David H. Paul, Inc.

Membrane Element Autopsy

Final Report

Prepared for:

Sample Report

Membrane Manufacturer

Serial #XXXXXXX

First Element, First Stage

Lab Number

November 20, 2024



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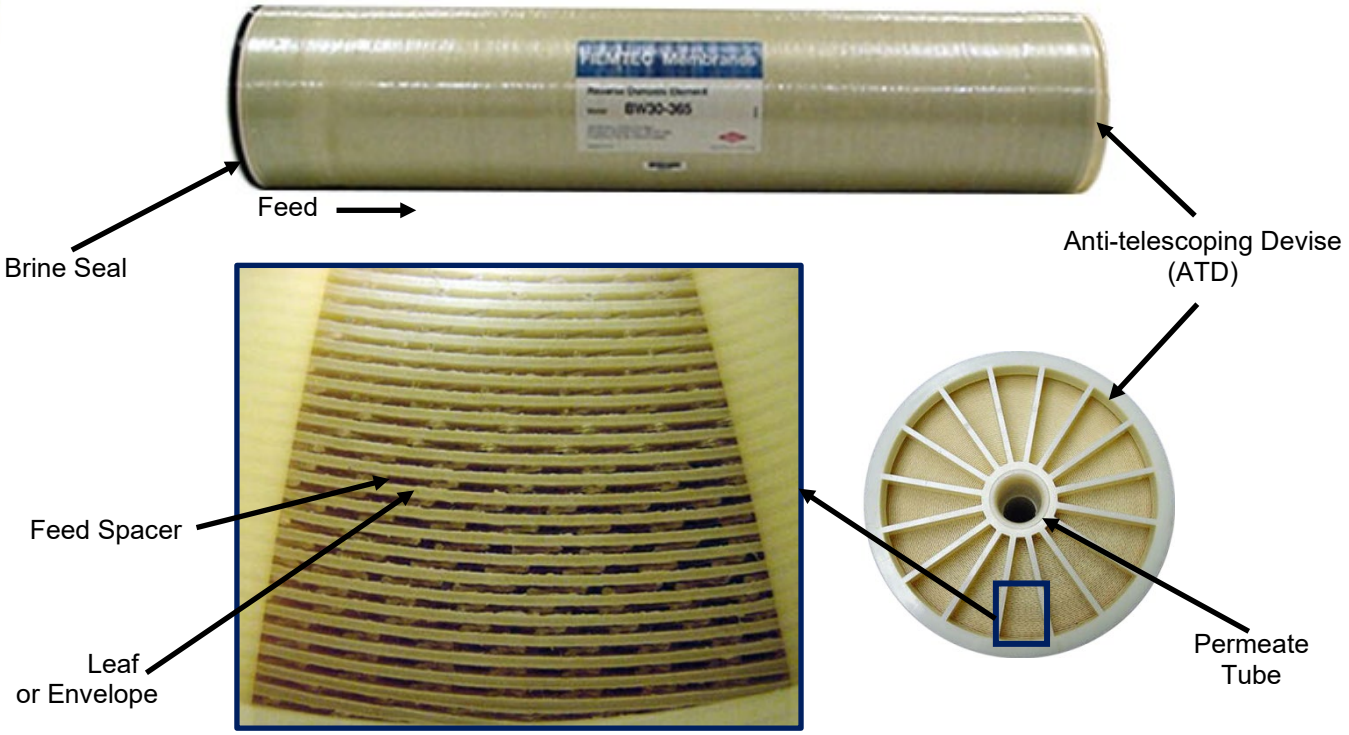
Executive Summary

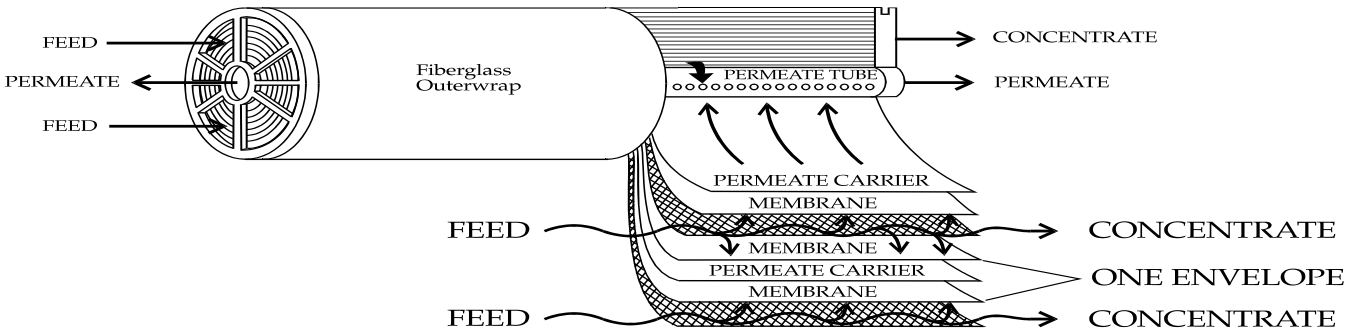
“The autopsy of the element revealed significant issues including fouling, and membrane damage. The fouling is characterized by biological deposits and silt and iron oxide deposits. Pretreatment and/or membrane cleaning equipment or operation may be insufficient. The membrane damage is blistering of the membrane surface due to permeate pressure exceeding feed/concentrate pressure at some point.”

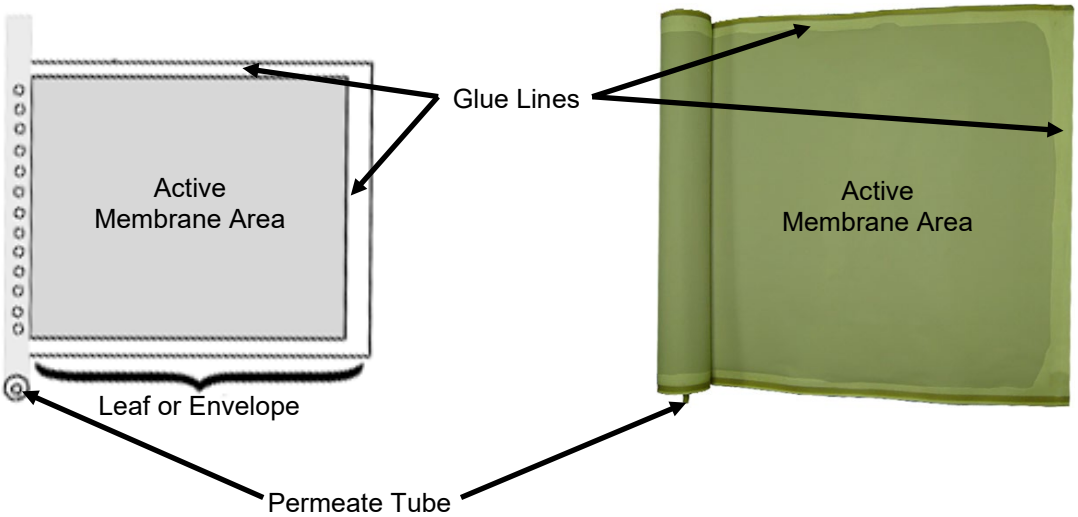
“The autopsy of the element revealed several significant issues including fouling, channeling, membrane damage, and cracked fiberglass. The fouling is characterized by slimy biological deposits and high levels of silica (glass) fouling. Channeling was observed in multiple envelopes, resulting in feed spacer displacement towards the concentrate end. Dye penetration testing confirmed compromised membrane integrity. In addition, the cracked fiberglass wrapping on the element is indicative of high pressure drop. A weakness in the casing can result in the element’s ability to function effectively as designed and can lead to further damage or failure.”

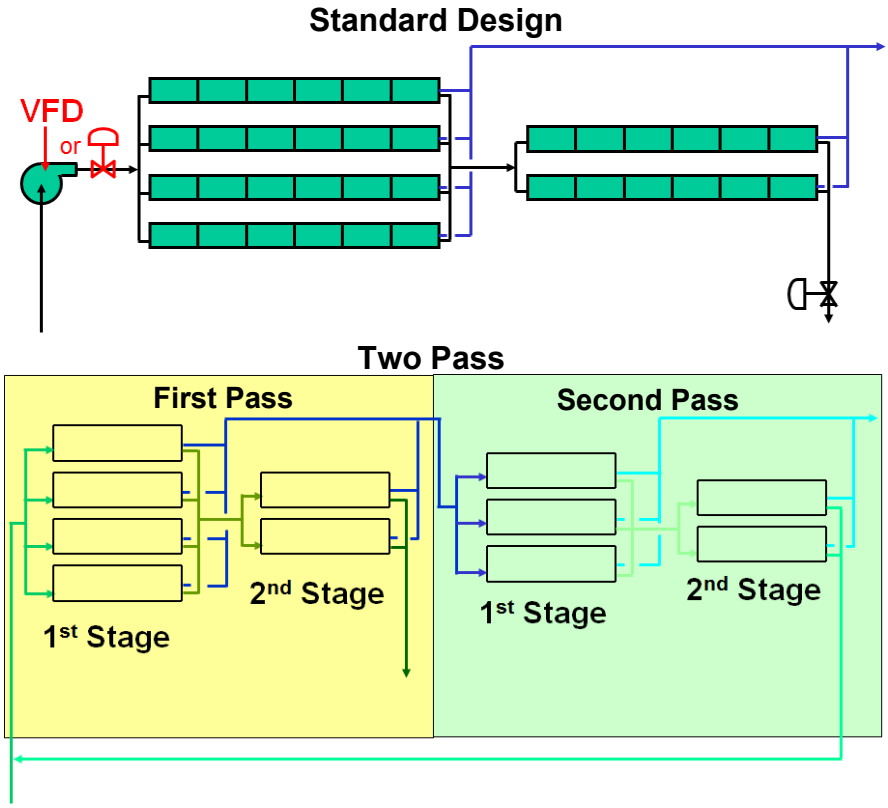
For the next level of detail, go to Statement of Results.

Membrane Element Terminology









Autopsy Tracking

Contact Person: _____

Contact Phone Number: _____

Contact E-mail: _____

Date Element Shipped: _____

Date Element Received: _____

Date Autopsy Initiated: _____

Date Report Delivered: _____

Background Information & Process Flow

The following is the questionnaire that the client completed:

David H. Paul, Inc.
2050 Afton Place
Farmington, NM 87401
(877) 711-4347
www.dhptraining.com

David H. Paul, Inc. Membrane Element Autopsy Questionnaire

Emergency service? (1 week turn around)	☐ Yes ☐ No
Additional Recommendations & Consulting?	☐ Yes ☐ No

Plant Information	
Contact Name:	
Company Name:	
Plant Name:	
Address, City, State & Zip Code:	
Contact Number:	
Fax:	
E-mail:	

Billing Information	
Contact Name:	
Company Name:	
Address, City, State & Zip Code:	
Contact Number:	
Fax:	
E-mail:	
PO Number:	

1. Number of Membranes sent for autopsy:		
2. What is the manufacturer and model # of membrane elements installed in each stage of the RO unit? (For Example: FilmTec BW 30-400)		
3. Are all of the membrane elements in the RO Unit the same type (model)?	☐ Yes ☐ No	
If not, how are they mixed together?		
4. Where was the element(s) located in the RO Unit? (For example: First Element, First Stage)		
5. Has the element(s) sent always been in same position described above?	☐ Yes ☐ No	
If no, please explain		
6. What was the startup date of the RO system as a whole?		
7. How long have the current elements been in service?		
8. What is the feed water source for the RO Unit in question? (If the feed water source is municipal drinking water, tell us whether the raw water to the municipal plant is well water or surface water).		
9. Is the feed water chlorinated at any point?	☐ Yes ☐ No	
If yes, what is the residual going into the RO?	Total: ppm	Free: ppm

10. What is the temperature range of the feed water?	°F	°C	
11. Describe any "non-standard" features of the RO unit. (interstage booster pump, first stage permeate back pressure, etc.)			
12. List the pre-treatment equipment, chemical injections, and dosages in the order of which they appear in the process. (Please answer this question thoroughly. Ex: Raw Water, Multi-Media Filter, Heat Exchanger, Scale Inhibitor Injection, Cartridge Filter, RO Unit)			
13. What is the Array of the RO Unit? (The Array is the number of pressure vessels in each stage: If the Array is 6:3, there are 6 pressure vessels in the first stage & 3 pressure vessels in the second stage)			
14. How many membrane elements are there per pressure vessel?	1st stage	2nd stage	3rd stage
15. Please provide pressures for the RO unit in question.	Feed psi	Interstage 1 psi	Interstage 2 psi
	Concentrate psi	Permeate psi	Other psi
16. Provide the pressure drop data of each stage.	1st stage psi	2nd stage psi	3rd stage psi

17. Please provide the RO Unit Permeate flow rate	gpm	
18. Please provide the RO Unit Concentrate flow rate	gpm	
19. How much concentrate is recycled to the front of the RO unit? *(if any)*	gpm	
20. How many hours per day is the RO Unit typically operating?		
21. What was the longest period that the RO Unit has been shut down?		
22. Prior to shut down, is there a Post Flush of the RO Unit?	☐ Yes ☐ No	
If yes, then what type of flush water is used? (Ex: permeate, RO feed, DI, etc.)		
23. Based on current performance what do you expect is the useful life of the element(s) sent?		
24. How often is the RO unit in question being chemically cleaned?		
25. List the general solutions and procedures that are used for chemical cleanings. (For Example: High pH cleaning-Sodium Hydroxide, pH 11, 95°F, circulate 1 hour at 200gpm, soak 1 hour, circulate 1 hour at 250 gpm, flush and rinse to quality.)		
26. If a scale inhibitor is being used, please list the type and dosage (ppm)	Name & Type:	Dosage:

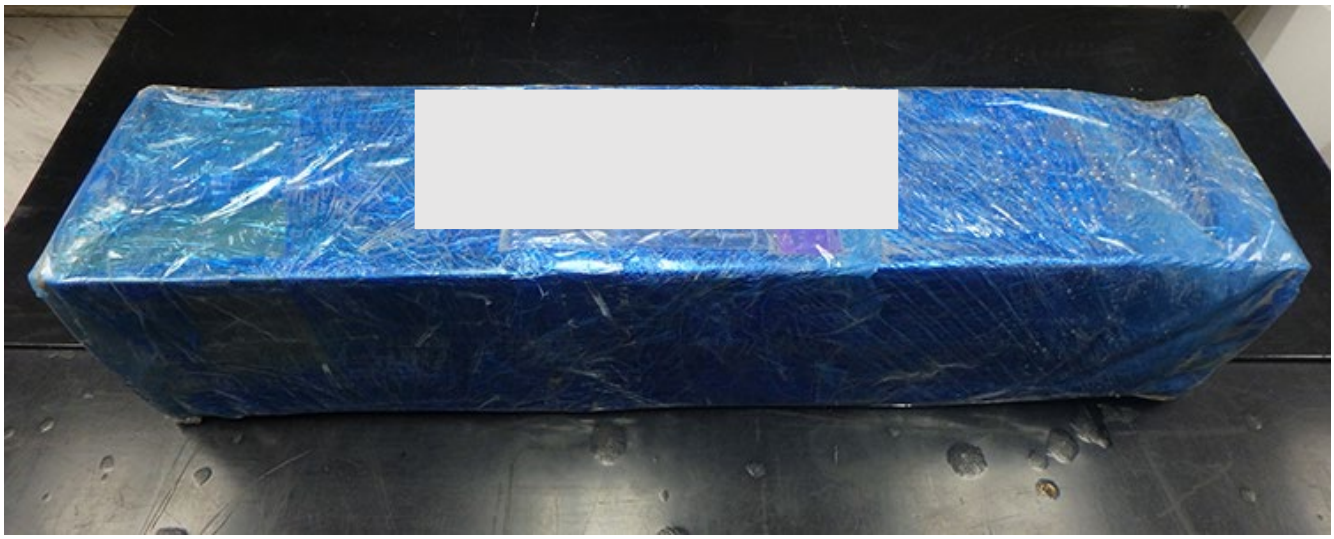
27. What is the end use requirement/permeate application? (Ex: boiler feed water, DI water, potable water, etc.)	
28. Describe the problem(s) that have caused you to order an autopsy?	
29. If there are multiple parallel RO units, are all units having the same problem?	☐ Yes ☐ No ☐ Not Applicable
30. Is there any additional information about the design or operation of the RO that might help us interpret the autopsy results?	

