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Integrated Membrane Systems for Water Reuse

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Abstract

The term "Integrated Membrane System" (IMS) is frequently used to describe water treatment systems that incorporate membranes. An IMS can be defined either as a system that integrates two or more membrane processes or as a system combining a membrane process with other treatment processes.

In a typical application of wastewater recycling, the treatment objectives might be to minimize the volume of waste for disposal, to achieve zero liquid discharge, to reduce total dissolved solids, to remove total suspended solids, to achieve high quality water for reuse or to minimize capital and operating costs. Since many of these treatment objectives cannot be achieved with any single process, an IMS is often used for wastewater recycling to achieve multiple treatment objectives.

Membrane processes used today for wastewater recycling include both pressure-driven processes and electrically-driven processes. Pressure-driven processes include microfiltration, ultrafiltration and reverse osmosis. Electrically-driven processes include electrodialysis reversal and electrodeionization.

In summary, IMS can be used to achieve multiple treatment objectives in water recycling applications. Integrated membrane systems can produce water of the required product quality to be recycled while minimizing the waste volume and minimizing capital and operating costs.

GE Water & Process Technology has recently installed several of these Integrated Membrane Systems. This paper describes the IMS processes, and includes discussion and operating data from several plants.

Introduction

It is now coming to the attention of most small communities, large municipalities, and entire countries that there is a limited water supply available for power plants, for drinking water and for other water consuming activities such as irrigation of golf courses and for agriculture. Most ground and surface water supplies are not as plentiful as needed and are becoming more expensive. This realization is leading to more recycling and reuse of both domestic waste and industrial wastewater for reuse applications ranging from irrigation and industrial process water, to ultrapure water for boiler feed, and even to direct and indirect potable reuse.

End-users are beginning to realize that water recycling is a way to save money rather than a burden. The demand for water recycling technologies has driven the manufacturers of water treatment equipment to create innovative designs to meet the objectives for water reuse. These new solutions can include a variety of technologies. An IMS can be used to meet multiple objectives for a water reuse project. This paper will describe what an IMS is, the membrane technologies used in IMS, and then will discuss the process and operating data from several different sites that are using an IMS.

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Integrated Membrane Systems

The term "Integrated Membrane System" is frequently used to describe a water treatment system that incorporates different membrane and conventional water treatment technologies to achieve a particular product water quality goal. An IMS can be defined either as a system that integrates two or more membrane processes, or as a system combining a membrane process with other treatment methods.

Typical treatment objectives for a wastewater recycling application may be to minimize the volume of waste for disposal, to achieve zero liquid discharge, to reduce total dissolved solids, to remove total suspended solids, to achieve high quality water for reuse, or to minimize capital and operating costs. Since many of these treatment objectives cannot be achieved with any one single process, an IMS is often constructed to accomplish all of the final treatment objectives. For instance, a combination of electrodialysis reversal and crystallization/evaporation might be combined to achieve zero liquid discharge of process wastewater while minimizing capital and operating costs.

Membrane Processes Used in Integrated Membrane Systems

Membrane processes used today for wastewater recycling include both pressure-driven processes and electrically-driven processes. Pressure-driven processes include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Electrically-driven processes include electrodialysis reversal and electrodeionization.

Pressure Driven Processes

Ultrafiltration and Microfiltration

Ultrafiltration (UF) and microfiltration (MF) membranes are used primarily to remove suspended solids and bacteria. These membranes systems are available in different physical configurations that include spiral wound, hollow fiber, flat sheet, tubular and ceramic. Hollow fiber MF/UF is the most common configuration used today on large wastewater applications due to the ability to handle tough waters at a reasonable cost, and the small footprint. Also, the hollow fiber technology has gained wide acceptance in systems for indirect potable water reuse applications because of its capability to achieve 4-6 log removal of giardia cysts and cryptosporidium oocysts.

MF membranes range in nominal pore size from 0.05-1.0 µm. UF membranes are usually rated on molecular weight cut-off (MWCO) but can also be said to have a nominal pore size of 0.01-0.1 µm. Most MF and UF membranes can guarantee an SDI of less than 3 and a turbidity less than 0.1 NTU, regardless of feedwater variations.

