High-Flux Membrane Filtration for Oil and Water Separation

James Peters
R&D Manager
Specialty Coatings and Materials
PPG

Abstract

Environmental regulations and water scarcity have created a need for economical water treatments that increase reuse. This paper will review the new PPG membrane that has a unique composite single-layer microstructure that provides high-flux, excellent separation capabilities and exceptional durability to improve the filtration and recovery of industrial wastewater.

Specifically, this document will detail the intrinsic properties of the PPG membrane, compare performance in relation to competitive membranes, and review three case studies that quantify the performance of the membrane in lab-scale to commercial-sized filters, on a variety of industrial wastewaters.

Introduction

This paper introduces the new PPG filtration membrane.

More than 70 percent of our planet is made of water, yet for reasons related to population growth, climate change, increased agricultural demands, environmental regulations and other factors, it has become an increasingly threatened and finite resource. By 2050, experts estimate that up to half of the world's population will not have adequate access to potable water.

Beyond its basic role of sustaining life, water also is critical to countless industrial processes related to the production and manufacture of oil and gas, power, food, beverages, textiles and many other goods. To help minimize the impact of these processes on the world's water supply, filtration companies and industrial manufacturers have developed and adopted over the past century a sophisticated array of materials and technologies aimed at cleaning, recovering, recycling or reusing the wastewater they generate.

This paper will introduce one such material, the new PPG filtration membrane that—compared to polyacrylonitrile (PAN), polyvinylidene fluoride (PVDF) and other commonly used filtration membranes—more effectively and economically cleans water entrained with free and emulsified oils, suspended solids, bacteria and other organic and non-organic contaminants.

Although the PPG membrane can be used in a variety of separation applications, the focus of this technical paper is on the separation of oil and water, principally from oil extraction activities. The content will be presented in two parts:

Part one describes the PPG membrane and its intrinsic filtration properties, and includes a review of its performance characteristics compared to PAN membrane, the most commonly used filtration membrane for oil and water separation.

Part two is a summary of three field tests that quantify the effectiveness of the PPG membrane in separating oil and water at production sites in the Middle East, Texas and North Dakota.

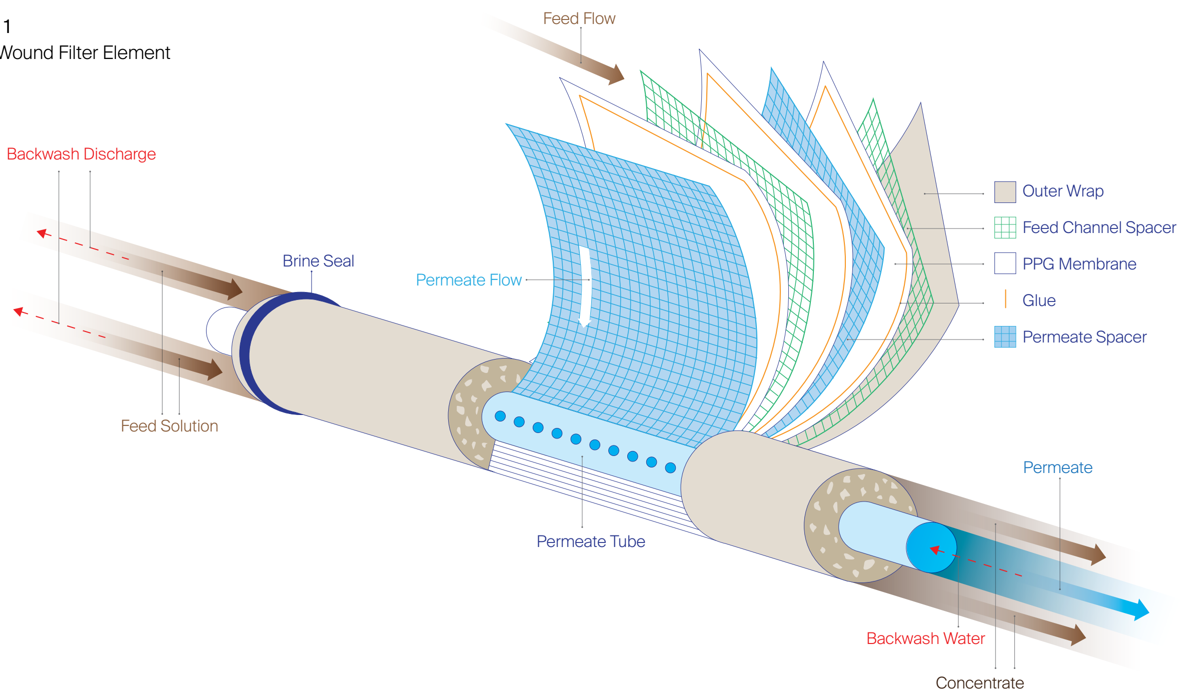
Use of Membranes for Oil and Water Separation