Shipping Container and Element Packaging

Arrival: The element was shipped on Thursday May 9, 2024. Element arrived at the DHP laboratory on Friday May 10, 2024.

1. **Shipping Container:** Immediately upon arrival, the element-shipping container was inspected for damage that may have occurred during transit. The box was in moderate shape with obvious signs of leakage.

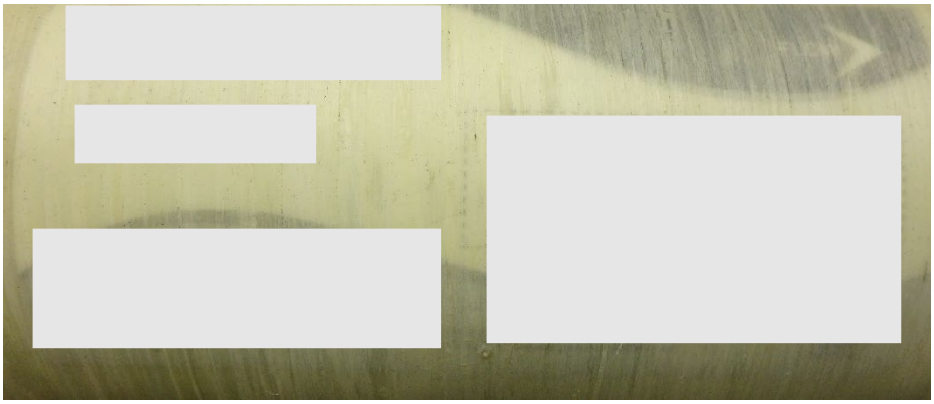
2. **Element Packing:** After the initial external shipping inspection, the element was removed from the shipping container and inspected for any damage that may have occurred during transit. The element was shipped loosely in a box that was then wrapped in plastic wrap and packing tape. Element showed no signs of damage caused from shipping.



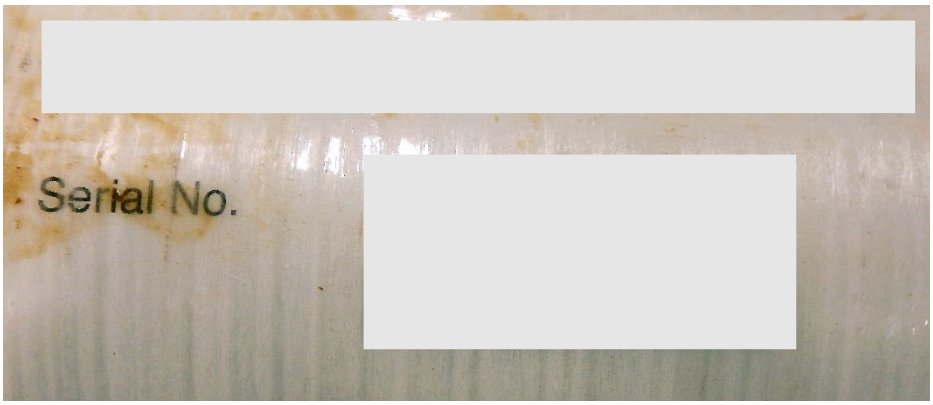


Membrane Element

Model Number



Serial Number



Element Weight as Received

Before disassembly the element weighed 32.40 lbs.

Vacuum Hold Test

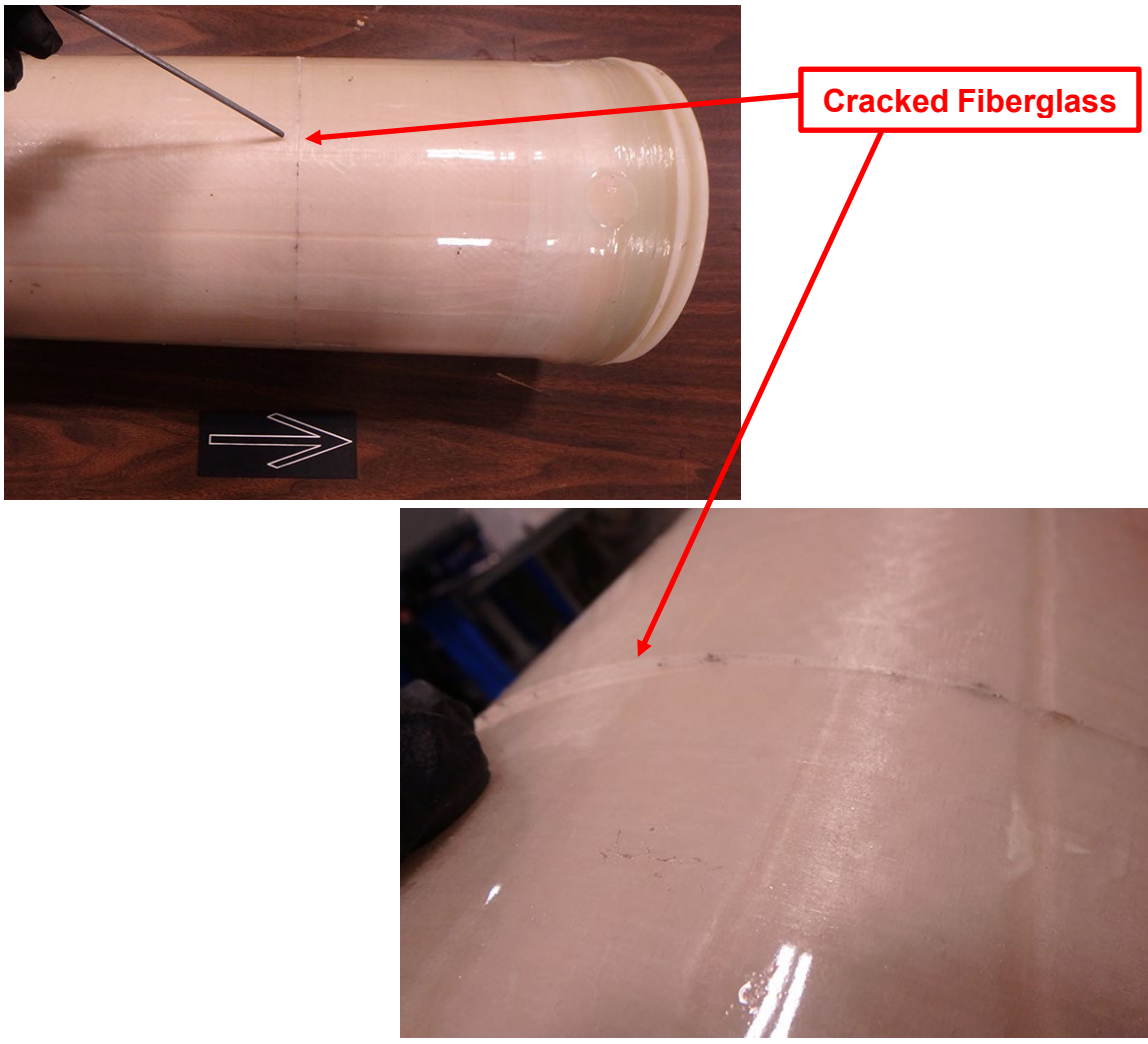
A vacuum hold test is performed to see if there is any mechanical bypass of the membrane, such as chemical damage, glue line leaks, membrane perforations, etc. A vacuum of 25-30 inches of mercury is applied to one end of the permeate tube with the other end plugged. A timer is set for 2 minutes and the loss is measured. Greater loss than 6 in Hg is a fail, indicating a leak.

Vacuum hold test result: This element passed, with only 0.8 in Hg loss.

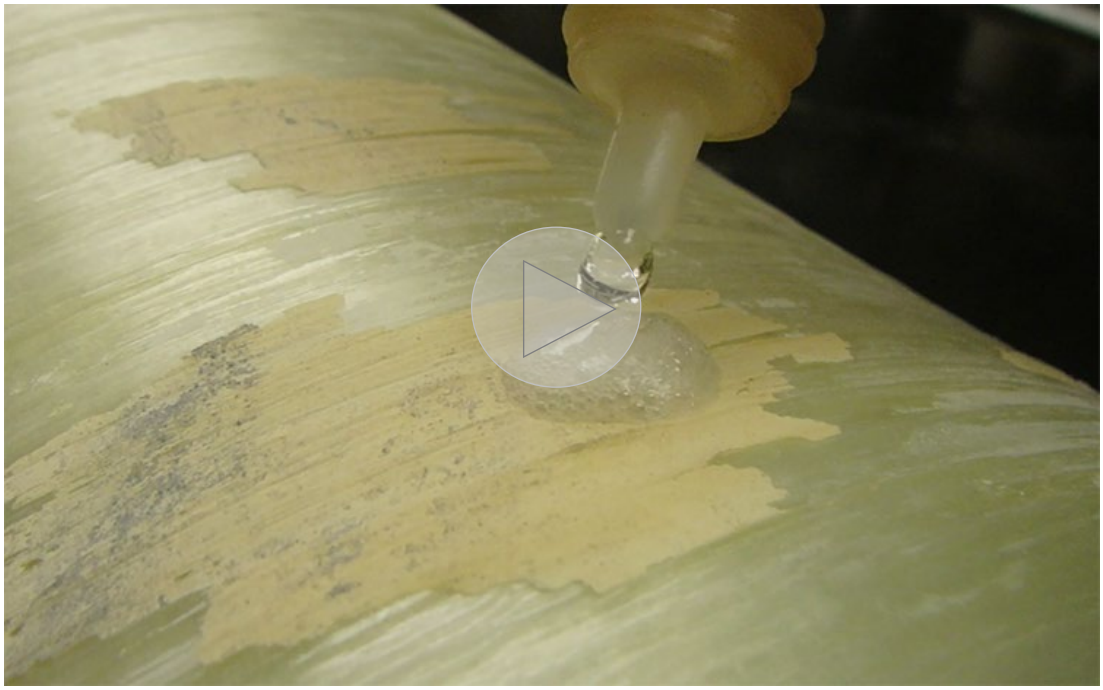
External Evaluation

Fiberglass Wrap: Cracked fiberglass around most of the circumference between the middle of the membrane and the concentrate end ATD was noted. Moderate pink staining on the surface of the fiberglass was also noted.





Additional: Hydrochloric acid was dripped on the white substance on the fiberglass wrap. Fizzing was observed indicating carbonate scale was present. See the video by clicking on the photo below.



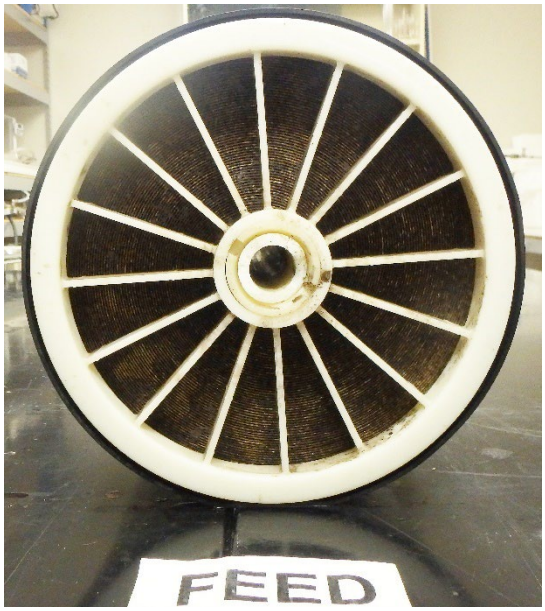
Brine Seal & Anti-Telescoping Device (ATD)

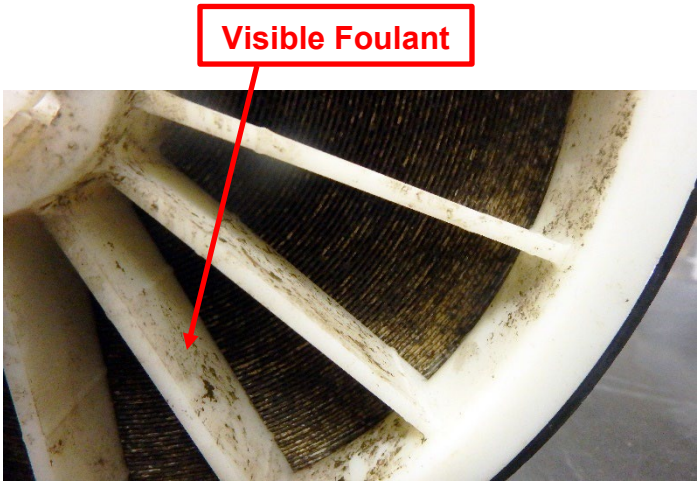
Brine Seal: The seal had a torn section missing, but was soft and pliable.