Spiral wound UF membranes use flat sheet membranes rolled into a spiral around a permeate core tube. Most of these membranes are made of a polysulfone material and are housed in 8-inch diameter pressure vessels. Feed water is pressurized to about 20-100 psig and is fed to the feed water spacer at high crossflow velocities. The high velocities are used to scour the membrane. The product water is collected in the core of the membrane module. Spiral wound systems cannot be physically backwashed, therefore, over time the membranes become fouled and the feed pressures increase. At a certain feed pressure set point, a chemical clean-in-place (CIP) is performed. This can occur as often as every few weeks to several months depending on the feed water quality.

Hollow fiber MF/UF membranes consist of several thousand hollow fibers, typically 0.5-1.0 µm in diameter, bundled into a membrane element. These systems can be either outside-in or inside-out. With the outside-in systems, the source water is fed to the outside of the hollow fibers and is pushed through the membranes. The clean water (product) is collected on the inside of the fibers and the suspended particles are left behind. The opposite happens in inside-out systems. The fiber construction materials include polysulfone, PVDF, polypropylene, polyethylene, polyethersulfone, and polyacrylonitrile. They can be operated either in dead-end mode, meaning that all of water that is fed to the system is sent through the membrane, or in crossflow mode like the spiral wound membrane.

Hollow fiber membranes can be backwashed to periodically clean the membranes. The frequency depends on the feed water quality, and the membrane flux, but usually occurs every 20 minutes to every few hours. Figure 1 illustrates the production and backwash modes of operation for an inside-out hollow fiber. Some systems incorporate an air scrubbing procedure after a certain number of water backwashes, or add chemicals such as chlorine to the backwash water, to enhance the cleaning effects.[1]

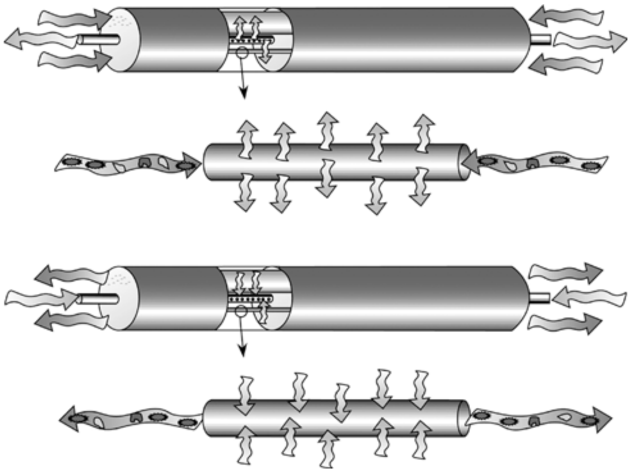


Figure 1: Inside-out Hollow Fiber Process Principles

The MF/UF technologies are typically used to treat highly turbid waters, to guarantee virus and bacteria removal for drinking water, or as pretreatment to RO systems for better performance of the system and to prolong RO membrane life.[2] MF and UF are being applied today for reuse of secondary-treated municipal effluent because they provide a barrier to bacteria and pyrogens, and because they minimize the costs of operation of RO systems used to remove dissolved solids from municipal effluent for reuse.

Another type of MF system is the Membrane Bioreactor (MBR). MBRs can be configured in a hollow fiber, tubular, or flat sheet design and are used to directly treat domestic or industrial wastewater streams. MBRs replace the conventional sedimentation step by removing the suspended materials with a membrane to produce water with less than 10 mg/l of suspended solids. The MF membrane used in an MBR can be placed directly into an aeration tank (submerged) or external to the tank to treat a side stream. The source water is drawn through the membranes using a vacuum pump leaving the suspended biomass material in the aeration tank. The filtrate, or product water, is suitable to use as feed to an RO system, for direct reuse for irrigation or some process applications.

Reverse Osmosis and Nanofiltration

Reverse osmosis (RO) is a pressure driven process that raises the water pressure on the high TDS (total dissolved solids) side of the membrane (feed side) to well above the osmotic pressure and forces water to flow through the membrane to the low TDS side of the membrane (product side). The RO membrane permits the passage of water molecules but is a barrier to most of the dissolved solids in the water. As the source water flows along the membrane, the TDS is further concentrated and finally discharged as a reject stream from the process. Nanofiltration (NF) is a similar process that works at lower pressure.