There are several proven methods for separating entrained oil from water. Technologies or the combination of technologies employed to execute this separation are selected based upon economics and the need to achieve specified targeted reuse or discharge limits. Membrane filtration is one tool that can be used for removing trace oil levels generally not captured by other bulk separation methods, but its use traditionally has been limited by low throughputs, poor durability and the inability to consistently achieve low residual oil levels.

A common way to utilize membrane for the separation of oil and water is in a spiral wound filter configuration (Figure 1). Oily water (feed solution) is pumped into one end of the filter, flows across the membrane surface (leaf) and is separated into two streams generally referred to as permeate (clean water) and concentrate (concentrated oily water).

An inherent benefit of the spiral wound filter design is that the high crossflow velocity of the oily water tends to wash the membrane surface clean from oil accumulation (fouling). The resulting pressure also helps the separation process by pushing clean water through the membrane (Figure 2). The rate at which clean water is separated by the membrane is generally referred to as flux rate. High-flux rates are key to determining the economic viability of membrane filtration.

Figure 1
Spiral Wound Filter Element



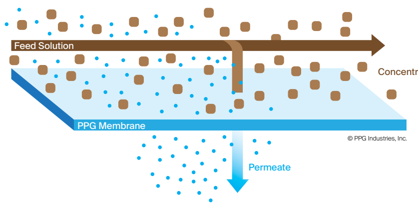


Figure 2
Crossflow Filtration

Spiral wound filters are used for many water purification applications because their design permits high volumes of filtration membrane to be packed into a high-density configuration. This makes them both economical and highly effective at removing contaminants.

High oil contents and high solids levels can shorten membrane lifetime. As a result, spiral wound filters are best-suited to "polishing" wastewater feeds that have been pretreated using upstream processes such as gravity separation, hydrocycloning, gas flotation or electro-coagulation.

The PPG filtration membrane described in this paper was developed to be an improvement over existing commercial membrane products designed for microfiltration and ultrafiltration processes. Although the PPG membrane can be employed in many types of filtration devices, it has been lab-tested and field-tested most extensively in spiral wound elements for oil and water separation. Consequently, the content of this paper concentrates exclusively on benchmarking the oil-water separation capabilities of the PPG membrane compared to PAN membrane, the predominant membrane type currently employed for such applications.

New High-Flux Membrane Technology

The new PPG filtration membrane is a proprietary single-layer thermoplastic composite that unites a hydrophobic (water-repelling) polymer matrix with hydrophilic (water-attracting) inorganic filler. This combination of hydrophobicity and hydrophilicity creates powerful capillary forces that produce higher flux rates and cleaner, higher-quality permeate than is possible with commercially available PAN membrane. Flux rate is generally measured according to gallons per square-foot (of membrane material) per-day (GFD).

Single-layer, symmetric membranes offer many advantages over commercial membrane technologies that employ membrane cast with a thin, surface layer of controlling porosity supported by a larger-porosity underlayer (Figure 3). Single-layer membranes create an inherently torturous pathway (Figure 4) that traps contaminates despite having a larger pore size than conventional membrane products.

