NORTHERN ARIZONA UNIVERISTY

Increased Calcite Nucleation (ICN) to Prevent Scaling in Boilers

Researching an Alternative to Water Softeners

Final Report

Submitted by: A. Alnashwan, M. Alsahali, K. De Silva, F. Yu

Submitted to: Dr. Dianne McDonnell

12/12/2018

Acknowledgement

The ICN Team would like to thank Jon Heitzinger, our client and the supporter for the project. Jon provided feedback when we had any questions and she provided the equipment that we need such as the pressure vessel for testing data. We would like to acknowledge and thank our technical advisor, Dr. Terry Baxter for providing us with feedback and experience regarding our project. Also, special thanks to Adam Bringhurst for preparing the lab equipment and chemical materials for the team. Finally, thanks to our grader instructor, Dr. Dianne McDonnell, for guiding us as we navigated complications in the project. We appreciate all the professionals who were grateful for our concerns and contributions.

Table of Contents

List of Figures

List of Tables

List of Equations

List of Abbreviations

NAU- Northern Arizona University
ICN- Increased Calcite Nucleation
EWS-Environmental Water Systems
SEM-Scanning Electron Microscopy
TSS-Total Suspended Solids
TDS-Total Dissolved Solids
PALK- Phenolphthalein Alkalinity
TLAK- Total Alkalinity
CH-Calcium Hardness
NCH-Non-Carbonate Hardness
VSS-Volatile Suspended Solids
FSS-Fixed Suspended Solids
FDS-Fixed Dissolved Solids
VDS-Volatile Dissolved Solids

1.0 Introduction

1.1 Research Goal

The Northern Arizona University (NAU) South Boiler Plant would like to explore alternatives to scale prevention in their boilers. Current ion exchange softener used by the boiler use up a large amount of water and salt. Therefore, the goal of this research project is to look in to an alternative technology that can prevent scaling under boiler conditions with lesser problems. The technology that will be tested is known as ICN or Increased Calcite Nucleation. The team's main goal is to test this specific technology's ability to work under high pressures and temperatures of the boiler whilst preventing scaling in interior of the boiler. Testing will be completed at the Northern Arizona University (NAU) University lab, in the Engineering building. In attempt to mimic the boiler conditions a pressure vessel [Appendix A] with pressure and temperature gauges will be used

The team used the manufacturer's claims on ICN units to establish the hypothesis for this research. The following table summarizes the hypotheses the team came up with:

Table 1: Predictions based on the Manufacturer claims that the EWS ICN reduces scaling by forming less sticky aragonite crystals and not the stickier calcite crystals

Parameter	Post Boiling Groundwater	Post Boiling Conditioned ICN Water
Total Suspended Solids (TSS) *Suspended Solids nucleate to form $CaCO_3$ precipitate (Calcite or Aragonite)*	**TSS** in the effluent **decreases** ***Calcite** sticks to Vessel and does not stay in the water*	**TSS** in the effluent will **increase** ***Aragonite** will not stick to vessel and stays in the water*
Total Alkalinity and Hardness as $CaCO_3$	Alkalinity and Hardness in the effluent **decrease** *Hardness and Alkalinity will be removed from the water as a precipitate*	Alkalinity and Hardness in the effluent **decrease** *Hardness and Alkalinity will be removed from the water as a precipitate*
Scanning Electron Microscope (SEM) *Images the polymorphs of Calcium Carbonate ($CaCO_3$)*	**Calcite** crystals from in the scale *Calcite formation is favored in freshwater*	**Aragonite** crystal from in the scale *ICN conditioner changes the crystal structure*

1.2Background Information

1.2.1 Scale Formation

Hard water scaling of plumbing fixtures occurs in the presence of calcium ions dissolved in water. These ions form precipitates as calcium carbonate. Water heater elements and heat exchangers are more susceptible to scale build-up; high temperatures increase the precipitation rates. This is due to the role that carbon dioxide (CO_2) plays in calcium carbonate formation. In the overall reaction as shown in equation 4, carbon dioxide falls on the same side of the equation as calcium carbonate. As the temperature increases, the solubility of the carbon dioxide decreases, and the gas leaves the system, resulting the overall reaction to "go to the right" and to produce more calcium carbonate [1&2]. The following equations show the steps of scale formation.

Equation 1: Reaction 01 [2]

$$\boldsymbol{HCO_3^-}(aq) \leftrightarrow \boldsymbol{OH^-}(aq) + \boldsymbol{CO_2}(aq)$$

Equation 2: Reaction 02 [2]

$$OH^{-}(aq) + HCO_3^{-}(aq) \leftrightarrow CO_3^{2-}(aq) + H_2O$$

Equation 3: Reaction 03 [2]

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \leftrightarrow CaCO_3(s)$$

Equation 4: Overall reaction [2]

$$Ca^{2+}(aq) + 2HCO_3^{-}(aq) \rightarrow CaCO_3(s) + H_2O + CO_2(aq)$$

The final product of this reaction, $CaCO_3$, tends to attach itself onto surfaces due to the electrostatic attraction between the particles and the surface of the heating or pipe element. Once attached to a surface, these particles can act as a nucleation point for more particles to attach. Nucleation is the initial process that occurs in the formation of a crystal from a liquid, or a vapor, in which number of ions, atoms, or molecules become arranged in a pattern characteristic of a crystalline solid [2].

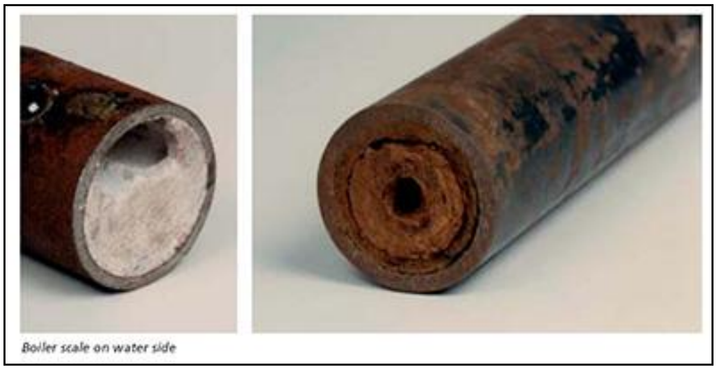

Figure 1: Scaling on pipes [2]

1.2.2 Alternative Water Softeners

1.2.2.1 Ion Exchange

Ion exchange resin is a common softener which uses ion exchange technology to remove the calcium and magnesium ions in the water. Cation exchange resins can generally retain good efficiency for 5 to 10 years (7 years average)[3], and anion exchange resins for 3 to 5 years (4 years average)[3]. However, the efficiency of the resin decreases each year and the cost of the resin has increased over recent years. The raw water supply into the devices has restrictions, the water intake should contain less than 5 ppm turbidity and 0.5 ppm hydrogen sulfide. Additionally, the levels of iron and manganese must be in the dissolved form [3].

1.2.2.2Electrically Induced Precipitation

Electrically Induced Precipitation method employs the use of currents in the formation of soft precipitates on electrodes. The process needs energy of up to 100W and the length of time that it can be used is limited due to the dangers associated with the use of DC energy. This method requires the use of backwash water which pushes the water backwards into the filters like a cycle to prevent maintenance. It is then reused it again for the cleaning of the electrodes, which needs to be handled manually [4].

1.2.2.3 Capacitive Deionization

Capacitive Deionization method absorbs ions from the water onto its electrodes. The ions are attached to the electrodes due to the charge difference, and then released when the electrodes are washed with salt water [4].

1.2.2.4 Electromagnetic Treatment

Electromagnetic Treatment method uses magnetic fields created by wires wrapped around a pipe. This process creates a soft precipitate by altering the ions. This particular soft precipitate prevents scale from forming on pipes and other appliances [4].

1.2.3 ICN by EWS

The Environmental Water System (EWS) manufactures ICN Conditioners for physical conditioning, as an alternative to salt softening. The ICN conditioner acts as a catalyst in the water. The bonds that trap foreign particles to water molecules are broken and those foreign particles are exposed to the open solution. The surfaces of these particles become available as nucleation points for the hardness minerals. The minerals cluster together to form microscopic seed crystals around the nucleation points. This process is called increased calcite nucleation (ICN). All the hardness minerals in the vicinity of these seed crystals eventually come in contact with its surface. The hardness minerals solidify there and no longer have an affinity for hard surfaces with which the water comes in contact [5].

The process is electrolytic with metal ion (Zn) dosing and the use of dissimilar metals that block scale growth sites and/or react with carbonate. The water forms the electrolyte in a galvanic cell as it flows through the cathode and active anode of the device. The dissolved zinc ions at the active anode site act as nucleation sites for scale precipitation when water is heated. The ICN Conditioner breaks apart the calcium and magnesium minerals, that easily adhere to surfaces (including your skin), from the bonds of the water molecules. Once in suspension, the minerals become attracted to each other and form concentric patterns which no longer adhere to surfaces, actively inhibiting scale formation. More of the less sticky needle-like aragonite forms instead of calcite which is usually associated with scale build up [5].

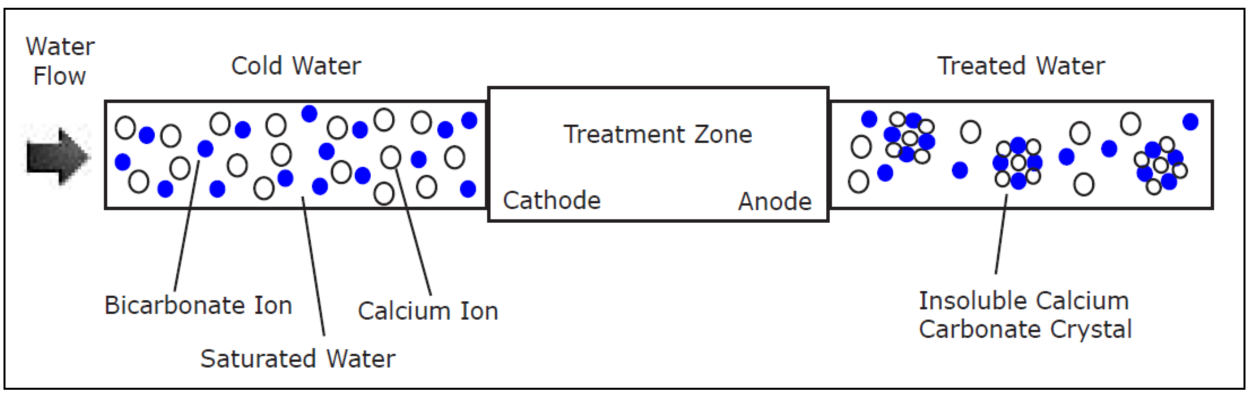

Figure 2: The Process Uses Dissimilar Metals to Prevent Scale Growth Sites and to Form Aragonite Crystals [5]

2.0 Methodology

2.1 Sampling Plan

Water sampling was done at Dr. Dianne McDonnell's and Mr. Kevin Baltzell's home. Water sampled from Dr. McDonnell's home represents the groundwater, while Mr. Baltzell's home represents the ICN treated water. For each sampling event the team collected approximately 5 gallons or 19 liters of groundwater and ICN water. This was done once per week starting from September 2018 through the end of November 2018. Samples were transported to the NAU environmental engineering lab, room 245 and batched in to the pressure vessel as shown in the figure below. The control for the system was the batching of groundwater into the pressure vessel. Likewise, ICN treated water was batched into the pressure vessel. The pressure vessel was used to simulate the conditions of the boiler at NAU South boiler plant with a temperature of 240°F and pressure of 160 PSI. The team took 4 samples, i.e. before and after heating the sample in the pressure vessel to test for hardness of water, Alkalinity of water, TSS and TDS of water, and SEM test. Additionally, the team took samples of the scale formed to run a separate SEM test on them.