RO systems can remove up to 90-95% of all TDS, while NF systems mainly remove divalent ions and organics. The RO and NF technologies are typically used after the water has been pretreated to remove organics, suspended solids, and metals that may oxidize or precipitate on the membranes. Pretreated water is then sent to an RO or NF system for desalination for drinking water, water reuse, or as part of a system to produce ultrapure water. RO is selected for indirect and direct potable water reuse applications because it provides an absolute barrier to bacteria and pyrogens and can remove pesticides, as well as providing water with low TDS.

Electrically-driven Processes

Electrically-driven membrane processes are those technologies that use an electric potential to drive a separation process. EDR and EDI use the same process principles to achieve two very different water quality objectives.

Electrodialysis Reversal

Electrodialysis is an electrically-driven process that uses a voltage potential to drive charged ions through a semi-permeable membrane, reducing the TDS in the source water. The process uses alternating, semi-permeable cation (positively charged ion) and anion (negatively charged ion) transfer membranes in a direct-current (DC) voltage potential field. The source water flows between the cation and anion membranes via flow spacers that are placed between the membranes. The spacers are used to provide a flow path for the water, support the membranes, and create turbulent flow.

The DC voltage potential induces the cations to migrate toward the anode through the cation membrane, and the anions to migrate toward the cathode through the anion membrane. The cations and anions accumulate in the reject water side of the membranes and low TDS product water is produced on the dilute side of the membranes. Figure 2 demonstrates how the electrodialysis reversal (EDR) system periodically reverses the polarity of the electric field, and consequently the dilute and concentrates compartments, to help flush scale forming ions off the membrane surface and minimize membrane cleaning.[3]

