High-Flux Polymeric Membrane for Industrial Water Separation

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Abstract

Water is essential to numerous industries such as chemical manufacturing, automotive production, oil and gas refinery and power generation, yet the increasing scarcity of this precious resource makes its recovery from these activities more critical than ever.

This paper describes a proprietary, high-flux polymeric permeable membrane that is engineered to make the recovery, recycling and reuse of industrial wastewater more efficient and economical as measured by primarily by flux rate and secondarily by separation capability and service life (durability).

Introduction

To help minimize the impact of industrial processes on the world's water supply, engineers, filtration equipment manufacturers and industrial companies have developed an extensive array of materials and technologies to clean, recover, recycle and reuse industrial wastewater by separating and removing entrained contaminants.

Recently, a global industrial manufacturer with specific expertise in permeable membrane technology developed a proprietary high-flux polymeric membrane that separates emulsified materials, total suspended solids (TSS) and free oil from industrial wastewater more effectively and economically than traditional polyacrylonitrile (PAN) or polyvinylidene fluoride (PVDF) filtration membranes.

The key to this enhanced performance is the polymeric membrane's exceptional flux rates, lower fouling and improve cleanability; and its excellent mechanical, thermal and chemical stability, which improve the membrane's durability and "backflushability".

The high-flux polymeric membrane also features a single-layer structure that is unique to the industry, with pore sizes that can be adjusted by the manufacturer to meet the specific filtration demands of the end-user.

The manufacturer has conducted extensive field trials with the high-flux polymeric membrane, which have proven its ability to outperform traditional PVDF, PAN and other permeable membrane technologies in a variety of industrial processes, as well as other applications not typically considered effective, economical or appropriate for membrane filtration.

This document is divided into three parts: Part one describes the high-flux polymeric membrane and its intrinsic filtration properties. Part two compares the crossflow and flux rates of the polymeric membrane against traditional polymeric membranes in flat-sheet and spiral wound element testing. Part three presents six case studies with test results from field trials covering several industrial wastewater processes.

Proprietary High-Flux Polymeric Filtration Membrane

There are several proven methods for separating entrained contaminants from water. Manufacturers typically employ a single technology or combination of technologies to recover and recycle industrial wastewater based on economic considerations, discharge limits or a combination of the two factors.

Permeable membranes are used most often to remove trace levels of contaminants not captured during bulk separation processes, such as gravity separation, hydrocycloning, gas flotation or electro-coagulation, which occur further upstream. Specifically, they are designed for the separation and recovery of trace-level contaminants from industrial wastewater—processes known as microfiltration (MF) and ultrafiltration (UF)—which are often removed with spiral wound elements. These devices, which also are sometimes used to pretreat industrial wastewater prior to filtration via reverse osmosis (RO), are fabricated with multiple sheets of permeable membrane wound tightly around a perforated permeate tube encased in fiberglass or plastic netting.

As illustrated above (Figure 1), feed water is pumped into one end of the element, which flows across the surface of the membrane—also called the membrane "leaf"—and is separated into two streams: permeate (clean water) and concentrate (separated contaminant). There are two primary benefits to this design. First, the high crossflow velocity of the wastewater feed helps keep the membrane surface free of contaminants. Second, the pressure of the feed across the membrane also facilitates the separation process by forcing clean water through it (Figure 2). The rate at which clean water is separated by the membrane is generally referred to as the "flux rate." Flux rate is the primary factor determining the economic viability of membrane filtration.

Spiral wound elements are favored for many industrial water purification applications because their design permits high volumes of permeable membrane to be packed into a confined space, making the units both economical and highly effective at removing contaminants. Conversely, the compactness of their design also makes spiral wound elements susceptible to contaminant build-up, which can cause the permeable membrane to foul quickly and reduce its service life. Consequently, spiral wound elements are best-suited to "polishing" wastewater that has been pretreated upstream.

The high-flux polymeric membrane described in this paper was developed to enhance this "polishing" function (also known as microfiltration and/or ultrafiltration) compared to existing permeable membranes commonly used for the same purpose.