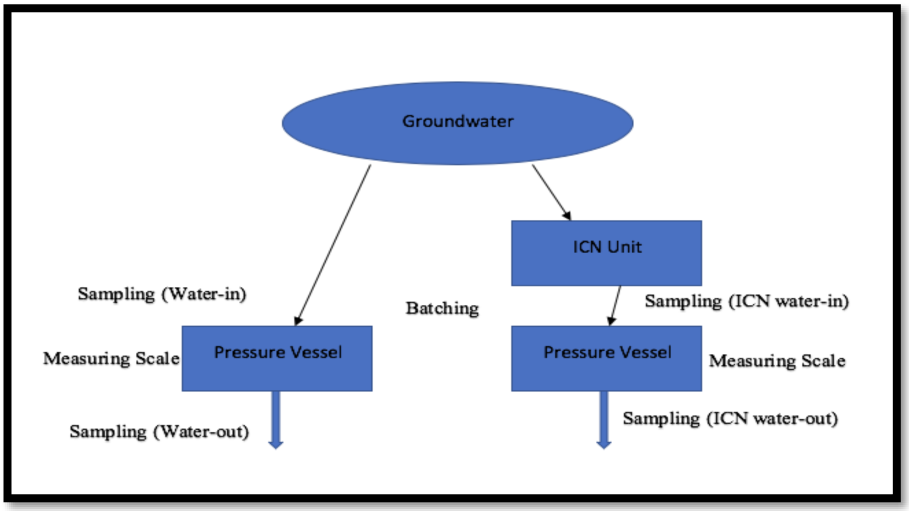

Figure 3: Project plan for sampling and conducting of tests

2.3 Batching of Samples

The team ran six batches of groundwater and ICN samples for six hours. Six 5 gallon or 19 liter samples of groundwater were batched and samples were taken for each batch as shown in figure 4. The batches were run continuously to ensure higher accumulation of scale inside the vessel. Once the batching of groundwater samples was completed the team conducted the measurement of scale formation. This was done using a weighing scale of 0.1 accuracy for gram unit. The initial weight of the vessel was recorded and then once the batches were completed the vessel was weighed with the scale build up. The difference of mass was the mass of scaled build up. The team used vinegar (as an acid with a lower normality) to clean up the scale formed in the vessel. Once the vessel was cleaned and dried, the team continued to run the 6 batches of the ICN samples. Once the ICN batching was completed, the team followed the same sampling plan and scale measurement procedures to acquire the required data.

2.4 Water Quality Procedures

2.4.1 Quality Control:

The team conducted the above describe procedure with the use of DI water and this was considered as the method blank to the experiment. This control was run at the end of the semester by using 3 batches of the DI water. Additionally, the team tested 3 samples of groundwater and ICN samples before getting batched and calculated the average to ensure the accuracy and precision of the results obtained.

2.4.2 Alkalinity Test:

Alkalinity is defined as the measure of water's capacity to neutralize acids: this is a test to calculate the carbonate and bicarbonate in the water. Using a titrant and indicators powder pillows the team conducted tests to determine the alkalinity of the water. The method and equations used are as follows:

- HACH Water Analysis Handbook: Alkalinity Method 8221 [7]

After the data were recorded, the calculation of the alkalinity test was conducted using the equations below:

Equation 5: Phenolphthalein Alkalinity

$$PALK = Titrant\ (ml) \times Normality \times 50{,}000 ml\ of\ sample$$

Equation 6: Total Alkalinity

$$TALK = Titrant\ (ml) \times Normality \times 50{,}000 ml\ of\ sample$$

Equation 7: Alkalinity

$$Alkalinity = PALK + TALK$$

2.4.3 Total Hardness Test:

Hardness determines the concentration of calcium and magnesium ions in the water. Using a titrant and an indicator, the calcium hardness (concentration of Ca2 +), magnesium hardness (concentration of Mg 2+) and total hardness were determined.

- HACH Water Analysis Handbook: Total Hardness Method 8226 [7]
- HACH Water Analysis Handbook: Calcium Hardness Method 8222 [7]

After the data were recorded, the calculations of the Total Hardness and Calcium Hardness were conducted using the equations listed below:

Equation 8: Hardness

$$Hardness = Titrant\ (ml) \times Normality \times 50{,}000 ml\ of\ sample$$

Equation 9: Magnesium Hardness

$$CH = CaHardness + MgHardness$$

Equation 10: Total Hardness

$$TotalHardness = CH + NCH$$

The values obtained from these calculations were used to determine the degree of hardness: soft, moderately hard, hard or very hard.

2.4.4 Total Suspended Solid and Dissolved Solid Test:

This test was used to determine the suspended and dissolved solids in the water.

- Standard Method Handbook: Total Solids Method 2540 B [8]
- Standard Method Handbook: Total Dissolved Solids Method 2540 C [8]

After the data were recorded, the calculation of TSS and TDS was conducted using the equations listed below:

Equation 11: Total Suspended Solids

$$\text{TSS} = \frac{(\text{Weight \#2} - \text{Weight \#1 (g)})}{\text{known sample volume (mL)}} \times \frac{1000\text{mL}}{\text{L}} \times \frac{1000\text{mg}}{\text{g}}$$

Equation 12: total dissolved solids

$$\text{TDS} = \frac{(\text{Weight \#2} - \text{Weight \#1 (g)})}{\text{know sample volume (mL)}} \times \frac{1000\text{mL}}{\text{L}} \times \frac{1000\text{mg}}{\text{g}}$$

1.3.4 Scanning Electron Microscopy Test:

Scanning Electron Microscopy was used to produce a micro image of the groundwater and ICN sample. This was conducted at NAU Imaging Core Facility in Building 88 (Wettaw). Samples of 150 mL volume were passed through a nitrocellulose filter with a pore size of 0.22 micro meters. This filter was placed inside the SEM unit shown in figure 5 and the images were taken. The test was conducted to see different crystal formation before and after the sample has passed through the ICN unit. Additionally, the team used the SEM technology to obtain images of the scale formed on the vessel.

3.0 Results

After obtaining the raw data form hardness and alkalinity test, the team used Equation 4 & 5 to calculate total hardness calcium hardness and magnesium hardness. The alkalinity is determined by equation 2, since the pH of all water samples is below 8, the Phenolphthalein alkalinity was assumed to be zero. Additionally, the TSS and TDS are calculated by equation 7-12. Table 1 represents the average of the data that the team collected through the batches. The results obtained for each batch test can be found in Appendix B.

Table 2: Water Quality Parameters Tested for the Groundwater Samples Collected Before and After Boiling

	Groundwater Before Boiled(Average of 3 batches)	Groundwater After Boiled (Average of 6 batches)
Total Hardness(mg$CaCO_3$/L)	150.0	73.3
Calcium Hardness (mg$CaCO_3$/L)	90.0	10.0
Magnesium Hardness (mg$CaCO_3$/L)	60.0	63.3
Total Alkalinity(mg$CaCO_3$/L)	260.0	140.0
Total Suspended Solid (mg/L)	26.7	35.0
Total Dissolved Solid (mg/L)	40.0	161.1

According to the hypothesis, the ICN will have to increase the TSS in the water and no scale will be formed. Thus, comparing with the above control group, the team did the same procedure for the ICN sample. The results of the water quality testing conducted for the ICN samples are presented in table 2. The water parameters were determined by the Equation 2, 4, 5, 7-12. Table 2 represents the average of the data that the team collected through the batches. The results obtained for each batch test can be found in Appendix B.

Table 3: Quality Parameters Tested for the ICN Samples Collected Before and After Boiling

	ICN Water Before Boiled (Average of 3 batches)	ICN Water After Boiled (Average of 6 batches)
Total Hardness (mg$CaCO_3$/L)	150.0	75.0
Calcium Hardness (mg$CaCO_3$/L)	80.0	11.7
Magnesium Hardness (mg$CaCO_3$/L)	70.0	63.3
Total Alkalinity (mg $CaCO_3$/ L)	240.0	146.7
Total Suspended Solid (mg/L)	40.0	60.0
Total Dissolved Solid (mg/L)	666.7	282.2

The following table is a summary table indicating the plus or minus error (based on standard deviation) of the average of data collected and the significant difference between groundwater and ICN sample data.

Table 4: Summary table

	Total Hardness		Total Alkalinity		TSS	
	Before Heat	After Heat	Before Heat	After Heat	Before Heat	After Heat
GW	150 +/- 0.0	73.3 +/- 5.2	260 +/-4.1	140 +/- 0.0	26.7 +/- 1.2	35 +/- 9.4
ICN	150 +/-0.0	73.4 +/- 8.2	240 +/- 0.1	146.7 +/- 10.3	40 +/-1.0	60 +/- 22.3
% Difference	0	0.13%	7.7%	4.8%	50%	71%

The SEM tests were used to prove the hypothesis: the ICN will create aragonite crystals and GW will have calcite crystals. The microscope images shown in Appendix C were taken from groundwater and ICN samples. These images were taken from groundwater and ICN samples before being heated up. The team wanted to see if there were any crystals formed in the water passed through the ICN unit compared to the raw groundwater samples. Images listed in Appendix C showed images of these samples at different magnitudes.

Appendix D shows the SEM images taken from the scale samples of both groundwater and ICN. The team decided to take these images to see if there's any difference in the presipitaion formed due to the two different samples. These images were taken after the six batches of both groundwater and ICN samples have been batched. The team scraped a bit of scale after the scale measurements were taken and sent the samples to the Imaging Core Facility at NAU.

Figure 4: Scale Scraped Down from Vessel

The team conducted 6 batches for both groundwater and ICN water to accumulate enough scale on the vessel. Using the laboratory electronic scales the team determined the amount of scale grown on the pressure vessel. The results are shown in the below table. The initial and final weights could be found in Appendix E.

Table 5: The Amount of Scale Formed: GW VS ICN

	Scale from Groundwater	Scale from ICN water
Weight (g)	10.1	3.3

4.0 Analysis of Results

To better analyze the performance of the ICN device, the team decided to compare the water quality test results of groundwater and ICN samples as shown below. Figure 4 shows the comparison of the water quality results of ICN water and groundwater samples before boiling. Although the magnesium and calcium hardness have a slight change over the six different samples that were tested, the total hardness does not vary much for both ICN and groundwater samples .Also, the alkalinity mostly remained the same after passing through the ICN device when compared with the untreated groundwater samples. The only thing that has significant increase is the total suspended solids which is 150% increased after passing through the ICN device as shown in Table.

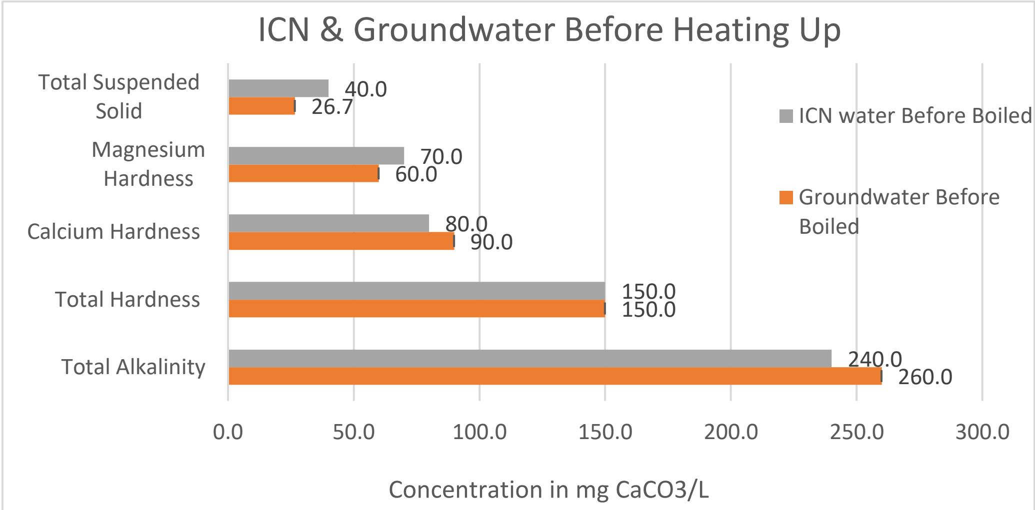

Figure 5: Comparison Between GW and ICN Before Boiling

The following graph shows the comparison of the water quality results of groundwater and ICN samples after boiling. According to figure 5, the values of hardness and alkalinity of both ICN and groundwater are still pretty similar to each other, that means the same amount of hardness and alkalinity have been removed. However, the total suspended solids of ICN water has been dramatically increased after boiling. According to the bar chart, it is almost twice as the groundwater.