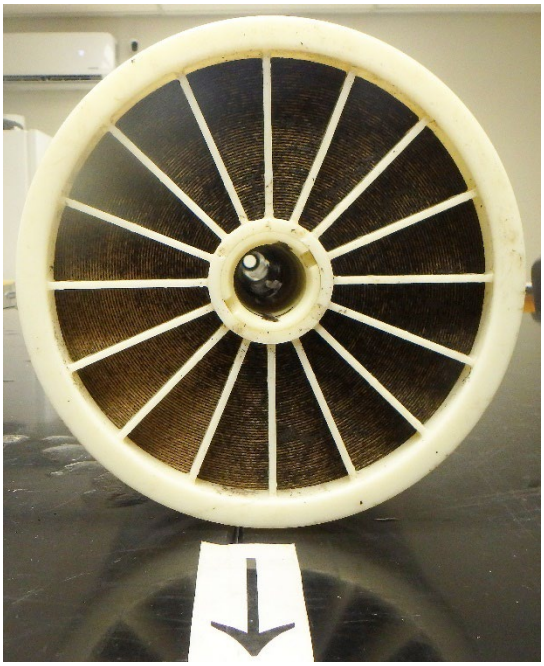


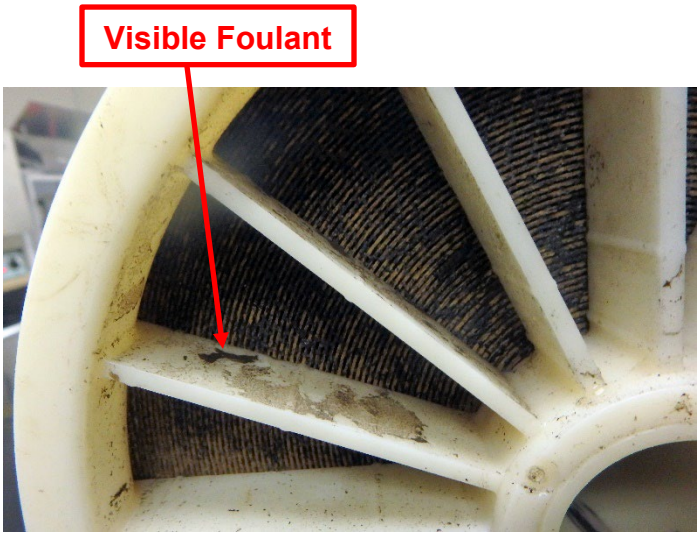
Feed ATD: This anti-telescoping device (ATD) was overall in good shape but had foulant and staining present.





Concentrate ATD: This ATD had some fouling and staining present.





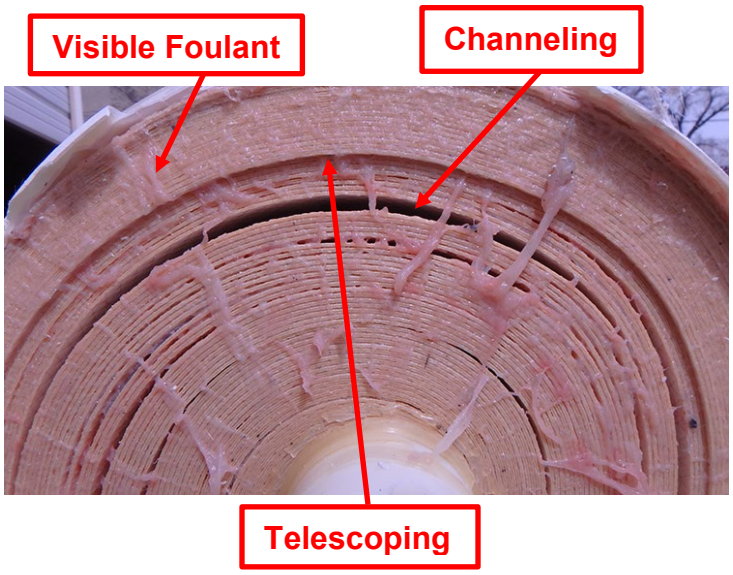
Additional: The ATD's were well made, and each had no visible manufacturing defects.

Scroll Ends

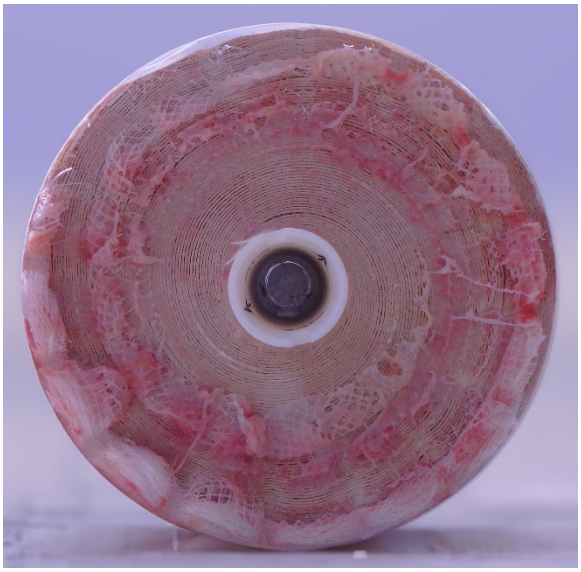
Before the element was unrolled, the scroll ends (or faces) of element were examined to learn more about the nature of the foulant (if present), to see if the feed water spacer is pushed into the feed-end and/or out of the concentrate end and to see if there is any deposition of material from upstream sources.

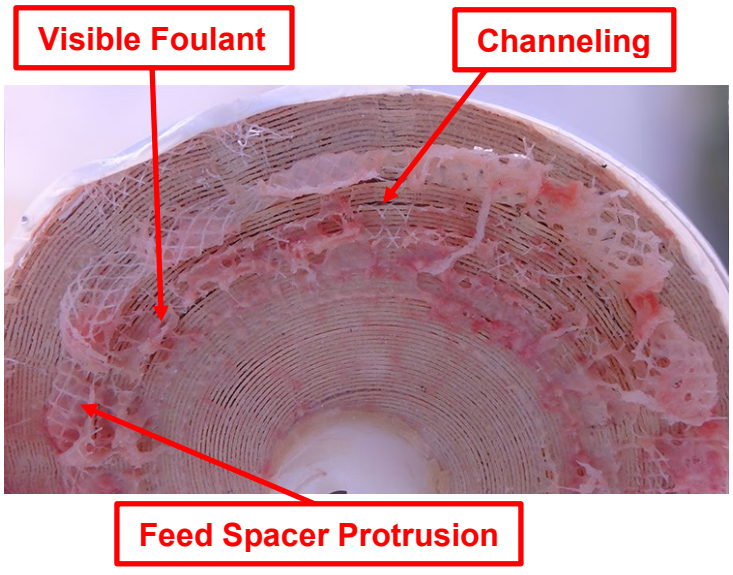
Feed End: The feed end of the element had excessive amounts of pink, stringy, slimy foulant. Moderate to severe channeling visible. Beginning signs of telescoping were observed.





Concentrate End: The concentrate end of the element had excessive amounts of pink, stringy, slimy foulant. Severe feed spacer protrusion was observed, an indication of channeling.





Internal Evaluation

After completion of the external evaluation, the element was then subjected to an internal evaluation. The internal evaluation began with an inspection of the leaves (envelopes) and the feed water spacers.

Membrane & Feed Water Spacer

First inch: There was some particulate foulant along with some slimy foulant present primarily on the active membrane but with some attached to the glue line and feed spacer as can be seen in the video by clicking the photo below.



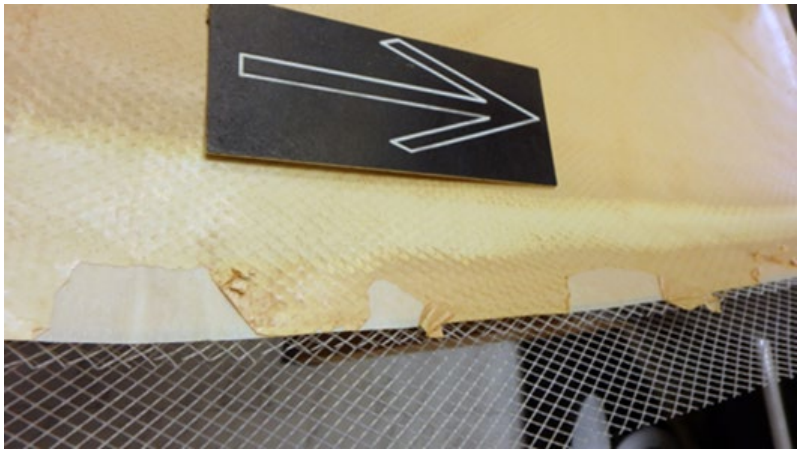
Leaves & Feed Water Spacers

Number of Leaves: 26

Number of Feed Water Spacers: 26

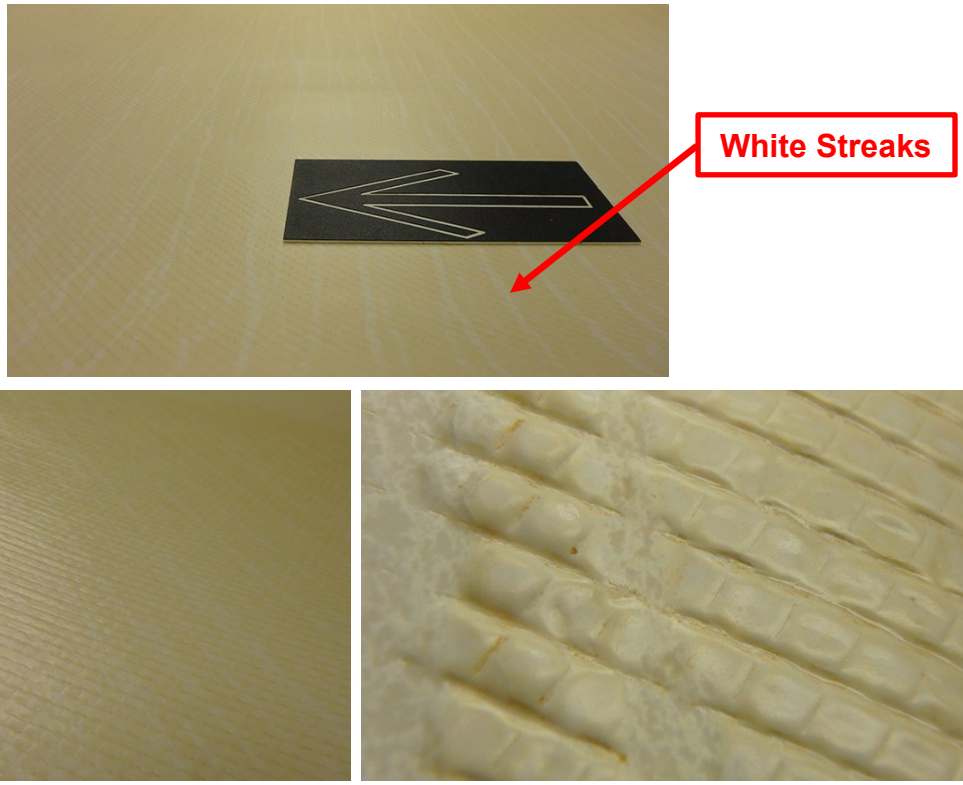


Condition of Leaves: All envelopes had some slimy foulant present along with some particulate granules. Seven envelopes had what appeared to be visible scale present. Additionally, some envelopes had membrane flaking from by the glue lines.

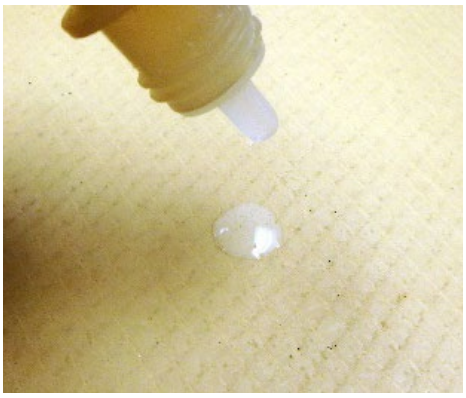


Membrane Close-up

Visual Inspection: Every membrane surface had evenly distributed rust/tan colored foulant with white streaks uniformly extending from the permeate tube to the outer end of each envelope. Each envelope had membrane blistering on the concentrate ends extending about a quarter of the way to the feed end.



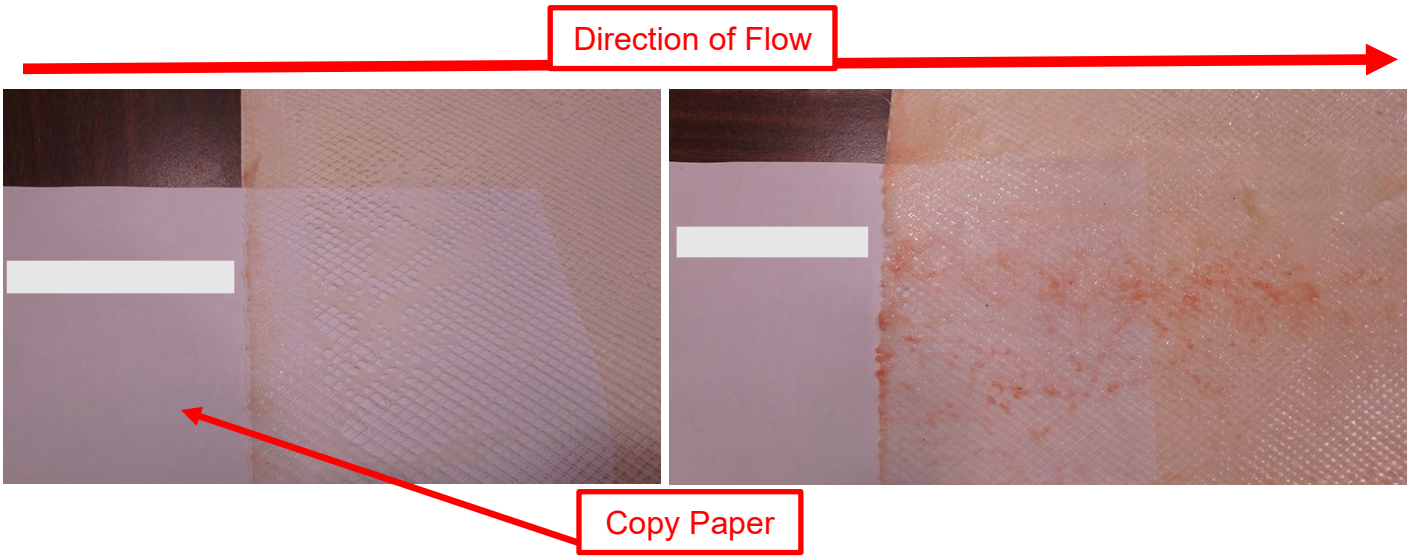
Test for Carbonate Scaling: Hydrochloric acid was dripped on the foulant on the concentrate end of the membrane. If carbonate scale is present, effervescing will be observed. Fizzing was observed especially on the white appearing scalant/foulant indicating carbonate scale was present. Click on the photo on the right below to see video.