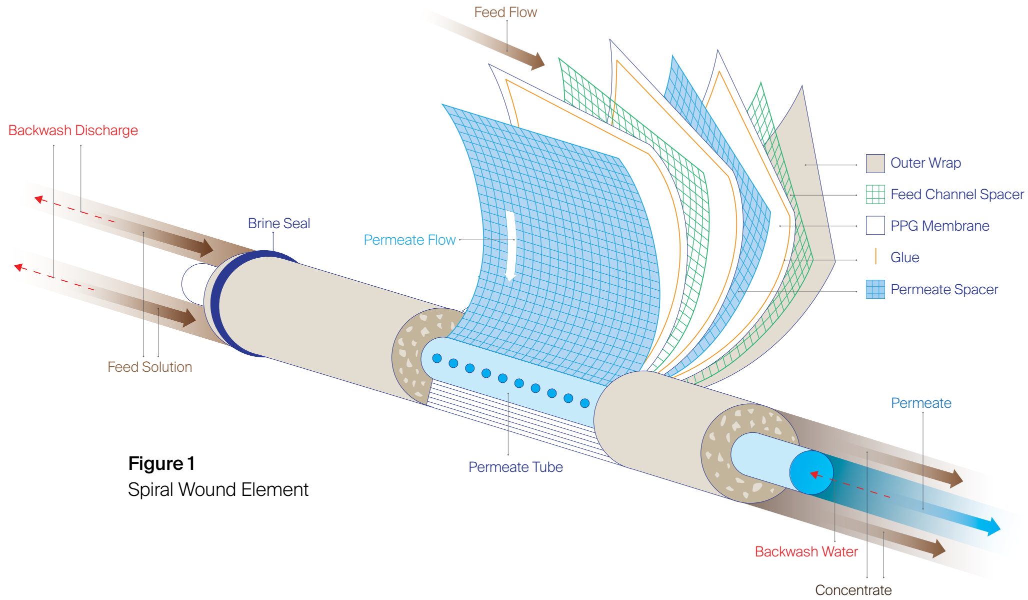


Figure 1
Spiral Wound Element

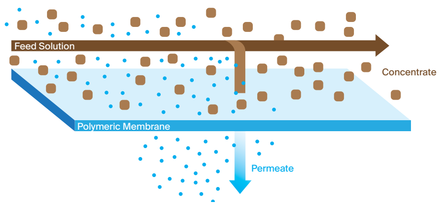


Figure 2
Crossflow Filtration

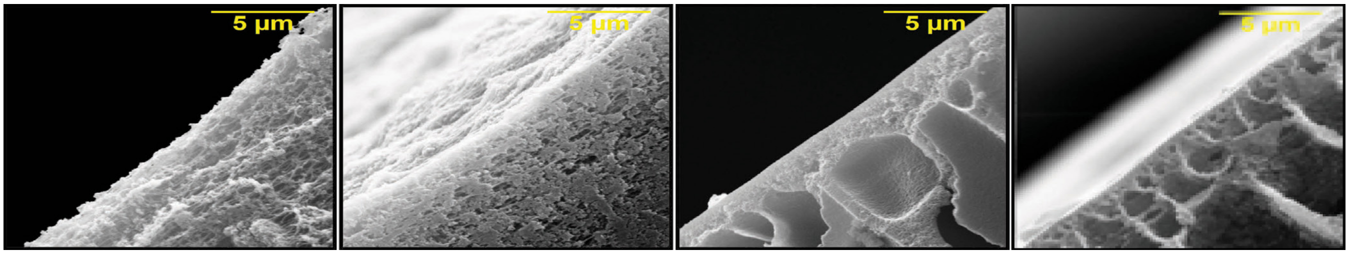
The high-flux polymeric membrane is a single-layer thermoplastic composite that unites a hydrophobic (water-repelling) polymer matrix with hydrophilic (water-attracting) inorganic filler.

The hydrophobic/hydrophilic combination creates powerful capillary forces that generate higher flux rates and cleaner, higher-quality permeate than is currently possible with permeable membrane fabricated from PVDF, PAN and/or other membrane materials.

As a single-layer symmetric material, the high-flux polymeric membrane offers two main advantages over commercial two-layer membrane technologies such as PVDF and PAN membrane. First, as shown in Figure 3, PAN and PVDF membrane have a thin layer of controlling porosity on the surface that is easier for oil and contaminants to penetrate and pass through than the single-layer polymeric membrane, which is denser and more restrictive to contaminants.

Second, compared to two-layer PAN and PVDF membrane, the single-layer design of the high-flux polymeric membrane increases its durability by allowing the feed water to reverse flow (or backwash) through its surface. In addition to enhancing the membrane's self-cleaning function, this action helps prevent the accumulation of waste particles on its surface. The result is a combination of high flux and enhanced separation, as well as the potential for extended service life not yet achieved by other permeable membrane elements.