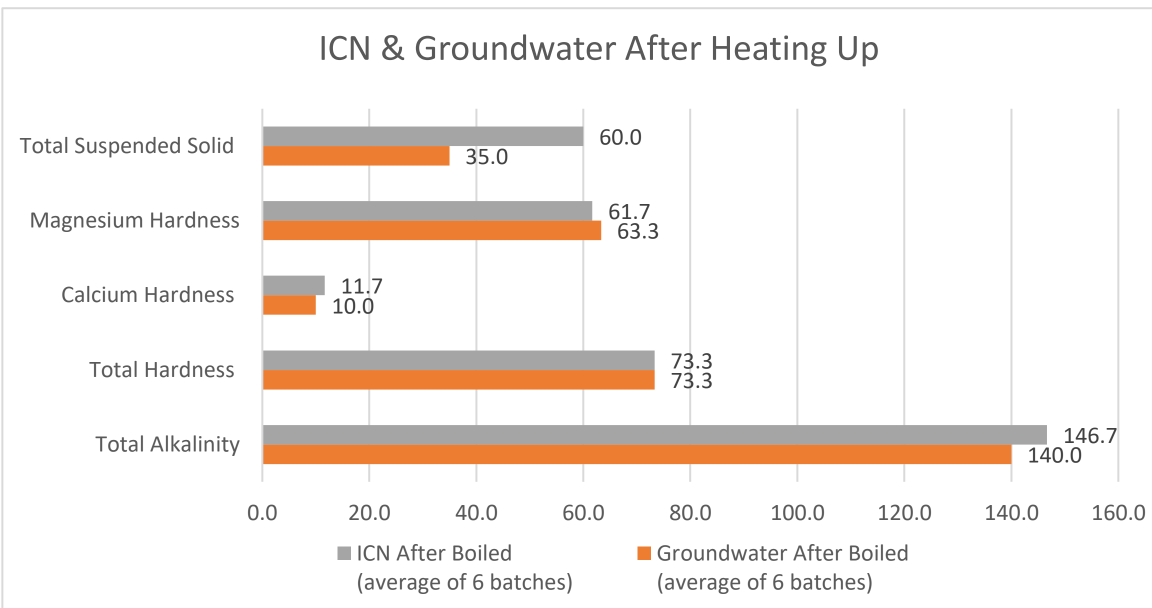

Figure 6: Comparison Between GW and ICN After Boiling

Based on the above analysis, the ICN devices does not affect a lot on removing hardness and alkalinity, instead, it increased the TSS in the water. To better demonstrate how the TSS changed, the team made the TSS percentage increased table and TSS compression chart.

From the graph shown below, it is clear that the total suspended solids have increased after boiling. However, the boiled ICN sample created more suspended solids than boiled groundwater. As shown in table 4 after heating the ICN water, the suspended solids increased more than twice compared to the groundwater. Table 4 below shows the percentage of total suspended solids increase for groundwater after boiled, ICN water, and ICN water after boiled. The ICN water after boiled produced the largest amount of total suspended solids which was increased by 225%.

Figure 7: Comparison of Total Suspended Solid

Table 6: The Percentage Increase of Total Suspended Solid

	Groundwater After Heating	ICN Water Before Heating	ICN Water After Heating
Percentage Increase	131.3%	150.0%	225.0%

The scale produced by ICN batches and groundwater batches had a significant difference in weight. The amount of scale produced by ICN batches was 3.3g, which is about 67% less than the amount of scale produced by groundwater batches.

5.0 Discussion and Conclusion

Scaling in water supply networks can cause various problems. They are mainly due to the deposit of $CaCO_3$ which can lead to damages of the water piping. For example, boiling processes in factories do not work well when they are fouled with these deposits [11].

According to the team's hypothesis, the nonreactive aragonite crystals will not attach on the vessel during the boiling procedure. Thus, the objective of the test was to see whether the ICN device is efficient enough to prevent this scale formation. As shown in the analysis above, the hardness and alkalinity of the groundwater and the ICN sample before and after boiling changed similarly. The manufacturers claim that the ICN conditioners do not reduce water hardness but prevents scaling by forming nonreactive aragonite crystals. The alternative hypothesis that the team came up with as shown in table 1 is that the water passing through the ICN before and after would have a decrease in hardness and alkalinity. Thus, the results proved this hypothesis correct. The next main hypothesis the team used was that water passing through ICN unit will increase its TSS with slightly minimal to no scale formed, and for groundwater TSS would decreases significantly and scale will be formed once the water is heated to high temperatures. However, the results obtained showed the TSS increased for both groundwater and ICN samples after heating up [Figure 4, 5, 6]. Additionally, the team noticed that the ICN sample scaled under the boiler conditions. Therefore, the hypothesis team predicted was proved wrong. The only difference was that the TSS result for the ICN sample was greater than the groundwater sample, where else the scale build up for the ICN sample was lower than the scale build up observed for the groundwater sample. As a result, the team concluded that the ICN unit will not prevent scaling under the NAU South boiler plant boiler conditions. However, the scale build up with the ICN treated water was 67% less than the scale built up observed with the untreated groundwater. The team recommends conducting more research on the ICN unit and compares the obtained results with various other alternative water softener units to verify the efficiency of the unit. However, at surface conditions, aragonite spontaneously turns into calcite over geologic time, but at higher pressures aragonite, the denser of the two, is the preferred structure. High temperatures work in calcite's favor. At surface pressure, aragonite can't endure temperatures above around 400°C for long. Since the boiler at NAU works under both high pressure and temperature, it is unclear how stable the aragonite crystals formed from the ICN unit will be. Therefore, more research needs to be conducted to verify the stability of the formed aragonite crystal.

Additionally, the team recommends looking into several variables that can alter the results obtained for the ICN unit. For example, does excess magnesium or zinc inhibit or decrease the likelihood of forming a precipitate. The EWS ICN unit does use zinc in the treatment process stage of the unit. However, it is unclear how this step in the treatment process helps the aragonite crystal growth. Several research done by complementary experimental procedures, show a high effect of zinc on the crystallization of calcium carbonate [11]. It was found that zinc can modify the crystallization of calcium carbonate. It may be due to the precipitation of zinc or its adsorption on the crystals of calcium carbonate. To verify this, the team recommends more research to be conducted.

6.0 Summary of Engineering Work

6.1 Schedule Modifications

Effective project scheduling plays a crucial role in ensuring project success. Therefore to keep this project on track and to manage quality to decrease product errors, the team has set realistic time frames and assigned resources appropriately to come up with the overall project schedule.

Table 7: The Predicted Overall Project Schedule

Project Task	**Start Date**	**Finish Date**
1.0 Setting up station and apparatus	5/30/18	6/12/18
1.1 Obtain the Unit	5/30/18	6/4/18
1.2 Set up the station and optimization of the procedures	6/4/18	6/12/18
2.0 Lab testing	6/12/18	10/31/18
2.1 Batching of Groundwater:	6/13/18	8/31/18
2.1.1 Hardness test	6/13/18	8/31/18
2.1.2 Alkalinity test	6/13/18	8/31/18
2.1.3 TS test	6/13/18	8/31/18
2.1.4 Scale formation	6/13/18	8/31/18
2.1.5 SEM tests	6/13/18	8/31/18
2.2 Batching of ICN water:	8/31/18	10/31/18
2.2.1 Hardness test	8/31/18	10/31/18
2.2.2 Alkalinity test	8/31/18	10/31/18
2.2.3 TS test	8/31/18	10/31/18
2.2.4 SEM tests	8/31/18	10/31/18
3.0 Analysis	10/1/18	11/20/18
4.0 Deliverables	9/20/18	12/20/18
4.1 30% Report	9/20/18	9/20/18
4.2 60% Report	10/6/18	10/25/18
4.3 90% website	11/15/18	12/2/18
4.4 Final Report	11/20/18	12/4/18
4.5 Final Presentation	11/20/18	12/4/18
5.0 Project Management	5/30/18	12/7/18

The above table represents the team project schedule that was projected during the last semester. The team was hoping to start the project over the summer of 2018; however this did not go as planned. Due to the difficulty of obtaining a suitable pressure vessel and finding the adequate funding for the purchase of the vessel took more time than what the team had initially expected. Therefore the team's actual start date for the project was pushed back till the end of July 2018. The table below shows the modified schedule the team followed through this semester.

Table 8: Actual Overall Project Schedule

Project Task	Start Date	Finish Date
1.0 Setting up station and apparatus	7/31/18	9/01/18
1.1 Obtain the Unit	7/31/18	8/13/18
1.2 Set up the station and optimization of the procedures	8/15/18	9/01/18
2.0 Lab testing	9/7/18	11/15/18
2.1 Batching of Groundwater:	9/7/18	10/20/18
2.1.1 Hardness test	9/7/18	10/20/18
2.1.2 Alkalinity test	9/7/18	10/20/18
2.1.3 TS test	9/7/18	10/20/18
2.1.4 Scale formation	9/7/18	10/20/18
2.1.5 SEM tests	10/20/18	10/23/18
2.2 Batching of ICN water:	10/25/18	11/10/18
2.2.1 Hardness test	10/25/18	11/10/18
2.2.2 Alkalinity test	10/25/18	11/10/18
2.2.3 TS test	10/25/18	11/10/18
2.2.4 SEM tests	11/11/18	11/15/18
3.0 Analysis	11/16/18	12/01/18
4.0 Deliverables	9/20/18	12/20/18
4.1 30% Report	9/20/18	9/20/18
4.2 60% Report	10/6/18	10/25/18
4.3 90% website	11/15/18	12/2/18
4.4 Final Report	11/20/18	12/4/18
4.5 Final Presentation	11/20/18	12/4/18
5.0 Project Management	7/15/18	12/7/18

The team was able to stay on top of the project though the entire schedule was pushed back by two months. This is because the team allocated more than enough time for each task and sub task when the projected schedule was created. Therefore, all the minor problems and pauses that the team came across were overcome easily.

6.2 Project Modifications

The team's initial research was based on Template Assisted Crystallization (TAC) technology. The team prepared the project proposal (completed in Spring 2018) and conducted the background research on this. However, when trying to purchase the unit, the team ran into several difficulties. The TAC units were not affordable since the prices were out of the projects budget. Therefore, the team had to look in to alternative technologies with similar outcomes.

The grading instructor, Dr. Dianne McDonnell was able to help the team in finding a new technology that could be purchased or used in order to complete the research project. This is how the team came across ICN technology and luckily Dr. McDonnell's neighbor had this unit installed in their house. The team could not set up the unit to be tested in the lab; however we were able to obtain the samples from the neighbor's house. This was the main project modification the team had to adapt to.