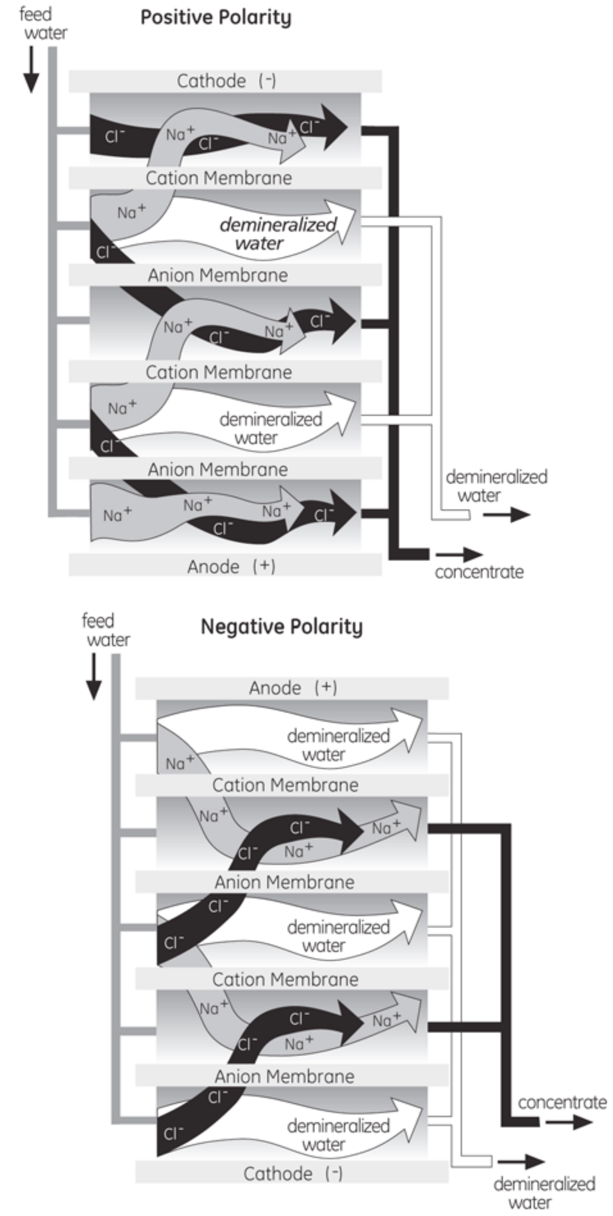


Figure 2: EDR Reversal Process

EDR is typically used on hard-to-treat, high hardness, lower salinity waters (from 200-5,000 TDS). With the help of the reversal process EDR can handle higher saturation levels of precipitating compounds allowing it to achieve higher water recoveries than RO. Up to 95% recovery with 90% salt removal has been accomplished. EDR membranes are tolerant to a continuous free chlorine residual of 0.5 ppm, which has made EDR an attractive choice for many water reuse applications. EDR has been used to produce drinking water, as a preconcentrator for crystallizer/evaporator feed water, to treat or produce process water, and in water reuse for non-potable applications.

Electrodeionization

Electrodeionization (EDI) also employs direct current electrical power as the energy source for desalting. Ions in solution are attracted towards electrodes with the opposite electrical charge. By dividing the spaces between the electrodes with cation and anion selective membranes to create compartments, salts can be removed from half the compartments and concentrated in the remaining compartments.

One main difference between EDR and EDI is the content of the desalting compartments. The EDI desalting compartments are filled with mixed bed ion exchange resin beads. The resin beads serve as a medium for transport of the ions making the transfer mechanism for removal of the ions in an EDI system a two-stage process. First, ions are transported to the ion exchange resin by diffusion and then through the resin and the membrane by the DC electric current. When excess current is applied, water splitting (breaking water into its hydrogen and hydroxide components) occurs where the beads contact each other and where the beads contact the membrane. The water splitting helps to keep the resin in the regenerated form making regeneration of the resin unnecessary, and to ionize the non-ionized species for removal.[4]

EDI is used for ultrapure water applications and usually requires RO permeate quality water as feed. The systems are typically run at a 95% water recovery and can achieve 99% TDS removal producing as high as 18 MΩ/cm water.

Case Studies of Integrated Membrane Systems

Sasol, Ltd.

In 1997, the authors' company commissioned an IMS at Sasol, Ltd.'s coal-to-fuel mining plant in Secunda, South Africa. Sasol Ltd. had to install the system to prevent major polluting of local river streams from their mine drainage water. Table 1 shows the water quality coming from the mines. The high concentrations of calcium sulfate raise a challenge in achieving high water recovery because very high concentrations of calcium sulfate can easily form scale in membrane systems. Overall water recovery was important since Sasol utilizes large quantities of water to produce steam for gasification, process heating, electricity generation, and for general process cooling. A combination of EDR and RO was selected to treat the water because RO could produce the high water quality and EDR could achieve the high water recovery that Sasol needed.

Table 1: Sasol Mine Water Effluent Water Analysis

Ion	Concentration (mg/l)
Sodium	1,115
Calcium	291
Magnesium	174
Potassium	6.5
Ammonia	0.0
Strontium	6.3
Barium	0.02
Chloride	280
Bicarbonate	112
Sulfate	3,211
Total Dissolved Solids	5,196

The membrane desalination facility installed consists of a clariflocculator (clarifier, reaction zone, and flocculation chamber built in one unit), sand filters, a 6,800 m^3/day RO system, and a 7,600 m^3/day EDR system.

After the water is pretreated, it is fed to the EDR facility. The EDR acts as a roughing demineralizer to remove most of the minerals. The EDR product is fed to the RO system. The RO plant produces water that is sent directly to the Boiler Water Treatment Plant for final polishing. The RO concentrate is returned to the EDR as concentrate make up which the EDR process concentrates further. The IMS permits Sasol to achieve 70% water recovery while producing water with 20 ppm TDS, ten times better than their raw water intake. The plant has been running successfully for almost four years allowing the customer to achieve its water reuse objectives.