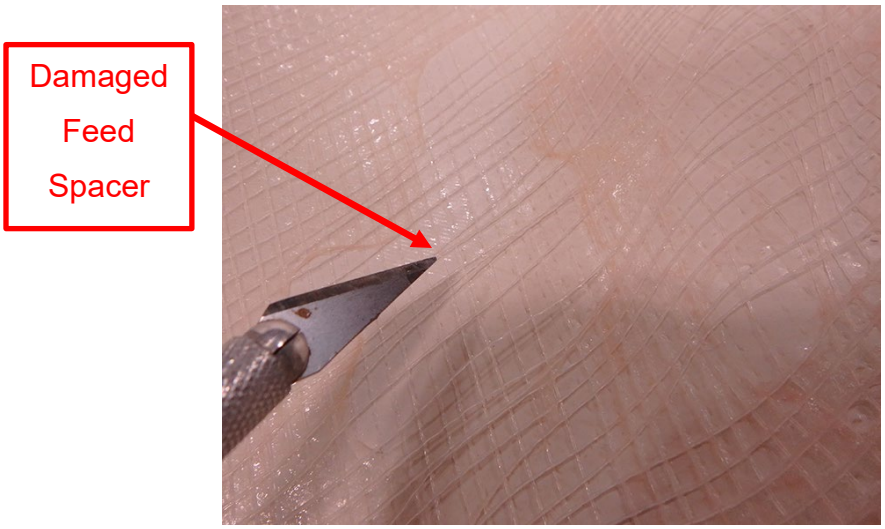




Feed Water Spacer

Condition of Spacers: All feed spacers within this element underwent inspection, revealing fouling throughout the feed-to-concentrate ends. Approximately half of the feed spacers exhibited moderate accumulations of white/clear foulant, while the remainder displayed severe channeling with excessive accumulations of pink/tan/white foulant in low-flow regions, alongside moderate accumulations of white/clear foulant in high-flow areas. Additionally, multiple areas of the feed spacers throughout the membrane exhibited damage. One envelope's feed spacer was almost entirely displaced towards the concentrate end, while another envelope's feed spacer was displaced over a quarter of the distance from the edge of the feed end of the membrane element.

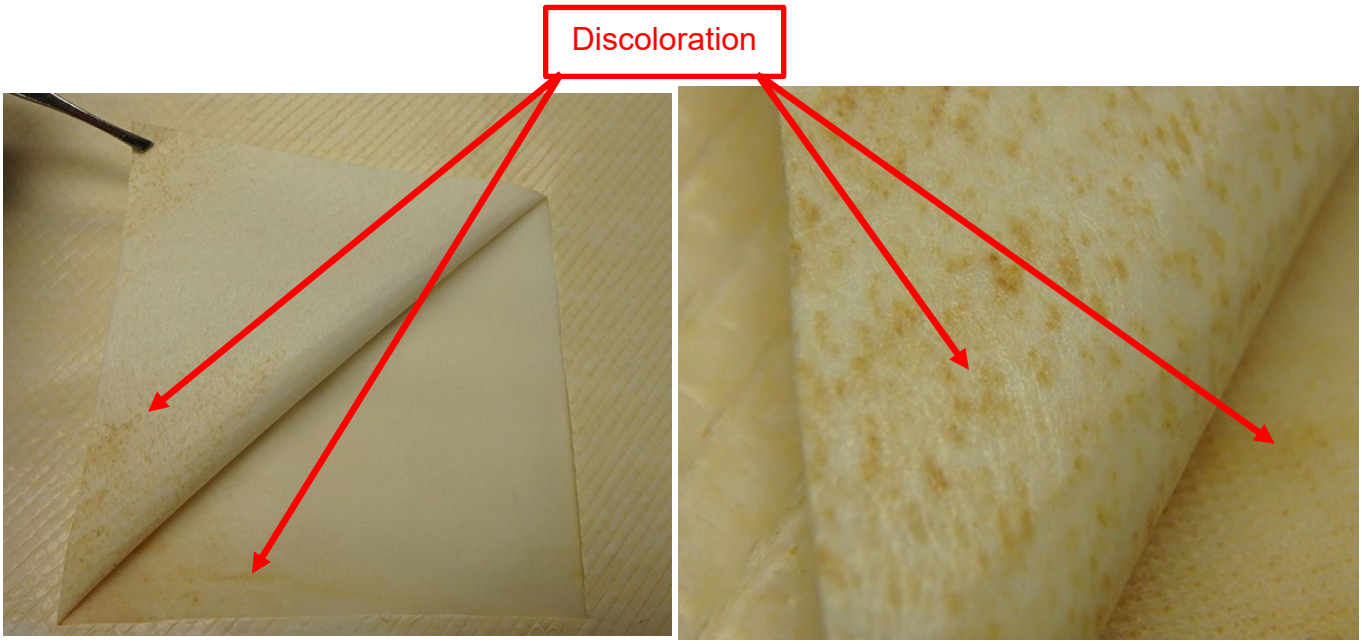




Spacer Thickness: 30 mil (measured with calipers). Manufacturer's specification sheet specifies 28 mil feed spacers. The feed spacer damage may have contributed to the additional thickness.

Membrane Backing & Permeate Spacers (Permeate Carriers)

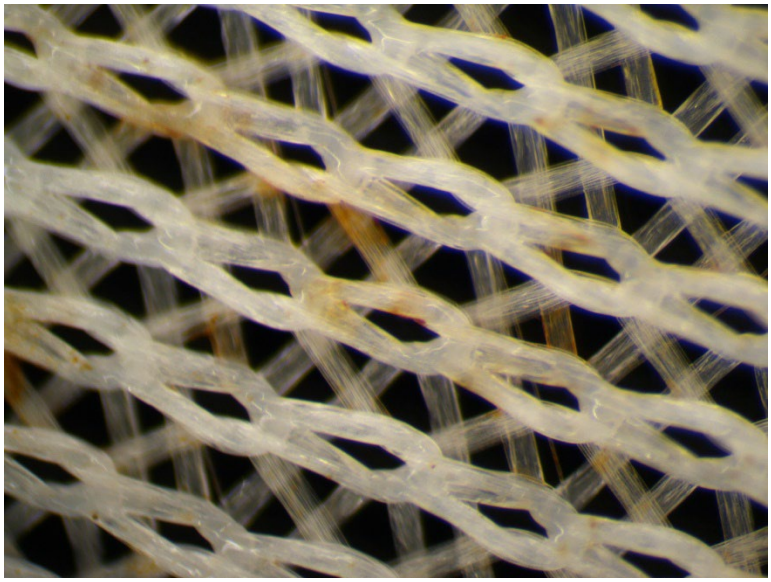
One to several leaves are opened to inspect the backing material of the membrane and the permeate spacer. Moderate discoloration was noted only on the concentrate end of the membrane backing and permeate spacer material.



Membrane Backing: Moderate discoloration and visible damage



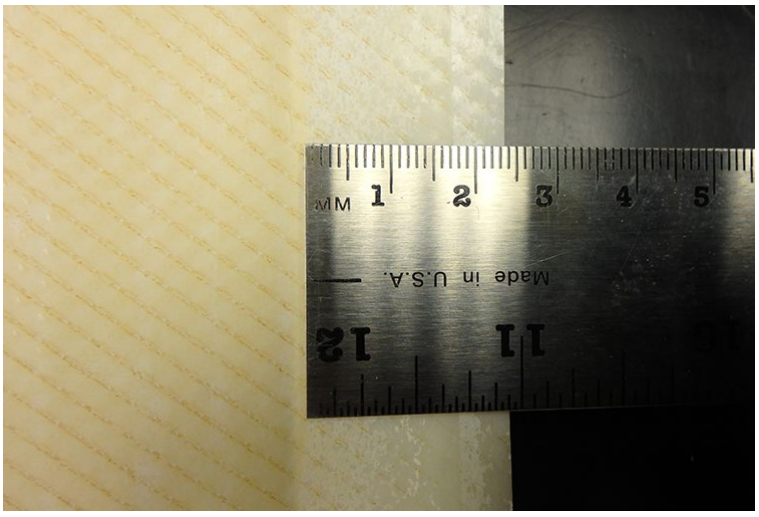
Permeate Spacer: Mild Discoloration



Permeate Tube & Glue Lines

Permeate Tube: The tube was in good physical condition. No damage was noted.

Glue Lines: The glue lines appeared uniform with no abnormalities observed. The glue lines in this element were on average approximately 23.5 mm (0.93”) wide.



Glue Adhesion Strength: Strong glue lines, tore before pulling apart.

Additional: Glue lines are inactive and do not contribute to the active membrane surface area. See video of glue line strength below by clicking on the picture.



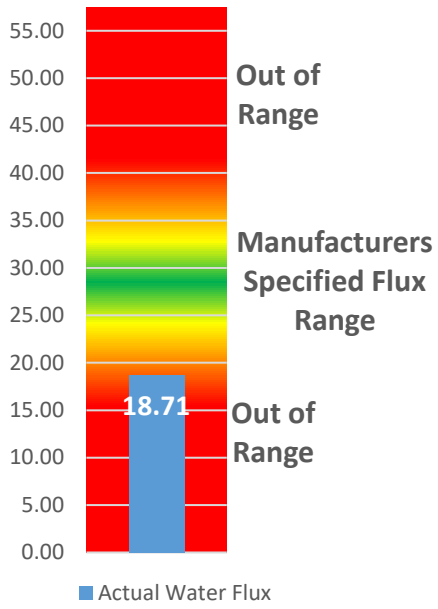
Membrane Performance

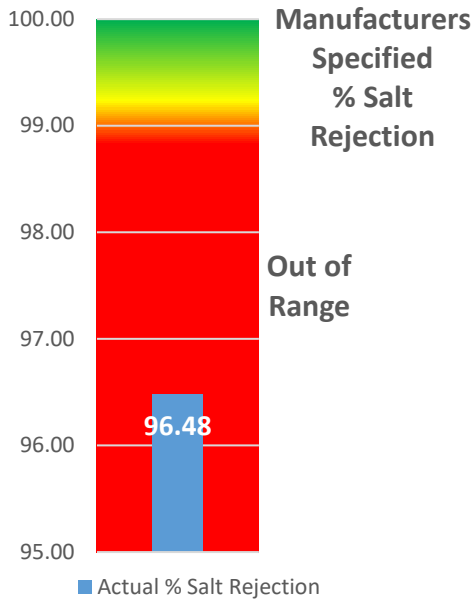
This portion of the autopsy is performed to assess the condition of the membrane through a salt and dye rejection evaluation.

Salt Rejection & Water Flux: Sections of membrane were cut from the feed, middle, and concentrate ends of an envelope in the element and tested. The test conditions were as follows: 150 psi applied pressure, 2,000 mg/l NaCl feed, 77°F (25°C).

Membrane Sample	Water Flux (GFD)	% Salt Rejection
Feed Strip	**18.87**	**96.10**
Middle Strip	**17.65**	**97.19**
Concentrate Strip	**19.60**	**96.14**
Average	**18.71**	**96.48**

MEMBRANE MANUFACTURER MEMBRANES under standard testing conditions are listed as producing 28.75 GFD (11,500 GPD) of permeate with a salt rejection of 99.3% and a minimum salt rejection of 99.1%.





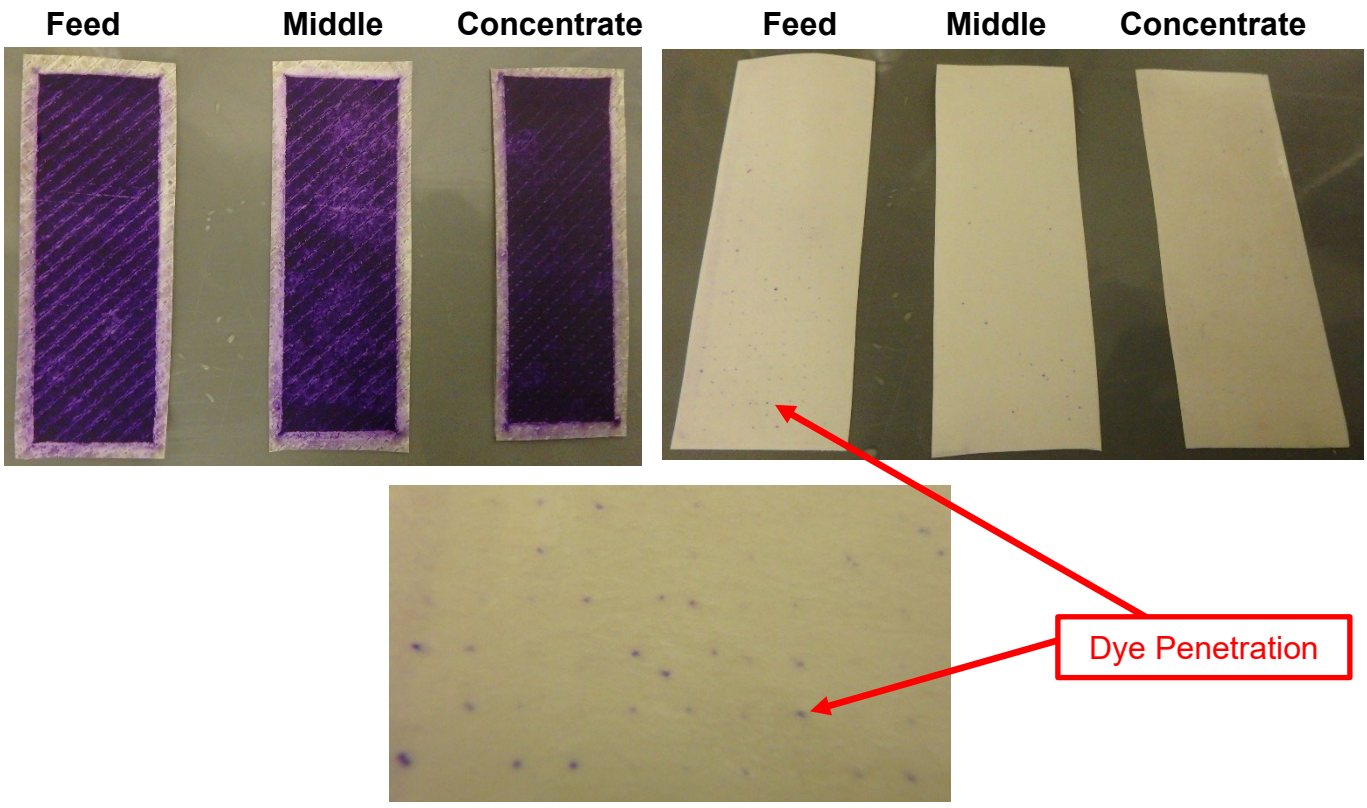
Membrane Dye Testing

Sections of membrane were cut from the feed, middle and concentrate ends of the element. Each was tested with a dye solution to determine if the membrane had been damaged.

