David H. Paul, Inc.

# Chemical Compatibility Study & Antiscalant Performance Challenge

# EXAMPLE Report

Prepared for:

## Client

**DATE**



## Table of Contents

Executive Summary ..... 2
Tracking ..... 3
New/Virgin Membrane Element ..... 4
Model Number ..... 4
Serial Number ..... 4
MEMBRANE MANUFACTURER Specification Sheet ..... 5
Chemical Information ..... 5
Product Data Sheet ..... 5
Safety Data Sheet ..... 5
Certificate of Analysis ..... 5
Procedures ..... 6
Two-Hour Cleaning Test ..... 6
Two-Week Soak Test ..... 7
Antiscalant Performance Challenge ..... 8
Statement of Results ..... 11
Introduction ..... 11
Chemical Compatibility Study ..... 11
Antiscalant Performance Challenge ..... 12
**: 77°F Control and 5ppm chemical concentration** ..... 13
**: 95°F Control and 20ppm chemical concentration** ..... 19
**: 77°F - 95°F Control and 5ppm chemical concentration** ..... 25
**: 95°F Control and 20ppm chemical concentration** ..... 31
**Acid Testing** ..... 37
Summary of Findings ..... 38
Conclusion ..... 39
Release of Liability ..... 40
DHP, Inc. Contacts ..... 40

## Executive Summary

A comprehensive chemical compatibility study was conducted by David H. Paul, Inc. (DHP) to evaluate the effects of CLIENT CHEMICAL on a reverse osmosis membrane element. This study included a two-hour cleaning procedure followed by a two-week soak test. The results indicate that CLIENT CHEMICAL is compatible with the MEMBRANE MANUFACTURER membrane element, with no observed chemical damage to the membrane.

Furthermore, an antiscalant performance challenge was conducted to evaluate the efficacy of CLIENT CHEMICAL in preventing the precipitation of scalant, specifically calcium carbonate, onto the membrane surface. Two different feedwaters were used at two different concentrations each. Testing on FEEDWATER #1, indicated that dosages of 5 ppm and 20 ppm were both insufficient in preventing calcium carbonate scale formation, likely due to elevated copper levels. Similarly, FEEDWATER #2, indicated that a dosage of 5 ppm was insufficient to prevent calcium carbonate scaling, also presumably due to copper levels. However, it appears that a dosage of 20 ppm may have been adequate to mitigate scale formation.

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

# Tracking

Contact Person:

Contact Phone Number:

Contact E-mail:

Date Study Initiated:

Date Final Report Delivered:

# New/Virgin Membrane Element

## Model Number




## Serial Number



## MEMBRANE MANUFACTURER Specification Sheet

ENTERED HERE

# Chemical Information

ENTERED HERE

### Product Data Sheet

ENTERED HERE

### Safety Data Sheet

ENTERED HERE

### Certificate of Analysis

ENTERED HERE

# Procedures

## Two-Hour Cleaning Test

1) Cut all membrane coupons needed, making some extra for errors. Prior to beginning the study, soak all coupons in DI Water for a minimum of 24 hours

2) Perform the **Two-Hour Cleaning Test** using the following procedure: *A total of six (6) tests*
   a. Run control test for 15 minutes.
      i. Hook cell blocks to a standard test feed tank
      *See membrane specification sheet for testing conditions for that particular manufacture and model*
      ii. After a maximum of 3 hours to stabilize the membrane, run timed test for 15 minutes
      *Note: Stabilized membrane is considered when conductivity of the permeate stays within 0.9 µS for two measurements 10 minutes apart*
      iii. Log results for Water Flux and Salt Passage

**NOTE: Run 2 sets of coupon tests as control standard only. Run 2 more sets of coupon tests starting with the control standard, then begin running 2hr cleaning test directly after, connecting to DI rinse tank and rinsing before connecting to cleaning solution tank**

   b. Mix Client's cleaning material with DI water as specified by Client and corresponding Test with DOUBLE THE NORMAL STRENGTH.
   *See client's cleaning solution & strength specifications, and double it for the test*

   c. Clean with the cleaning solution
      i. Switch the cell blocks to the cleaning solution feed tank
      ii. Run test for 2 hours at 50 psi at 77° F
      iii. Log pH and temperature every 15 minutes

   d. Rinse membrane of the cleaning solution using DI water
      i. Switch the cell blocks to a DI rinse tank
      ii. Run concentrate and permeate to drain
      iii. Rinse until concentrate and permeate are the same conductivity as the DI feedwater

   e. Retest membrane at the standard test conditions for 15 minutes
      i. Switch the cell blocks to a standard test tank
      ii. After a maximum of 3 hours to stabilize the membrane, run timed test for 15 minutes
      iii. Log results for Water Flux and Salt Passage for each test

   f. If water flux and/or salt passage increase 10% or more, run a dye test to visualize membrane damage
      i. Switch membrane coupons to dye test and run for 15 minutes at 100 psi
      ii. Photograph results (use stereomicroscope if dye penetration is present)

   g. Repeat tests starting at line a above two (2) more times

## Two-Week Soak Test

1) Cut all membrane coupons needed, making some extra for errors. Prior to beginning the study, soak all coupons in DI Water for a minimum of 24 hours
   *NOTE: Skip this if already completed during the "Procedure Two-Hour Cleaning Test". Ensure enough coupons are soaked for all tests needed.*

2) Perform the **Two-Week Soak Test** using the following procedure: *A total of six (6) tests*

   a. Soak more than two sets (6) of membrane coupons in normal strength cleaning solution at a typical room temperature of 70 - 77° F for two weeks.
      *NOTE: monitor soaking progress and ensure coupons stay fully submerged as to not dry out*

   b. Rinse the cleaning solution from ALL coupons
      i. Flush both sides of membrane with DI water to flush cleaning solution off surfaces
      ii. Soak membrane in DI Water for 10 minutes
      iii. Take conductivity of rinse water
      iv. Repeat step ii until conductivity of DI rinse water does not change after 10-minute soak
      v. Let membrane soak a minimum of 24 hours in DI water

   c. Test membrane at the standard test conditions
      i. Place membrane coupons in cell blocks and hook to a standard test feed tank.
         *See membrane specification sheet for testing conditions for that manufacture and model*
      ii. After a maximum of 3 hours to stabilize the membrane, run the timed test for 15 minutes
         *Note: Stabilized membrane is considered when conductivity of the permeate stays within 0.9 µS for two measurements 10 minutes apart*
      iii. Log results for Water Flux and Salt Passage for each cell block

   d. If water flux and/or salt passage increase 10% or more, run a dye test to visualize membrane damage
      i. Switch membrane coupons to dye test and run for 15 minutes at 100 psi
      ii. Photograph results (use stereomicroscope if dye penetration is present)

   e. Repeat steps starting at line c above one (1) more time

# Antiscalant Performance Challenge

## SCOPE OF SERVICE

DHP will Perform the **Antiscalant Performance Challenge** using the following procedure: *A total of twenty-four (24) tests; one (1) control/baseline per two (2) given concentrations per two (2) feedwaters.*

1) Cut all membrane coupons needed, making some extra for errors. Prior to beginning the study, soak all coupons in DI Water for a minimum of 24 hours

2) Run **control/baseline** using feedwater

    a. Measure turbidity of DI water using a Pyxis SP-800 spectrophotometer for a baseline

    b. Measure the following on the provided feedwater
        i. pH using a Myron-L meter
        ii. Conductivity using a Myron-L meter
        iii. Turbidity using a Pyxis SP-800 spectrophotometer
        iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
        v. TDS using evaporation method
        vi. Temperature using a Myron-L meter
        vii. Calcium Hardness using titration methods
        viii. Alkalinity using titration methods

    c. Calculate the scaling potential (Langelier Saturation Index, Barium Sulfate, and Silica) on the provided feedwater
        i. Enter the provided feedwater analysis into DuPont's WAVE design software program to calculate the feed water LSI and the concentrate LSI at 75%, 80%, 85%, and 90% recovery
        *Prior to shipping the sample, the Client will provide a full feedwater analysis, as well as the pH and temperature taken at the time of sampling*

    d. Hook cell blocks to a standard test feed tank. After running a minimum of 3hrs to stabilize the membrane, run timed test for 15 minutes. *See membrane specification sheet for standard testing conditions (psi & flow), or consult with Client for desired conditions*
    *Note: Stabilized membrane is considered when conductivity of the permeate stays within 0.9 µS for two measurements 10 minutes apart*
        i. Log results for Water Flux and Salt Passage

    e. After stabilization test, record the following on the feedwater;
        i. pH using a Myron-L meter
        ii. Conductivity using a Myron-L meter
        iii. Turbidity using a Pyxis SP-800 spectrophotometer
        iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
        v. TDS using evaporation method
        vi. Temperature using a Myron-L meter

f. Send the permeate to drain, and continue recirculating the concentrate
   i. Monitor the turbidity of the concentrate, take a set of readings every 15 minutes
   ii. Test water flux and percent salt passage readings every 2 hours

g. The baseline is complete once normalized flux decreases at least 10%, turbidity of the concentrate increases, and/or salt rejection decreases 0.7%, all indicating scaling. Notate time taken to reach scaling point

*NOTE: Turbidity is dependent on the type of scale formation. If scale adheres to the membrane surface, turbidity will remain unaffected. While differential pressure (ΔP) is typically used as an indicator, it is not a reliable measurement in this case due to the minimal ΔP observed with the small surface area of cell block testers*

h. Record the following after completion of the control/baseline;
   i. pH using a Myron-L meter
   ii. Conductivity using a Myron-L meter
   iii. Turbidity using a Pyxis SP-800 spectrophotometer
   iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
   v. TDS using evaporation method
   vi. Temperature using a Myron-L meter

*3)* Begin the **Antiscalant Performance Challenge**

a. Read and record the following on the provided feedwater before mixing Client's antiscalant;
   i. pH using a Myron-L meter
   ii. Conductivity using a Myron-L meter
   iii. Turbidity using a Pyxis SP-800 spectrophotometer
   iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
   v. TDS using evaporation method
   vi. Temperature using a Myron-L meter

*b.* Mix Client's scale inhibitor with feedwater provided as specified by Client and corresponding test, then read and record the following of the mixed solution; *Either Either 5ppm OR 20ppm*
   i. pH using a Myron-L meter
   ii. Conductivity using a Myron-L meter
   iii. Turbidity using a Pyxis SP-800 spectrophotometer
   iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
   v. TDS using evaporation method
   vi. Temperature using a Myron-L meter

c. Hook cell blocks to a standard test feed tank. After running a minimum of 3hrs to stabilize the membrane, run timed test for 15 minutes
    i. Log results for Water Flux and Salt Passage

d. After stabilization test, record the following;
    i. pH using a Myron-L meter
    ii. Conductivity using a Myron-L meter
    iii. Turbidity using a Pyxis SP-800 spectrophotometer
    iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
    v. TDS using evaporation method
    vi. Temperature using a Myron-L meter

e. Begin the antiscalant performance challenge test
    i. Send the permeate to drain, and continue recirculating the concentrate
    ii. Monitor the turbidity of the concentrate, take a set of readings every 15 minutes
    iii. Take a set of water flux and percent salt passage readings every 2 hours
    iv. The challenge is complete once the same amount of time has elapsed as the control/baseline

f. Ending analyses: Record the following after completion of the test;
    i. pH using a Myron-L meter
    ii. Conductivity using a Myron-L meter
    iii. Turbidity using a Pyxis SP-800 spectrophotometer
    iv. Metal levels using a spectrophotometer (iron, copper, & aluminum)
    v. TDS using evaporation method
    vi. Calcium Hardness using titration methods
    vii. Alkalinity using titration methods

g. Calculate the LSI (Langelier Saturation Index) on the concentrated feedwater in the tank. This figure may not be entirely reliable, but it could provide valuable insights.

h. Repeat test starting at step 1) above for different feed rate and/or different feedwater

4) Provide Client with report of findings

# Statement of Results

## Introduction

David H. Paul, Inc. (DHP) used the new/virgin unexposed membrane element listed below for chemical compatibility and antiscalant performance challenge.

**Model Number:**

**Serial Number:**

## Chemical Compatibility Study

| | Membrane **Maximum** Specification (see manufacture's Spec. sheet) | Membrane **Minimum** Specification (see manufacture's Spec. sheet) | **Initial** Performance @ Manufacture's Standard Test Conditions | After Chemical Compatability Study ***"Final"*** | Percent Difference from **Final** to **Maximum** Spececificaton | Percent Difference from **Final** to **Minimun** Specification | Percent Difference from **Initial** to **Final** Cell Test | **Initial Normalized Salt Rejection** | Difference from **Normalized Salt Rejection** to **Maximum** Specification |
|---|---|---|---|---|---|---|---|---|---|
| Salt Rejection (%) | 99.70% | 99.50% | 98.74% | 98.66% | -1.05% | -0.84% | **-0.08%** | 98.95% | -0.75% |
| Salt Passage (%) | 0.30% | 0.50% | 1.26% | 1.34% | 126.68% | 91.11% | **6.22%** | 1.05% | 0.75% |
| Permeability (gfd/NDP) | 0.152 | 0.121 | 0.106 | 0.107 | -34.68% | -12.70% | **0.57%** | | |
| Membrane Flux (gfd) | 30.588 | 24.471 | 21.43 | 21.55 | -34.68% | -12.70% | **0.57%** | | |

| **Standard Test Conditions** | |
|---|---|
| NaCl Total Dissolved Solids, TDS *(ppm)* | |
| Standard Spec *(psi)* | |
| Permeate Pressure *(psi $P_o$)* | |
| Net Driving Pressure, NDP *(psi)* | 201.76 |
| Stated Membrane Area *($ft^2$)* | |
| Stated Flux @ Standard Test Conditions *(gpd)* | |
| Flow rate *(mL/min)* | |
| pH | |
| Temprature *(°F)* | |
| Temprature *(°C)* | 25.07 |
| Temp Correction Factor | 1.002064042 |

| **Cell Test Data - Average of ALL Membrane Coupons** | | | | | |
|---|---|---|---|---|---|
| | **Initial/Control** | **After Two-Hour Cleaning** | Percent Difference from **Initial** to **Two-Hour** | **After Two-Week Soak** | Percent Difference from **Initial** to **Two-Week** |
| Feed Conductivity | 3866 | 3876 | | 3848 | |
| Perm Conductivity | 48.56 | 47.81 | -1.56% | 55.40 | 13.16% |
| Flux 15 minutes mL: | 17.6 | 17.7 | 0.57% | 17.7 | 0.57% |
| % Salt Rejection: | 98.74% | 98.77% | **0.02%** | 98.56% | **-0.19%** |
| Flux 15 minutes gfd: | 21.43 | 21.55 | **0.57%** | 21.55 | **0.57%** |

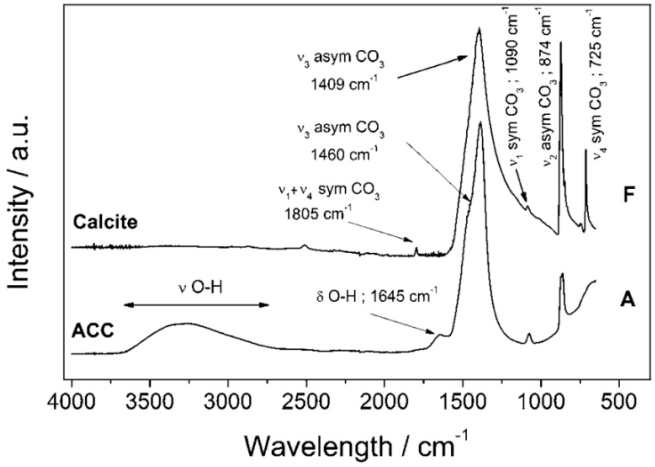
Chemical compatibility testing revealed that CLIENT CHEMICAL resulted in a 0.57% increase in membrane flux and a 0.08% decrease in salt rejection. These findings indicate that the chemical is compatible with the new/unexposed MEMBRANE MODEL membrane element.