High-Flux Polymeric Membrane Technology



Single-Layer MF | Single-Layer UF | PAN UF | PVDF UF

Figure 3
Unique Single-Layer Membrane
SEM photographs of membrane cross-sections at 10,000x magnification. The high-flux microfiltration (MF) and ultrafiltration (UF) membranes (at left) feature single-layer structures while the cast structure of PAN and PVDF membranes (at right) create a thin layer of controlling porosity on top of a larger porosity support structure.

Flat-Sheet And Spiral Wound Element Testing: Polymeric Membrane vs. PVDF and PAN Membrane

Figure 4 depicts results of pure water flux-testing of flat-sheet ultrafiltration (UF) polymeric, PVDF and PAN membrane in a crossflow unit (Sterlitech SEPA CF) run at 50 pounds per square-inch (psi) transmembrane pressure (TMP). The feed flow is 1.5 gallons-per-minute (gpm) on a 42-square-centimeter sample. The high-flux polymeric UF membrane shows higher flux rates than PAN UF and PVDF UF membrane. Flat-sheet testing with high-flux polymeric microfiltration (MF) (far left column in chart) shows the highest flux due to the membrane's larger pore size.

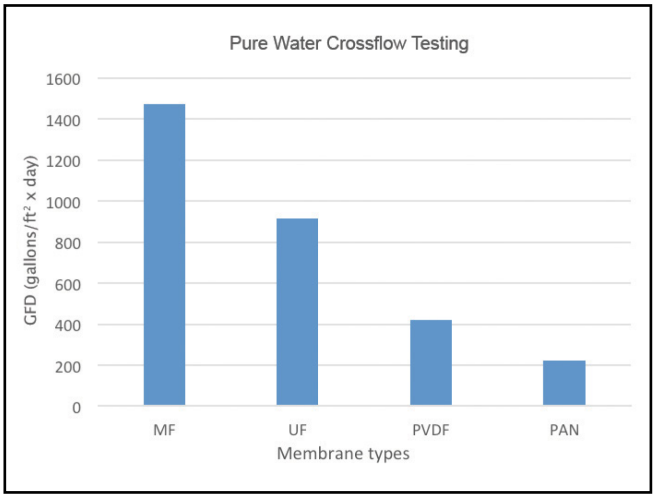


Figure 4
Crossflow Flat-Sheet Testing: Polymeric High-Flux Membrane vs. PVDF UF and PAN UF Membrane

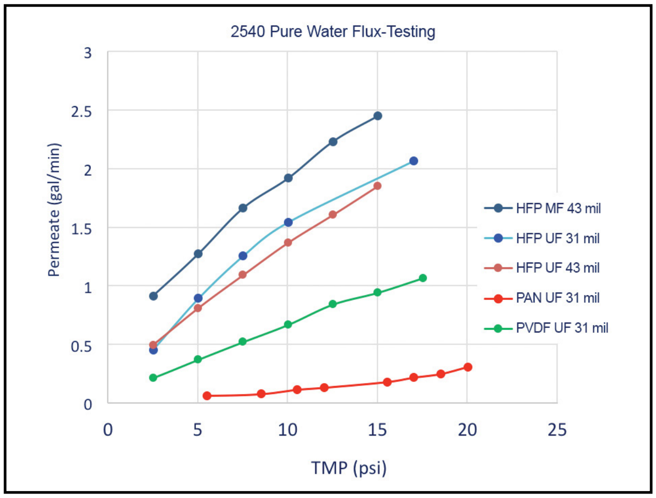


Figure 5
Flux Rate 2540 Element Testing: Polymeric Membrane vs. PVDF and PAN Membrane

Flux Rate 2540 Element Testing: High-Flux Polymeric Membrane vs. PVDF and PAN Membrane

The same four ultrafiltration (UF) membranes tested in Figure 4 were tested for flux in 2540 spiral wound filters. As shown in Figure 5, among the three UF filters with 31-mil-thick feed spacers, the unit equipped with the high-flux polymeric (HFP) membrane demonstrated significantly higher flux rates than the two units constructed with PAN and PVDF membrane.

For additional direct comparison, two 2540 UF filters with 43-mil feed spacers were tested for flux—one with HFP UF membrane and the other with HFP MF membrane. Thicker 43-mil spacers were tested because they are more commonly used in oil separation applications. The lower flux rates for these two filters is due to the increased thickness of the feed spacers.

Case Studies Laboratory and Field Trials

The following six case studies describe lab and field testing of the high-flux polymeric membrane in a range of industrial wastewater separation applications:

Case Study #1: High Solids Paint Filtration

To test the effectiveness of the high-flux polymeric membrane in dewatering high-solids (>20% solids) paint, a manufacturer with an industrial paint line substituted two 7640 ultrafiltration (UF) spiral wound elements equipped with the material as a "plug-and-play" replacement for a conventional spiral wound element equipped with PVDF permeable membrane.