The single-layer design also yields increased membrane durability because it supports the self-cleaning function of the membrane by allowing reversal of flow (backwashing), which removes accumulated particles and oil from the membrane surface. This combination provides high-flux rates, excellent separation and durability.

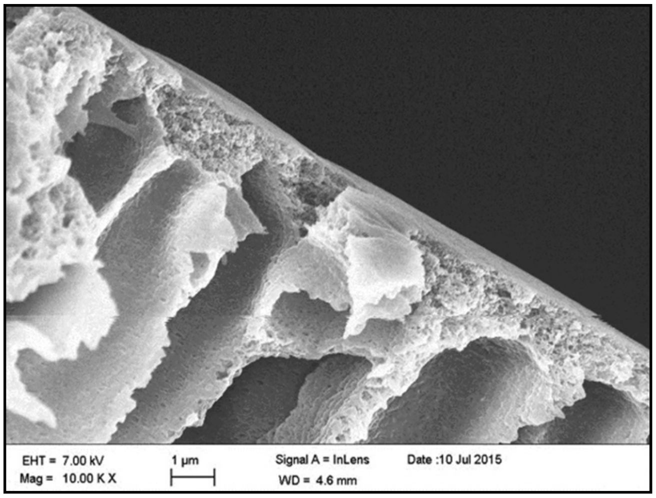


Figure 3
PAN Membrane
Large pores underlay a thin, single layer of controlling porosity, which makes the membrane less effective at trapping small particles of contaminants.

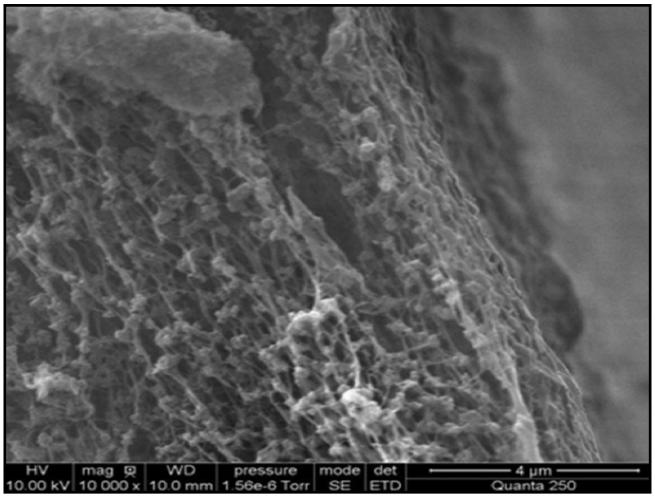


Figure 4
PPG Membrane
The single-layer membrane creates a torturous path that traps contaminates beyond the surface layer.

Crossflow Flat-Sheet Testing: PPG Membrane vs. PAN Membrane

Laboratory tests were conducted to compare flux rates between the PPG membrane and PAN membrane. The first was crossflow flat-sheet testing using a Sterlitech SEPA CF crossflow cell. During crossflow testing, a liquid solution consisting of 10% salt and 0.25% crude oil was streamed at rates of 1.5 gallons per minute (GPM) at 25 pounds per square inch (psi) across both the flat (unwound) surface of the PPG membrane and the PAN membrane for a period of 100 hours each. Crossflow conditions were selected to achieve single-digit (parts-per-million) ppm oil levels in the permeate.

As the results depicted in Chart 1 indicate, the PPG membrane showed inherently higher flux rates than the PAN membrane throughout the entire testing period.