## Antiscalant Performance Challenge

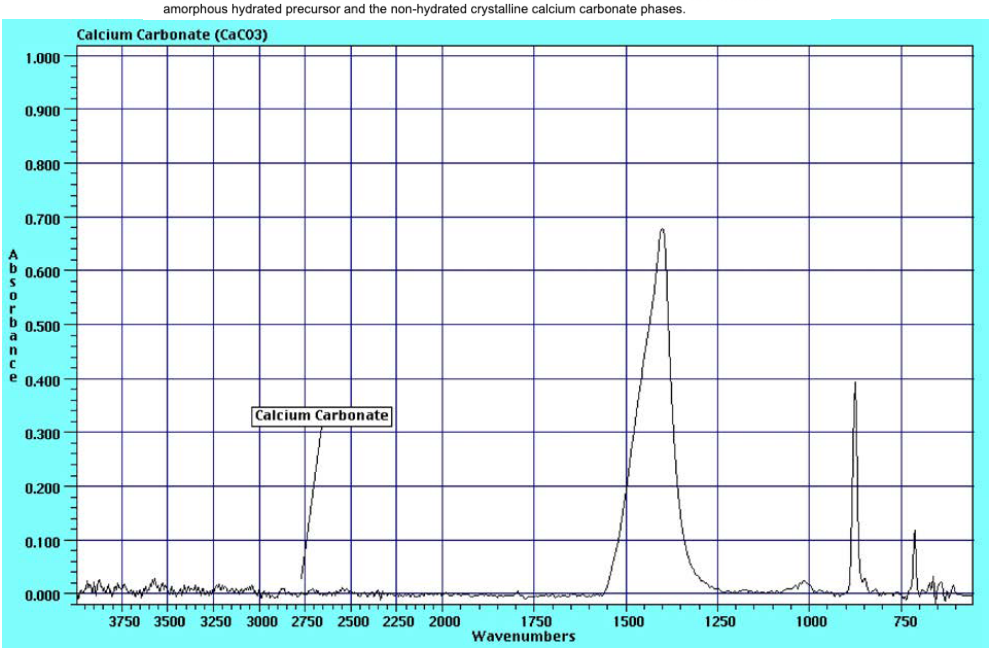
A membrane cell test performance challenge was conducted on CLIENT CHEMICAL, evaluating its effectiveness in preventing scale buildup using two different feedwater compositions and two concentration levels. Post-testing, membrane samples were analyzed using Scanning Electron Microscopy (SEM), Energy-Dispersive X-Ray Spectroscopy (EDS), and Fourier Transform Infrared Spectroscopy (FTIR) to assess surface characteristics and confirm scale inhibition performance.

FTIR Reference Spectra

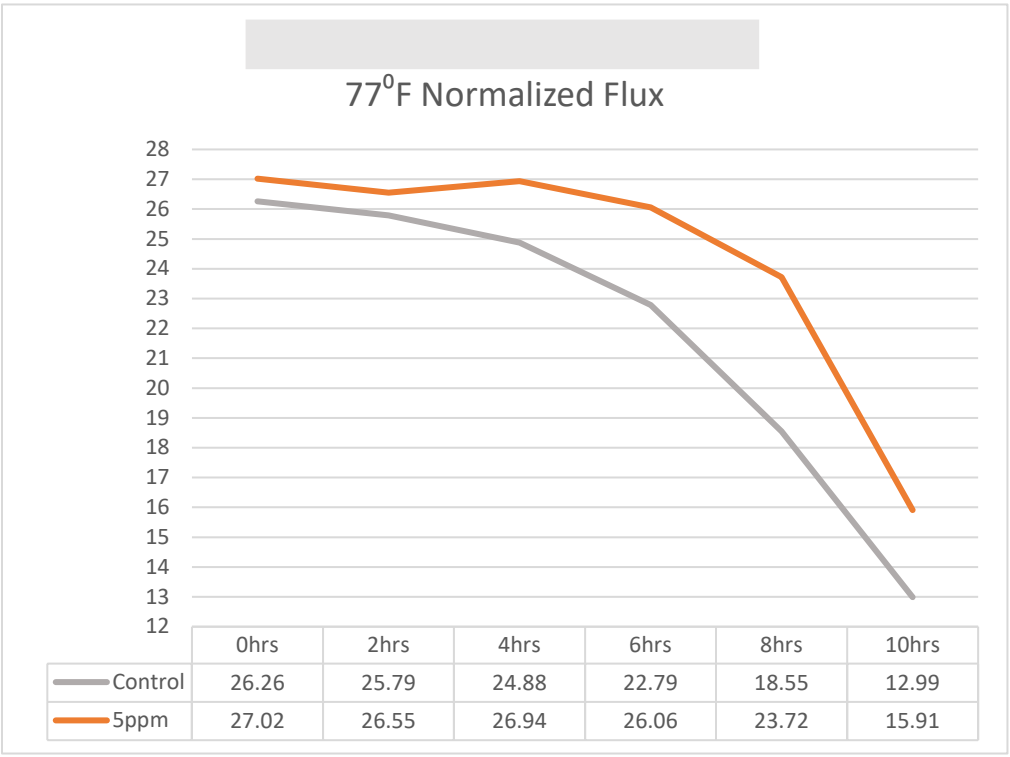
Calcium Carbonates (the observed primary scaling species present on the membrane surface) have various similar spectra with variations depending on degree of crystallinity and the presence of amorphous phases, so definitive spectral identification becomes complicated when mixed with other species.



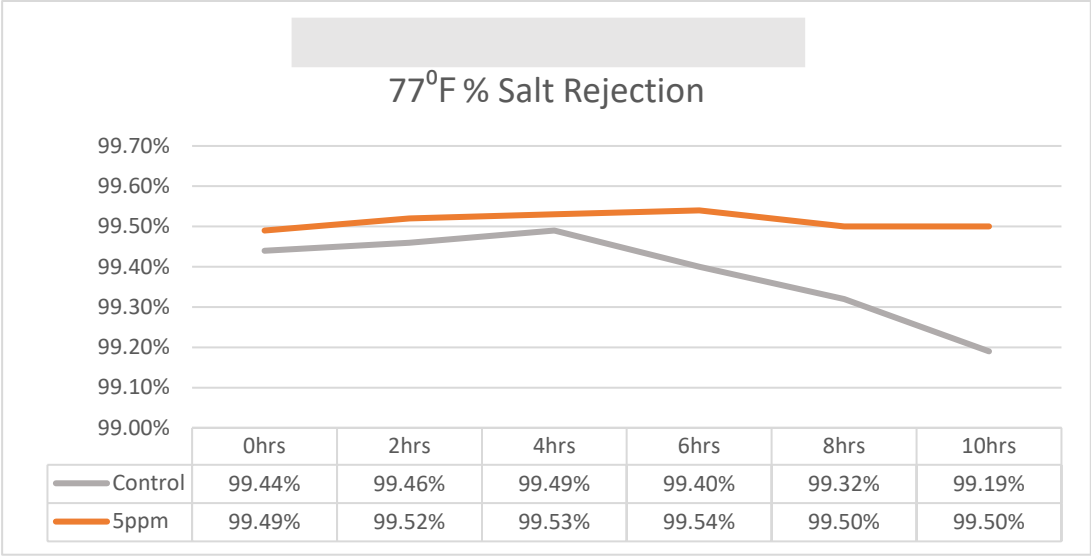

Fourier Transform Infrared (FTIR) spectra of ACC and calcite showing the change in water content from the amorphous hydrated precursor and the non-hydrated crystalline calcium carbonate phases.



## 77°F Control and 5ppm chemical concentration




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|
| Control | 26.26 | 25.79 | 24.88 | 22.79 | 18.55 | 12.99 |
| 5ppm | 27.02 | 26.55 | 26.94 | 26.06 | 23.72 | 15.91 |




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|
| Control | 99.44% | 99.46% | 99.49% | 99.40% | 99.32% | 99.19% |
| 5ppm | 99.49% | 99.52% | 99.53% | 99.54% | 99.50% | 99.50% |

| 77°F Control: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -50.51% |
| Salt Rej. | -0.25% |

| 5ppm: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -41.10% |
| Salt Rej. | 0.00% |

| Control | | | |
|---|---|---|---|
| | Before Control | Initial (stabilized) | End of **Control** |
| pH | 7.93 | 8.67 | 7.90 |
| Conductivity *(µS/cm)* | 556.3 | 594.2 | 1269 |
| Turbidity *(NTU)* | 0.00 | 0.0 | 0.4 |
| Evap. TDS *(ppm)* | 595.63 | 601.99 | 6,756.76 |
| Temperature *($^oF$)* | 69.1 | 73.5 | 65.5 |
| Calcium Hardness (ppm) | ~180 | | |
| Total Alkalinity (ppm) | ~120 | | |
| Total Iron *(ppm)* | ND | ND | ND |
| Copper *(ppm)* | ~0.390 | 0.046 | 0.007 |
| Aluminum *(ppm)* | ND | ND | ND |

| 5ppm | | | | |
|---|---|---|---|---|
| | Feedwater (before) | Mixture (after) | Stabilized | End **(FINAL)** |
| pH | 7.18 | 7.45 | 7.90 | 8.45 |
| Conductivity *(µS/cm)* | 574.1 | 576.2 | 644.5 | 1414 |
| Turbidity *(NTU)* | 0.0 | 0.0 | 0.0 | 0.0 |
| Evap. TDS *(ppm)* | 584.71 | 1,064.97 | 1,048.70 | 3,439.49 |
| Temperature *($^oF$)* | 69.3 | 70.1 | 73.6 | 74.8 |
| Calcium Hardness (ppm) | | | | ~440 |
| Total Alkalinity (ppm) | | | | ~240 |
| Total Iron *(ppm)* | ND | ND | ND | ND |
| Copper *(ppm)* | ~0.255 | ~0.255 | 0.080 | 0.164 |
| Aluminum *(ppm)* | ND | ND | ND | ND |

## Scanning Electron Microscopy (SEM), Electron Dispersive Spectroscopy (EDS), & Fourier Transform Infrared (FTIR)

Elemental compositions suggested major components appearing to be calcium carbonate with lower levels of other oxides. SEM images of the 'Control' sample showed large, well defined grain structures. The '5ppm' sample showed reduced grain sizes relative to the 'Control' surface with many more fine grains/particles present. FTIR data confirms the primary component on both samples to be calcium carbonate, with the '5ppm' sample appearing to have been chemically modified to an amorphous calcium carbonate structure.

**Table 1**

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

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 18.87 | 60.04 | 0.59 | 0.63 | 0.43 | 0.27 | 0.08 | 0.71 | 18.01 | 0.10 | 0.22 | 0.04 |
| 5ppm | 19.29 | 60.75 | 0.73 | 0.77 | 0.55 | 0.32 | 0.13 | 0.63 | 16.61 | 0.06 | 0.16 | - |

**Table 2**

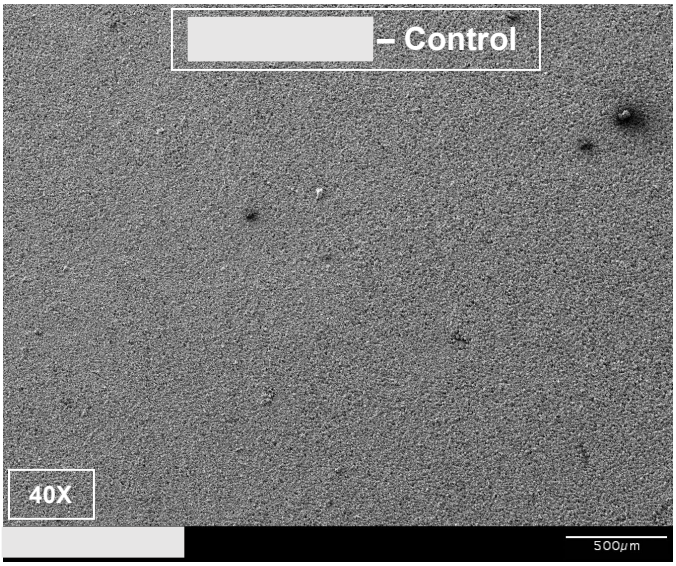
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon and Oxygen**
**WITHIN 1-2µm EDS ANALYZED LAYER**

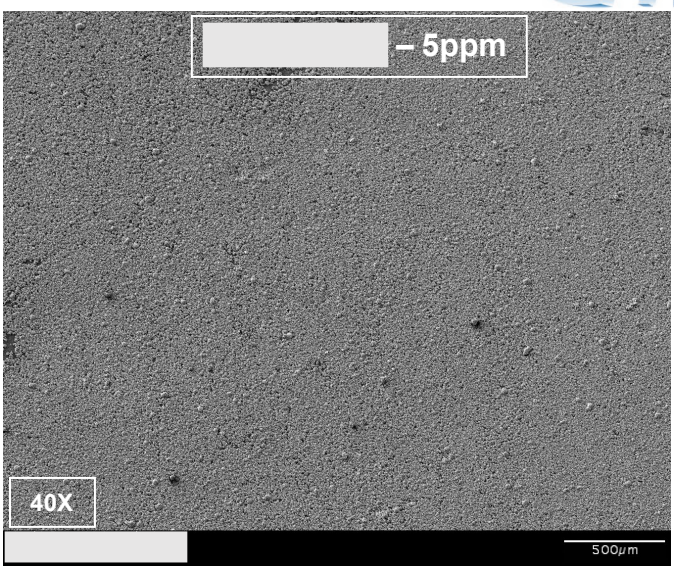
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | - | - | 2.80 | 2.99 | 2.04 | 1.28 | 0.38 | 3.37 | 85.44 | 0.47 | 1.04 | 0.19 |
| 5ppm | - | - | 3.66 | 3.86 | 2.76 | 1.60 | 0.65 | 3.16 | 83.22 | 0.30 | 0.80 | - |

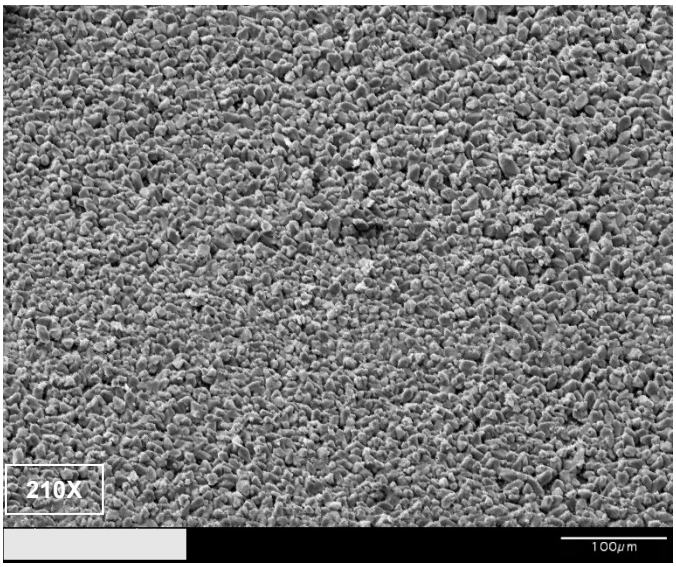
**Table 3**

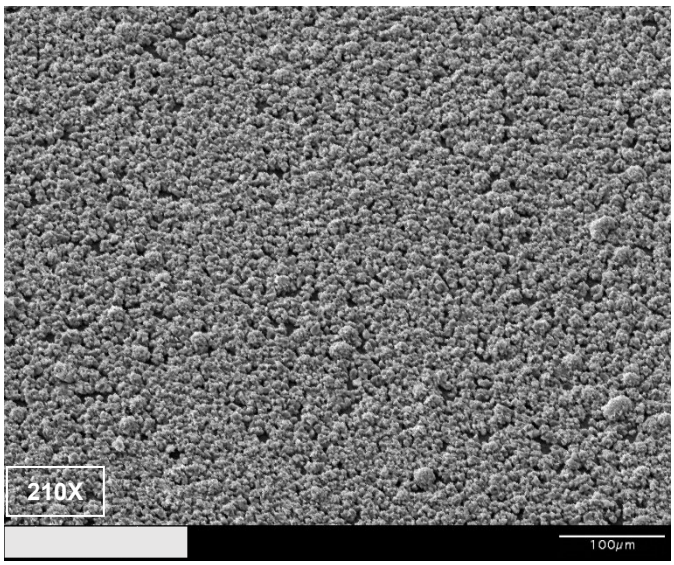
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon, Oxygen and Sulfur**
**WITHIN 1-2µm EDS ANALYZED LAYER**