Results: Membrane damage is present verified by dye test results as shown below.

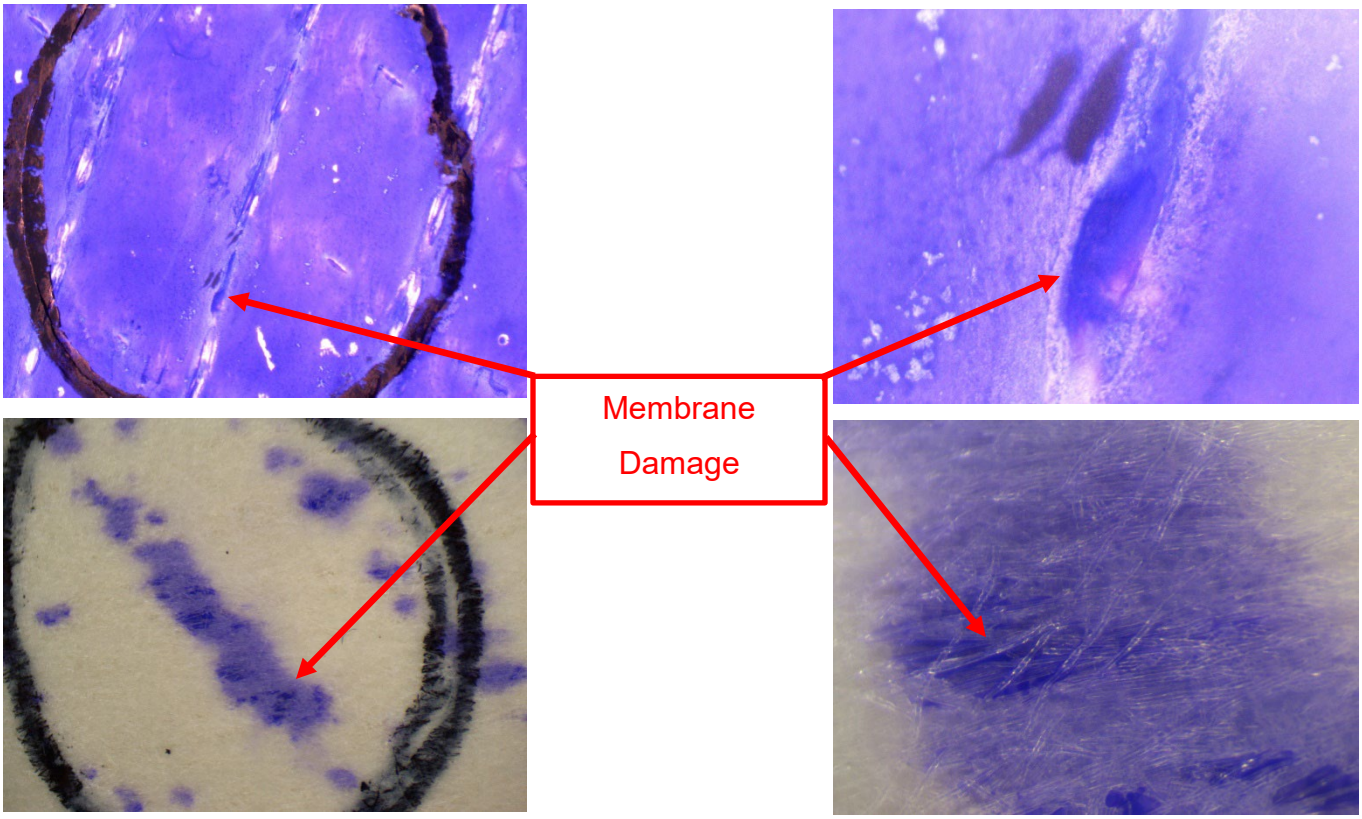
Feed Side: Shown on the top left below, the feed side of the membrane is typically highly stained due to bacteria and other foulants on the surface of the membrane. The purple color seen is normal for the feed water side of the membrane.

Permeate Side: Shown on the right below, Intact membrane will reject the relatively high molecular weight dye. The permeate side of the membrane is stained if there is membrane damage. This membrane has slight membrane damage.



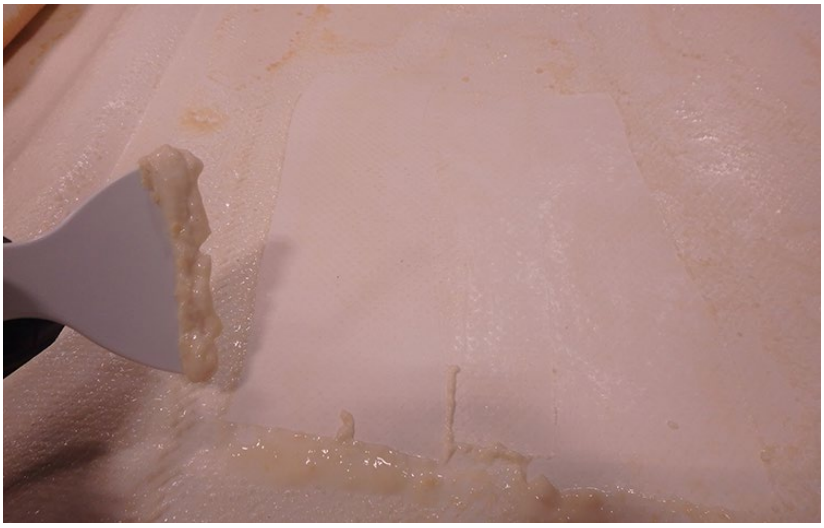
Stereomicroscopic Dye Penetration Analysis:

High-resolution stereomicroscopic photographs were captured to visually document the extent of membrane damage. The presented images depict close-up views of both the membrane surface and its backing in identical locations. The top images illustrate the feed water surface of the membrane, while the corresponding bottom images reveal the membrane backing within the same specified area. Images on the left are a wider shot, while images on the right are close-ups of the same area.



Foulant Evaluation

Appearance of Foulant: There was foulant present across all of the membrane. The membrane surface was scraped on one envelope to visualize the foulant as can be seen below. Foulant was then allowed to dry and scraped as can be seen by clicking on the second photo below to view the video.





Odor of Foulant: Amalgamation of scents, predominantly characterized by cleaning agents, solvents, or other chemical substances. Discernible traces of mild rancid milk in some areas and subtle hints of plastic and a faint alcohol undertone contribute to the overall odor.

Weight of Foulant: 0.00417 grams of foulant per cm^2 = 3.17lbs. foulant per element.
The foulant from one membrane sheet was dried in an oven, the dehydrated weight of the foulant measured 9.2885 grams.



Foulant WET



Foulant DEHYDRATED



Foulant ASHED

Loss on Ignition (LOI):

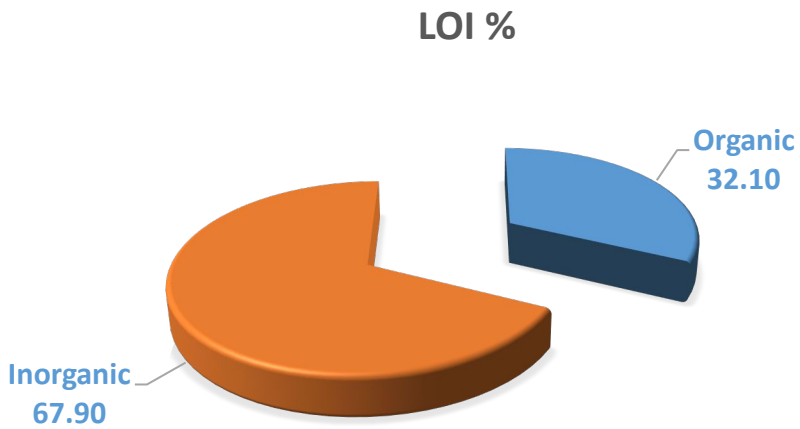
This modified LOI procedure involves taking all available foulant from a membrane leaf. This test compares the weight of the sample after drying to remove entrained water, with the weight after ashing at 550°C. Organic materials will ash at this temperature, but inorganic materials will not ash. LOI then, expressed as a percentage, is a measurement of the relative amount of organic material in the sample.

From this data, we are able to estimate the amount of foulant located within the membrane element. However, this estimation does not include foulant that is attached to the feed water spacer or the inactive glue lines. This also does not account for any foulant that couldn't be scraped from the membrane.

Results:

Loss on Ignition (LOI)	32.10%
Weight of foulant (wet) per sheet	1.4544g (0.00321lbs)

Based on the average weight of wet foulant per ft^2 of membrane, this element has around 72.72 grams (0.16lbs) of foulant on the active membrane alone. This foulant, on average, is around 32.10% organic.



Chemical Solubility Testing

When an RO membrane is dipped in NaOH caustic or HCl acid, color changes are often used as visual indicators of the membrane's condition, degree of fouling, the presence of certain contaminants, or degradation products.

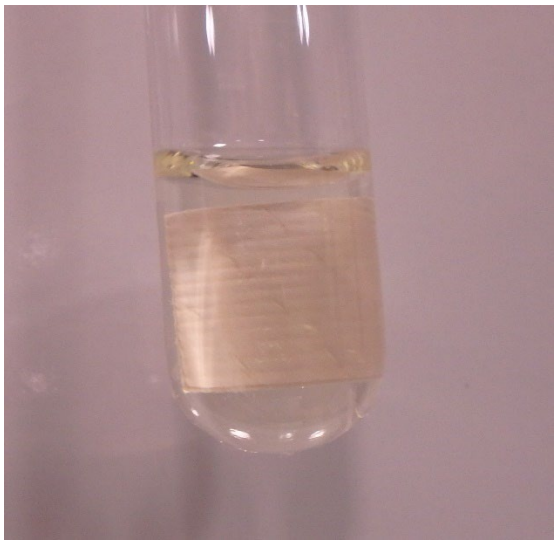
ACID & CAUSTIC	**White Gray**	Suggests the presence of inorganic scaling/fouling	Indicates the presence of mineral deposits. Acid often dissolves these scales, which might cause effervescence.
	Blue Green	Suggests the presence of transitional metals	Indicates the presence of copper, nickel (blue), or other transition metals.
	No Significant Color Change	The membrane could be in good condition, though it's still important to confirm performance through additional testing	The membrane is relatively clean or the fouling materials do not react visibly with the acid or caustic (silica).
CAUSTIC	**Yellow Light Brown**	Suggests that the membrane is fouled with organic/NOM material	Indicates the presence of organic foulants or natural organic matter (NOM), such as humic substances.
	Dark Brown Black	Suggests significant organic fouling, oxidized metals, OR membrane degradation	The presence of heavy organic fouling, the oxidation of certain metals such as iron, or could suggest membrane material degradation.
ACID	**Yellow Light Brown**	Suggests that the membrane is fouled with organic material/NOM OR iron or manganese	Indicates the presence of organic foulants or NOM such as humic substances OR iron or manganese deposits.
	Dark Brown Black	Suggests significant organic/biological fouling OR oxidized metals	Indicates heavy organic/ biological fouling OR oxidized metals, such as iron oxide (rust) or manganese deposits.
	Red Pink	Suggests the presence of iron-related fouling	Indicates the presence of iron bacteria or iron oxides.

Results:

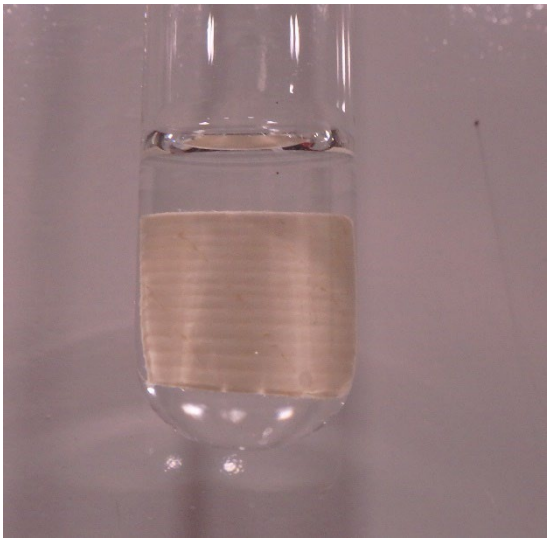
Samples taken from the membrane and the inorganic residue of the LOI are analyzed for their solubility in concentrated HCl acid and NaOH caustic solutions. The solubility and any color change in the solution provide insights into the composition and nature of the foulant.

Membrane Surface: No color change

HCl Acid



NaOH Caustic



LOI Residue: No color change

HCl Acid



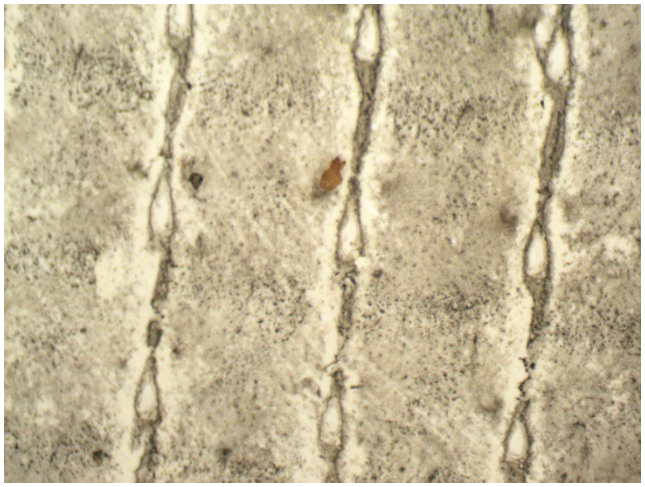
NaOH Caustic

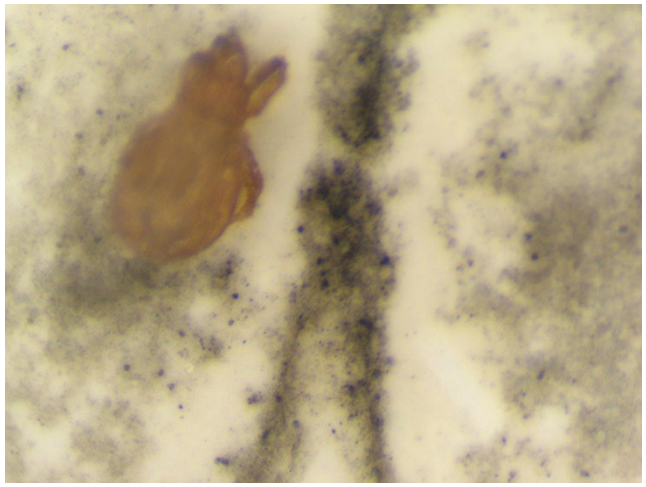


Microscopic Evaluation

Following the visual foulant inspection, the foulant was sampled and subjected to wet mount procedures and viewed under a compound light microscope. The dried membrane was also photographed using a stereomicroscope.