7.0 Summary of Engineering Costs

7.1 Project Staffing

The team decided to have four main personnel for this research project. The following table shows the project personnel and their hourly rates:

Table 9: Project personnel

Personnel	Code	Rate $/hr
Senior Engineer	SENG	255
Junior Engineer	JENG	175
Lab Technician	LT	103
Research Analyst	RA	135

For each personnel, the amount of hours that need to be contributed for each project task was determined.

Table 10: Staffing plan for the project

	SENG	JENG	LT	RA
Task Name	**Hours**			
Setting up the apparatus	2	8	4	5
Batching of Samples	48	125	329	27
Water quality testing	12	80	80	27
Analysis of results	6	15	5	20
30% proposal	10	10	2	2
60% proposal	10	10	2	2
Final proposal	30	20	5	5
Webpage	5	5	2	2
Final presentation	10	10	3	3
Total task hours	133	283	432	93
Total engineering hours	941			

The above table shows the staffing needed for each major task. The hours are accounted for the sub tasks under each major task as well. The SENG overlooks the entire project, JENG will be conducting and available for all the tasks that need to be completed, LT will be taking over the water quality testing or lab work and the RA will be handling the analysis conducted for the research. The total engineering hours for this research project came up to be 710.

7.2 Project Costs

The following table represents the total material and equipment costs for the project:

Table 11: Total Material and Equipment Costs

Materials	Quantity	Unit Cost $/hr	Total Cost $
Pressure Vessel	1	800	800.0
Vinegar	6	5	30.0
SEM Tests	5	40	200.0
Total material and equipment cost			1030.0

Table 10 represents the total labor costs and the total engineering billing cost including the material and labor costs.

Table 12: Labor costs and the total billing cost of engineering services

Personnel	**Total Hours**	**Rate $/hr**	**Total Cost $**
SENG	133	255.0	33915
JENG	283	175.0	49525
LT	432	103.0	44496
RA	93	135.0	12555
Total labor cost			140,491
Total engineering billing cost			141,521

8.0 References

[1] “South Heating and Cooling Plant,” *Northern Arizona University*, Internet: http://library.nau.edu/speccoll/exhibits/louies_legacy/southheating.html [Accessed: 11-Feb-2018]

[2] "Scaling in boilers," *Lenntech*, Internet: https://www.lenntech.com/applications/process/boiler/scaling.html [Accessed: 27-Jan-2018]

[3]W. S. Miller, "Understanding Ion-Exchange for water treatment system," *GE water and process Technolgies*, vol. 35, no. 8, pp. 149-153, 2018.

[4]M. K. Ahn, C. Han, "Technologies for the Removal of Water Hardness and Scaling Prevention,"*Journal of Energy Engineering*,vol. 26, no. 2, pp. 73-79, 2017

[5]P. Fox, M. Wiest, T. Thomure, W. Lee, "Evaluation of Alternatives to Domestic Ion Exchange," *WateReuse Research Foundation*, Tempe, AZ, Rep. 01, 2011

[6]D. McDonnell, “EWS, Inc.Physical Conditioning Discussion, Documentation and Position Papers”, Personnel Communications-Email, 2018.

[7] "HACH Methods”, Internet: httpshttps://www.hach.com/ [Accessed 10 October 2018].

[8] E.W. Rice, R.B. Baird, A.D. Eaton, “Standard methods for the examination of water and wastewater”, 23rd Edition, Washington, DC, New York: American Public Health Association, 2005.

[9] A. Alden, “Calcite vs Aragonite”, 2017, Internet: https://www.thoughtco.com/calcite-vs-aragonite-1440962

[10] J. Heitzinger, E. Vaughan, “NAU chiller/boiler information”, Personnel Communications-Email, 2018.

[11] S. Ghizellaouia, M. Euvrardb, “Assessing the effect of zinc on the crystallization of Calcium Carbonate”, *Desalination*, vol 220, pp.394–402, 2008.

9.0 Appendices

Appendix A-Pressure Vessel

Figure 8: Pressure Vessel Used to Stimulate Boiler Conditions

Appendix B-Water Quality Testing Raw Data

Initial GW Test Results:

Table 13: Alkalinity Titration Data of GW Before Heating Up

Alkalinity		
mL of titrate	**Color**	
0	green	
1	green	
2	green	
3	green	
4	Light green	
5	Light green	
6	Light green	
7	Light green	
8	Light green	
9	Blue/Green	
10	Blue	
11	BLUE	
12	pink	
13	Pink	<4.5 pH

Table 14: Calculated Alkalinity for GW Before Heating Up

Alkalinity		
T ALK	260	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 15 GW- Total Hardness and Calcium Hardness Raw Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	15	Titration Volume (mL)	9

Table 16 GW- Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	150
CH	150
NCH	0

Table 17 GW-Total Suspended Solids and Dissolved Solids Raw Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1043	**Wd1 (g)**	51.4847
Wf2 (g)	0.1047	**Wd2 (g)**	51.4853
Wf3 (g)	0.1045	**Wd3 (g)**	51.483

Table 18: GW-TS & DS results

Suspended Solid (mg/L)	
TSS	26.67
VSS	13.33
FSS	13.33333333
Total Solid (mg/L)	
TS	66.67
TVS	166.67
TFS	0
Dissolved Solid (mg/L)	
TDS	40
VDS	153.3
FDS	0

Batch 01 GW Test Results:

Table 19: GW-Batch#1- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	Blue -Gray	
7	Pink	4.5 pH

Table 20 GW-Batch#1- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 21 GW-Batch#1-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	8	Titration Volume (mL)	1

Table 22 GW-Batch#1-Total Hardness Results

mg/ L as CaCO3	
Mg	70
TH	80
CH	80
NCH	0

Table 23: GW-Batch#1-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1049	**Wd1 (g)**	159.9199
Wf2 (g)	0.1051	**Wd2 (g)**	159.932
Wf3 (g)	0.1048	**Wd3 (g)**	159.9121

Table 24: GW-Batch#1-TS & DS results

Suspended Solid (mg/L)	
TSS	13.33
VSS	0
FSS	0
Total Solid (mg/L)	
TS	820.00

TVS	0
TFS	0
Dissolved Solid (mg/L)	
TDS	806.6666667
VDS	0
FDS	0

Batch 02 GW Test Results:

Table 25: GW-Batch#2- Alkalinity Results

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	purple	
7	Pink	4.29 pH

Table 26: GW-Batch#2-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 27: GW-Batch#2- Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 28: GW-Batch#2-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1046	**Wd1 (g)**	47.7574
Wf2 (g)	0.1051	**Wd2 (g)**	47.7582
Wf3 (g)	0.1048	**Wd3 (g)**	47.5578

Table 29: GW-Batch#2, TS & DS results

Suspended Solid (mg/L)	
TSS	33.3
VSS	0
FSS	0
Total Solid (mg/L)	
TS	86.7
TVS	0
TFS	0
Dissolved Solid (mg/L)	

TDS	53.3
VDS	0
FDS	0

GW Batch 03 Test Results:

Table 30: GW-Batch3-Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	purple	
7	Light Pink	4.49 pH

Table 31: GW-Batch#3- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 32: GW-Batch#3- Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	8	Titration Volume (mL)	1

Table 33: GW-Batch#3- Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1033	**Wd1 (g)**	46.8747
Wf2 (g)	0.1041	**Wd2 (g)**	46.8751
Wf3 (g)	0.1034	**Wd3 (g)**	46.8749

Table 34: GW-Batch#3-TS & DS results

Suspended Solid (mg/L)	
TSS	53.3
VSS	0
FSS	6
Total Solid (mg/L)	
TS	80
TVS	0
TFS	20
Dissolved Solid (mg/L)	
TDS	26.7

VDS	0
FDS	13

GW Batch 04 Test Results:

Table 35: GW-Batch4-Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	gray	
6	gray	
7	pink	4.23 pH

Table 36: GW- Batch#4-Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 37: GW-Batch#4-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 38: GW-Batch#4-Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 39: GW-Batch#4- Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)	15		
Wf1 (g)	0.1054	**Wd1 (g)**	46.7107
Wf2 (g)	0.1059	**Wd2 (g)**	46.711
Wf3 (g)	0.1057	**Wd3 (g)**	46.7108

Table 40: GW-Batch#4- TS & DS results

Suspended Solid (mg/L)	
TSS	33.3
VSS	0

FSS	20
Total Solid (mg/L)	
TS	53.3
TVS	0
TFS	26.7
Dissolved Solid (mg/L)	
TDS	20
VDS	0
FDS	6.7

GW Batch 05 Test Results:

Table 41: GW-Batch5- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	green-blue	
8	pink	4.4 pH

Table 42: GW- Batch#5- Alkalinity Results

Alkalinity		
T ALK	160	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 43: GW-Batch#5, Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 44: GW-Batch#5-Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 45: GW-Batch#5- Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1031	**Wd1 (g)**	48.2399
Wf2 (g)	0.1036	**Wd2 (g)**	48.2402
Wf3 (g)	0.1033	**Wd3 (g)**	48.238

Table 46: GW-Batch#5-TS & DS results

Suspended Solid (mg/L)	
TSS	33.3

VSS	0
FSS	13.4
Total Solid (mg/L)	
TS	53.3
TVS	0
TFS	0
Dissolved Solid (mg/L)	
TDS	20
VDS	0
FDS	0

GW Batch 06 Test Results:

Table 47: GW-Batch6, Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	pink	4.26 pH

Table 48: GW- Batch#6-Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 49: Batch#6-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 50: GW-Batch#6-Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 51: GW-Batch#6- Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		**15**	
Wf1 (g)	0.102	**Wd1 (g)**	47.9851
Wf2 (g)	0.10245	**Wd2 (g)**	47.9857
Wf3 (g)	0.1021	**Wd3 (g)**	47.9854

Table 52: GW-Batch#6-TS & DS results

Suspended Solid (mg/L)	
TSS	30.00
VSS	0.00
FSS	6.666666667
Total Solid (mg/L)	
TS	70.00
TVS	0.00
TFS	26.67
Dissolved Solid (mg/L)	
TDS	40
VDS	0
FDS	20

Initial ICN Test Results:

Table 53: ICN, Alkalinity Raw Data

Alkalinity		
mL of titrate	**Color**	
0	green	
1	green	
2	green	
3	green	
4	Light green	
5	Light green	
6	Light green	
7	Light green	
8	Light green	
9	Light green	
10	Blue/Green	
11	blue/gray	
12	pink	3.8 pH

Table 54: ICN, Alkalinity Results

Alkalinity		
T ALK	240	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 55: ICN, Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	15	Titration Volume (mL)	8

Table 56: ICN, Total Hardness Results

mg/ L as CaCO3	
Mg	70
TH	150
CH	150
NCH	0

Table 57: ICN, Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.2108	**Wd1 (g)**	159.9195
Wf2 (g)	0.2114	**Wd2 (g)**	159.9295
Wf3 (g)	0.2112	**Wd3 (g)**	159.9267

Table 58: ICN, TS& DS results

Suspended Solid (mg/L)	
TSS	40.00
VSS	0
FSS	26.7
Total Solid (mg/L)	
TS	706.67
TVS	0
TFS	506.67
Dissolved Solid (mg/L)	
TDS	666.6666667
VDS	0
FDS	480

ICN Batch 01 Test Results:

Table 59: ICN Batch01-, Alkalinity Raw Data

Alkalinity		
mL of titrate	**Color**	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	Blue -Gray	
7	Pink	4.46 pH

Table 60: ICN, Batch01- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 61: ICN, Batch 01-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	8	Titration Volume (mL)	1