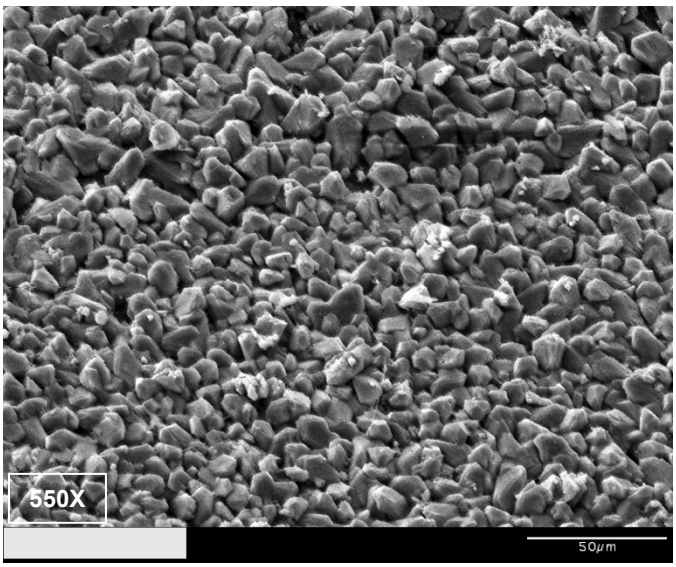
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | - | - | 2.90 | 3.09 | 2.11 | 1.33 | 0.39 | - | 88.41 | 0.49 | 1.08 | 0.20 |
| 5ppm | - | - | 3.78 | 3.98 | 2.85 | 1.66 | 0.67 | - | 85.93 | 0.31 | 0.83 | - |

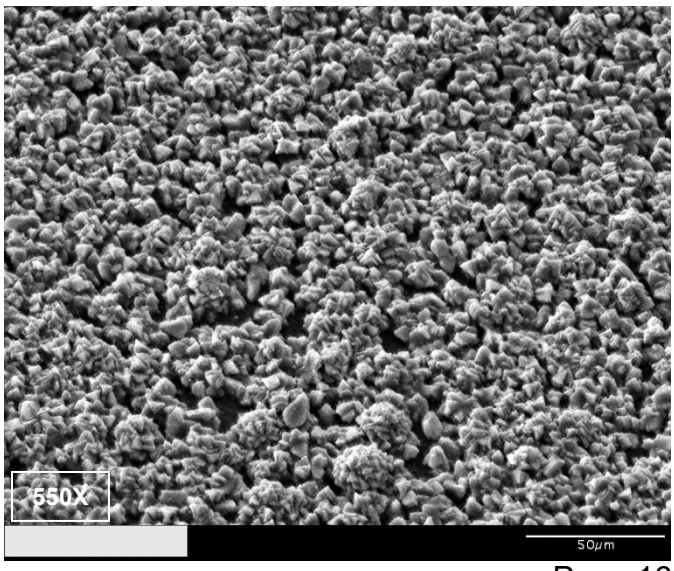

– Control
40X
500µm

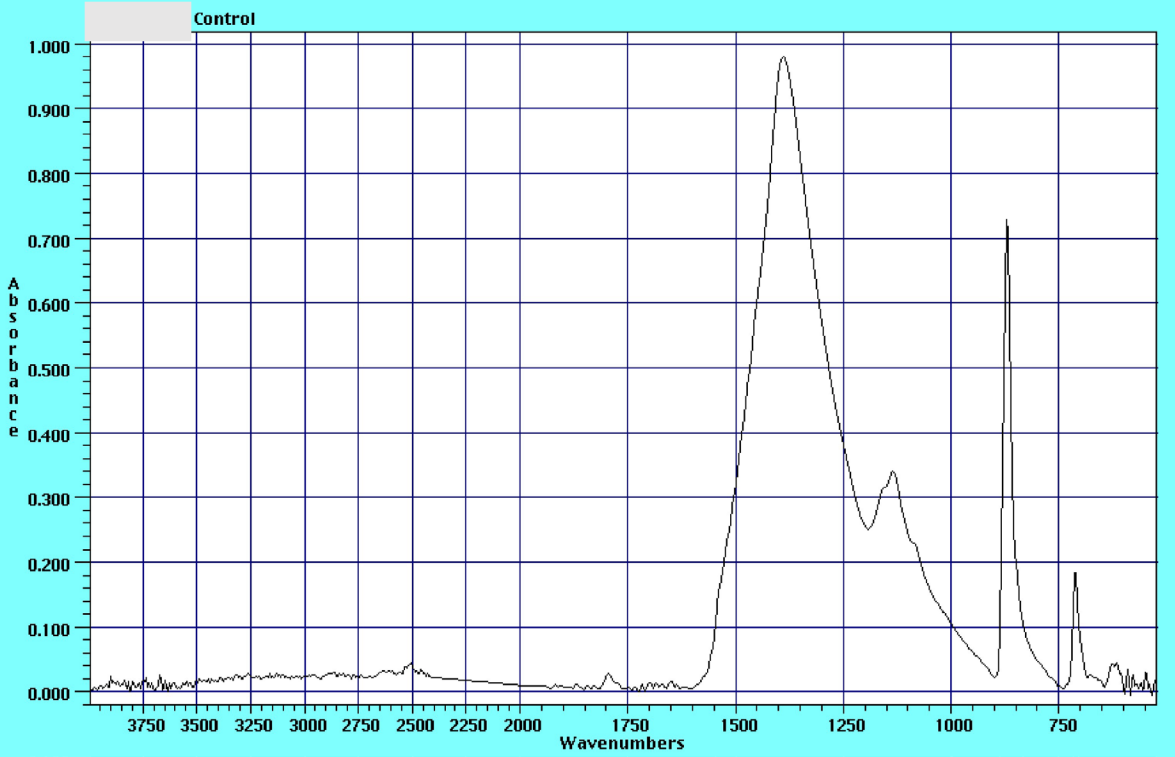

– 5ppm
40X
500µm

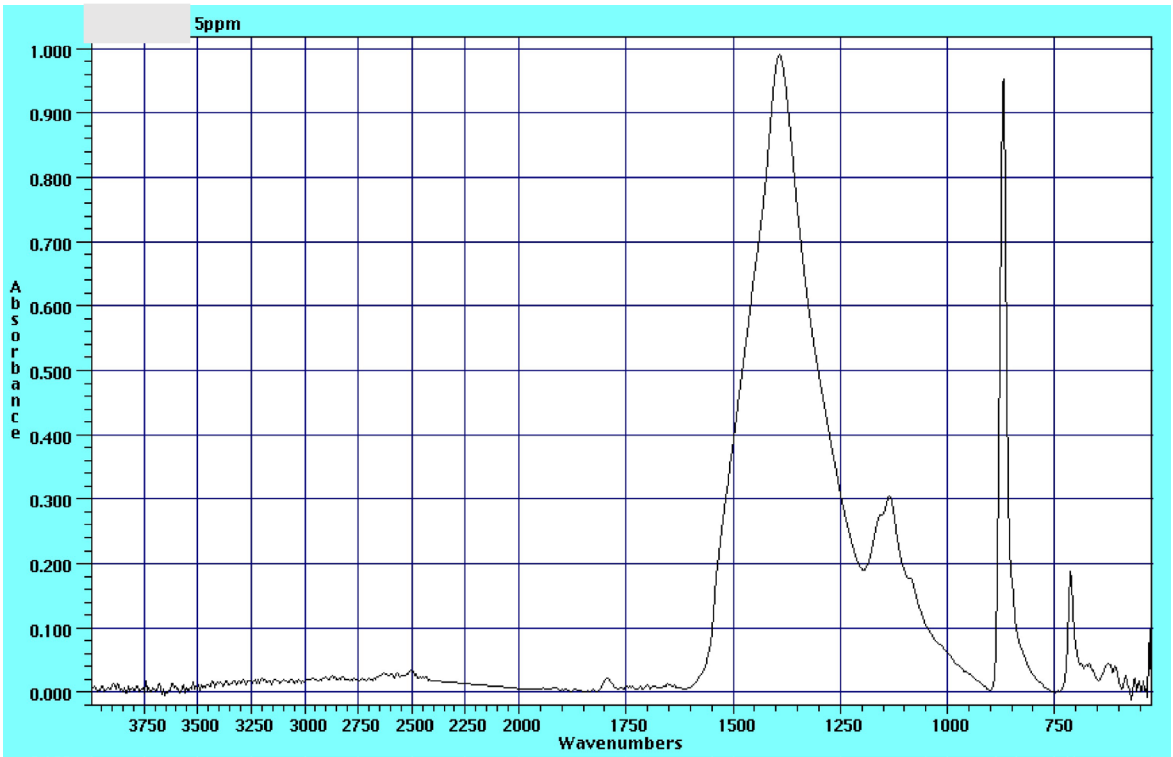

210X
100µm


210X
100µm

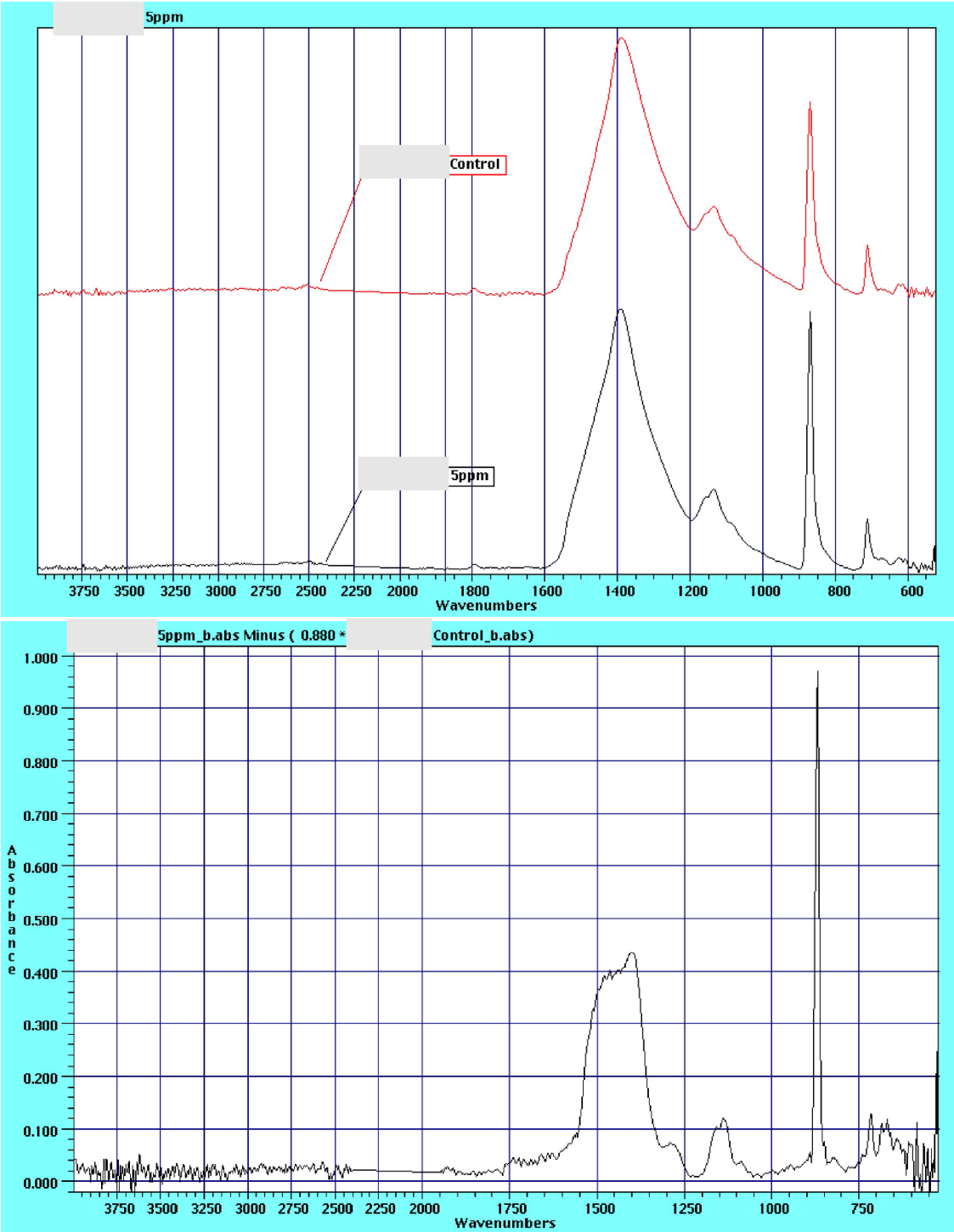

550X
50µm


550X
50µm



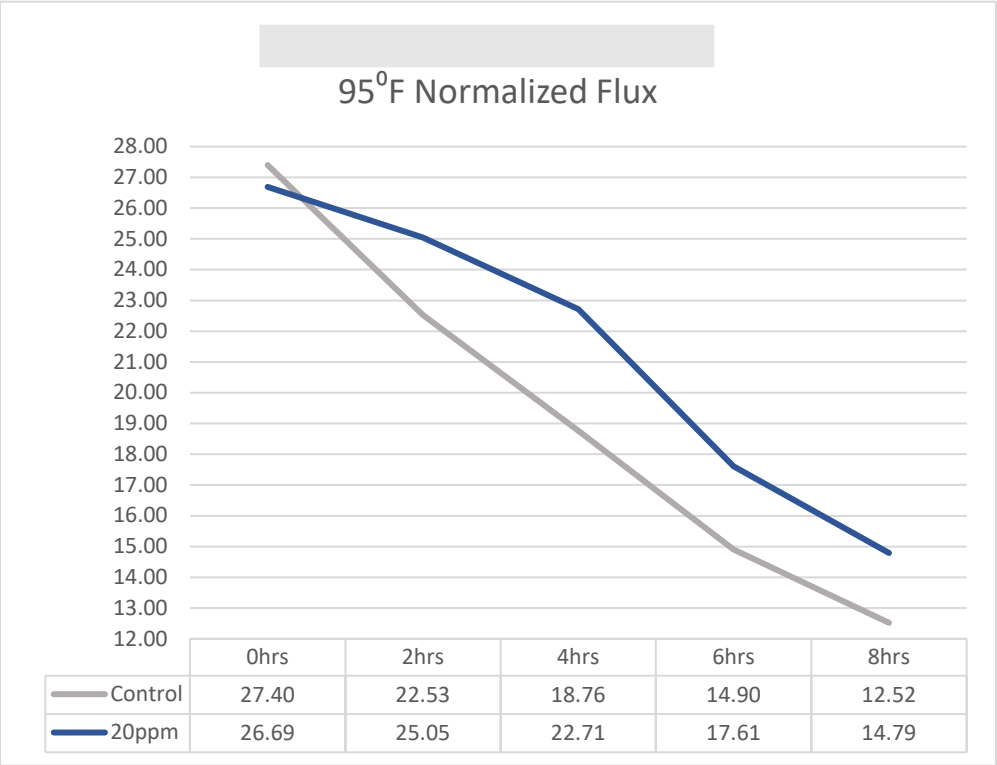




The Control and 5ppm Membrane Sample surfaces are virtually identical by FTIR. Both consist of what appears to be calcium carbonate, though the 5ppm sample has some minor additional contributions.