As Figure 6 illustrates, the 7640 filter equipped with the high-flux polymeric membrane maintained higher flux rates over a longer period of time in the production paint tank than did the 7640 filters, equipped with PVDF permeable membrane.

The total feed rate for the two filters was 200 gallons per minute (gpm) at 45 pounds per-square-inch (psi) transmembrane pressure (TMP). The high-flux polymeric membrane provided 3,000 hours of superior flux with no supplementary cleaning compared to the conventional membrane, which required cleaning approximately every 1,000 hours.

The paint manufacturer was able to maintain a consistently high-solids level in the paint tank, resulting in a longer, more efficient and prolific paint-production run. As a result of the testing, the company has begun to replace PVDF filters with high-flux polymeric membrane filters at its manufacturing locations. One plant reported that it was able to reduce the number of operating filters from three to two while still maintaining the necessary flux rate, resulting in significant cost savings.

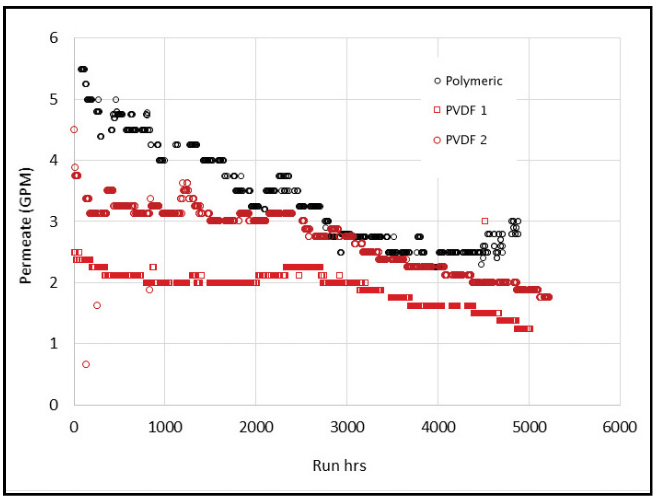


Figure 6
Filtration Results on Production High-Solids Paint Line
Where red lines end, flux rates had passed a critical threshold, requiring the filters to be replaced.

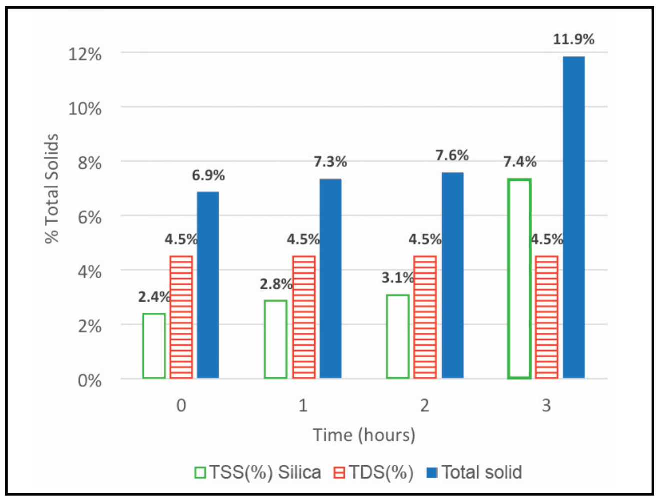


Figure 7
Filtration Skid Pilot Test
Total suspended solids (TSS) measures the total volume of silica recovered during the filtration process.

Case Study #2: Waste Silica Slurry Concentration

A large producer of industrial silica requested pilot testing of the high-flux polymeric membrane in two 8040 spiral wound filters to determine its effectiveness in separating water from silica-water slurry at a commercial production plant. The goal was to reclaim more silica from the slurry solution to increase manufacturing yield and to reduce the plant's overall waste disposal costs.

As Figure 7 shows, the volume of solids (silica) recovered from the slurry during the pilot test nearly tripled during three hours of semi-continuous processing, dramatically improving yield and reducing residual wastewater volume. Based on the success of the pilot testing, the manufacturer decided to equip its slurry operation with a skid of sixteen 8040 spiral wound filters with the high-flux polymeric membrane. Plant operators expect to recoup the cost of this investment in six months. The temperature of the silica-water slurry runs at 160^{o} F., well within the temperature capabilities of the membrane.

Case Studies Laboratory and Field Trials

Case Study #3:

Glycol Quench Solution Recovery

Mixtures of water and polyalkylene glycol often are used in the heat-treatment of metals and other conductive materials as quenching solutions.