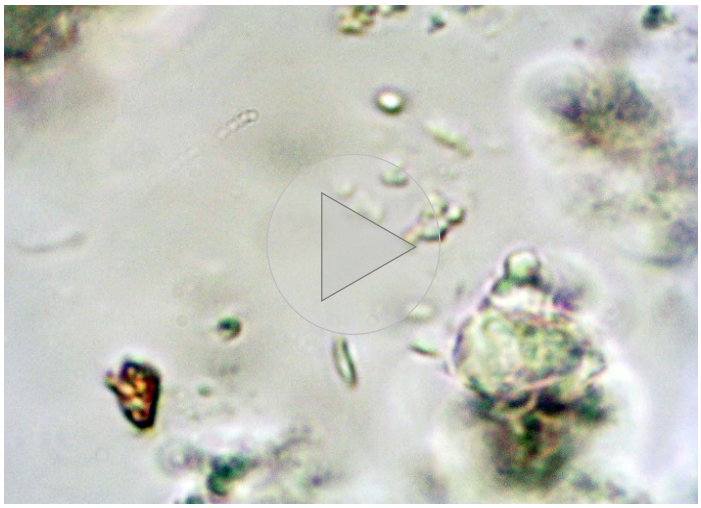
Stereomicroscopic Evaluation: Overall the membrane surface had significant amount of foulant as well as a bug. Stereomicroscopic photos of the foulant was taken. Photo on left is a wide shot of the foulant, and bug. Photo on right is close-up of the same area.





Compound Light Microscope Evaluation

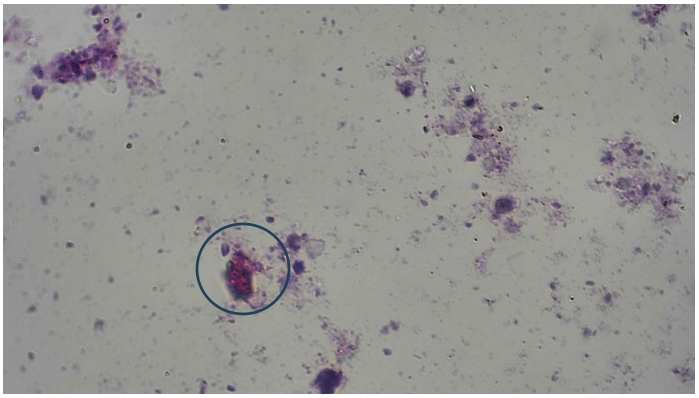
Wet Mount: Portions of the foulant were subjected to examination under a compound light microscope. Click the picture below to see the video clip for better visualization.

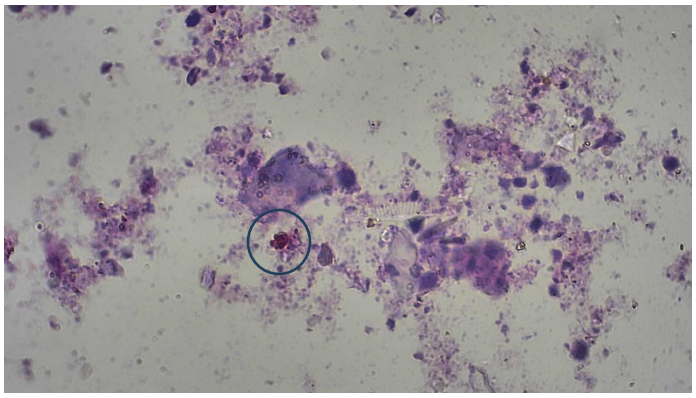


Gram Stain

The presence of Gram-positive or Gram-negative bacteria can provide insights into the types of microbial contaminants in the water and their potential impact on the treatment process

Gram-Positive Bacteria	Gram-Negative Bacteria
Appearance: Gram-positive bacteria retain the crystal violet stain and appear purple	Appearance: Gram-negative bacteria retain the counterstain, appearing pink or red
Cell Wall Structure: These bacteria have a thick peptidoglycan layer in their cell walls	Cell Wall Structure: These bacteria have a thinner peptidoglycan layer but possess an outer membrane containing lipopolysaccharides
Implications: The presence of Gram-positive bacteria could indicate contamination from organic material or soil. They might be less likely to survive in chlorinated water, but their resistance to physical stress might allow them to persist in biofilms within the system	Implications: The presence of Gram-negative bacteria might indicate potential contamination from fecal matter. Their resistance to chlorine and other disinfectants means that additional or alternative treatment methods (such as UV) may be necessary





Results: Mostly Gram-positive bacteria, with a few Gram-Negative, were observed

EDS & FTIR Analytical Summary

A 12” x 12” sample of membrane was removed from the element and tested using the following analyses:

1. **Energy Dispersive Spectroscopy (EDS):** This test uses an electron beam to determine the quantities of individual elements found in the sample.
2. **Scanning Electron Microscopy (SEM):** This test uses a highly focused electron beam to form a picture of the sample.
3. **Fourier Transform Infrared (FTIR):** This test compares the wavelength of the foulant/scalant found on the surface of the membrane sample against a library of other recorded wavelengths.

Results:

The purpose of this study was to identify the surface residue on two submitted samples. **The specimens for analysis were delivered on March 26, 2024 via FedEx courier and were identified as “LAB NUMBER”. Elemental compositions of the sample surface residues indicated primarily the presence of silica (SiO2) for both samples with low levels of other inorganic oxides and low levels of organic material. Sample “LAB NUMBER” had a higher level of silica coating. FTIR data show both residues to consist of mainly of silica (glass) as well with low levels protein, membrane material and cellulose. Elemental distribution maps did not indicate any discernable localized areas of particular elements amid the silica coating though the “LAB NUMBER” exhibited isolated regions of exposed membrane material based on the presence of carbon and sulfur.**

Scanning electron microscopy (SEM) uses a highly focused electron beam (less than 10nm diameter) which can be scanned in a raster on the sample surface. Interactions between the samples and the incident electrons lead to the ejection of low energy secondary electrons about the location of the incident electron beam. The intensity of secondary electrons produced at each point is used to form a picture of the sample. Magnification factors from 10X to 300,000X can be obtained. The depth of field is inherently quite large which allows the micrographs to be in focus at all points across a rough surface.

Energy dispersive x-ray spectroscopy (EDS) is an effective method for analyzing for the main components as well as low-level (nominally 0.1%) contaminants in relatively thick (several micron) layers. A focused beam of electrons is used to bombard a solid in order to knock out electrons from inner electron orbital shells of atoms in the near surface region of the sample. Electrons from outer shells can move into the inner shell vacancies as replacements for the ejected electrons. For each such atomic relaxation transition the energy difference between the outer and inner shell electrons is released by the atom. This energy is emitted either as a characteristic x-ray or as an outer shell electron which has absorbed the energy released by the atomic relaxation process. EDS spectra display an intensity versus energy plot of x-rays emitted by the sample bombarded by the electron beam of a scanning electron microscope (SEM). The vertical scale is x-ray intensity at each energy position. The horizontal scale runs from 0 to 20 or 0 to 10 keV and the x-ray peaks which appear on the spectrum have energies in the same range. Since each element emits x-rays of characteristic energies it is a simple matter to relate an x-ray peak to its corresponding element using a table of major x-ray emission energies. Only those elements boron and heavier in the periodic table are included in this study. The electron beam may be scanned in a raster on the sample while the spectra are collected or the beam scan may be disabled to allow analysis of a particular spot usually noted on a corresponding micrograph, if applicable.

Infrared spectroscopy (IR) studies the molecular vibration spectrum of a sample by passing infrared radiation through it and measuring the amount of absorption at each frequency. IR spectra generally include the range of 4000-400 cm-1. The detected bands relate directly to functional groups in the molecules of the sample under study. Specific organic and inorganic compounds can be identified by correlating observed band intensities and shapes to spectra found in published compilations or in internal studies of standard materials. Fourier transform infrared spectroscopy (FTIR) is an application of the IR technique in which the collected data is mathematically transformed with a background spectrum collected with no sample in the excitation beam. The difference in the two methods is primarily in the speed with which spectra of comparable signal-to-noise characteristics can be acquired with, FTIR being faster by at least two orders of magnitude.

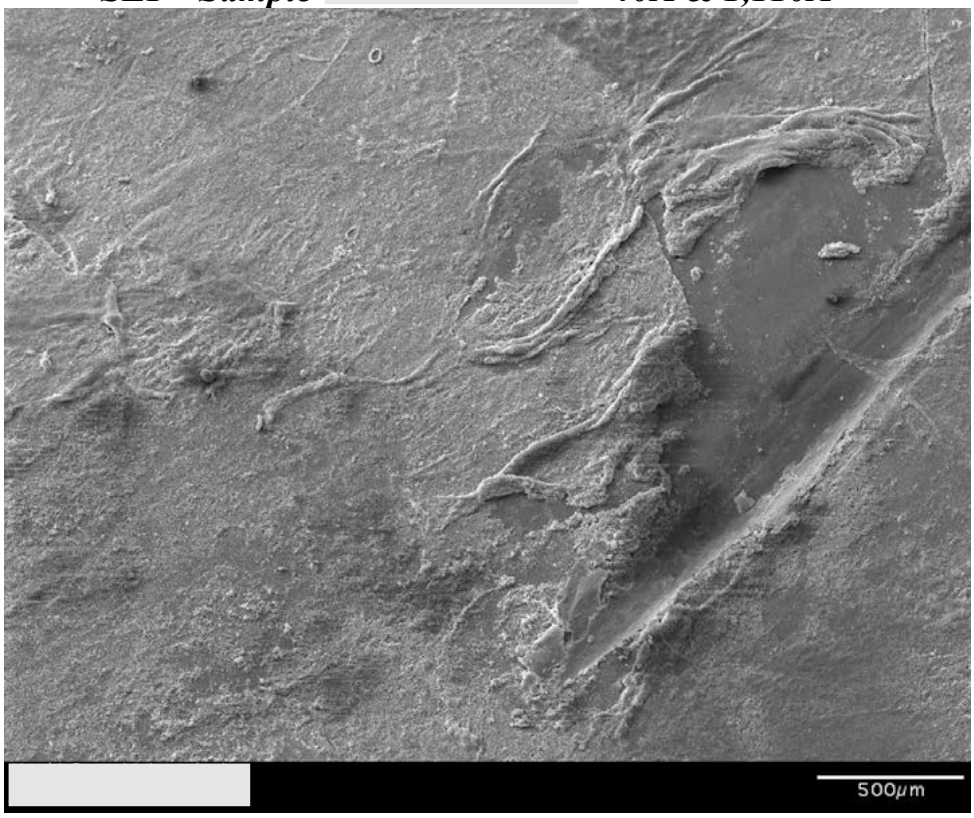
The as-received sample was cut to an appropriate size and placed onto the goniometer stage of a scanning electron microscope marketed by Topcon (ISI), Inc. of Paramus, NJ. EDS data were collected from the sample for elemental identification using a Si(Li) crystal detector manufactured by Gresham Scientific Instruments Ltd. of Buckinghamshire, UK coupled to a multichannel analyzer interface manufactured by 4pi Analysis, Inc. and resident in an Apple Macintosh® G4 workstation. After coating with a thin layer of gold for conductivity, SEM micrographs of the sample were collected into the modified Apple Macintosh® G4 workstation. An intermediate imaging interface manufactured by 4pi Analysis, Inc. of Durham, NC was used for the SEM and elemental distribution maps image collection. SEM Images are shown on page 33. Elemental distribution maps are shown on page 35.

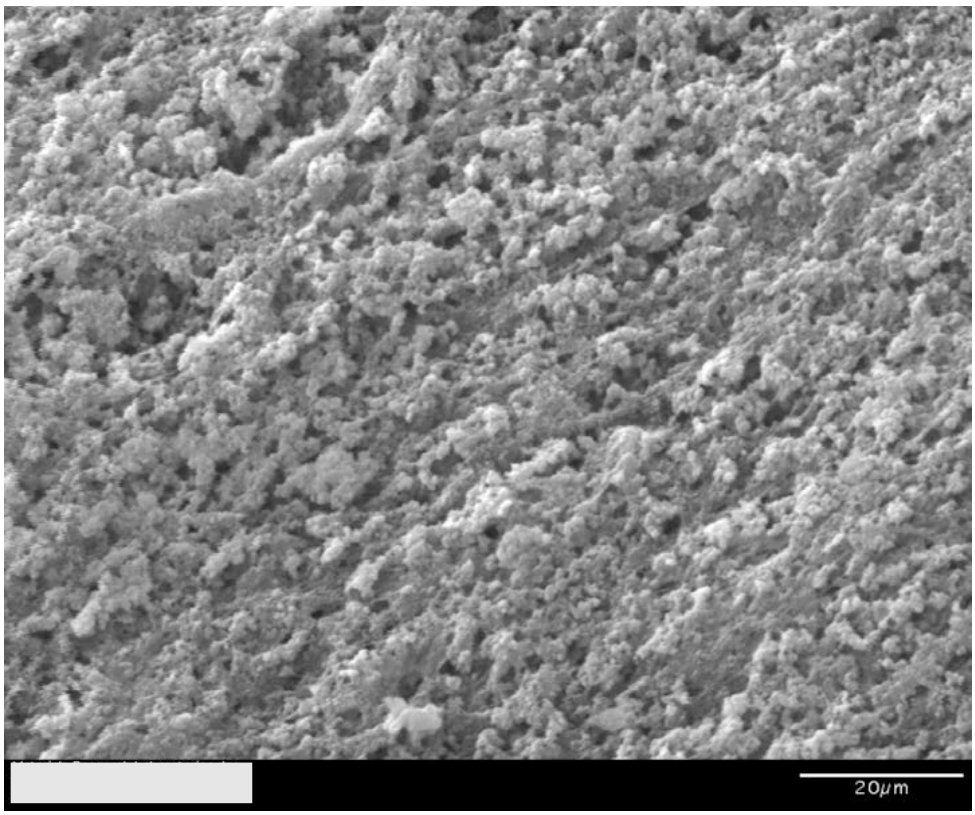
The EDS results have been summarized on Table 1, page 34. The data in the table are in weight concentration. Atomic and oxide concentrations can also be viewed in the actual spectral data on page 36. Table 2 on page 34 lists the normalized inorganic components of the 'residue' with carbon and oxygen excluded from the calculation as much of these elements' concentrations are most likely from the polyamide membrane. Table 3 on page 34 lists the normalized inorganic components of the 'residue' with carbon, oxygen, and sulfur excluded from the calculation as much of these elements' concentrations are most likely from the polyamide membrane and polysulfone backing strata.