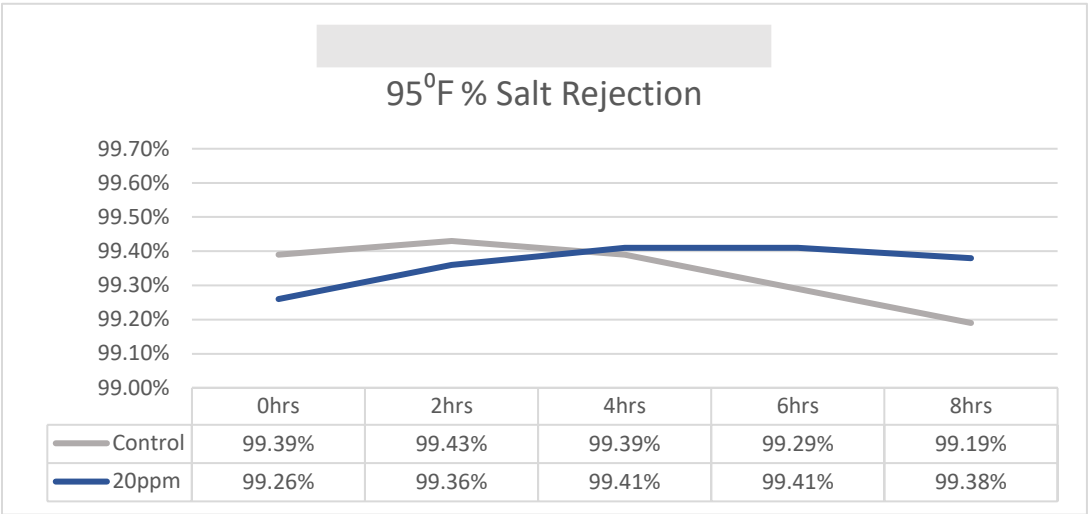



Subtracting the ‘Control’ signal from the ‘5ppm’ signal yields a pattern similar to Amorphous Calcium Carbonate (ACC) without the broad -OH structure at 3300 cm-1 and with a magnified n2 asymmetric CO3 peak at 874 cm-1. The extra peak at about 1150 cm-1 may indicate an additional unidentified species or carbonate structure.

## 95°F Control and 20ppm chemical concentration




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs |
|---|---|---|---|---|---|
| Control | 27.40 | 22.53 | 18.76 | 14.90 | 12.52 |
| 20ppm | 26.69 | 25.05 | 22.71 | 17.61 | 14.79 |




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs |
|---|---|---|---|---|---|
| Control | 99.39% | 99.43% | 99.39% | 99.29% | 99.19% |
| 20ppm | 99.26% | 99.36% | 99.41% | 99.41% | 99.38% |

| 95°F Control: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -54.26% |
| Salt Rej. | -0.20% |

| 20ppm: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -44.60% |
| Salt Rej. | 0.12% |

| Control | Before Control | Initial (stabilized) | End of **Control** |
|---|---|---|---|
| pH | 8.63 | 8.32 | 8.22 |
| Conductivity *(µS/cm)* | 603.7 | 624.5 | 1269 |
| Turbidity *(NTU)* | 0.0 | 1.4 | 0.3 |
| Evap. TDS *(ppm)* | * | * | * |
| Temperature *(°F)* | 74.3 | 89.2 | 92.6 |
| Calcium Hardness (ppm) | ~190 | | |
| Total Alkalinity (ppm) | ~100 | | |
| Total Iron *(ppm)* | ND | ND | ND |
| Copper *(ppm)* | ~0.233 | 0.036 | ND |
| Aluminum *(ppm)* | ND | ND | ND |

*Farmington Control Evaporative TDS has been removed due to contamination of weight dishes

| **20ppm** | Feedwater (before) | Mixture (after) | Stabilized | End **(FINAL)** |
|---|---|---|---|---|
| pH | 7.66 | 8.28 | 8.42 | 8.32 |
| Conductivity *(µS/cm)* | 553.1 | 555.3 | 585.9 | 1648 |
| Turbidity *(NTU)* | 0.0 | 0.0 | 3.2 | 16.6 |
| Evap. TDS *(ppm)* | 987.27 | 893.64 | 804.50 | 3,599.46 |
| Temperature *(°F)* | 66.5 | 66.8 | 80.2 | 73.5 |
| Calcium Hardness (ppm) | | | | ~570 |
| Total Alkalinity (ppm) | | | | ~270 |
| Total Iron *(ppm)* | ND | ND | ND | ND |
| Copper *(ppm)* | ~0.307 | ~0.302 | ~0.216 | ~0.434 |
| Aluminum *(ppm)* | ND | ND | ND | ND |

## Scanning Electron Microscopy (SEM), Electron Dispersive Spectroscopy (EDS), & Fourier Transform Infrared (FTIR)

Elemental compositions of the “95°F Control” sample showed the major components as calcium carbonates with lower levels of other oxides. SEM images of the ‘Control’ sample showed to have well defined grain structures. The ‘20ppm’ sample showed what appeared to be the substrate membrane material being exposed with various size grains distributed over the surface. The ‘20ppm’ sample shows evidence of the underlying membrane material as suggested by the SEM images along with smaller contributions from calcium carbonate species and protein. These additional species are much more prevalent on the “20ppm” sample vs the “20ppm” sample. FTIR data confirms the primary component on the ‘Control’ sample to be forms of calcium carbonate.

**Table 1**

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

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | 19.34 | 61.05 | 0.77 | 0.88 | 0.55 | 0.37 | 0.27 | 0.78 | - | 18.87 | 0.02 | 0.10 |
| 20ppm | 24.64 | 69.16 | 0.51 | 0.43 | 0.41 | 0.32 | 0.19 | 0.38 | - | 3.55 | 0.03 | 0.38 |

**Table 2**

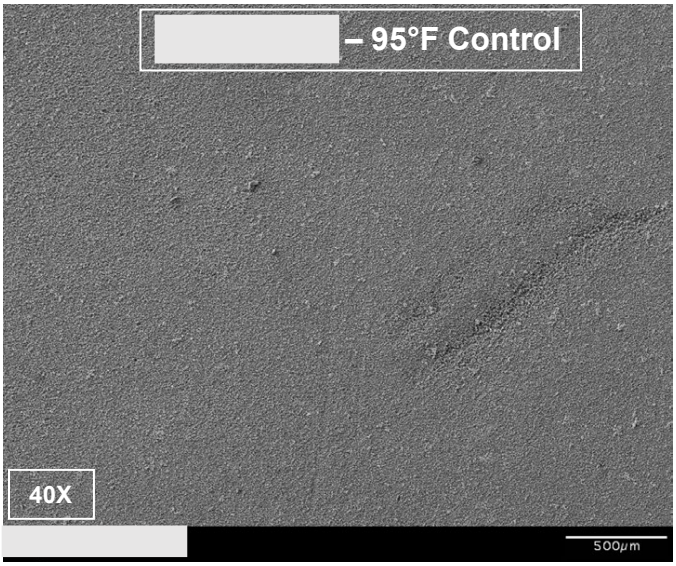
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon and Oxygen**
**WITHIN 1-2µm EDS ANALYZED LAYER**

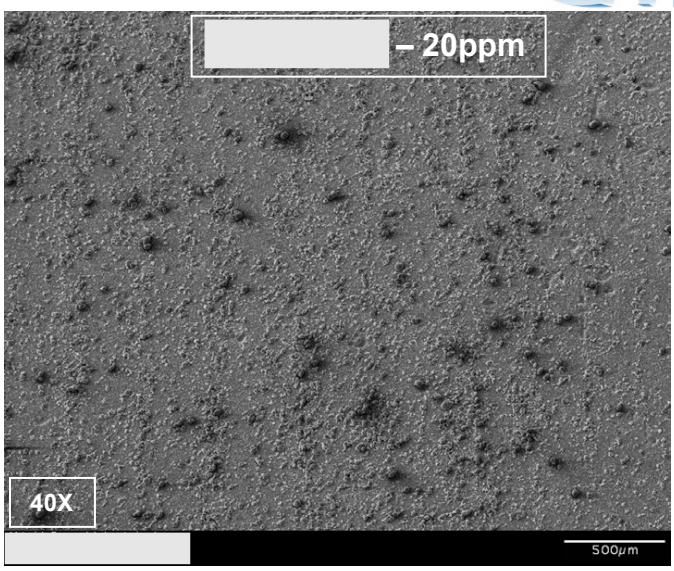
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | - | - | 3.93 | 4.49 | 2.80 | 1.89 | 1.38 | 3.98 | - | 80.93 | 0.10 | 0.51 |
| 20ppm | - | - | 8.23 | 6.94 | 6.61 | 5.16 | 3.06 | 6.13 | - | 57.26 | 0.48 | 6.13 |

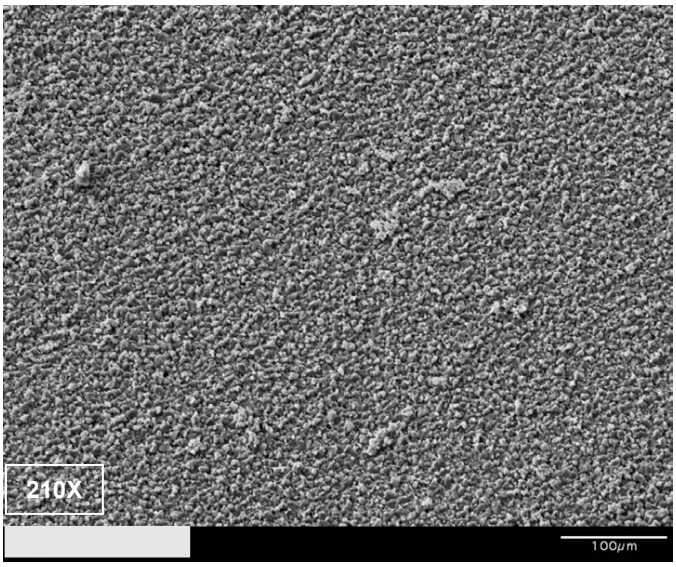
**Table 3**

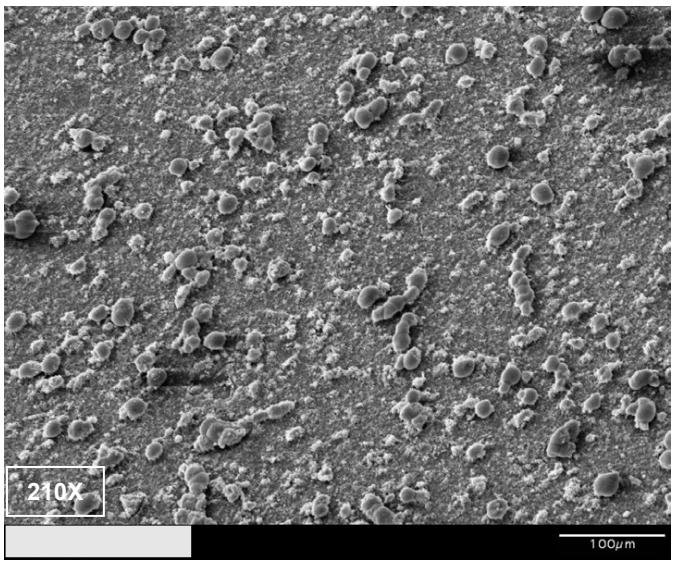
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon, Oxygen and Sulfur**
**WITHIN 1-2µm EDS ANALYZED LAYER**

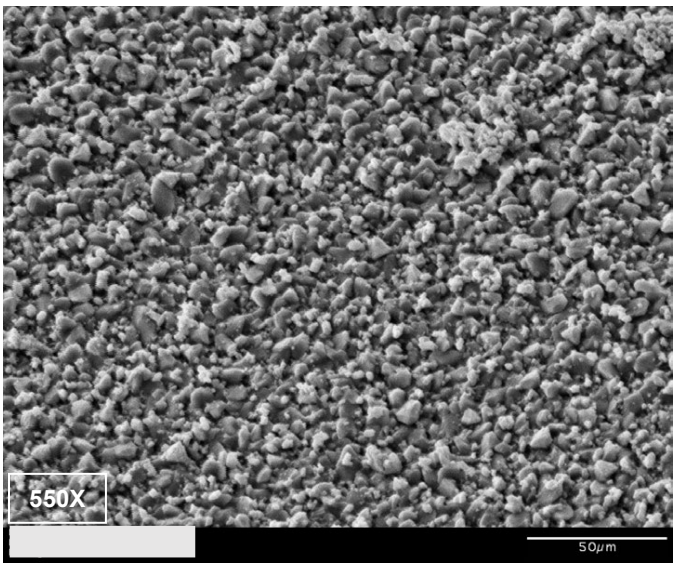
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | - | - | 4.09 | 4.67 | 2.92 | 1.96 | 1.43 | - | - | 84.28 | 0.11 | 0.53 |
| 20ppm | - | - | 8.76 | 7.39 | 7.04 | 5.50 | 3.26 | - | - | 61.00 | 0.52 | 6.53 |