Recently, a heat-treatment company requested lab-scale testing of the high-flux polymeric membrane to determine its efficacy for the recovery and reuse of polyalkylene glycol-based quench water. Quench water typically becomes contaminated with oil, grease and suspended solids after it has been used in multiple cycles to cool metal parts. As it becomes contaminated, the cooling rate of the quench solution can be impacted and thereby lose its ability to act as a quench solution.

Initially, the heat-treatment company provided a five-gallon sample of used quench solution for lab testing with the goal of recovering 70 percent of the solution as clean permeate that could be reused in the quench process. When initial testing exceeded that goal, the heat-treatment company requested larger-batch testing to verify the results.

The company supplied the lab with two 100-gallon drums of quench solution containing oil and grease and other suspended solids with an initial turbidity of 110 Nephelometric Turbidity Units (NTU). Initial feed viscosity was 8.32 centipoise (cPs). Oil and grease measured at 85 parts-per-million (ppm) according to a third-party environmental services lab.

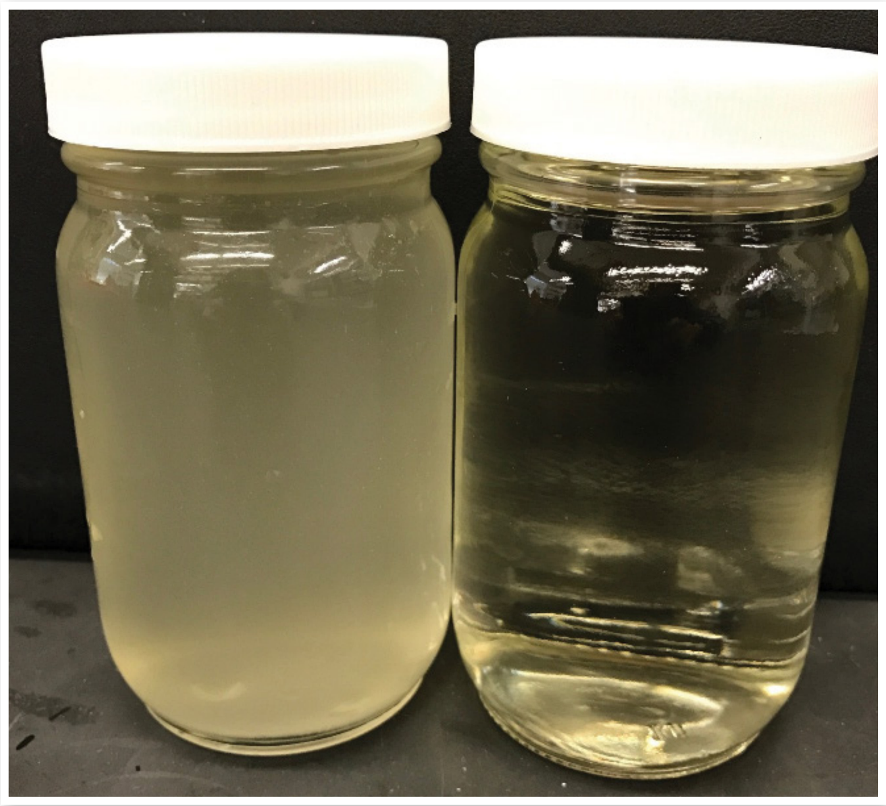


Figure 8
Initial Appearance of Feed (left) and Permeate (right)

Initial testing was accomplished by recirculating the permeate and concentrate back to the feed using 2540 spiral wound ultrafiltration (UF) elements equipped with the high-flux polymeric membrane and 43-mil-thick feed spacer. The initial setup utilized a metering pump circulating at a feed flow of approximately 1.5 gallons per minute (gpm) and controlled element transition membrane pressure (TMP) of 10-15 pounds per-square-inch (psi). Permeate samples were collected periodically and measured for turbidity.

During concentration, the initial setup was modified to separate the permeate and concentrate, and to collect the permeate into a separate tank without refeed. Concentration started with 50 gallons of quench wastewater feed with 16 gallons of additional feed added for every 16 gallons of collected feed to maintain a feed volume of 50 gallons until the feed was exhausted.

Once the initial feed volume was concentrated to 25 gallons, final testing was accomplished by recirculating the permeate and concentrate back to the feed. The permeate flow, feed and permeate turbidity were checked at 30-minute intervals. At the end of testing, five gallons of water was circulated to flush the element, and permeate flux (Figure 9) and transmembrane pressure (TMP) (Figure 10) were calculated. The appearance of the initial waste feed and treated permeate are shown in Figure 8. The properties of the initial waste feed and treated permeate are shown in Figure 11.