For FTIR analyses, the foulant 'residue' left intact was placed into contact with the diamond analysis crystal in a Specac GoldenGate® reflectance cell that is resident in the analysis chamber of a Mattson Instruments Galaxy 5000 Series infrared spectrophotometer. Infrared absorbance data were obtained for the sample. Comparisons were made between the FTIR data obtained and reference spectra. FTIR data collected from the residue area left intact on the membrane are included on page 37. Reference spectra are included on page 38.

Scanning Electron Microscopy (SEM)

SEI – Sample [redacted] – 40X & 1,110X





Electron Dispersive Spectroscopy (EDS)

Table 1

ESTIMATED WEIGHT CONCENTRATIONS (%)
WITHIN 1-2µm EDS ANALYZED LAYER

SAMPLE	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe
	9.50	59.98	0.31	0.05	0.18	28.72	-	1.07	0.12	-	-	0.05
	1.54	54.24	0.23	0.08	0.24	43.20	-	0.30	0.05	-	-	0.03

Table 2

ESTIMATED WEIGHT CONCENTRATIONS (%)
Normalized without Carbon and Oxygen
WITHIN 1-2µm EDS ANALYZED LAYER

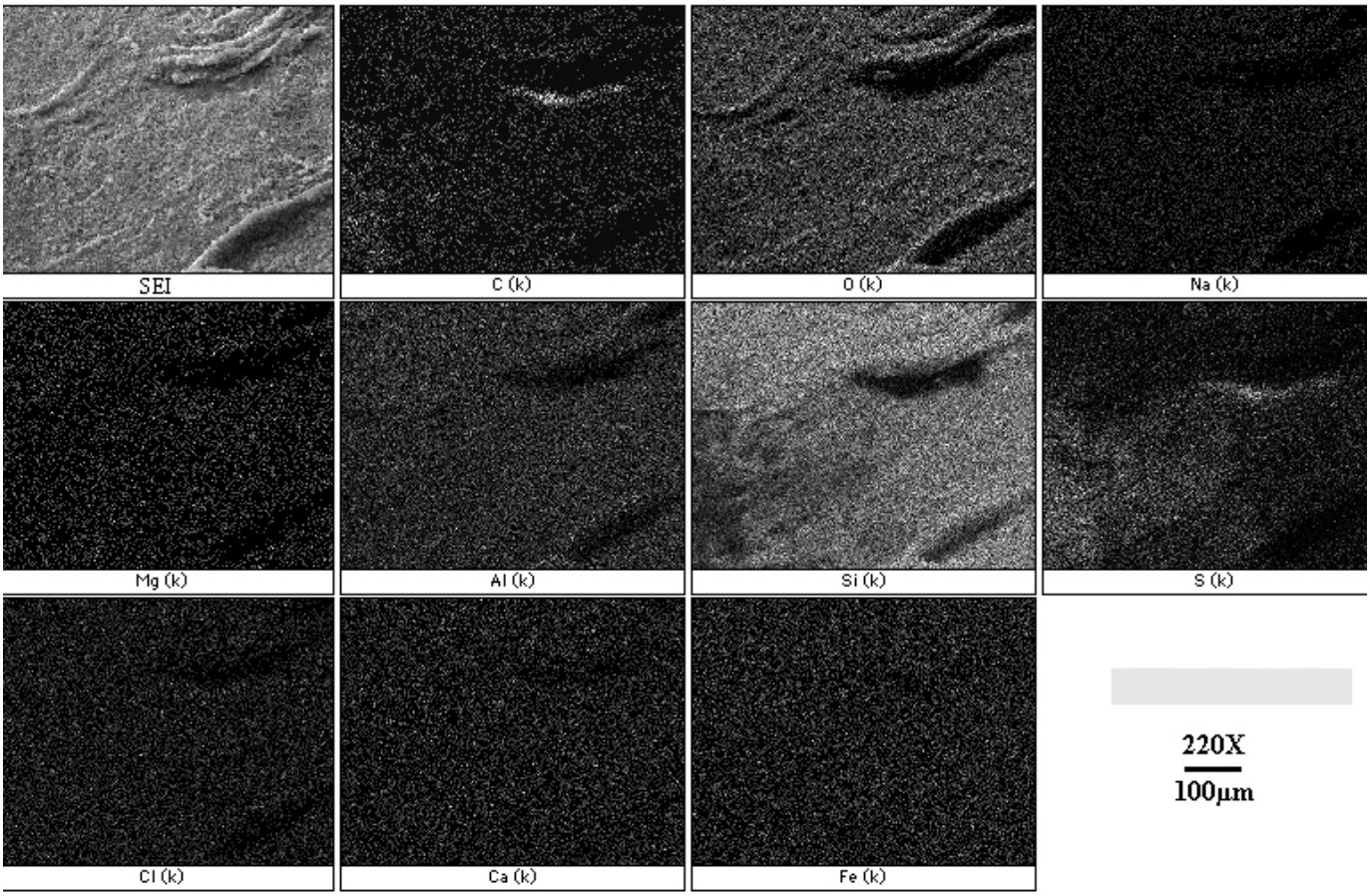
SAMPLE	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe
	-	-	1.02	0.16	0.59	94.16	-	3.51	0.39	-	-	0.16
	-	-	0.52	0.18	0.54	97.90	-	0.68	0.11	-	-	0.07

Table 3

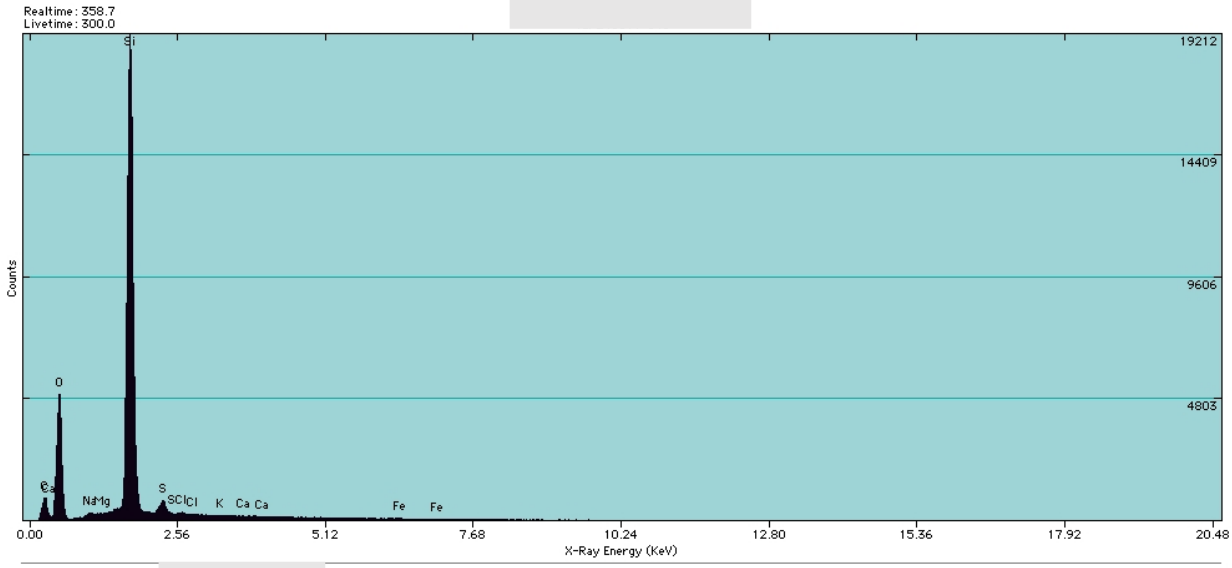
ESTIMATED WEIGHT CONCENTRATIONS (%)
Normalized without Carbon, Oxygen and Sulfur
WITHIN 1-2µm EDS ANALYZED LAYER

SAMPLE	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe
	-	-	1.05	0.17	0.61	97.59	-	-	0.41	-	-	0.17
	-	-	0.52	0.18	0.55	98.57	-	-	0.11	-	-	0.07

EDS Elemental Distribution Maps



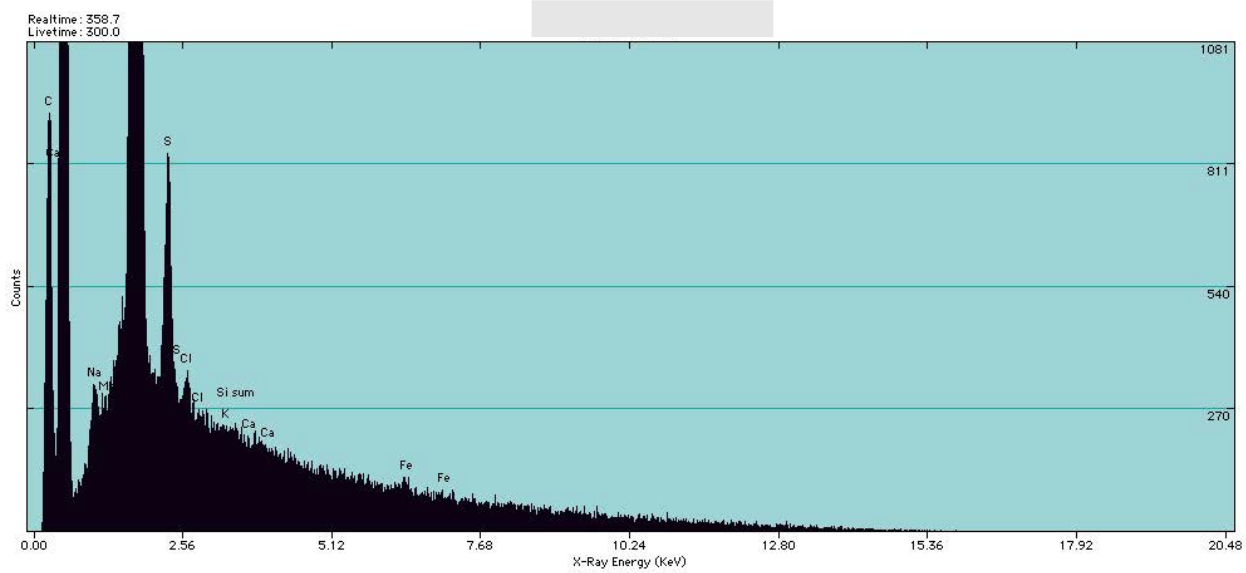
EDS Spectra



Quantitative Results for

Analysis: Bulk Method: Standardless
Acquired 26-Mar-2024, 20.0 KeV @10 eV/channel

Element	Weight %	Atomic %	Oxide %	
C	9.51	14.07	34.83	(CO2)
O	59.98	66.67	0.00	
Na	0.31	0.24	0.42	(Na2O)
Mg	0.05	0.04	0.09	(MgO)
Al	0.18	0.12	0.35	(Al2O3)
Si	28.72	18.18	61.44	(SiO2)
S	1.07	0.60	2.68	(SO3)
Cl	0.12	0.06	0.12	
K	0.00	0.00	0.00	(K2O)
Ca	0.00	0.00	0.00	(CaO)
Fe	0.05	0.02	0.07	(Fe2O3)
Total	100.00		100.00	



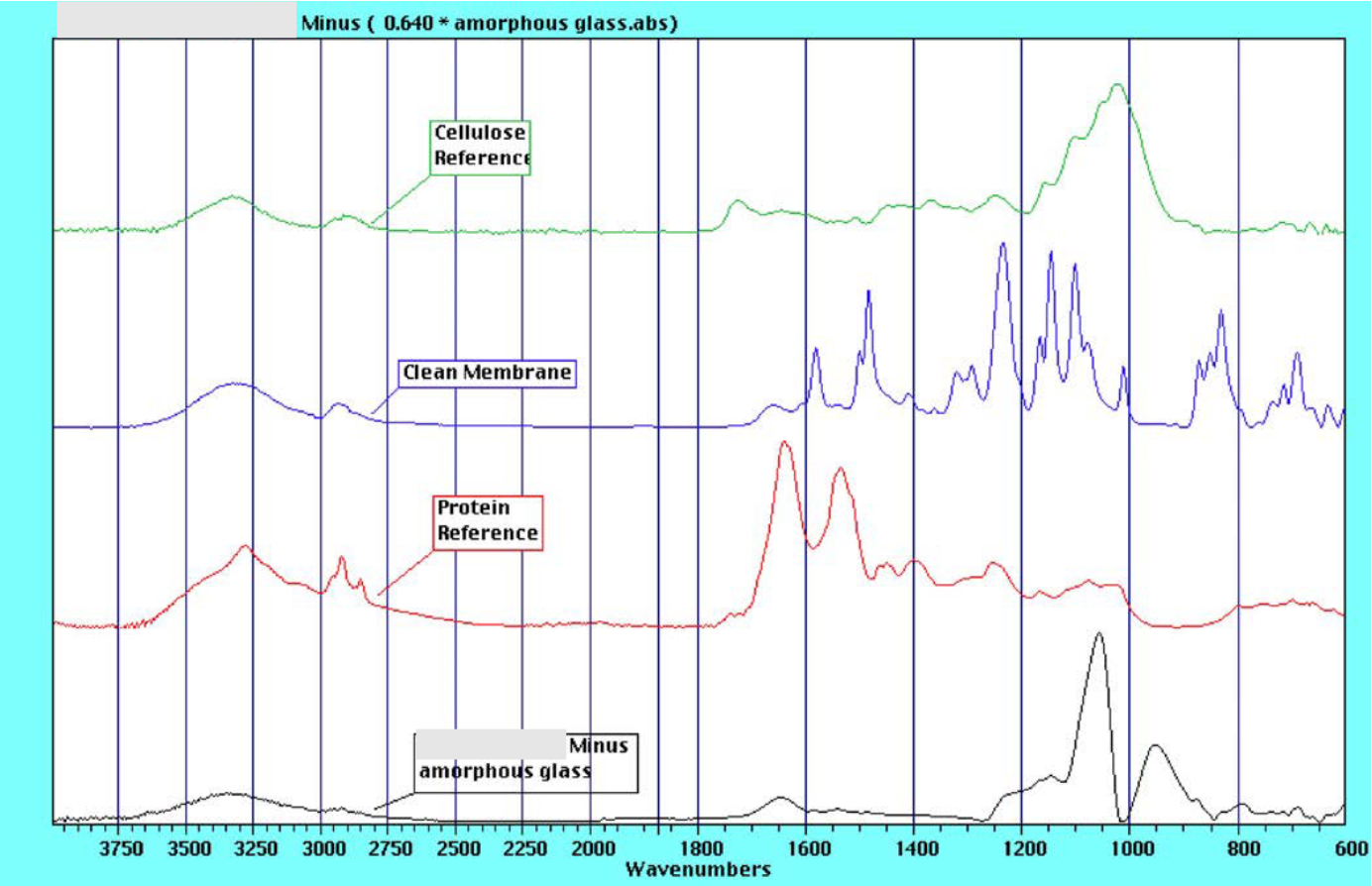
Quantitative Results for

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C	9.51	14.07	34.83	(CO2)
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Al	0.18	0.12	0.35	(Al2O3)
Si	28.72	18.18	61.44	(SiO2)
S	1.07	0.60	2.68	(SO3)
Cl	0.12	0.06	0.12	
K	0.00	0.00	0.00	(K2O)
Ca	0.00	0.00	0.00	(CaO)
Fe	0.05	0.02	0.07	(Fe2O3)
Total	100.00		100.00	