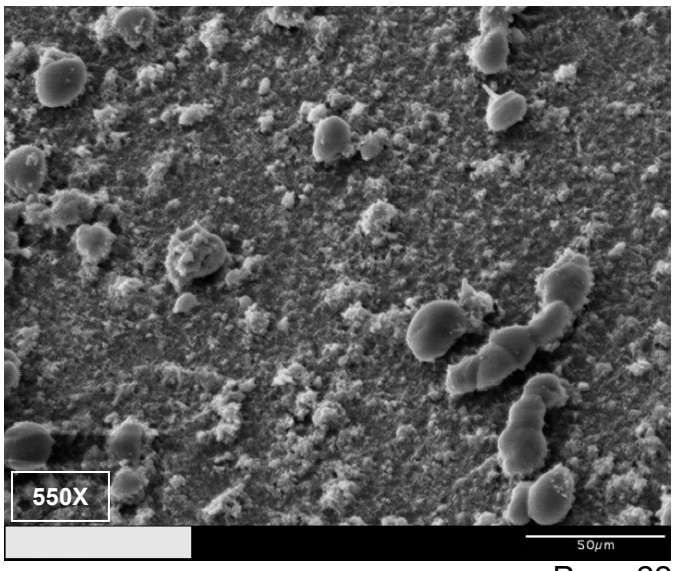

– 95°F Control
40X
500µm

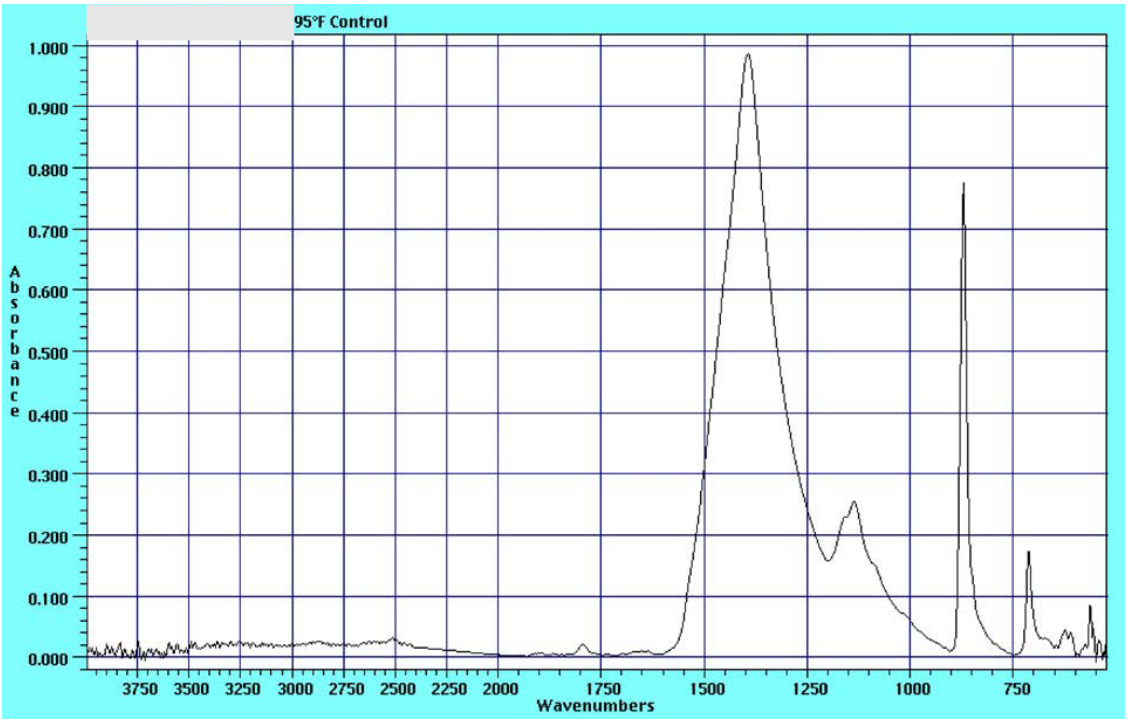

– 20ppm
40X
500µm

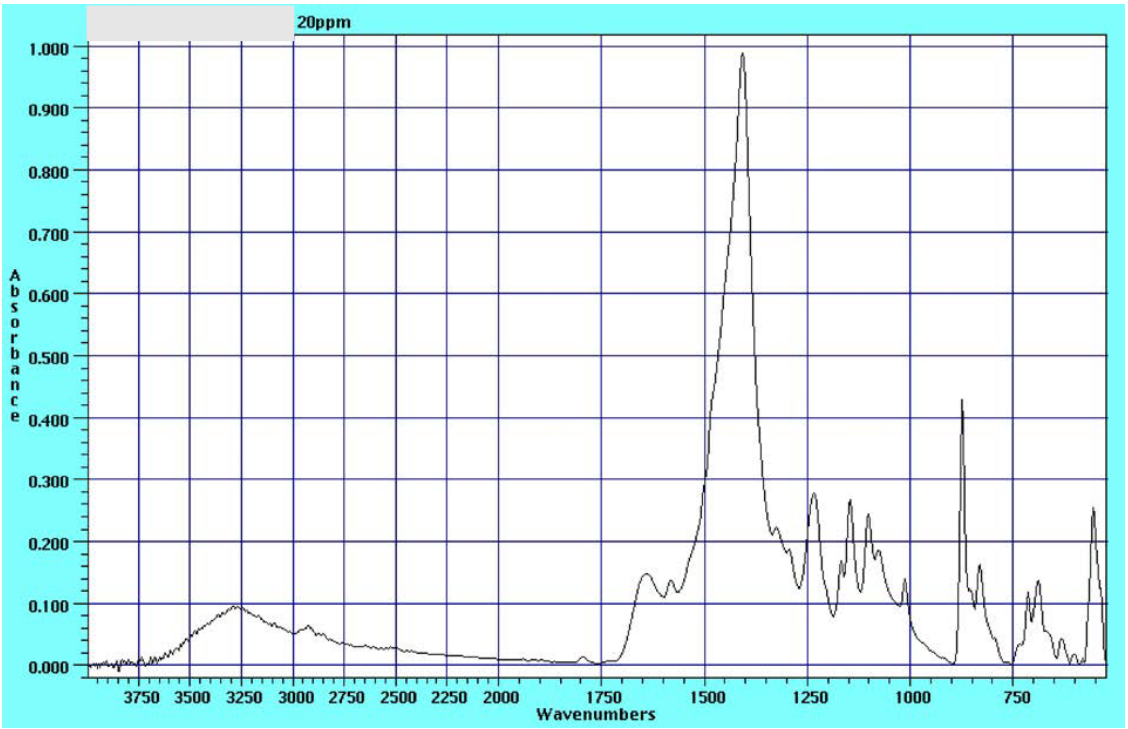

210X
100µm


210X
100µm

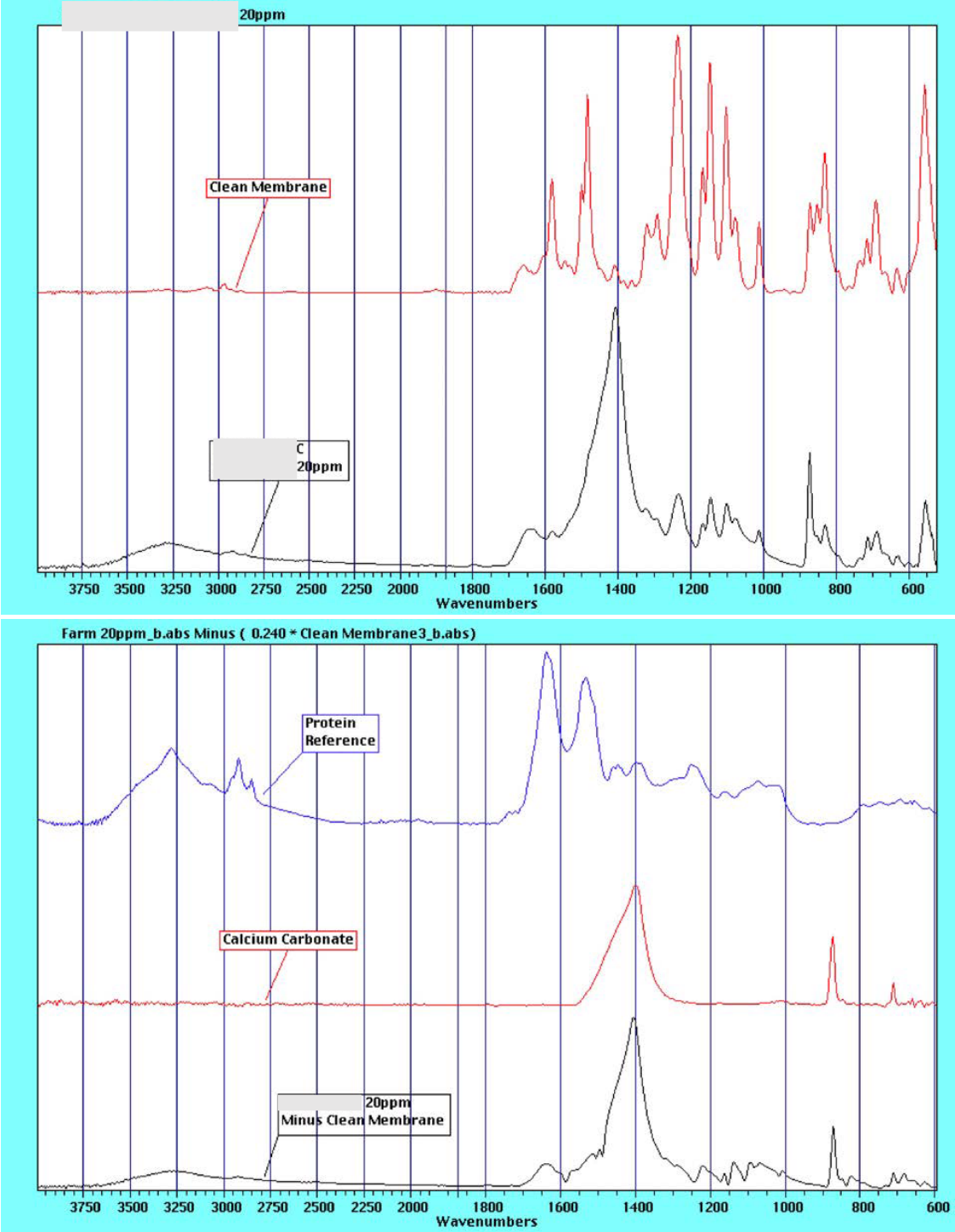

550X
50µm


550X
50µm



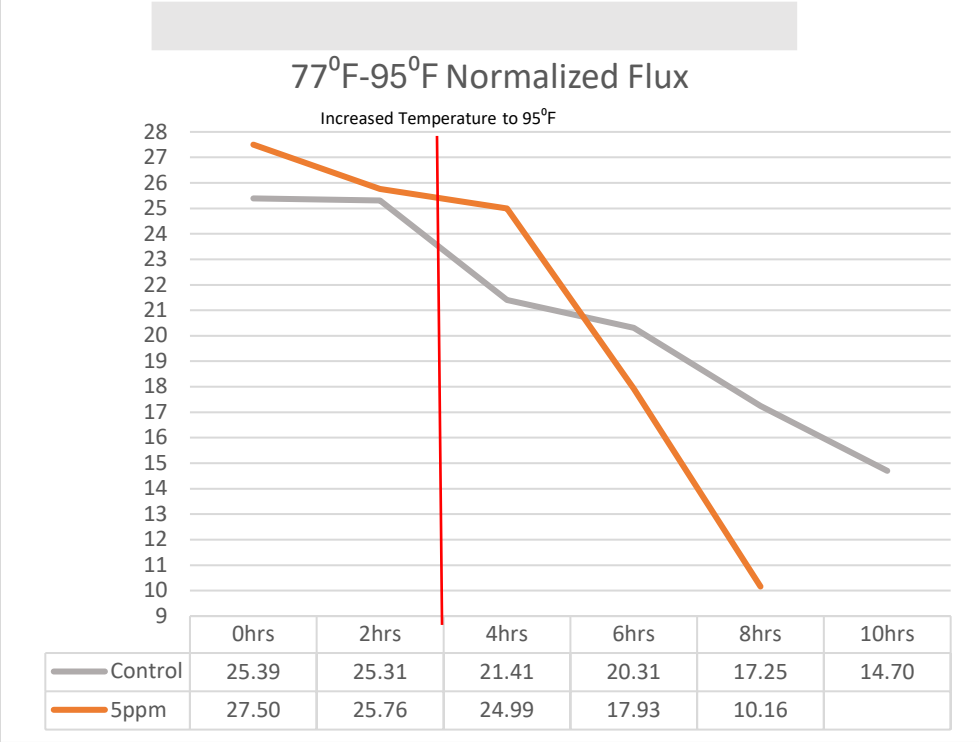




The 95°F Control and 20ppm Membrane Sample surfaces are both dominated by a signal for Calcium Carbonate (the '95°F Control' in the form of Calcite) but the 20ppm sample shows evidence for the underlying membrane substrate material and other possible species.

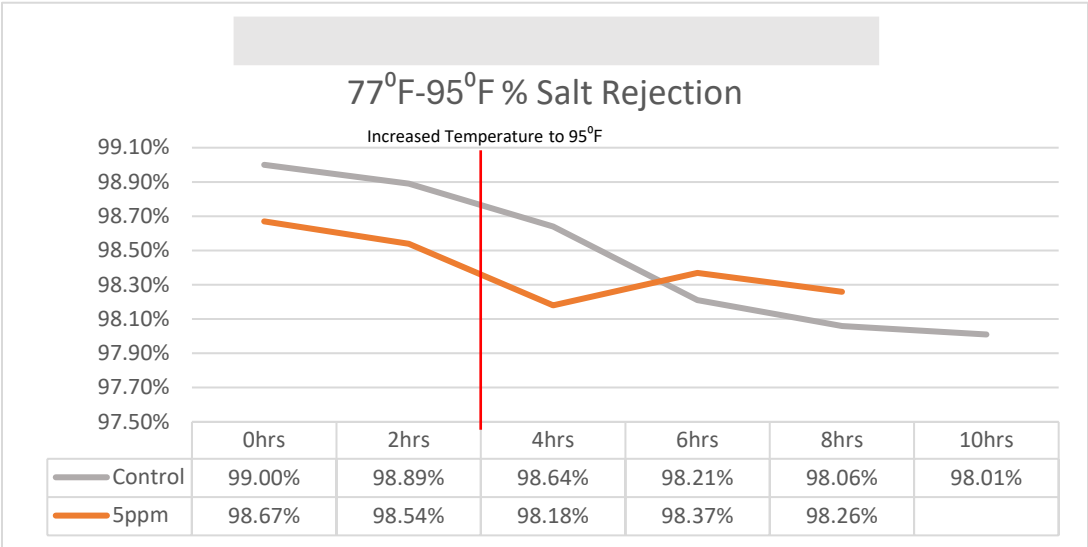



Subtracting a ‘Clean Membrane’ spectral signature from the ‘20ppm’ signal yields a pattern that indicates the strong presence of both Calcium Carbonate and Protein.

## 77°F - 95°F Control and 5ppm chemical concentration




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|
| Control | 25.39 | 25.31 | 21.41 | 20.31 | 17.25 | 14.70 |
| 5ppm | 27.50 | 25.76 | 24.99 | 17.93 | 10.16 | |




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs | 10hrs |
|---|---|---|---|---|---|---|
| Control | 99.00% | 98.89% | 98.64% | 98.21% | 98.06% | 98.01% |
| 5ppm | 98.67% | 98.54% | 98.18% | 98.37% | 98.26% | |

| 77°F - 95°F Control: Ending % Change from Stabilization | Average of all blocks |
|---|---|
| Flux gfd | -42.05% |
| Salt Rej. | -0.99% |

| 5ppm: Ending % Change from Stabilization | Average of all blocks |
|---|---|
| Flux gfd | -63.03% |
| Salt Rej. | -0.41% |

| | Before Control | Initial (stabilized) | End of **Control** |
|---|---|---|---|
| pH | 7.68 | 8.27 | 8.32 |
| Conductivity *(µS/cm)* | 3273 | 3316 | 7031 |
| Turbidity *(NTU)* | 0.00 | 0.0 | 0.1 |
| Evap. TDS *(ppm)* | 2396.67 | 2643.24 | 5417.18 |
| Temperature *($^oF$)* | 71.5 | 73.3 | 85.9 |
| Calcium Hardness (ppm) | ~300 | | |
| Total Alkalinity (ppm) | ~160 | | |
| Total Iron *(ppm)* | ND | ND | ND |
| Copper *(ppm)* | ND | ND | 0.014 |
| Aluminum *(ppm)* | ND | ND | ND |

| | Feedwater (before) | Mixture (after) | Stabilized | End **(FINAL)** |
|---|---|---|---|---|
| pH | 7.69 | 7.85 | 8.35 | 8.52 |
| Conductivity *(µS/cm)* | 3276 | 3276 | 3603 | 6754 |
| Turbidity *(NTU)* | 0.0 | 0.0 | 0.2 | 2.3 |
| Evap. TDS *(ppm)* | 2369.39 | 2383.43 | 2717.42 | 5936.34 |
| Temperature *($^oF$)* | 71.9 | 71.3 | 72.1 | 86.3 |
| Calcium Hardness (ppm) | | | | ~610 |
| Total Alkalinity (ppm) | | | | ~260 |
| Total Iron *(ppm)* | ND | ND | ND | ND |
| Copper *(ppm)* | ~0.483 | ND | 0.035 | 0.182 |
| Aluminum *(ppm)* | ND | ND | ND | ND |

## Scanning Electron Microscopy (SEM), Electron Dispersive Spectroscopy (EDS), & Fourier Transform Infrared (FTIR)

Elemental compositions suggested major components appearing to be calcium carbonate with lower levels of other oxides. FTIR data confirms the primary component to be calcium carbonate. The 'Sweetwater' samples exhibited higher magnesium (Mg) than the '[redacted]' samples. SEM images of the 'Control' sample showed large, well defined grain structures. The '5ppm' sample showed reduced grain sizes relative to the 'Control' surface, with many more fine grains/particles that appear to have been chemically modified to an amorphous calcium carbonate structure. The '5ppm' sample showed areas where the surface grains appeared to have been removed to reveal the underlying membrane material as suggested by SEM images.