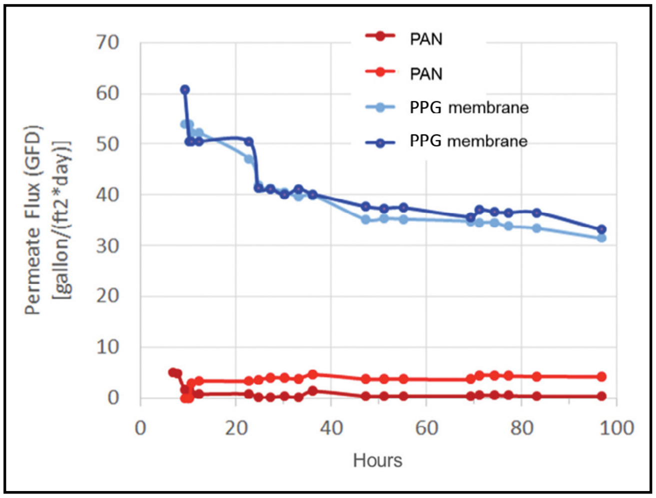


Chart 1
Crossflow Flat-Sheet Testing

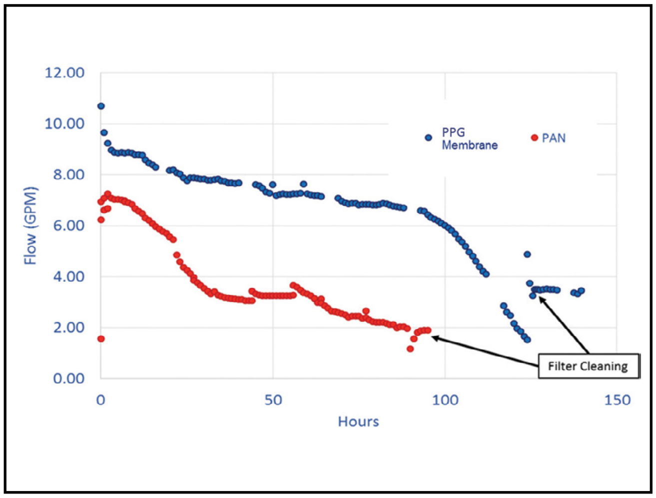


Chart 2
Flux Rate/Fouling Comparison

After its high-flux rate was validated, the PPG membrane was incorporated into a commercial 8040 (8-inch diameter, 40-inch long) spiral wound filter. This filter was tested against an 8040 commercially available PAN filter using the same 10% salt, 0.25% crude oil mixture. Testing of the two filters was accomplished over 150 hours.

Again, as the results depicted in the charts indicate, the PPG membrane showed higher flux rates in the spiral wound configuration than the PAN membrane did throughout the testing period (Chart2).ThePPGmembranealsoconsistently demonstrated less fouling—which translates into longer time intervals between cleanings (Chart 2)—as well as lower percentages of oil in the permeate (Chart 3) and better clarity (lower turbidity) (Chart 4).

Together, the flat-sheet and filter element test results indicate that the PPG membrane will maintain excellent oil-water separation capabilities with high-flux rates. That means, as a substitute or replacement material for PAN membrane, it has the potential to yield a host of benefits for system operators, including less capital investment in housing, pumps and related equipment; a smaller operational footprint; lower energy costs; reduced need for chemical treatment; easier environmental compliance; and the possibility of recovering/reclaiming oil for enhanced revenue.