Table 62: ICN, Batch01- Total Hardness Results

mg/ L as CaCO3	
Mg	70
TH	80
CH	80
NCH	0

Table 63: ICN, Batch01-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1061	**Wd1 (g)**	46.9783
Wf2 (g)	0.1075	**Wd2 (g)**	46.9901
Wf3 (g)	0.1062	**Wd3 (g)**	46.9636

Table 64: ICN, Batch01-TS& DS results

Suspended Solid (mg/L)	
TSS	93.33
VSS	0.00
FSS	6.666666667
Total Solid (mg/L)	
TS	880.00
TVS	0.00
TFS	0.00
Dissolved Solid (mg/L)	
TDS	786.6666667
VDS	0
FDS	0

ICN Batch 02 Test Results:

Table 65: ICN Batch02- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	green	
8	Pink	4.25 pH

Table 66: ICN, Batch02- Alkalinity Results

Alkalinity		
T ALK	160	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 67: ICN, Batch 02-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	8	Titration Volume (mL)	2

Table 68: ICN, Batch02- Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	80
CH	80
NCH	0

Table 69: ICN, Batch02-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1033	**Wd1 (g)**	47.5483
Wf2 (g)	0.1045	**Wd2 (g)**	47.553
Wf3 (g)	0.1034	**Wd3 (g)**	47.501

Table 70: ICN, Batch02-TS& DS results

Suspended Solid (mg/L)	
TSS	80.00

VSS	0.00
FSS	6.666666667
Total Solid (mg/L)	
TS	393.33
TVS	0.00
TFS	6.67
Dissolved Solid (mg/L)	
TDS	313.3333333
VDS	0
FDS	0

ICN Batch 03 Test Results:

Table 71: ICN Batch03- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	Pink	4.25 pH

Table 72: ICN, Batch03- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 73: ICN, Batch 03-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	6	Titration Volume (mL)	1

Table 74: ICN, Batch03- Total Hardness Results

mg/ L as CaCO3	
Mg	50
TH	60
CH	60
NCH	0

Table 75: ICN, Batch03-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1031	Wd1 (g)	46.8999
Wf2 (g)	0.104	Wd2 (g)	46.8961
Wf3 (g)	0.1033	Wd3 (g)	46.8931

Table 76: ICN, Batch03-TS& DS results

Suspended Solid (mg/L)	
TSS	60.00
VSS	0.00
FSS	13.33333333
Total Solid (mg/L)	

TS	60.00
TVS	0.00
TFS	0.00
Dissolved Solid (mg/L)	
TDS	0
VDS	0
FDS	0

ICN Batch 04 Test Results:

Table 77: ICN Batch04- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	Pink	4.35 pH

Table 78: Batch04- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 79: ICN, Batch 04-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	8	Titration Volume (mL)	1

Table 80: ICN, Batch04- Total Hardness Results

mg/ L as CaCO3	
Mg	70
TH	80
CH	80
NCH	0

Table 81: ICN, Batch04-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1043	Wd1 (g)	46.2849
Wf2 (g)	0.1049	Wd2 (g)	46.3101
Wf3 (g)	0.1044	Wd3 (g)	46.2911

Table 82: ICN, Batch04-TS& DS results

Suspended Solid (mg/L)	
TSS	40.00
VSS	0.00

FSS	6.666666667
Total Solid (mg/L)	
TS	1720.00
TVS	0.00
TFS	420.00
Dissolved Solid (mg/L)	
TDS	1680
VDS	0
FDS	413.3333333

ICN Batch 05 Test Results:

Table 83: ICN Batch05- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	pink	4.28 pH

Table 84: ICN, Batch05- Alkalinity Results

Alkalinity		
T ALK	140	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 85: ICN, Batch 05-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 86: ICN, Batch05- Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 87: ICN, Batch05-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1051	Wd1 (g)	46.8464
Wf2 (g)	0.1058	Wd2 (g)	46.9531
Wf3 (g)	0.1052	Wd3 (g)	46.8513

Table 88: ICN, Batch05-TS& DS results

Suspended Solid (mg/L)	
TSS	46.67
VSS	0.00

FSS	6.7
Total Solid (mg/L)	
TS	7160.00
TVS	0.00
TFS	333.3
Dissolved Solid (mg/L)	
TDS	7113.3
VDS	0
FDS	326.7

ICN Batch 06 Test Results:

Table 89: ICN Batch06- Alkalinity Raw Data

Alkalinity		
mL of titrate	Color	
0	green	
1	green	
2	green	
3	green	
4	green	
5	green	
6	green	
7	Purple	
8	Pink	4.1 pH

Table 90: ICN, Batch06- Alkalinity Results

Alkalinity		
T ALK	160	Total Alkalinity
P ALK	0	<8 pH (Assumption)

Table 91: ICN, Batch 06-Total Hardness and Calcium Hardness Row Data

Total Hardness		Calcium Hardness	
Titration Volume (mL)	7	Titration Volume (mL)	1

Table 92: ICN, Batch06- Total Hardness Results

mg/ L as CaCO3	
Mg	60
TH	70
CH	70
NCH	0

Table 93: ICN, Batch06-Total Suspended Solids and Dissolved Solids Row Data

Suspended And Dissolved Solid			
Sample (mL)		15	
Wf1 (g)	0.1035	Wd1 (g)	47.4361
Wf2 (g)	0.1041	Wd2 (g)	47.5132
Wf3 (g)	0.1037	Wd3 (g)	47.447

Table 94: ICN, Batch06-TS& DS results

Suspended Solid (mg/L)	
TSS	40.00

VSS	0.00
FSS	13.3
Total Solid (mg/L)	
TS	5180.00
TVS	0.00
TFS	740.00
Dissolved Solid (mg/L)	
TDS	5140
VDS	0
FDS	726.7