**Table 1**

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

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] Control | 18.70 | 59.66 | 0.74 | 1.35 | 0.48 | 0.29 | 0.08 | 0.38 | 18.19 | - | 0.14 |
| [redacted] 5ppm | 19.50 | 61.05 | 0.70 | 1.06 | 0.48 | 0.33 | 0.11 | 0.51 | 15.97 | 0.06 | 0.23 |

**Table 2**

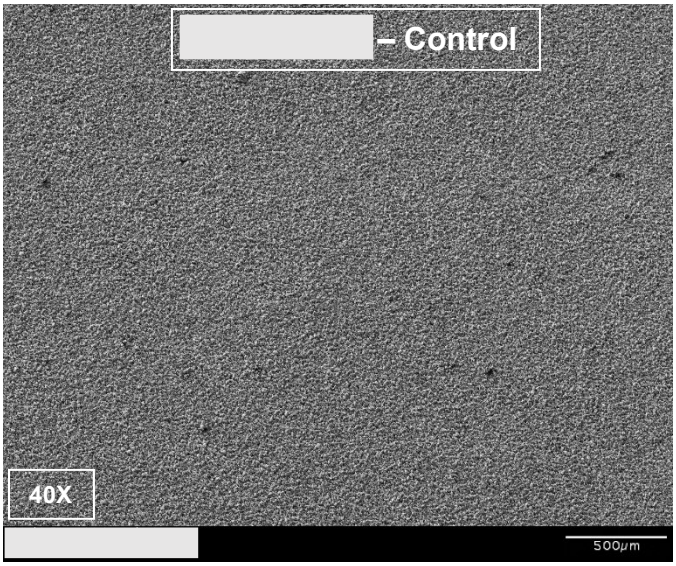
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon and Oxygen**
**WITHIN 1-2µm EDS ANALYZED LAYER**

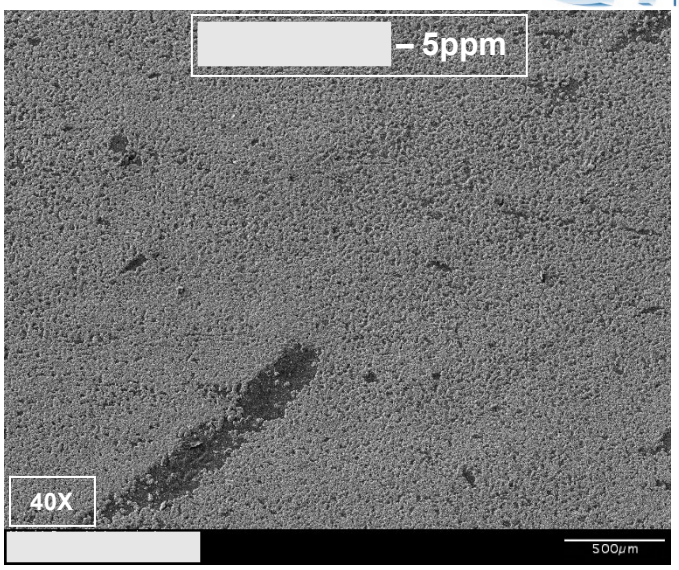
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] Control | - | - | 3.42 | 6.24 | 2.22 | 1.34 | 0.37 | 1.76 | 84.02 | - | 0.65 |
| [redacted] 5ppm | - | - | 3.60 | 5.45 | 2.47 | 1.70 | 0.57 | 2.62 | 82.11 | 0.31 | 1.18 |

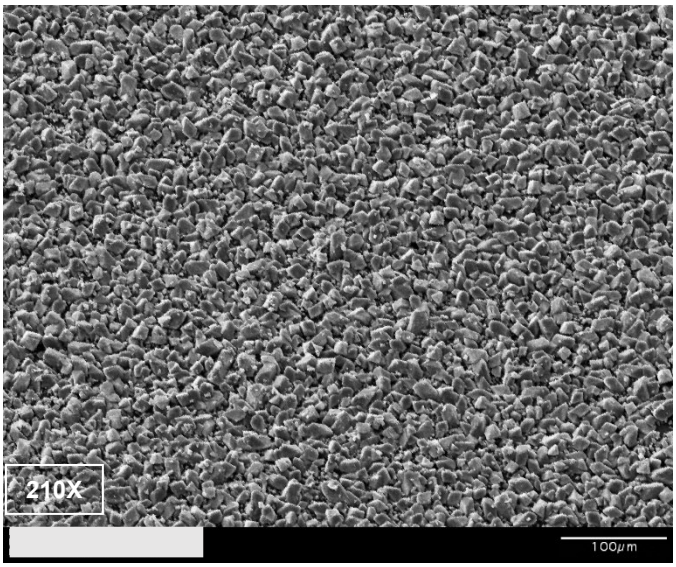
**Table 3**

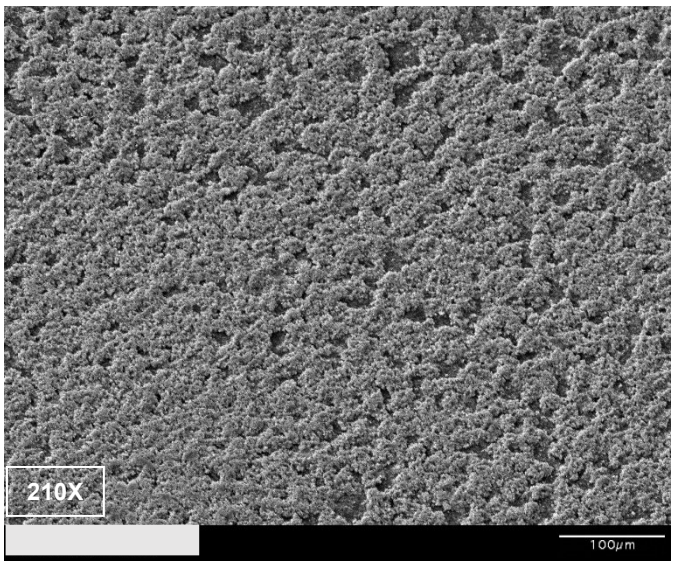
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon, Oxygen and Sulfur**
**WITHIN 1-2µm EDS ANALYZED LAYER**

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Ca | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] Control | - | - | 3.48 | 6.35 | 2.26 | 1.36 | 0.38 | - | 85.52 | - | 0.66 |
| [redacted] 5ppm | - | - | 3.70 | 5.60 | 2.53 | 1.74 | 0.58 | - | 84.32 | 0.32 | 1.21 |