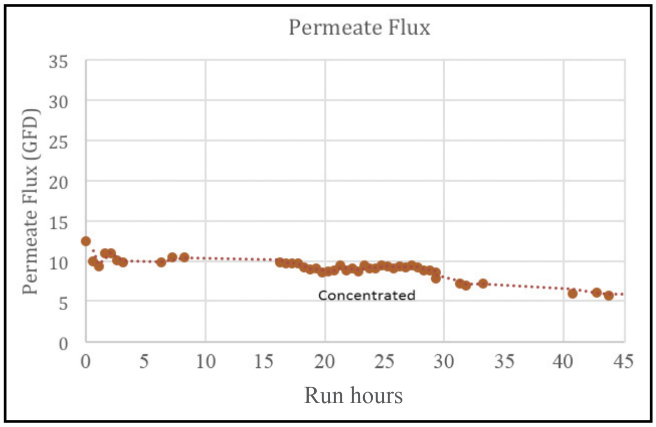


Figure 9
Permeate Flux with Time and Concentration

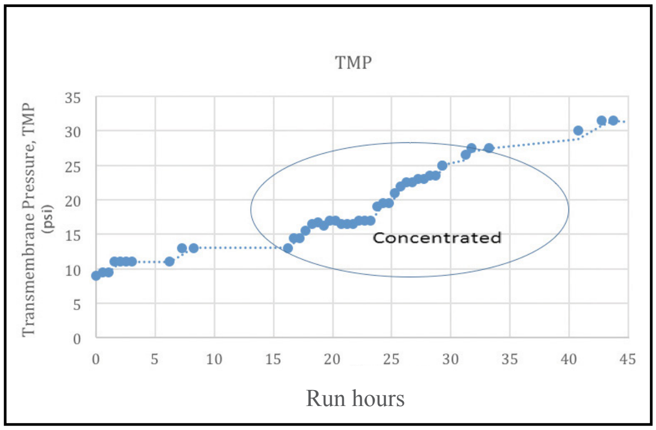


Figure 10
Element TMP Change with Time

Figure 11
Water Properties Before and After Filtration
The high-flux polymeric membrane demonstrated exceptional performance, generating permeate recovery and quality meeting or exceeding the heat-treatment company's target goal. The filter produced treated water at greater than 70 percent, significantly reducing total suspended solids (TSS) and oil and grease content, while maintaining flow/flux with a clean water flush.

Sample	TSS (ppm)	Average Turbidity (NTU)	Oil & grease (ppm)	Ash (%)
Initial feed	–	100-110	85	8.3
Feed after 75% recovery	–	800-1100	19,286	18.5
Initial UF permeate	<12	0.385	<5	-
UF permeate after 75% recovery	<12	0.569	<5	-

Case Studies Laboratory and Field Trials

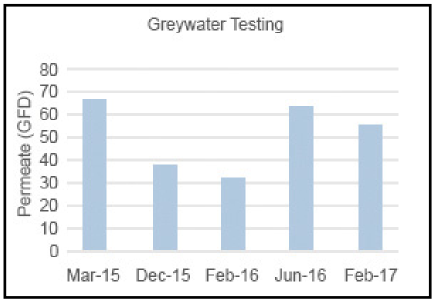
Case Study #4:
Greywater Filtration

A U.S. military base submitted simulated greywater for lab testing to benchmark the high-flux polymeric membrane material against several conventional permeable membrane products. The purpose was to compare the ability of each membrane to feed a reverse osmosis (RO) filter in a wastewater system designed to recycle greywater into shower water meeting NSF/ANSI 350-2011 standards for water reuse.

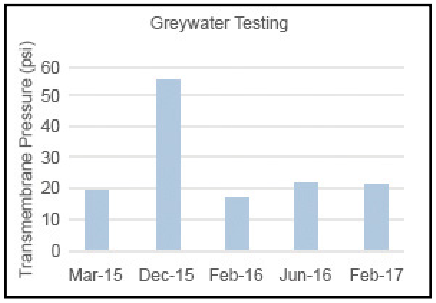
Figure 13 below depicts the results of greywater recycling. An 8040 microfiltration (MF) spiral wound filter with the high-flux polymeric membrane was tested from more than 3,000 hours, using backwashing only to preserve/restore flux. The figure shows consistent flux with none of the increase in transmembrane pressure (TMP) associated with filter fouling. Interestingly, the filter was operated intermittently for 3,000 hours for more than two years without showing negative impact from start-and-stop cycling.