Filter Element Testing:
PPG Membrane vs. PAN Membrane

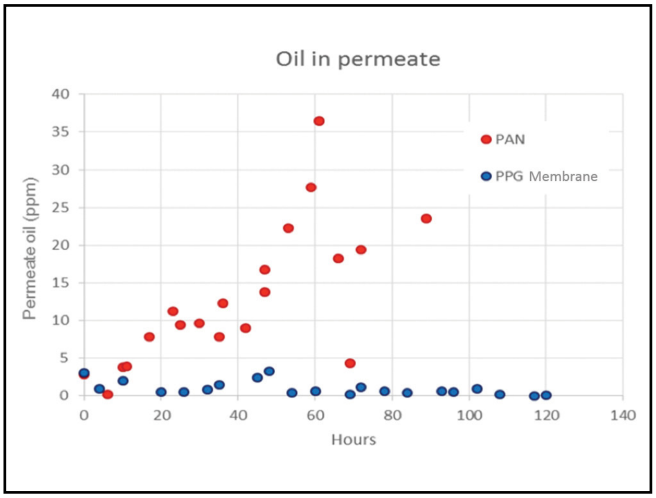


Chart 3
Oil in Permeate Comparison

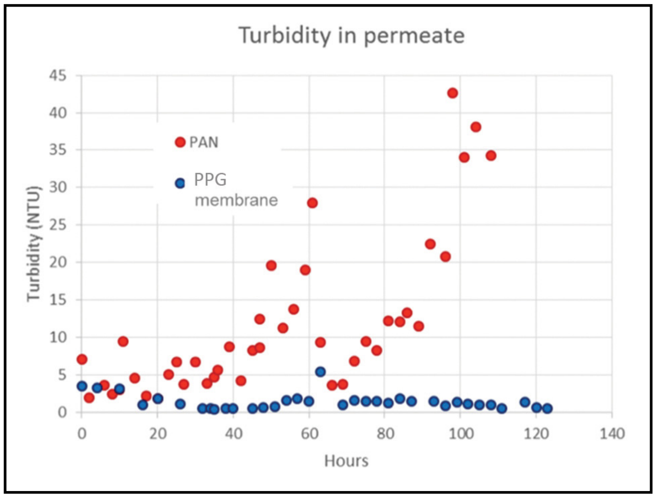


Chart 4
Turbidity Comparison

Field Trials

Several field tests have been completed to quantify the ability of the PPG membrane to recycle/reclaim produced water, flow-back water and gas and oil separation (GOSP) generated during drilling and fracking operations by various exploration and production companies. A brief summary of three such tests are provided here:

MIDDLE EAST OIL FIELD: A 7640 spiral wound filter element equipped with the PPG membrane was used to process oil flow-back water from a Middle East oil feed containing oil, as well as a mix of surfactants to enhance oil recovery (Figure 5). Existing alternative chemical treatments proved to be difficult and costly. The flow-back water contained about 140,000 ppm oil content with emulsification from the surfactants. Filtration was accomplished via circulation through the filtration using a 100 GPM feed rate. Permeate quality was maintained at a consistently low oil level of about 2 ppm oil (Figure 5). Permeate rates were measured at 8-18 GFD for 60 hours of filtration (Chart 5).

SOUTH TEXAS OIL DISPOSAL WELL: The PPG membrane was deployed in a spiral wound filter to treat oil-contaminated water at a disposal well in south Texas. After being pumped through the filter with a feed rate of 70 GPM at 15 psi transmembrane pressure (TMP), the solution, which initially contained 198,000 ppm oil, yielded permeate with 3 ppm oil (Figure 6) and significantly less turbidity than the incumbent multi-step chemical treatment (Figure 6).

PRODUCED WATER FROM NORTH DAKOTA OIL RIG: An 1812 spiral wound element equipped with the PPG membrane was used to treat produced water provided by a major U.S. drilling company. The produced water contained about 50 ppm of total oil and grease (TOG), 1.5% total solids and had a turbidity of 580 nephelometric turbidity units (NTU) (Table 1). After 30 hours of continuous testing, the element yielded permeate containing 1.5 ppm TOG and turbidity of less than 2 NTU (Figure 7) (Table 1). The membrane produced a consistent flux rate throughout the testing period (Chart 6) and no major fouling was found.

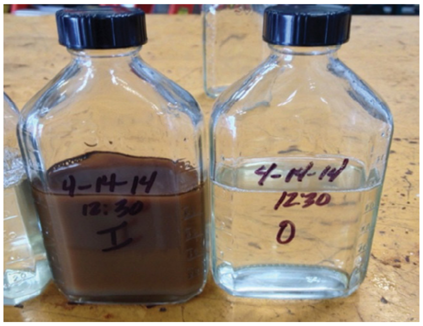


Figure 5
Oil flow-back water from a Middle East oil feed (left)
Filtered permeate (right)

