes to environmental protection.

Case Study I – Bokod Power Station

At the Bokod Power Station (235 MW) in Oroszlány, Hungary, the 52 m^3 h^{-1} demineralised, boiler feed water stream is produced directly from the cooling lake, which contains up to 100 mg dm^{-3} of suspended solids and $225 \cdot 10^6$ counts dm^{-3} of algae during bloom periods [7]. Prior to the installation of the MF & RO membrane systems, due to the cooling system blow-down discharges, the cooling lake has enriched in total

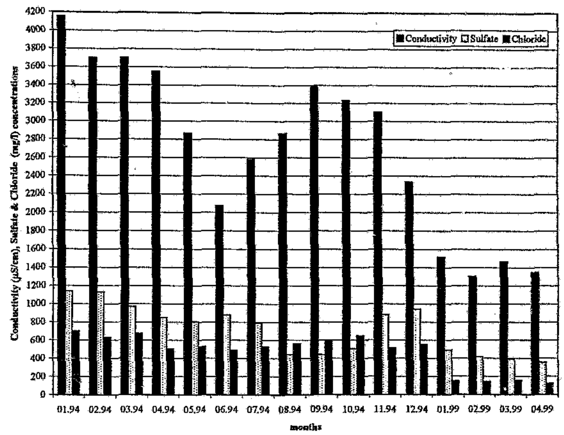

Fig.3 Bokod Power Plant – Conductivity, Sulphate and Chloride Content of the Cooling Lake

dissolved solids (TDS of 6000 mg dm^{-3}). Since the start up of the new treatment system (May 1994), the pressurised hollow fibre MF pre-treatment train delivers constantly a filtrate virtually free of suspended solids and with a silt density index (SDI) of less than three. The effluent of the RO system has a conductivity of 10-15 µS cm^{-1}. As a result of the combined MF and RO treatment system, the operating cost of the boiler feed water production has been reduced by more than 50% in comparison to the cost occurred during the formerly employed conventional technology.

The five year operation has demonstrated the reliable operation of both membrane systems, a constant high quality effluent production and a positive change in the cooling lake quality. *Fig.3* presents the conductivity, sulphate and chloride concentration of the water from the cooling lake through 1994 and during the first four months of 1999. Due to the implementation of the membrane treatment processes, the average total dissolved solids concentration has dropped to 800 mg dm^{-3}, in the cooling lake water.

Case Study II – Lagisza Power Plant

The main objectives of the stage-wise modernisation of the water treatment plant (WTP) at the Lagisza Power Station (875 MW) in Poland were to use the closed cooling water circuit blow-downs as the boiler feed water source and to improve the quality of the cooling water, facilitating the discharge of unused portion of blow-downs to surface water receivers. The three individual process train, each consisting of a pressurised hollow fibre MF unit, an RO system and mixed bed ion exchange (MBIX) columns, and each having a capacity of 50 m^3 h^{-1}, were commissioned at the end of June 1997, at the beginning of January 1998 and at the end of March 1998, respectively. The stage-wise completion was dictated by the fact that the WTP had to produce continuously a quantity of 150 m^3 h^{-1} demineralised water [8].

Since start up, the MF filtrate quality is constant, having an average turbidity content of 0.1 NTU (but always less than 1 NTU) and a SDI <3, while the source