Appendix C- SEM Images

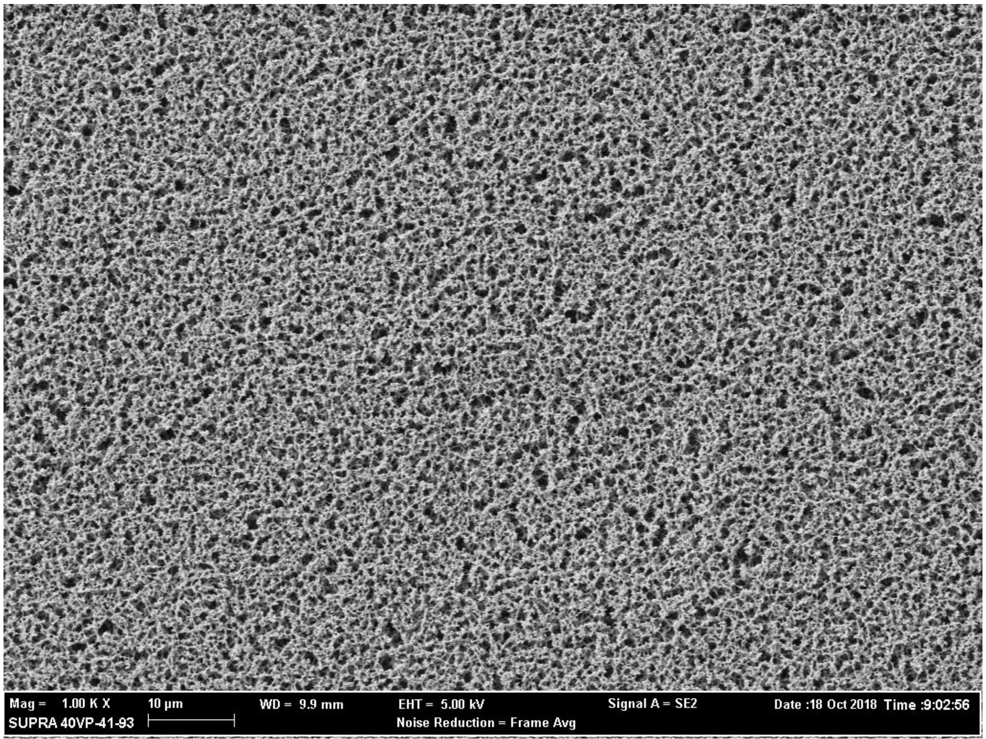

Figure 9: Blank Filter-Nitrocellulose-Image 01

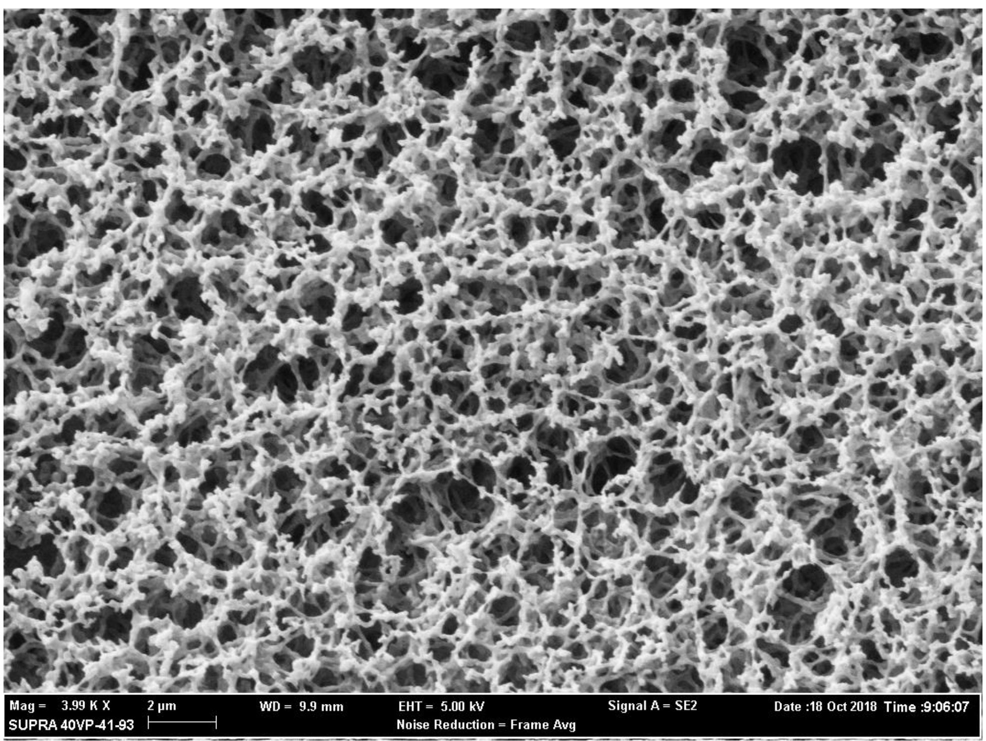

Figure 10: Blank Sample-Nitrocellulose-Image 02

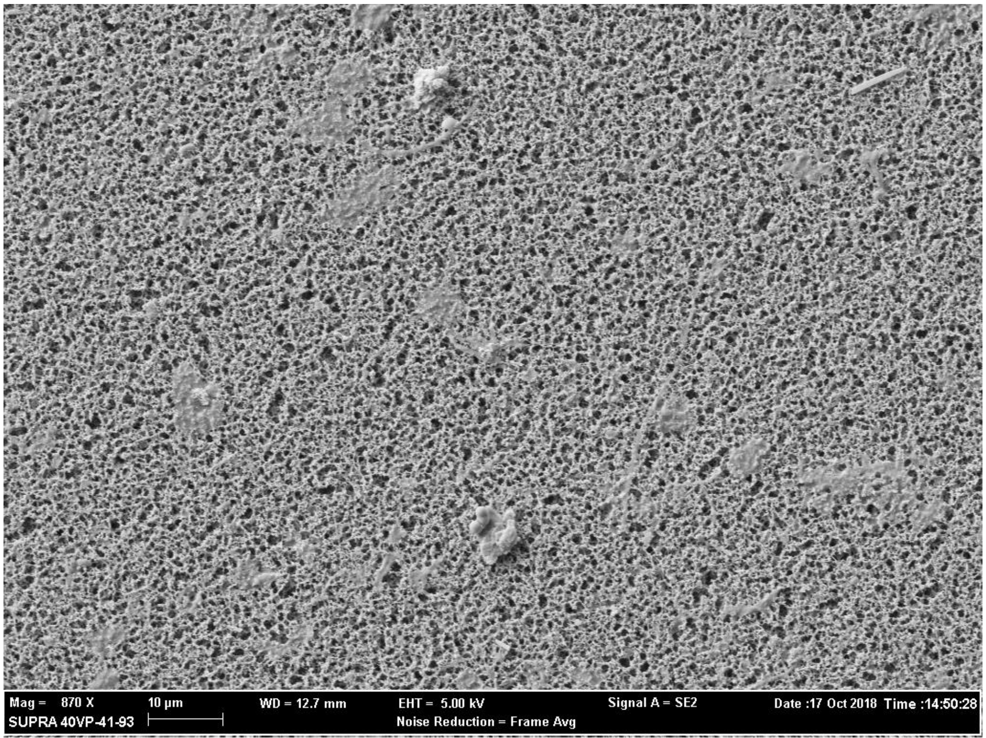

Figure 11: GW Sample-Image 01

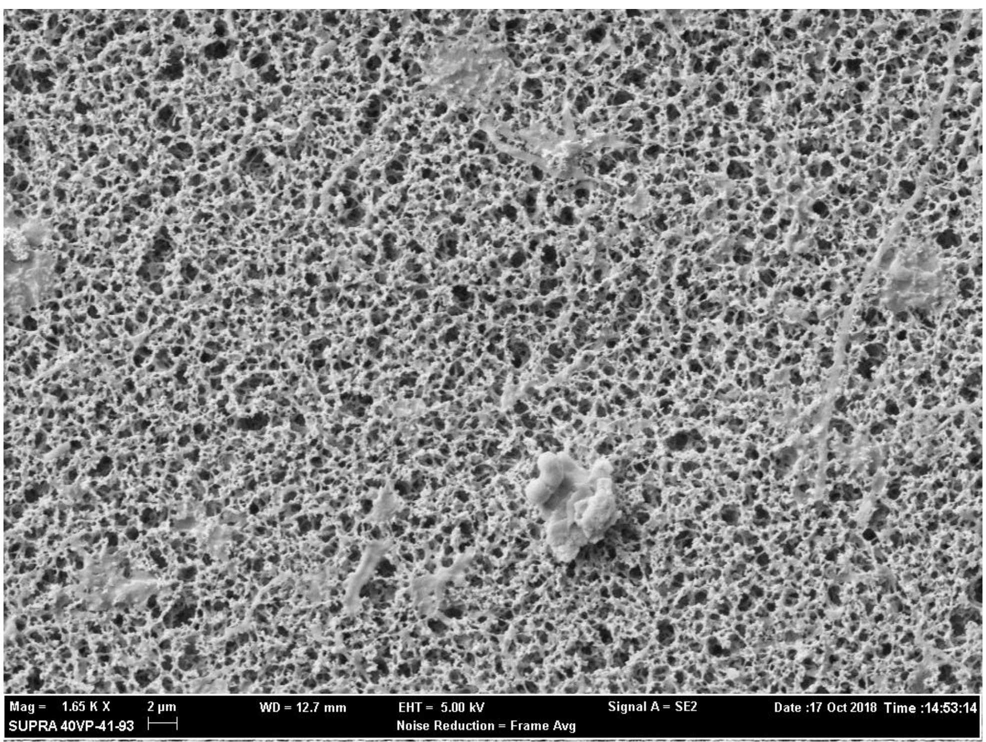

Figure 12: GW Sample-Image 02

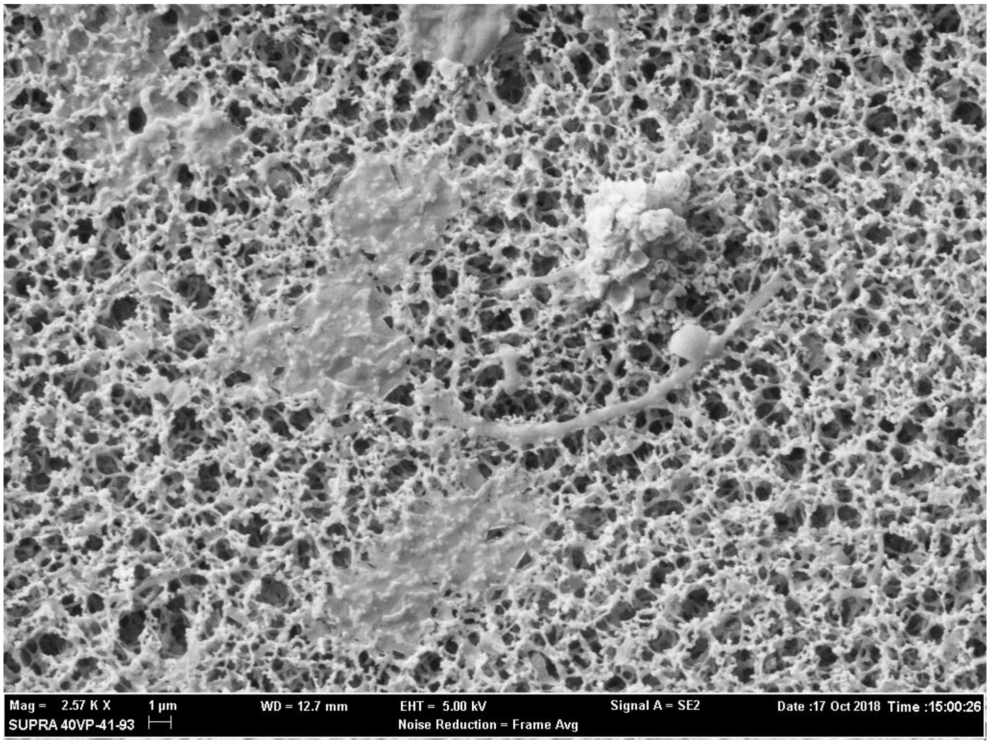

Figure 13: GW Sample-Image 03

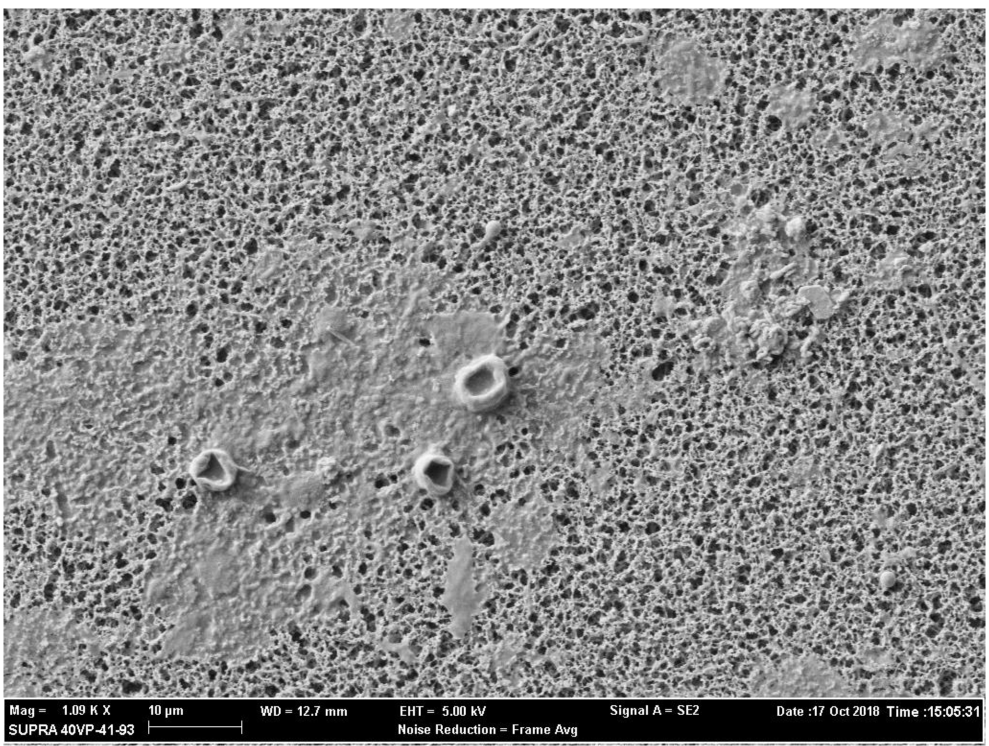

Figure 14: GW Sample-Image 04

Figure 15: GW Sample-Image 05