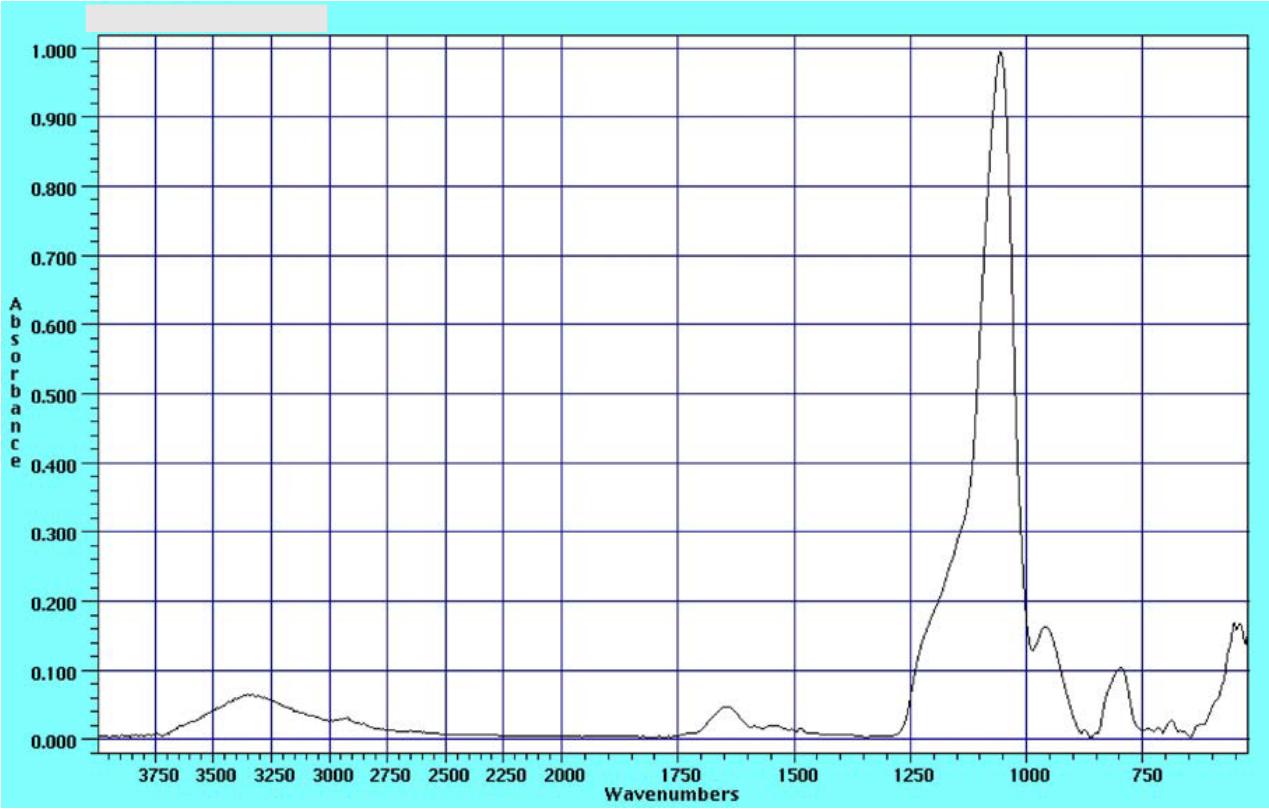
Fourier Transform Infrared (FTIR)

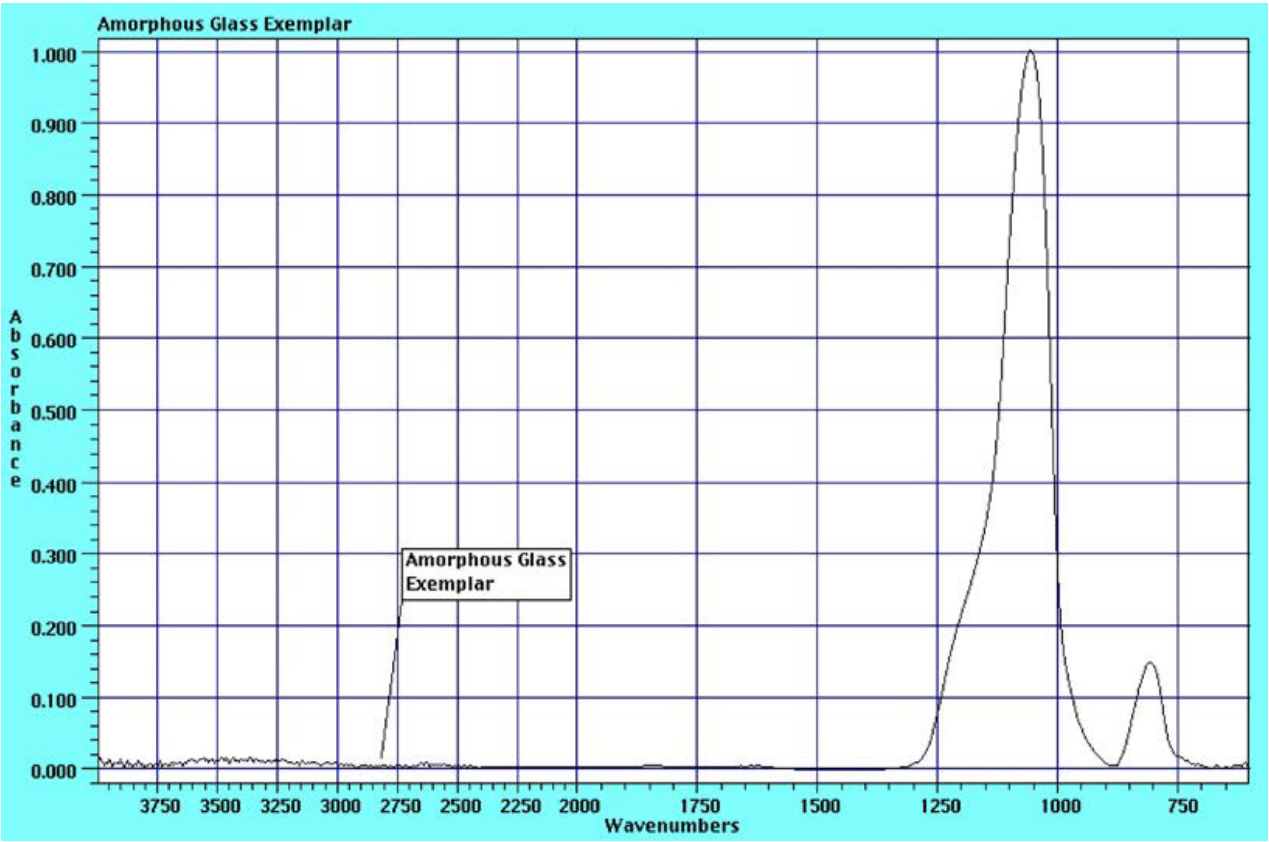
FTIR SPECTRA (Diamond Analysis)



The Membrane Sample residue was found by FTIR to consist primarily of silica (glass) with low levels of protein and membrane material also visible after subtraction of amorphous glass from the residue signal (see below). No significant cellulose is noted though some additional peaks may indicate a variant in the glass structure

FTIR REFERENCE SPECTRA





Statement of Results

Introduction

CLIENT sent David H. Paul, Inc. (DHP) the membrane element listed below for autopsy.

Model Number: _____

Serial Number: _____

Element Position: _____

Time in Service: _____

Based on the information provided by CLIENT, the RO unit:

- Feed water was well water from ----------
- Feed water was chlorinated
- Feed water temperature range was 60-70ºF
- Was a double pass system
- Total system differential pressure is 53psi
- The membrane has been in service for 8 months
- Hours of operation was 6 hours per day
- Longest period of shut down for the RO unit was 12 days
- Chemical cleanings are performed every 3 months
- Scale inhibitor is used
- Post-shutdown flush was performed using demineralized water

Purpose

“Not getting good permeate water. SP. Cond of first pass use to be around 40 now it is around 60-120. Second pass permeate water is at 4-5.5”

“Extreme fouling on the front side of the element, leading to mechanical damage and failure of the elements, starting with the first element and going all the way to the sixth. Biological contaminants permeate through the element and cover the front face of the next element in line. Daily biocide injections at 100ppm and regular RO cleaning is not preventing the biological build up or removing it once it occurs.”

Summary of Findings

Findings:

- Prior to disassembly, the element weighed 32.40lbs
- All membrane leaves had mild amounts of evenly distributed foulant
- All leaves had membrane blistering on the concentrate end
- The permeate side of the membrane showed some discoloration on the concentrate end
- Average water flux was 18.71 gfd. 28.75 is the expected gfd for this element
- Average NaCl rejection was 96.48% (salt passage 3.52%). 99.3% is maximum expected with a minimum of 99.1% (maximum salt passage 0.9%) for this element (almost 4 times maximum expected salt passage)
- Results from dye testing showed dye penetrated the membrane, which indicates membrane damage
- There were microorganisms according to protein being found using FTIR analysis and microscopy wet mounts
- LOI analysis indicated the membrane surface foulant tested was 32.10% organic (67.90% inorganic)
- EDS elemental analyses identified inorganic particulate matter including Na, Mg, Al, Si, P, Cl, K, Ca, and Fe
- The FTIR signatures indicate that the organic foulant consisted primarily of protein

Discussion

The exterior inspection of the element suggests; 1. The element was allowed to sit for some time with concentrate/reject water present (calcium carbonate scale present). 2. The element had been handled roughly at some point (slight damage to ATDs). Neither of these indications appear to have had any negative impact on performance.The following problems were observed during the interior autopsy of the element. Fouling (rust/tan colored), membrane damage (blistering and holes), channeling, and cracked fiberglass.

Fouling

The rust/tan colored foulant was evenly dispersed throughout the membrane element. Lab analysis found that the foulant was a mix of biological material and inorganic material. The biological fouling could be a result of excess sulfite injection or RO idle time. The inorganic fouling could be particulates in the feed water that are not removed by the RO pretreatment equipment and iron oxides either in the incoming feed water or picked up from steel/iron piping, if present, in the pretreatment system.

Channeling

Multiple envelopes had plugging and channeling occurring resulting in the feed spacer being pushed toward the concentrate end of the element. If other elements in the RO unit exhibit channeling (gaps between envelopes on the feed end and/or feed spacer extruding from the concentrate end) they would most likely not be able to be cleaned back to new or near-new condition. They would most likely need to be replaced.

Membrane Damage

Visual inspection and the dye test suggest membrane damage is due to blistering and holes possibly from iron oxides. Blistering of the membrane surface is usually caused by permeate pressure exceeding the feed/concentrate pressure. These blisters not only reduce the effective surface area, but likely led to further membrane breaches that allowed contaminants to pass directly into the permeate stream. The salt passage percentage on the water flux analysis suggests that the differential pressure seen by the membrane was not much higher than 5 psi, as ruptured blisters often have a much higher percentage than indicated here. Iron oxide could also be contributing to membrane damage, as indicated by the dye test results, with dye penetration observed on the feed-end strip even where blisters were not present.

Cracked Fiberglass

The presence of cracked fiberglass wrapping on the membrane signals potential vulnerabilities in its casing. These cracks can be caused by mechanical stress during handling or installation, excessive pressure fluctuations within the system, or prolonged exposure to harsh operating conditions. This can result in compromise to the membrane's ability to filter contaminants effectively and can lead to further damage or failure. Implementing preventive measures such as proper handling procedures, regular maintenance checks, avoiding water hammer, and monitoring of operating conditions can help mitigate the risk of damage to membrane housings.

Conclusion

The element showed flux loss likely due to fouling from silt, iron oxides and microbes. This suggests a review of the RO pretreatment equipment and its operation. If the membrane has been recently cleaned, the cleaning approach may be ineffective. The element also has significantly decreased salt rejection (salt passage almost 4 times the maximum expected). This could be due to permeate pressure exceeding feed/concentrate pressure at some point, causing blistering of the membrane. The design and operation of the RO unit should be evaluated to identify how this occurred. Steps should be implemented to remedy the issue to prevent further damage to current membranes, or pre-mature damage to new membranes.

Recommendation

(Optional, additional $500 + NM taxes with 30-minute consulting call)

- Inspect all elements, replace any or all elements that exhibit channeling
- CIP all elements that do not exhibit channeling with a high pH silica cleaning solution and high pH cleaning solution for biologicals
- Perform SDI (silt density test) before and after all pretreatment equipment to help troubleshoot pretreatment. After each piece of pretreatment equipment (including chemical injection points if any), the SDI value should decrease, or at minimum, stay the same. An increase of SDI after any pretreatment equipment indicates a problem. An SDI of <5 is minimal with an SDI of <3 being optimal for feeding into an RO unit
- Clean and sanitize the piping after the sodium bisulfite injection point to ensure that biological growth is controlled in the feed piping
- Do not over feed sodium bisulfite as this can contribute to certain bacterial growth. Keep a bisulfite residual of no more than 1.3 ppm
- Evaluate and install a silica scale inhibitor and/or dispersant to control silica/silicate scaling/fouling
- With the problems identified in this autopsy, it would be beneficial to have an experienced DHP consultant come on-site to help SWT correct the problems as quickly as possible

Release of Liability

The Membrane Autopsy Service (The Service) was performed in accordance with the standards of care, skill, and diligence normally provided by a professional in the performance of similar services. David H. Paul, Inc. makes no warranty of any kind with the respect to The Service and will not be liable for any damages resulting from the use or misuse of The Service. In no event shall David H. Paul, Inc. have any liability for The Service, including, but not limited to, special, indirect, incidental, consequential, or other direct damages whether such liability arises in contract, negligence, strict liability, or otherwise, and the Client hereby agrees to release and indemnify David H. Paul, Inc. against same.

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