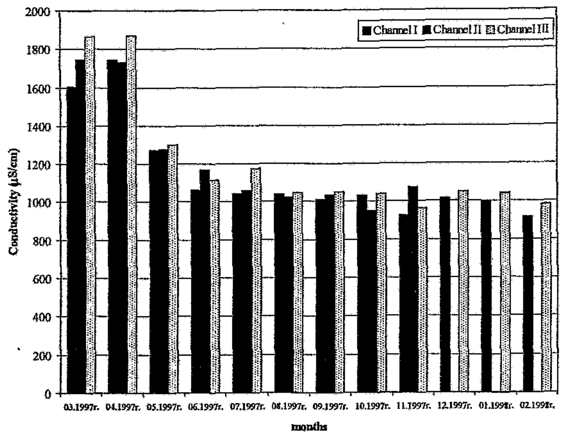

Fig.4 Lagisza Power Plant – Cooling Water Conductivity

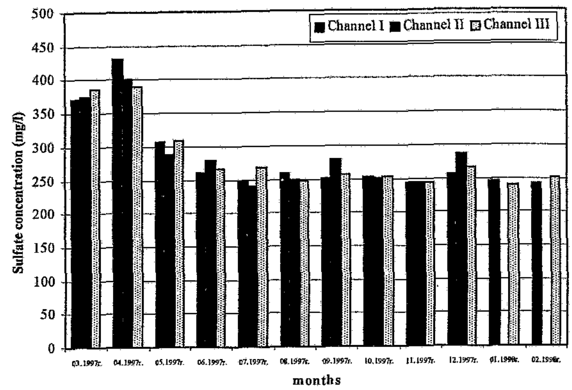

Fig.5 Lagisza Power Plant – Sulphate Concentration of the Cooling Water

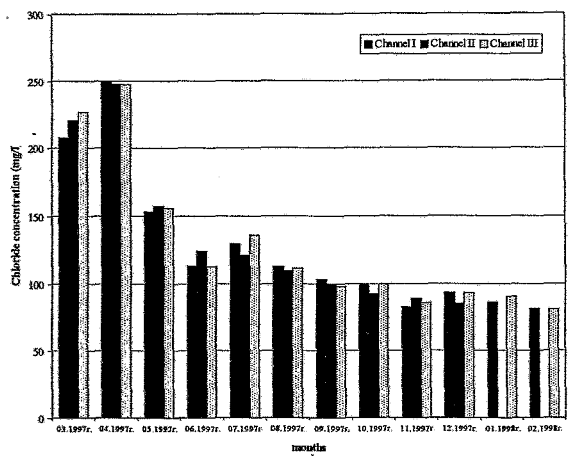

Fig.6 Lagisza Power Plant – Chloride Concentration of the Cooling Water

water suspended solid concentration varies between 15 – 34 mg dm^{-3}. The MF membrane pre-treatment step also prevents the bio-fouling of the RO membranes and reduces their cleaning frequency since assures at least 5 bacterial log removal. The RO membrane system performs the pre-treated water demineralisation, which is monitored through the conductivity reduction. On average, at an operating temperature of 30 °C, the RO feed water conductivity is approximately 900 µS cm^{-1} whereas the RO permeate conductivity is within the 2,5-7.5 µS cm^{-1} range, which represents a 99.1-99.7% reduction. The treated water after the ion exchange units has an average conductivity of 0,09 µS cm^{-1} (but always less than 0.1 µS cm^{-1}) and a silica content of <0.005 mg cm^{-3}.

In addition to the demineralised water production with excellent quality, the installed treatment process successfully improved the water quality in the cooling circuit in fairly short time. This quality improvement is well illustrated by *Figs.3*-6. The concentration of the three parameters presented, i.e. conductivity, sulphate and chloride, decreased after the installation of the new process train. Moreover, the improved quality of the cooling water circuit was well within the surface water discharge criteria, therefore, the Lagisza Power Plant obtained permission from the local authorities to discharge the unused portion of the cooling water blow-

Table 1 ZeeWeed® Pilot Study results on STP effluent

Parameter	Raw Feed (STP Effluent)	ZeeWeed® MF Effluent	# of Observations
Suspended Solids -TSS- (mg dm^{-3})	6-32	<2	75
Turbidity (NTU)	10-50	<1	10
Silt Density Index -SDI-	Unmeasurable	0.9-2.4	31
BOD_5 (mg dm^{-3})	2-32	<2	70
Fecal Coliforms (cfu/100cm^3)	3-600	<4	18

downs to the nearby rivers. Ultimately, the better cooling water quality reduced the quantity and/or frequency of the blow-down discharges, as well as the operational cost of the boiler feed water production (through reduced chemical consumption – 90% less chemical usage -, waste heat utilisation from cooling water condensation, reduced waste generation).

Case Study III – E.C Katowice Power Plant

The limited fresh water supplies for meeting projected water demand at the E.C. Katowice power plant, forced the management to look for alternative water sources. It was found that the most convenient source would be the secondary clarifier effluent from the local sewage treatment plant, located adjacent to the power plant. After the evaluation of treatment alternatives, ZeeWeed® microfiltration was selected to polish the sewage treatment plant effluent and supply water for the cooling circuit of the power plant. The ZeeWeed® tertiary treatment system is under construction and will be commissioned during this summer. It is designed to supply a 225 m^3 h^{-1} microfiltered permeate, by employing three separate ZeeWeed® treatment train, each having a capacity of 75 m^3 h^{-1}.

In a pilot study conducted at another location, on biologically treated sewage, the ZeeWeed® MF process demonstrated its ability to supply an effluent suitable for reuse or further RO treatment. The process efficiency is well illustrated by the results of the pilot study included in *Table 1*.

Conclusions

Water scarcity at a specific region, regulatory pressure and economical considerations impact the decision making process of industrial water consumers during the evaluation of raw water source alternatives. The inefficiency of conventional filtration plants to treat troublesome waters has forced engineers to look into new technologies. The combination of microfiltration and reverse osmosis membrane technologies enable the power industry and other industrial firms to consider "difficult to treat" waters as their raw water source. Furthermore, the application of coupled MF and RO treatment trains allow the reuse of sewage treatment effluents and recycle of technological wastewaters. Moreover, these applications also limit the discharge of pollutants, therefore, they contribute to the process of natural environment preservation.

Due to its predictable, reliable, flexible and stable nature, the MF process is not only effective in pretreating the raw water for the RO technology but also minimises the capital and operating costs of the downstream technologies (i.e. RO, IX) through the reduction of the RO membrane inventory and chemical usage.

Immersed outside-in membranes are competing against dead-end outside-in microfilters and cross flow inside-out membranes due to their lower energy requirements. Microfiltration plants, being modular, can be built to treat volumes as small as 2 $m^3 h^{-1}$ but are also currently being sold for treatment of > 3154 $m^3 h^{-1}$.

SYMBOLS

MF	microfiltration
RO	reverse osmosis
TDS	total dissolved solids
SDI	silt density index
MBIX	mixed bed ion exchange
IX	ion exchange
WTP	water treatment plant
STP	sewage treatment plant

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