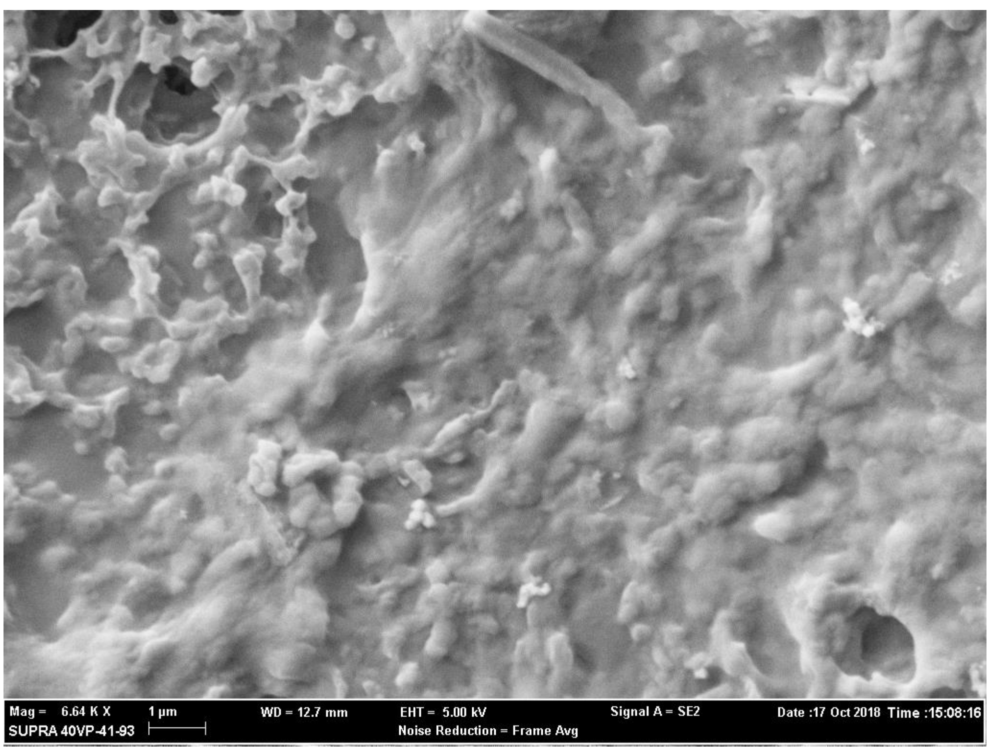

Figure 16: GW Sample-Image 06

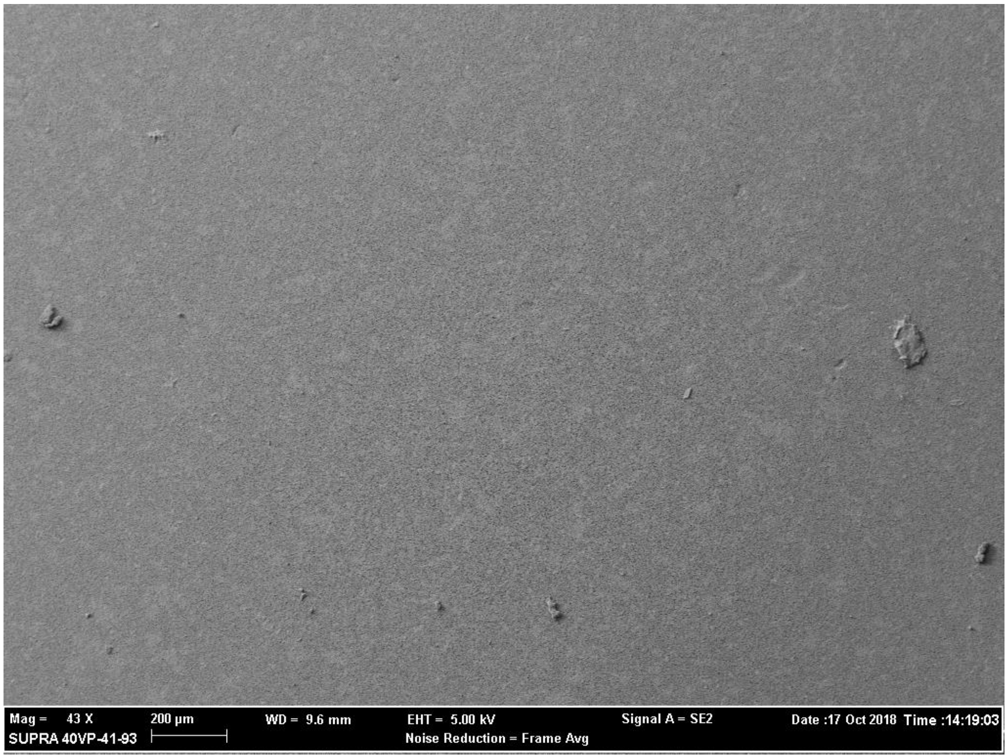

Figure 17: ICN Sample-Image 01

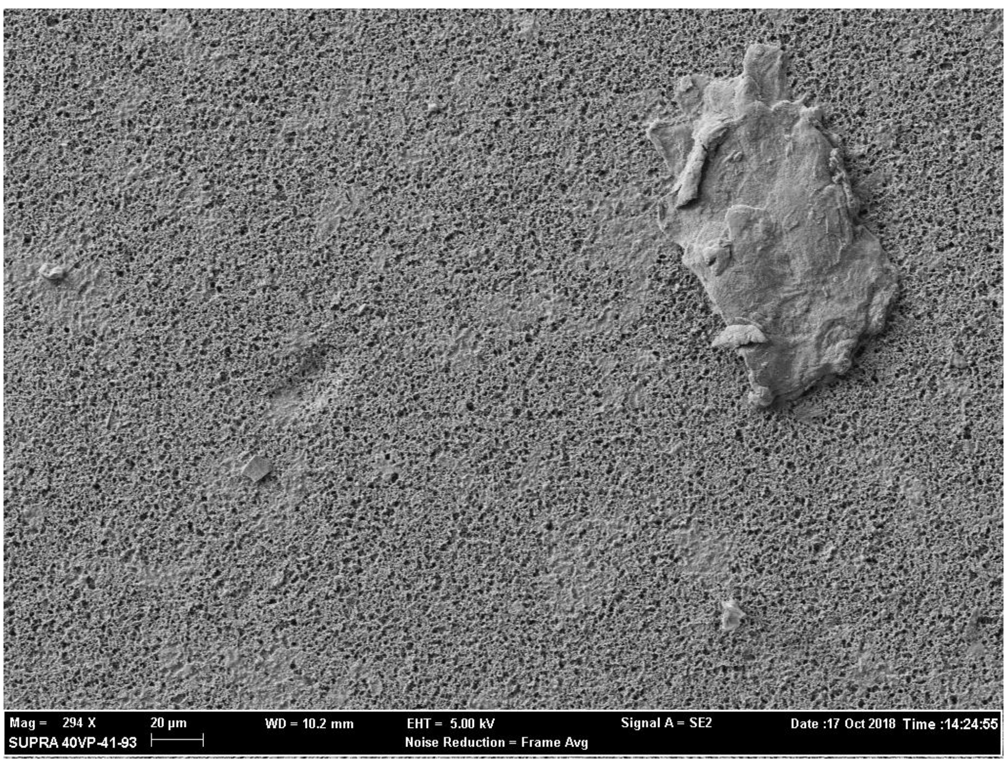

Figure 18: ICN Sample-Image 02

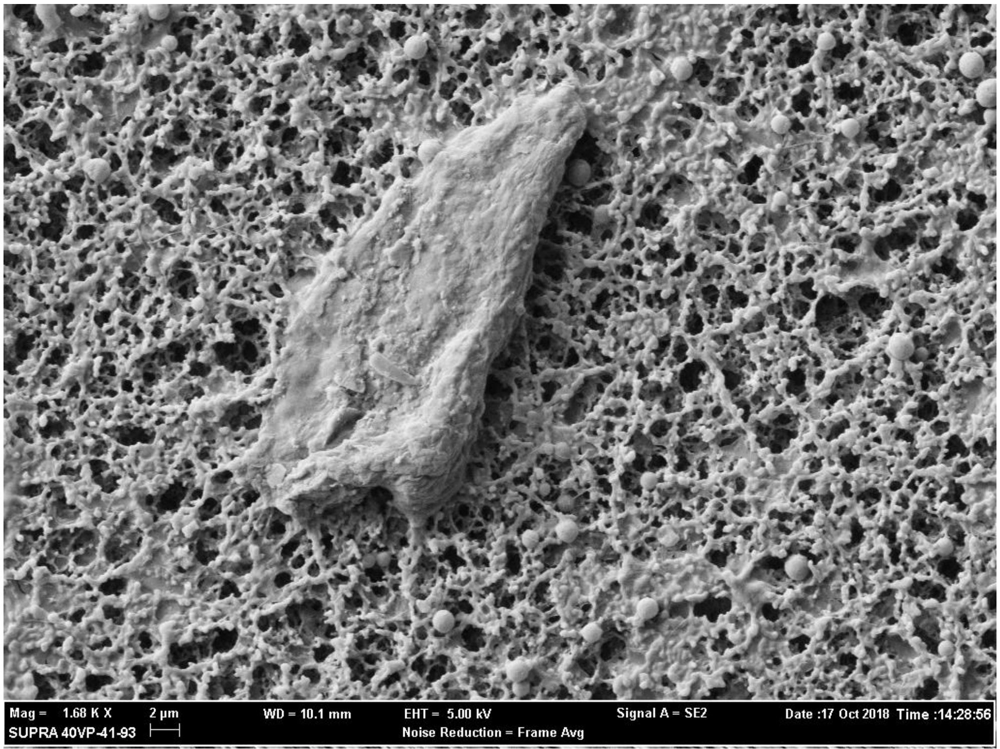

Figure 19: ICN Sample-Image 03

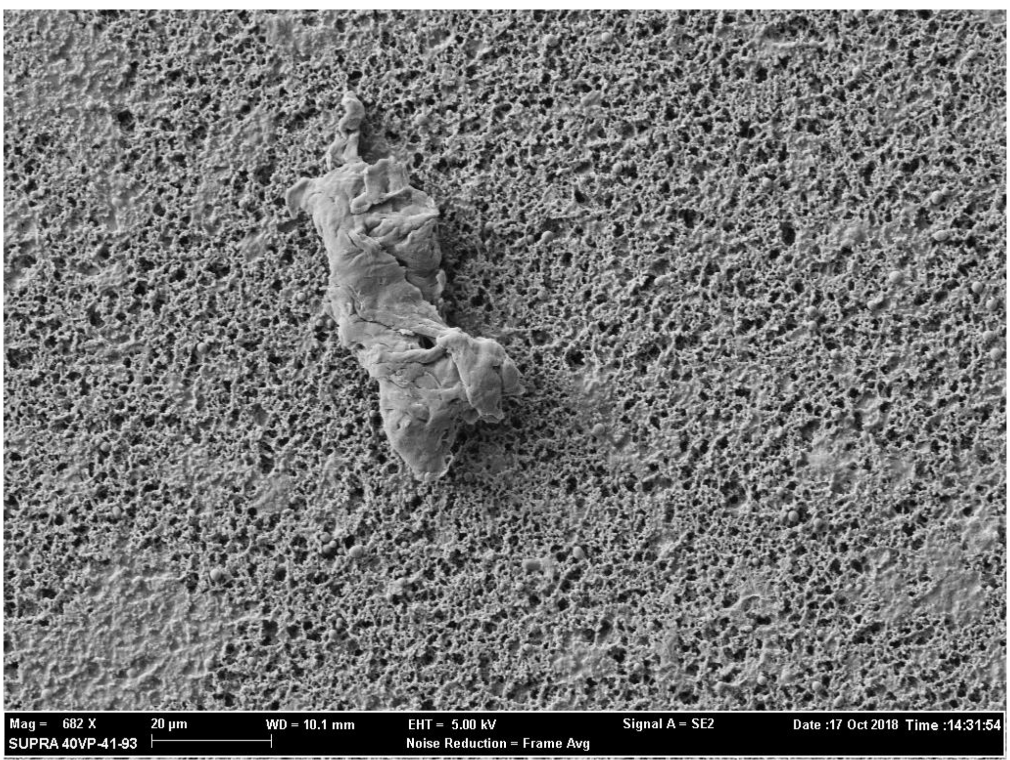

Figure 20: ICN Sample: Image 04

Appendix D- Scale SEM images

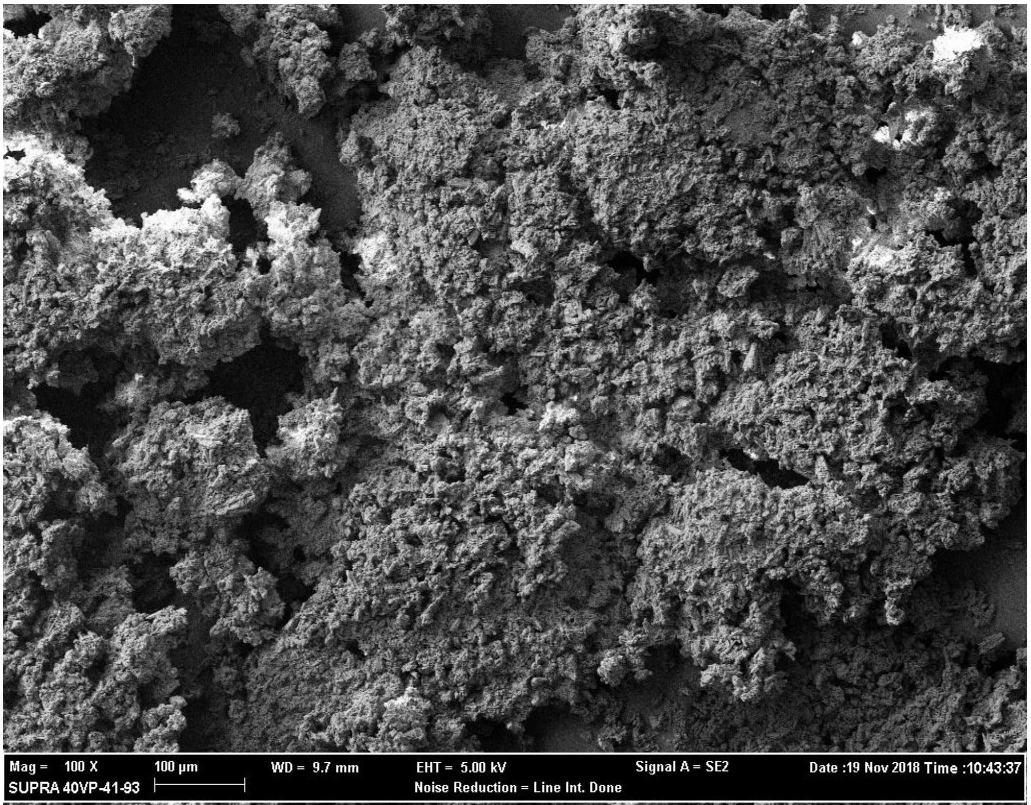

Figure 22: GW Scale Sample-Calcite-Image01

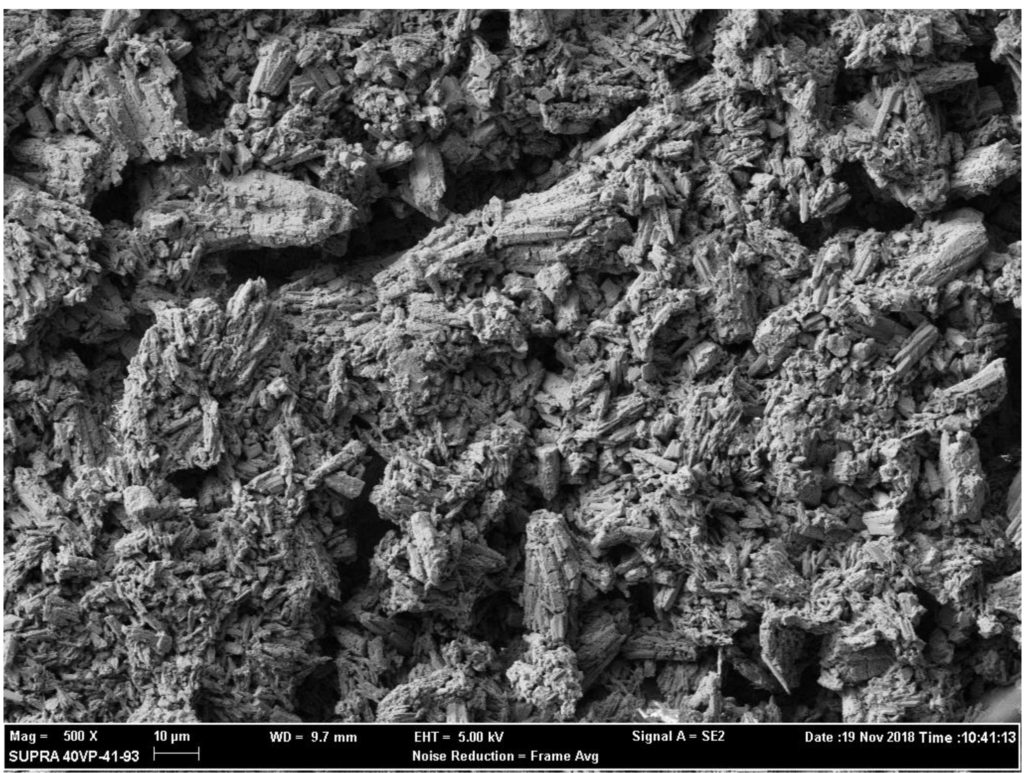