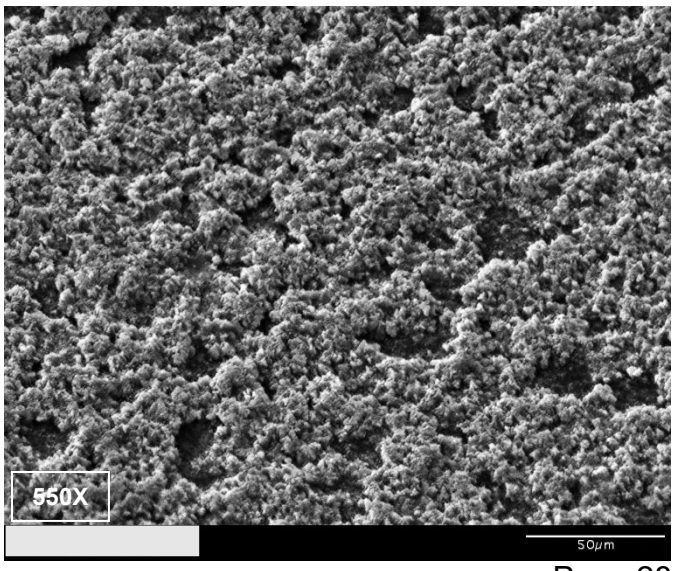

– Control
40X
500µm

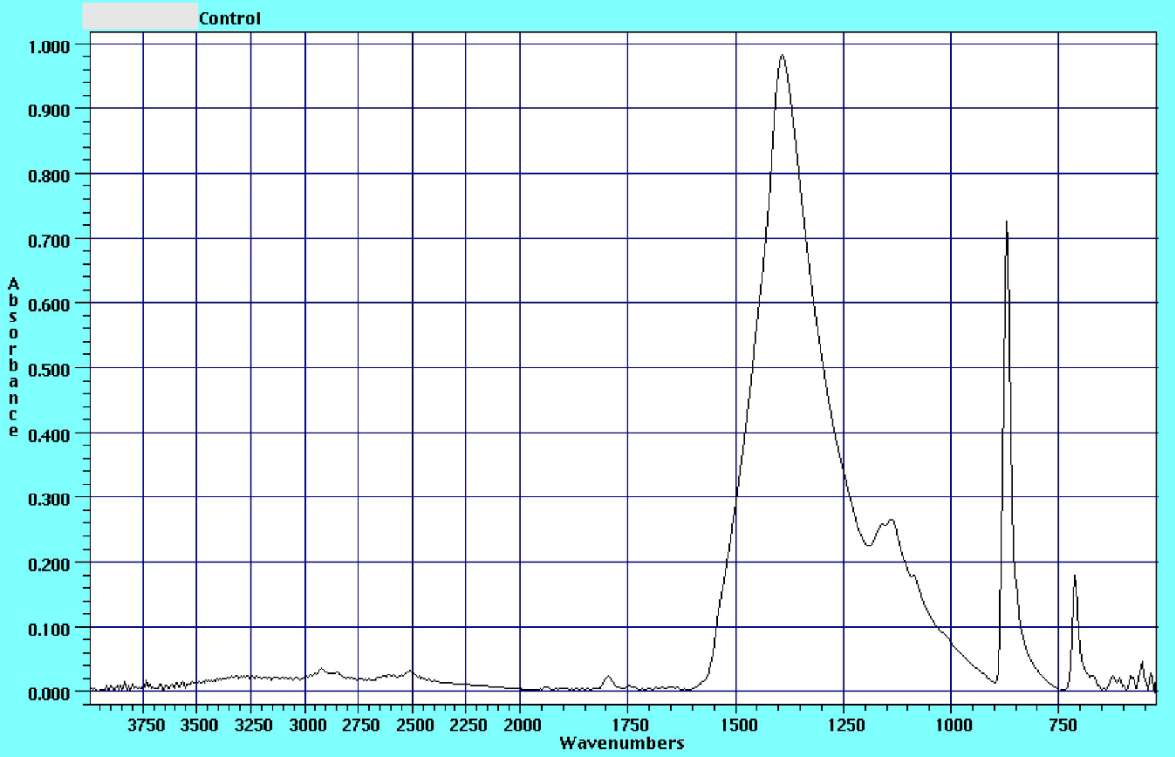

– 5ppm
40X
500µm

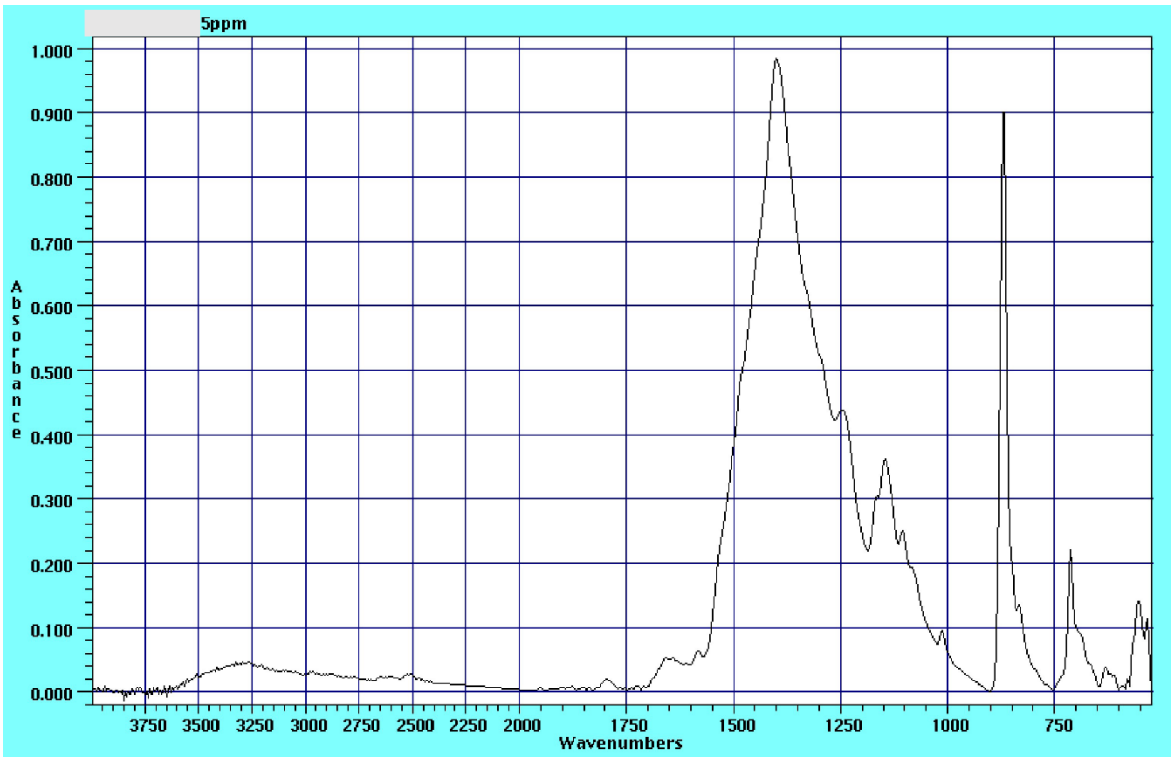

210X
100µm


210X
100µm


550X
50µm

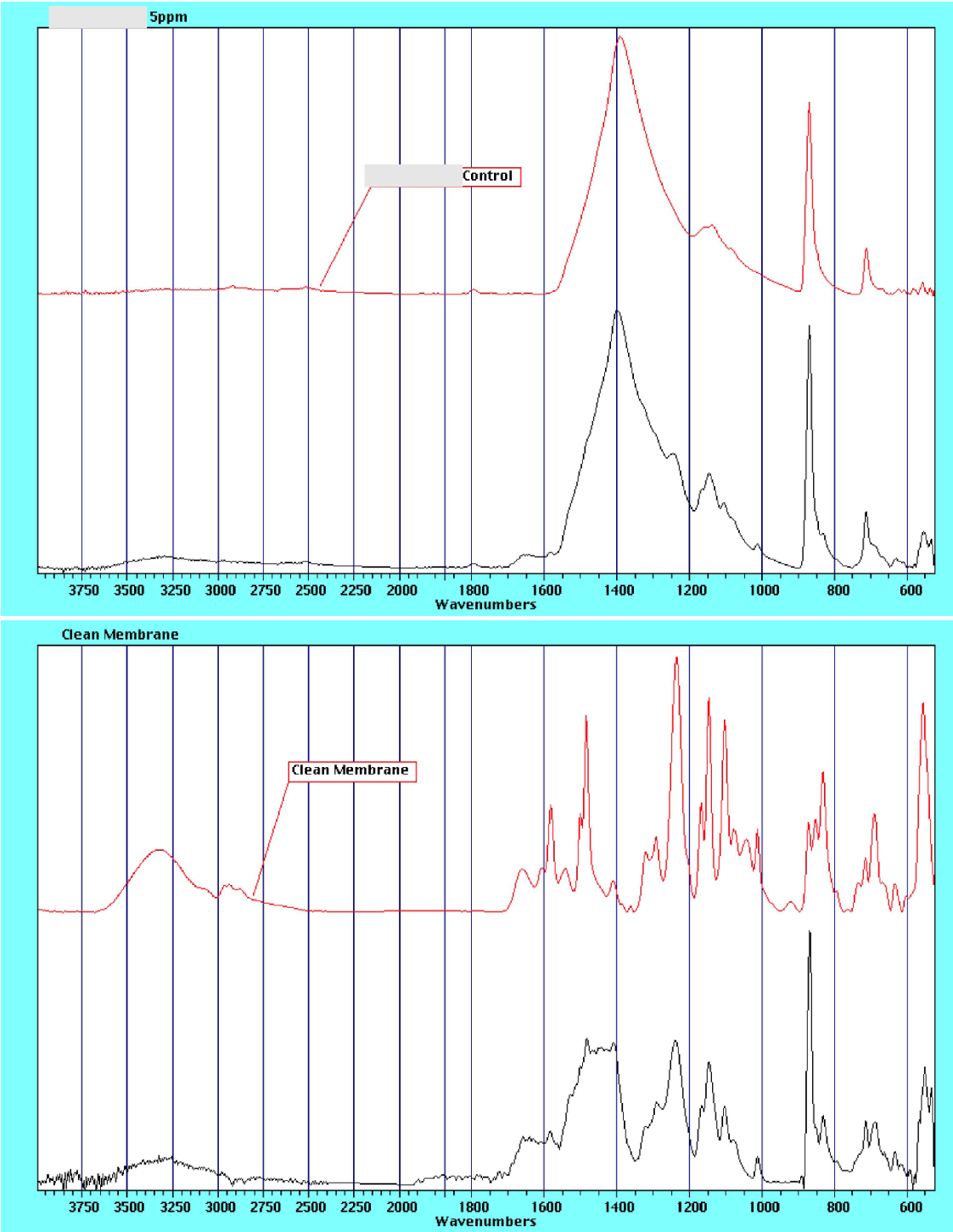

550X
50µm



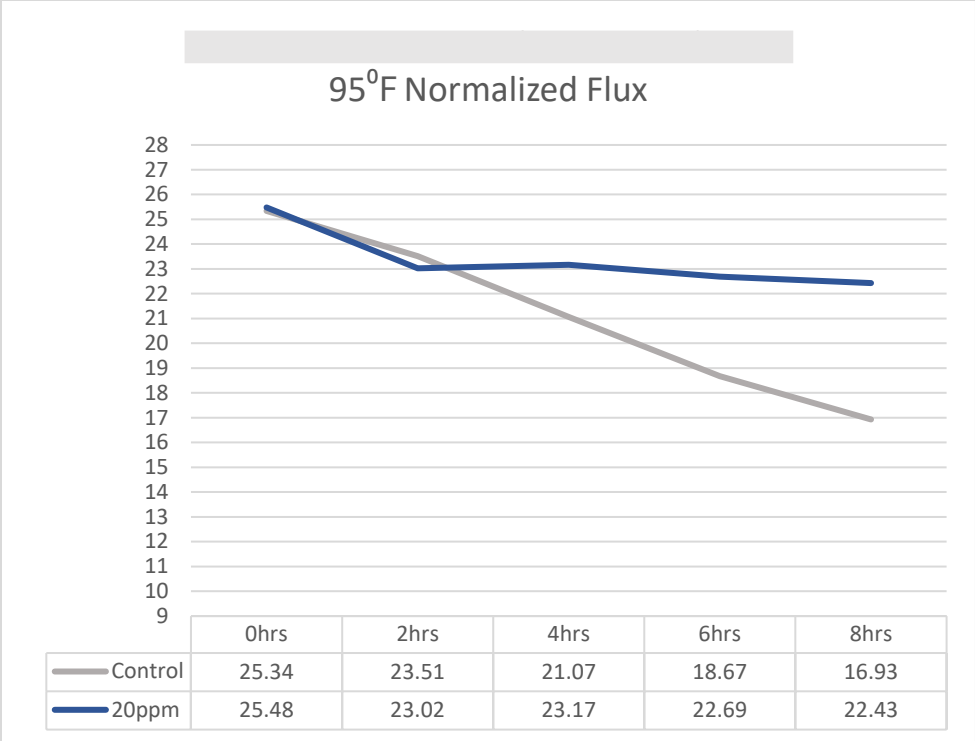

The Control and 5ppm Membrane Sample surfaces are very similar by FTIR.

Both consist mainly of what appears to be calcium carbonate but the 5ppm sample shows additional contributions from another species.

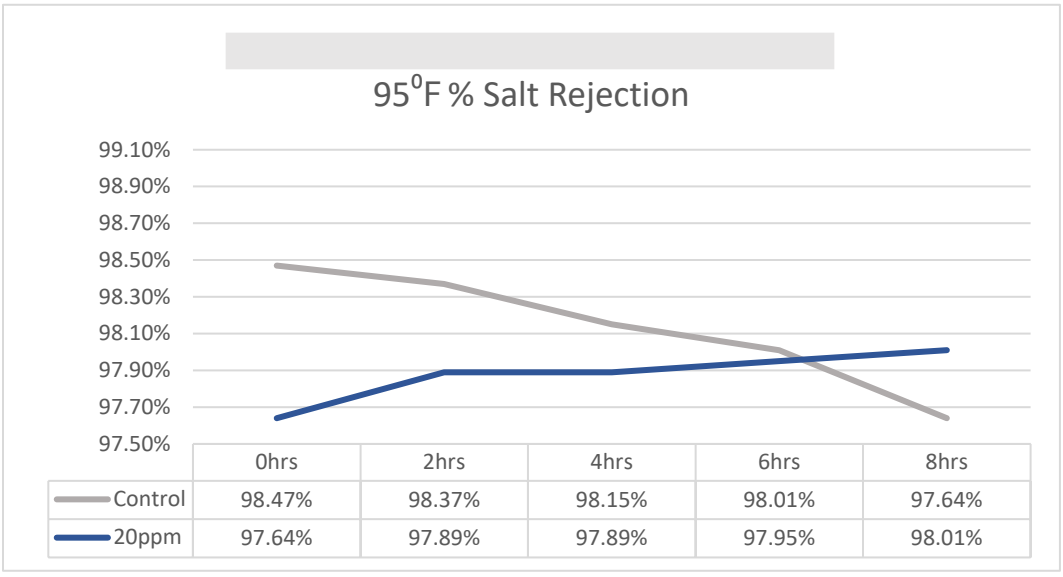



Subtracting the ‘Control’ signal from the ‘5ppm’ signal yields a pattern with obvious matches to clean membrane material along with the amorphous calcium carbonate signals mentioned for the Farmington samples. This suggests that the surface has been removed in localized areas as is shown in the SEM images of the Sweetwater 5ppm sample.

## 95°F Control and 20ppm chemical concentration




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs |
|---|---|---|---|---|---|
| Control | 25.34 | 23.51 | 21.07 | 18.67 | 16.93 |
| 20ppm | 25.48 | 23.02 | 23.17 | 22.69 | 22.43 |




| | 0hrs | 2hrs | 4hrs | 6hrs | 8hrs |
|---|---|---|---|---|---|
| Control | 98.47% | 98.37% | 98.15% | 98.01% | 97.64% |
| 20ppm | 97.64% | 97.89% | 97.89% | 97.95% | 98.01% |

| 95°F Control: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -33.20% |
| Salt Rej. | -0.83% |

| 20ppm: Ending % Change from Stabilization | |
|---|---|
| | Average of all blocks |
| Flux gfd | -11.96% |
| Salt Rej. | 0.38% |

| Control | Before Control | Initial (stabilized) | End of **Control** |
|---|---|---|---|
| pH | 7.46 | 8.67 | 8.16 |
| Conductivity *(µS/cm)* | 3266 | 3412 | 7231 |
| Turbidity *(NTU)* | 0.0 | 1.0 | 0.4 |
| Evap. TDS *(ppm)* | 2,421.35 | 2,558.93 | 5,668.15 |
| Temperature *($^oF$)* | 67.5 | 85.1 | 86.2 |
| Calcium Hardness (ppm) | ~310 | | |
| Total Alkalinity (ppm) | ~160 | | |
| Total Iron *(ppm)* | ND | ND | ND |
| Copper *(ppm)* | ND | 0.072 | ~0.005 |
| Aluminum *(ppm)* | ND | ND | ND |

| 20ppm | Feedwater (before) | Mixture (after) | Stabilized | End **(FINAL)** |
|---|---|---|---|---|
| pH | 7.93 | 8.36 | 8.43 | 8.69 |
| Conductivity *(µS/cm)* | 3277 | 3281 | 3322 | 7149 |
| Turbidity *(NTU)* | 0.0 | 0.0 | 2.2 | 4.1 |
| Evap. TDS *(ppm)* | 2,462.27 | 2,480.04 | 2,438.46 | 5,801.77 |
| Temperature *($^oF$)* | 72.2 | 71.6 | 84.8 | 87.6 |
| Calcium Hardness (ppm) | | | | ~630 |
| Total Alkalinity (ppm) | | | | ~310 |
| Total Iron *(ppm)* | ND | ND | ND | ND |
| Copper *(ppm)* | ND | ND | 0.009 | 0.140 |
| Aluminum *(ppm)* | ND | ND | ND | ND |

## Scanning Electron Microscopy (SEM), Electron Dispersive Spectroscopy (EDS), & Fourier Transform Infrared (FTIR)

Elemental compositions of the “95°F Control” sample showed the major components as calcium carbonates with lower levels of other oxides. The ‘ ’ sample exhibited a higher magnesium (Mg) content than the ‘ ’ sample. SEM images of the ‘Control’ sample showed to have well defined grain structures, but the ‘ ’ sample exhibited much smaller grain sizes than the ‘ ’ sample. The ‘20ppm’ sample showed evidence of the underlying membrane material with various size grains distributed over the surface as suggested by the SEM images. The ‘20ppm’ sample shows small contributions from calcium carbonate species and protein. FTIR data confirms the primary component on the ‘Control’ sample to be forms of calcium carbonate.

**Table 1**

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

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | 19.89 | 61.70 | 0.79 | 1.09 | 0.40 | 0.27 | 0.16 | 0.59 | - | 15.02 | - | 0.09 |
| 20ppm | 25.55 | 71.28 | 0.31 | 0.20 | 0.16 | 0.14 | 0.08 | 1.58 | 0.14 | 0.36 | 0.02 | 0.19 |

**Table 2**

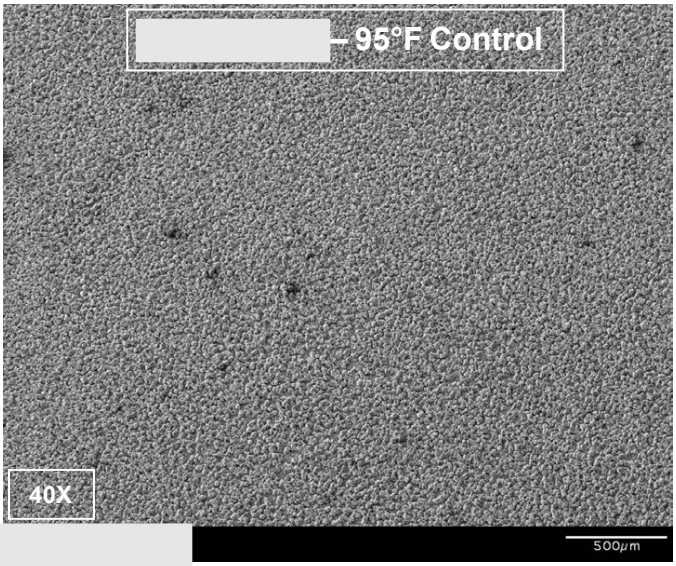
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon and Oxygen**
**WITHIN 1-2µm EDS ANALYZED LAYER**

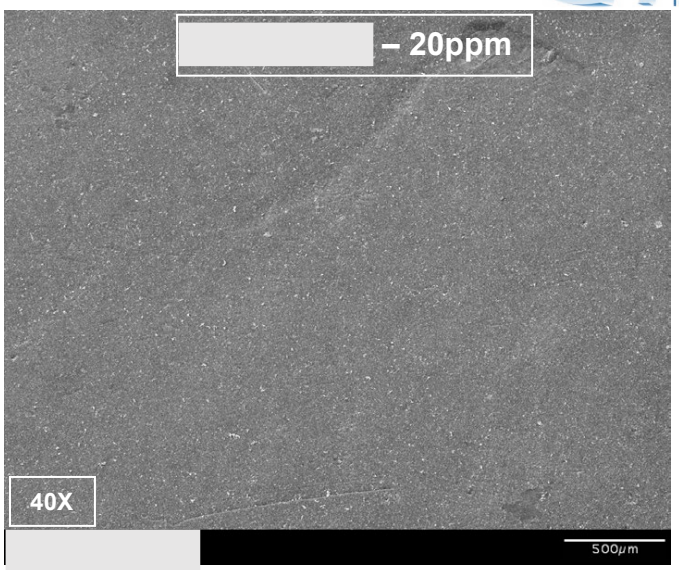
| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | - | - | 4.29 | 5.92 | 2.17 | 1.47 | 0.87 | 3.20 | - | 81.59 | - | 0.49 |
| 20ppm | - | - | 9.75 | 6.29 | 5.03 | 4.40 | 2.52 | 49.69 | 4.40 | 11.32 | 0.63 | 5.97 |

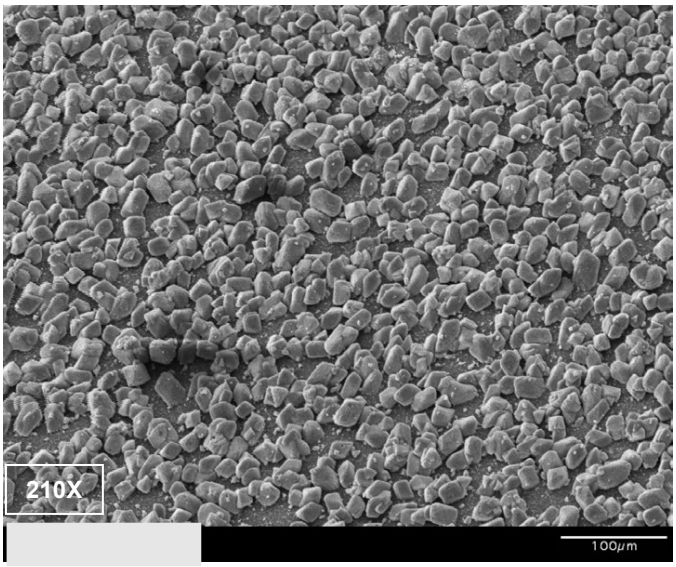
**Table 3**

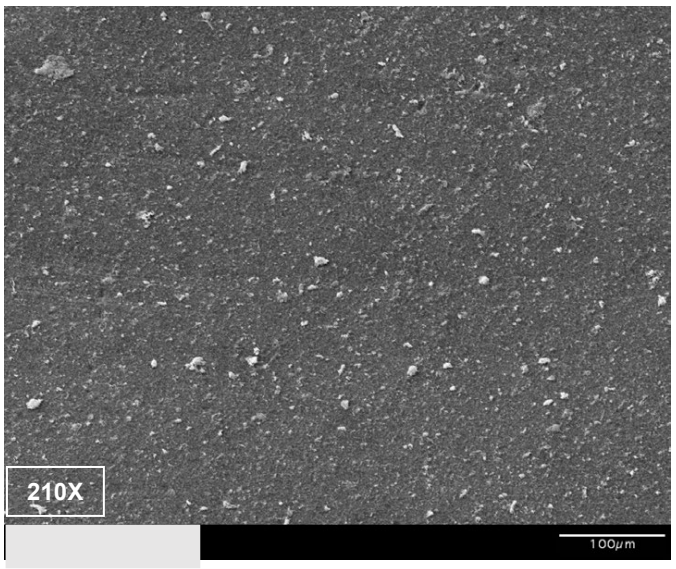
**ESTIMATED WEIGHT CONCENTRATIONS (%)**
**Normalized without Carbon, Oxygen and Sulfur**
**WITHIN 1-2µm EDS ANALYZED LAYER**

| SAMPLE | C | O | Na | Mg | Al | Si | P | S | Cl | Ca | Cr | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95°F Control | - | - | 4.43 | 6.12 | 2.24 | 1.52 | 0.90 | - | - | 84.29 | - | 0.51 |
| 20ppm | - | - | 19.38 | 12.50 | 10.00 | 8.75 | 5.00 | - | 8.75 | 22.50 | 1.25 | 11.88 |