Parameter	Feed	2514 UF	2514 MF	Concentrate
Total Solids (mg/L)	386	144	N/A	858
Total suspended Solids (TSS) (mg/L)	91	<10	3	164
Turbidity(NTU)	67.6	0.77	0.10	417
Conductivity (uS/cm)	146.9	210	110.2	351
pH	6.82	6.56	6.66	6.28

Figure 12
Lab Filtration of NSF/ANSI 350-2011 Greywater with 2514 Filter Elements



Permeate Flux



Transmembrane Pressure (TMP)

Figure 13
Field-Testing Results: Customer-Supplied Greywater

C a s e   S t u d y   # 5 :

Industrial Paint Production

An industrial latex paint manufacturer recently submitted waste feed from its latex paint production line for laboratory testing. The goal was to determine if a spiral wound filter made with the high-flux polymeric membrane could cleanse the feed water to levels required for reuse.

Using a 2514 spiral wound microfiltration (MF) and ultrafiltration (UF) elements, the laboratory was able to return the feed water to the manufacturer's required standards of cleanliness for use as a raw material for paint manufacturing as illustrated in the photo (Figure 14) and chart (Figure 15). The high-flux polymeric membrane is now being pilot-tested by the same manufacturer with the goal of reducing paint line's waste removal costs.

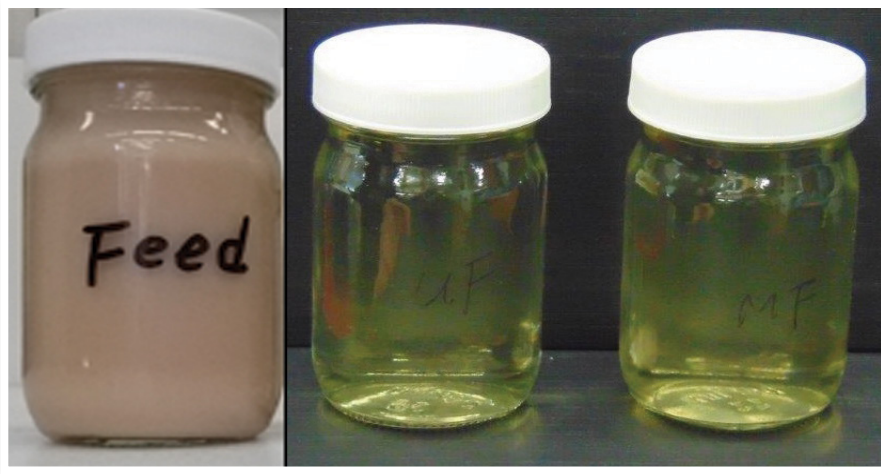


Figure 14
Feed Water and Permeate from Industrial Paint Production
The photo (at left) shows the untreated wastewater feed. The photo (at right) shows the same feed after processing through ultrafiltration (left) and microfiltration (right) using a 2514 spiral wound filter.

Sample	Turbidity (NTU)	Total Dissolved Solids (TDS) (%)	Total Suspended Solids (TSS) (ppm)	Ash (%)	Conductivity (uS / cm)
Feed	>4000	-	6.64	1.62	1564
UF permeate	2.144	0.10	0.0005	0.04	1208
MF permeate	3.71	0.11	0.0003	0.1	1239

Figure 15
Test Results: Wastewater Filtration from Latex Paint Production Plant

Case Studies Laboratory and Field Trials

Case Study #6:

Automotive Plant Wash Water

An automotive parts manufacturer was seeking to remove cutting fluid/oil and suspended solids from water used in its parts-washing process, then to filter the water for recycling and reuse in the parts washer. The company's existing water treatment did not condition the parts-water to a desired quality and left an emulsified oil appearance. Consequently, the manufacturer requested lab testing to investigate the potential of purifying and recovering its wastewater to the highest achievable rates using a spiral wound filter with the high-flux polymeric membrane.

The parts manufacturer had previously used modified PAN membrane in a spiral wound element for this function and found moderate success, but considered the cost prohibitive and the required footprint for the filtration system too large to reasonably accommodate.

During lab testing, the wastewater feed was circulated in 2514 ultrafiltration (UF) membrane elements with constant concentration for 25 hours at a stable flux of 38 gallons per square-foot per-day (GFD). The turbidity of the permeate tested stable at less than 0.3 Nephelometric Turbidity Units (NTU) and oil and grease measured at 26 parts-per-million (ppm) on a feed concentration of 450 ppm.