Figure 21: GW Scale Sample-Calcite-Image02

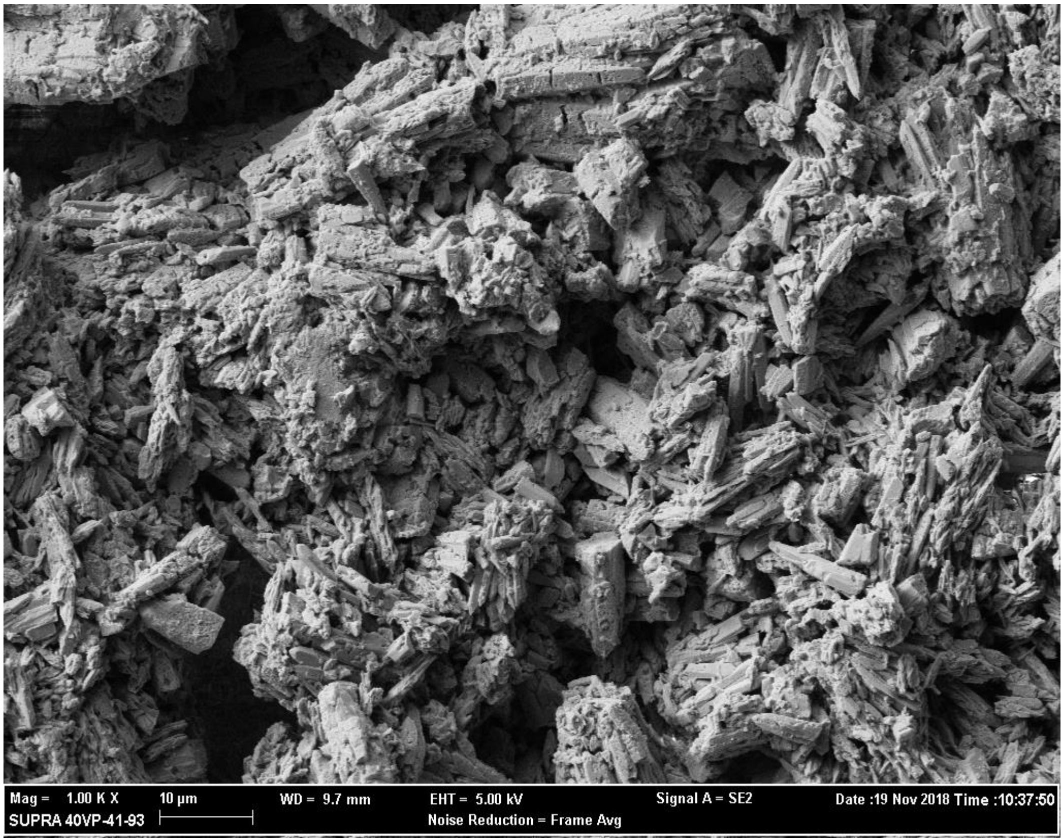

Figure 23: GW Scale Sample-Calcite-Image03

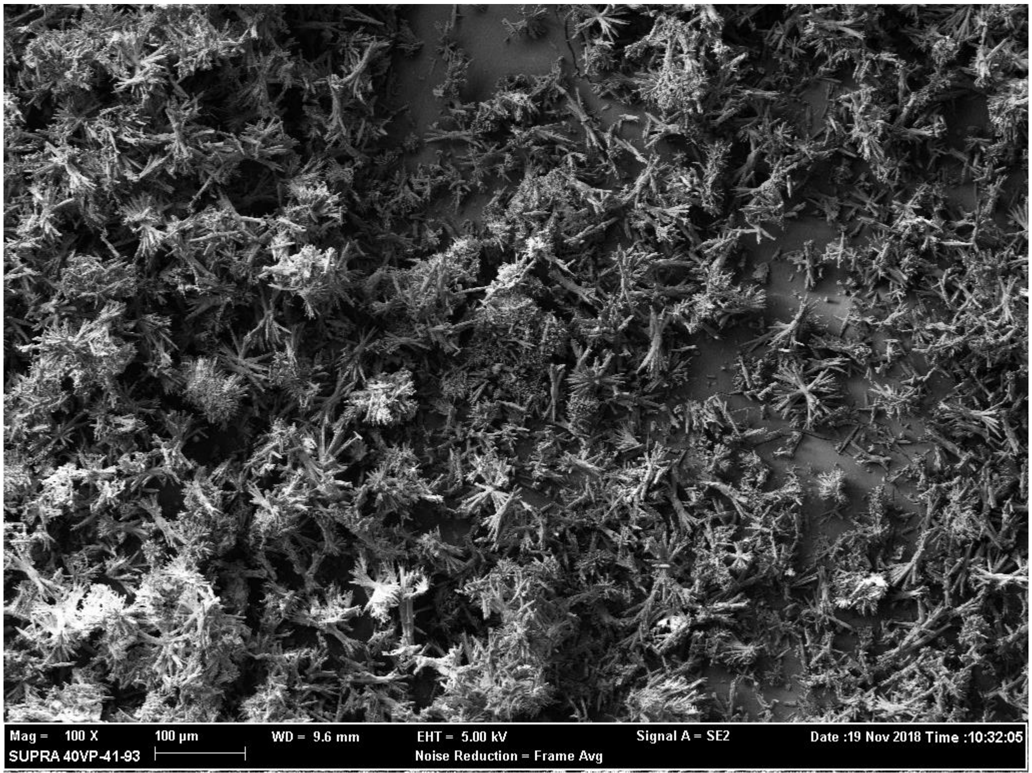

Figure 24: ICN Scale Sample-Aragpmote-Images01

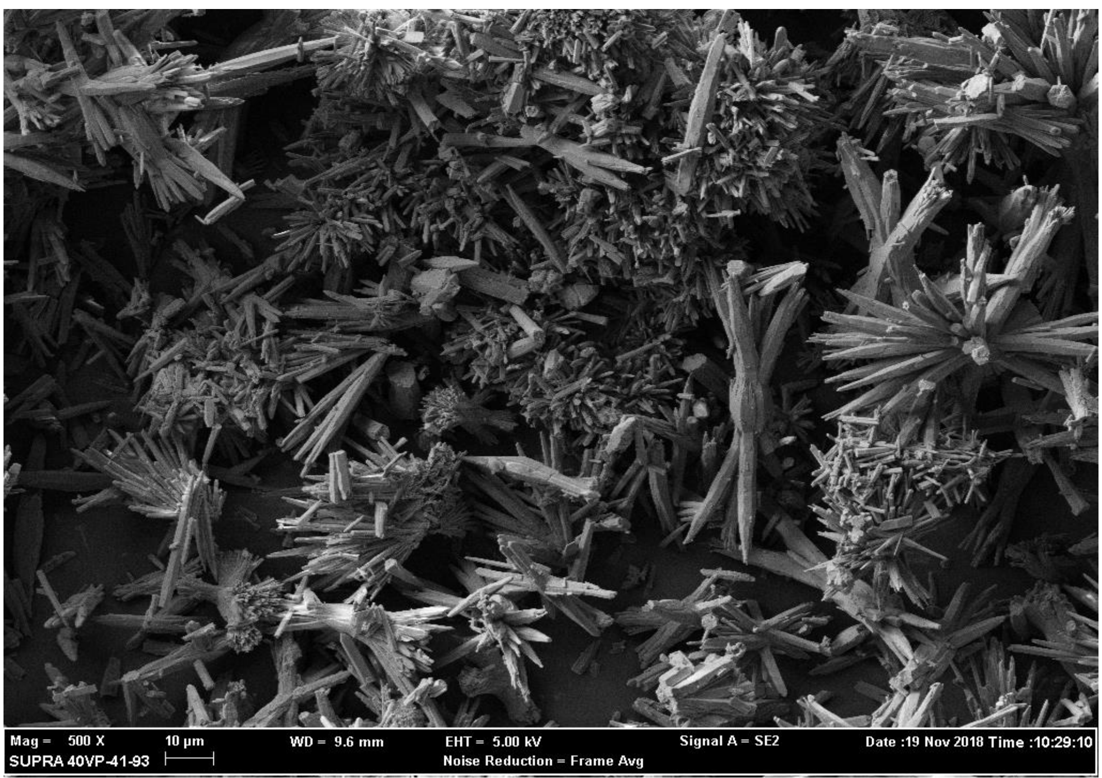

Figure 25: ICN Scale Sample-Aragpmote-Images02

Figure 26: ICN Scale Sample-Aragpmote-Images03

Appendix E-Scale Measurements

Table 95: Initial and Final Pressure Vessel Measurements

GW Batches		
	Before De-Scaling the Vessel	After De-Scaling the Vessel
Weight (g)	10513.5	10503.5