Figure 6
Oil-contaminated water and permeate following treatment (left)
Oil-contaminated water after incumbent chemical treatment process (right)

Figure 7
Produced water provided by major U.S. drilling company (left)
Filtered permeate (right)

Test Items	Permeate 1	Permeate 2	Raw Water
Al (ppm)	<10	<10	<10
B (ppm)	<10	<10	<10
Ba (ppm)	<2	<2	8
Ca (ppm)	345	236	566
Fe (ppm)	<2	<2	32
Mg (ppm)	141	140	215
Mn (ppm)	2	2	2
Na (ppm)	2670	2710	4000
S (ppm)	740	757	1160
Zn (ppm)	<2	<2	<2
Turbidity (NTU)	1.2	1.6	580
TOG (ppm)	1.3	1.6	50

Table 1
Produced water composition (right Raw water column); Permeate composition (left Permeate 1&2 columns)

Conclusion and Summary

Spiral wound elements have emerged over the past 50 years as the most popular filtration technology for challenging separations. The new PPG membrane described in this work represents a significant technological advance because it has demonstrated the ability to greatly improve the contaminant separation capabilities of spiral wound filters while maintaining or enhancing flux rates – all without altering the fundamental design of the filter.

Such an advance has the potential to expand the use of spiral wound filtration throughout the industry, improving the economics and environmental impact of oil recovery, as well as the treatment, recovery and reuse of water in countless applications related to municipal drinking and wastewater; food, beverage and pharmaceutical production; mining; metal processing; pulp and paper production; power generation and more.

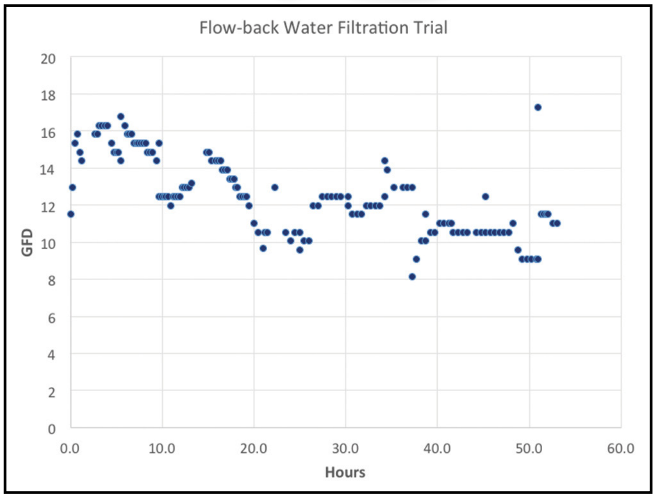


Chart 5
Permeate rates

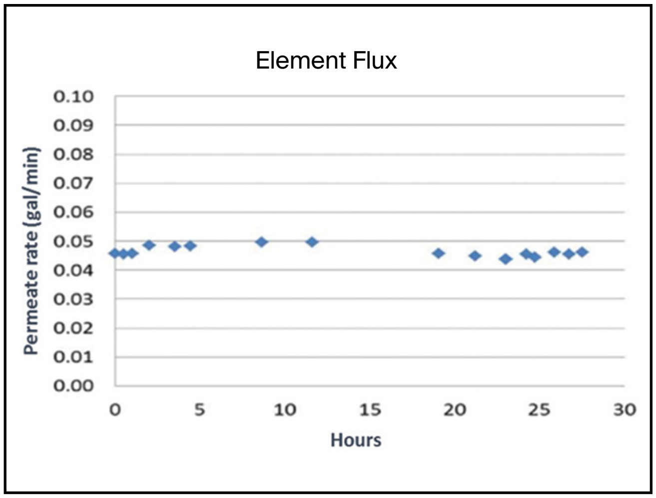


Chart 6
Flux rate

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.

PPG Filtration Technologies
440 College Park Drive
Monroeville, PA 15146 USA

Contact us:
filtration@ppg.com
www.ppgfiltration.com