Northern California Power Agency

In 1994, Northern California Power Agency (NCPA) installed a new 49-MW power generation facility in Lodi, California, USA. NCPA signed a 10-year own-and-operate agreement with GE Ultrapure Water Group. GE built a water treatment plant to treat clarified secondary-treated municipal effluent from the Lodi White Slough Water Pollution Control Facility. The recycled water is first chlorinated and filtered for general use at the power generation facility. 200 gpm of filtered water is used as cooling tower makeup. An integrated membrane system consisting of UF, UV, RO and mixed-bed polishing ion-exchange, treats 600 gpm of filtered water for use as boiler feed.[2]

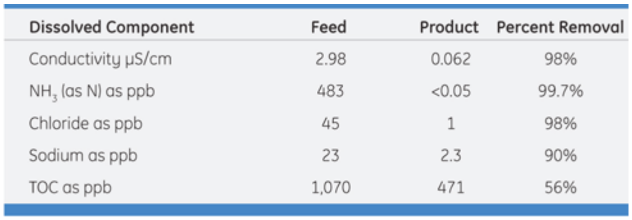
The UF system selected was a spiral-wound UF system. UF was selected as pretreatment to the RO to minimize operating costs of the system. In 1994, hollow fiber membrane filtration had only been recently introduced to the marketplace and was not considered as an option. UF reduces organics and silt in the filtered water. UV further reduces organics to ensure that the RO is not susceptible to organic fouling. This system has been operating reliably for six years. RO is used to remove dissolved solids to minimize the loading on the ion-exchange system so that high quality water for boiler feed can be produced while minimizing the consumption of chemicals for ion-exchange regeneration.

Guadalupe Power Plant

The Guadalupe Power Plant is a natural gas-fueled, 1,000-MW plant located in Guadalupe, Texas, USA. The plant meets its strict discharge regulations by operating as a Zero Liquid Discharge (ZLD) facility. The wastewater treatment process consists of raw water treatment, an evaporator, crystallizer, EDI, and ion exchange system used for polishing. The evaporator and crystallizer turn the wastewater into a solid product for disposal to a landfill site, while the EDI and ion exchange system treat the evaporator distillate to achieve the high water quality required for the water to be reused as boiler feed and cooling tower make-up.

Raw surface water is softened by the clarifiers and used as cooling tower make-up. The chemistry of the make-up water determines the amount and composition of the Cooling Tower Blowdown (CTBD) that is sent to the evaporator. The first step evaporates 97% of the wastewater. The distillate is clean enough to be sent directly to the EDI system. The excess from the evaporation process is sent to the cooling towers as make-up, and the brine from the evaporator is sent to a Calandria crystallizer. Solids from the crystallizer are sent to a belt press filter and shipped off site as non-hazardous material for landfill. The EDI system can treat 820 m^3/day continuously receiving and producing the water qualities shown in Table 2.

Table 2: EDI Feed and Product Composition at the Guadalupe Power Plant



Dissolved Component	Feed	Product	Percent Removal
Conductivity μS/cm	2.98	0.062	98%
NH_3 (as N) as ppb	483	<0.05	99.7%
Chloride as ppb	45	1	98%
Sodium as ppb	23	2.3	90%
TOC as ppb	1,070	471	56%

The EDI system produces 15-16 MΩ/cm water. This corresponds to a 95% conductivity removal at 95% water recovery. The EDI concentrate is sent back to the raw water clarifiers so that the EDI process generates no additional wastewater. The EDI system together with the evaporator and crystallizer have been operating successfully for over 1,000 hours.[5]

The entire IMS at this plant has several benefits. It has helped the plant to meet its strict environmental discharge regulations while allowing reuse of water that would have been discharged. The EDI replaces the traditional ion exchange resin beds. With EDI, regeneration of the resin is unnecessary. This process reduces, if not eliminates, the need for on-site chemical storage, handling, and the production of waste encountered from the regeneration process.

Conclusions

Integrated membrane systems consist of water treatment systems that use two or more water treatment technologies, including membranes, to meet various product water quality objectives. There are many Integrated Membrane Systems that have been operated successfully treating a variety of waters for multiple reuse applications. Limited water supplies, or strict environmental discharge limits, drive the design of many Integrated Membrane Systems for water reuse. Combining different treatment technologies can help to maximize water recovery, achieve high water quality for water reuse, and minimize life-cycle costs.

It is expected that the use of IMS for water reuse will grow substantially in the years to come. To date there are several examples of successfully operated IMS treatment systems for water reuse. All of these have helped the user to avoid disposal of wastewater, while supplying usable water for their intended purposes.

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