The solution was concentrated from 100 gallons to 10 gallons. The flux dropped to 22 gfd over the first five hours, then stabilized for 20 hours until the feed was 10 times more concentrated. The feed turbidity increased from 750 NTU to 4200 NTU as concentrated levels increased from 1:1 to 10:1 while the permeate turbidity was maintained at less than 1 NTU through the entire test. The volume of total suspended solids (TSS) and oil and grease of the feed and permeate are depicted in Figure 16.

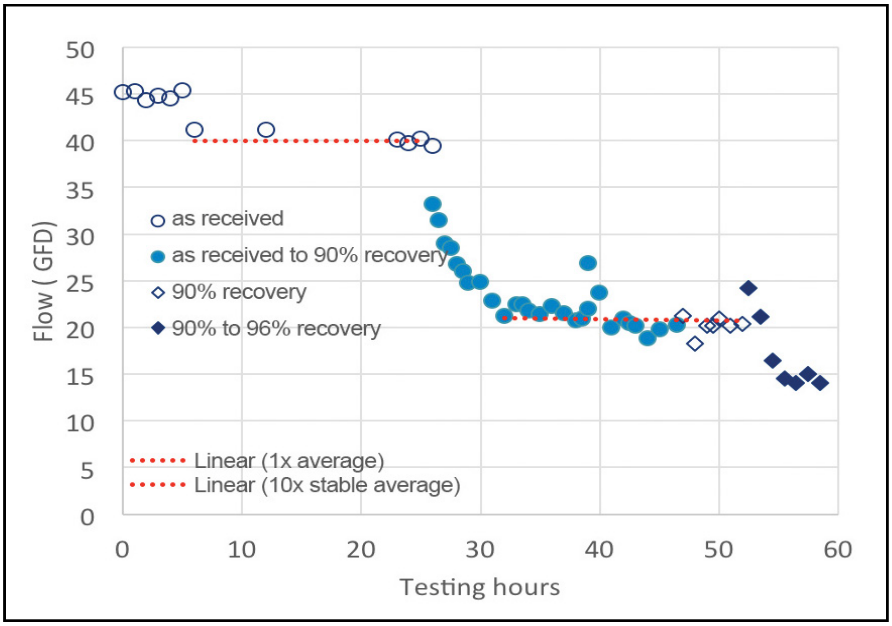


Figure 16
Flow Change with Time

The spiral wound filter with the high-flux polymeric membrane significantly reduced the percentage of total suspended solids (TSS) and oil and grease while slightly reducing conductivity and showing no change in pH value.

The permeate and feed appearance at 90 percent clean-permeate recovery is shown in Figure 17. The samples were scanned by the Cary 300 UV-V to measure the L* (the indication of lightless) with distilled water used as the reference. The L* value was measured to be 100 percent on the permeate and 0.94 percent on the feed.

The solution was further concentrated to 96 percent clean-permeate recovery, maintaining a stable flux of 14 gfd. The turbidity of the permeate was maintained at less than 0.3 NTU while the turbidity of feed exceeded the meter test limits capability.

The high-flux polymeric membrane demonstrated exceptional performance, generating permeate quality that met or exceeded the parts manufacturer's target and maintenance-stable flux rates. The high-flux polymeric membrane also produced clean permeate water at a recovery rate of greater than 90 percent. Larger scale testing has been recommended to validate the technology and to properly scale up for the client's 80 gfd rate requirement.

Figure 17
Comparison of Feed and Permeate Appearance

Conclusion and Summary

The new high-flux polymeric membrane described in this paper represents a significant advance in membrane technology because the new material has a demonstrated ability to greatly improve wastewater recovery in a variety of industrial process when incorporated in spiral wound filters.

As the six case studies described in this paper illustrate, the potential benefits for on-site wastewater plant operators can include increased product yield, reduced waste and reduced waste disposal costs. The use of the high-flux polymeric membrane in spiral wound filter also can reduce footprint (space) requirements for filtration systems, which can results in less capital investment; lower operating costs due to diminished energy consumption and extended service life for filter elements.

The specifications for this product are the dimensions and element properties identified on this Product Data Sheet. The operating parameters on this Product Data Sheet are based upon information believed by PPG to be currently accurate; however, PPG makes no representations or warranties regarding the accuracy of the operating parameters or any other information on this Product Data Sheet. PPG also makes no representations or warranties regarding the performance or results of this product, or regarding freedom from patent infringement in the use of any formulae or process on this Product Data Sheet. Improvements in filtration technology may cause operating parameters to vary from what is on this Product Data Sheet.

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