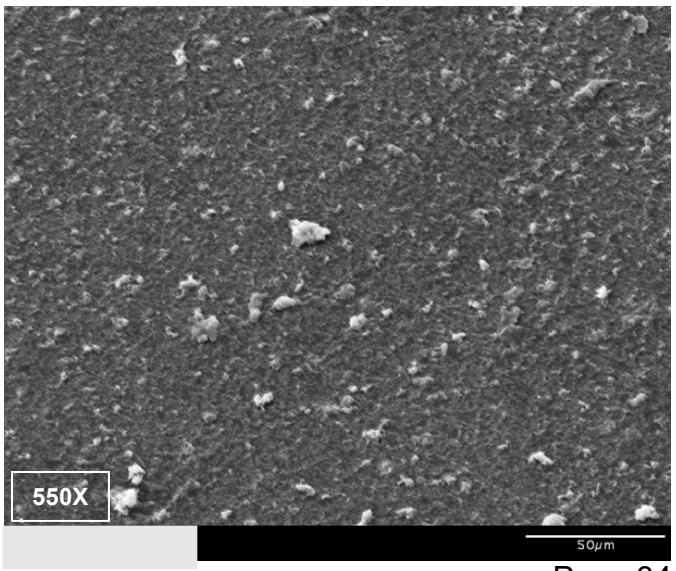

– 95°F Control
40X
500µm

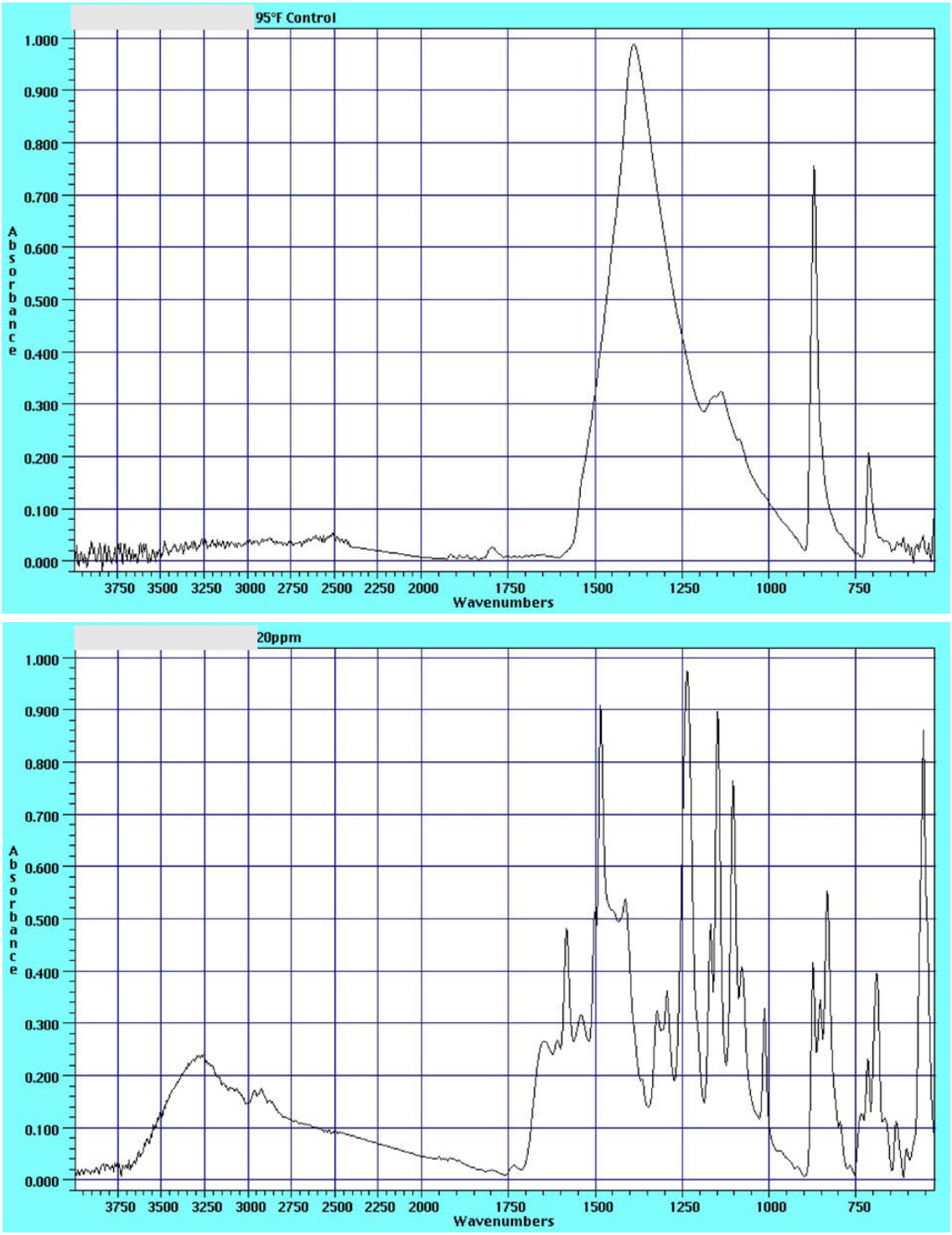

– 20ppm
40X
500µm


210X
100µm

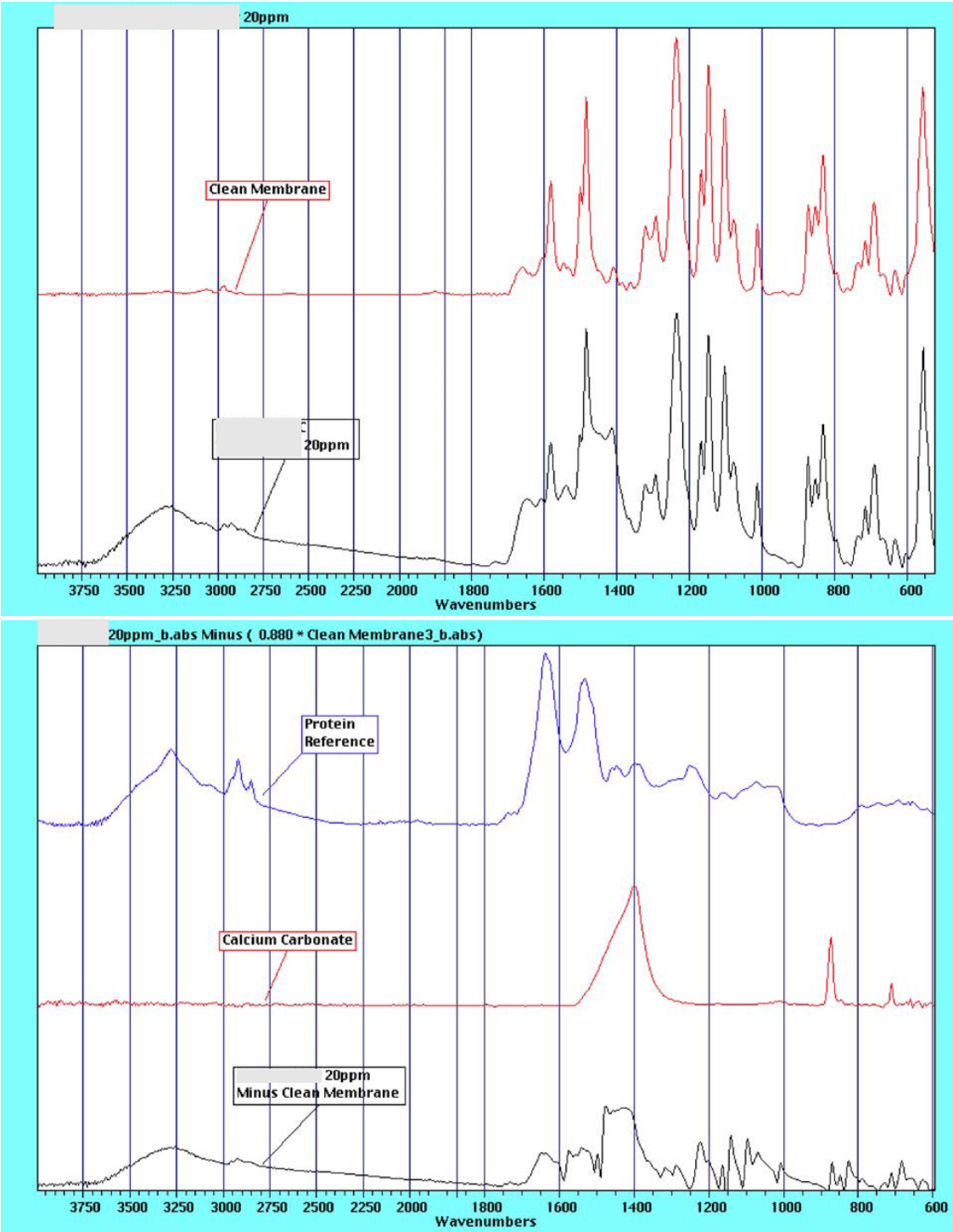

210X
100µm


550X
50µm


550X
50µm




The 95°F Control and 20ppm Membrane Sample surfaces are substantially different. The '95°F Control' surface is dominated by a signal for Calcite but the 20ppm sample is dominated by a signal from the underlying membrane substrate material with other low-level species.

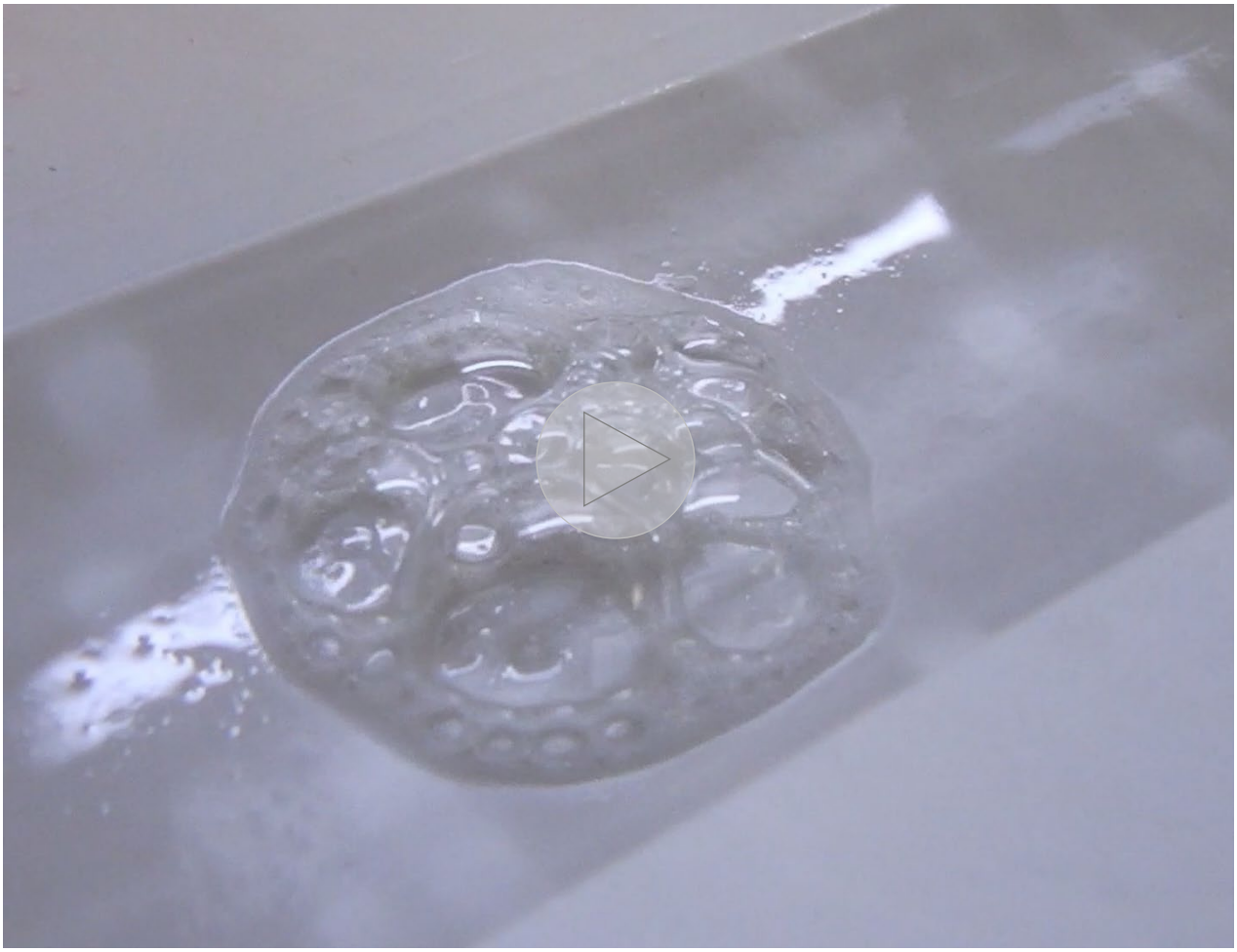



Subtracting a ‘Clean Membrane’ spectral signature from the ‘20ppm’ signal yields a pattern that indicates the presence of both Calcium Carbonate and Protein in low concentrations.

## Acid Testing

Acid testing was conducted on all coupons, with effervescence observed on all samples except for the 20ppm coupon. This reaction aligns with data from Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and Fourier Transform Infrared Spectroscopy (FTIR), providing additional validation of the results.

Click on the photo below to play video



## Summary of Findings

**Chemical Compatibility:**

**Overall** *average of both tests*

- Testing revealed a 0.57% increase in membrane flux
- Testing revealed a 0.08% decrease in salt rejection

**Two-Hour Cleaning Test** *at double the recommended dosage*

- Testing revealed a 0.57% increase in membrane flux
- Testing revealed a 0.02% increase in salt rejection

**Two-Week Soak Test** *at the recommended dosage*

- Testing revealed a 0.57% increase in membrane flux
- Testing revealed a 0.19% decrease in salt rejection

**Antiscalant Performance Challenge**:

**feedwater**

- Testing revealed that 5ppm of CLIENT CHEMICAL was not sufficient in preventing scale formation, resulting in a 41.10% total decrease in water flux
- Testing revealed that 20ppm of CLIENT CHEMICAL was not sufficient in preventing scale formation, resulting in a 44.60% total decrease in water flux. However, it did reduce the amount of calcium carbonate scale compared to the 5ppm concentration

**feedwater**

- Testing revealed that 5ppm of CLIENT CHEMICAL was not sufficient in preventing scale formation, resulting in a 63.03% total decrease in water flux
- Testing revealed that 20ppm of CLIENT CHEMICAL may be effective in preventing scale formation, resulting in an 11.96% total decrease in water flux. However, this level may be on the lower end of the recommended range, as traces of calcium carbonate were still observed

## Conclusion

The results indicate that CLIENT CHEMICAL is compatible with the new/unexposed MEMBRANE MODEL membrane element, with no observed chemical damage to the membrane.

Regarding the antiscalant performance challenge, any scale that begins to crystallize will be rejected and accumulate on the membrane surface as particulate matter, since we are recirculating the concentrate rather than discharging it from the system. Turbidity proved to be an unreliable measure of the timing of scale formation and, therefore, is not included as part of the overall analysis. EDS and FTIR analysis indicated that calcium carbonate is the primary scaling species present on the membrane surface. According to SEM images, CLIENT CHEMICAL demonstrates active modification of the scale crystals, altering their structure through crystal modification. This creates an imperfect crystalline structure, causing the crystals to either redissolve into the solution or inhibiting further crystal growth.

Testing on FEEDWATER #1, indicated that dosages of 5ppm and 20ppm were both insufficient in preventing calcium carbonate scale formation, likely due to elevated copper levels. Similarly, FEEDWATER #2, indicated that a dosage of 5ppm was insufficient to prevent calcium carbonate scaling, also presumably due to copper levels. However, it appears that a dosage of 20ppm may have been adequate to mitigate scale formation. SEM imaging, EDS, and FTIR all showed reduced calcium carbonate present on the membrane surface; however, 20ppm may be on the lower end of the recommended range, as traces of calcium carbonate were still observed.

## Release of Liability

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