EVALUATION OF THE PERFORMANCE OF AN ELECTROMAGNETIC UNIT TO PREVENT SCALE FORMATION IN WATER HEATING AND COOLING STSTEMS

Final report

Presented to:

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I. CONTEXT AND OBJECTIVE OF STUDY

Calcium carbonate ($CaCO_3$) deposited in water systems leads to scale formation. It decreases flow rate, reduces heat transfer, and favors microbial proliferation of toxic bacteria. This issue may be solved by electromagnetic water treatment, without adding any chemicals. To solve this problem, Field Controls LLC Company has developed a new electromagnetic water treatment unit (ClearWave). This proposal summarizes the work to be carried out under an agreement between Field Controls LLC and INRS-ETE. The purpose of this collaboration contract is to verify the efficiency of the ClearWave unit to avoid scale formation in the water pipes. At the end of this first part of the study, future directions will be proposed for the next step leading to ClearWave unit optimization.

II. APPROACH Of STUDY

This protocol is designed to verify in the pilot scale, the effectiveness of ClearWave unit against the scale formation using different type of water with variable calcium hardness under the effect of electromagnetic fields. The tests will be conducted in a skid-pilot at the INRS-ETE laboratory. The pilot unit should be able to recirculate water at a recycling flow rate ranging between 3 and 7 GPM with 2-minute On/Off intervals.

The Field Controls company will provide the pilot ClearWave unit. During this study, several parameters will be tested. <u>Firstly</u>, one intensity of electromagnetic field B will be tested and the results will be compared with the tests carried out in the absence of electromagnetic field (control test, CONT). Generally, the presence of magnetic field increases the formation of *aragonite form* of $CaCO_3$ having a low adhesion compared to *calcite form*. <u>Secondly</u>, the temperature effect will be tested. In this study, the temperature can play a very important role because it can directly influence the solubility of calcareous and CO_2 in the hardness water. Generally, with a high temperature, the solubility of calcareous decreases and the deposition rate of $CaCO_3$ increases due to a decrease in the solubility of dissolved oxygen and an increase in the diffusion coefficients. During this study, two temperatures (5ºC/41ºF and 70ºC/158ºF) will be tested. <u>Thirdly</u>, the hardness concentration (initial concentration) effect will be also studied. The tests will mainly be carried out by simulating different levels of water hardness from industrial cooling systems (150 and 400 ppm with less than 0.3 ppm of total iron in tested solution) in order to define the efficiency of ClearWave against scale formation. The effectiveness of the process will be evaluated from the calcium hardness (after each hour of operation) according to the equation below:

$$R_a(\%) = \frac{[Ca]_i - [Ca]_t}{[Ca]_i}.100$$

Where R_a is the removal rate of hardness, $[Ca]_i$ is the initial concentration of calcium and $[Ca]_t$ is the calcium concentration at time "t" during the process. A maximum efficiency of 100% will be obtained when R_a (%) is equal to zero. Fourthly, the recycling flow rates will be also studied, because it can change the solubility of dissolved oxygen and the mass transfer, which can greatly affect the scale formation. In the other hand, the recycling flow rate is a major factor influencing the scale nature, speed formation and adhesion. During this study, two flow rates can be tested: 3 GPM and 7 GPM, respectively.

III. EXPERIMENTAL

a) Preparation of synthetic water

Experiments will be performed using synthetic solution in order to simulate water from industrial cooling systems. One liter of synthetic solution (**S1**) simulating an effluent from cooling systems contains 0.155g Na_2SO_4, 0.8g $Ca(NO_3)_2{,}4H_2O$, 0.325g $MgCl_2{,}6H_2O$, and 0.5g $NaHCO_3$. The total hardness of this solution is estimated to 400 ppm equivalent of $CaCO_3$. Another solution (**S2**) of total hardness of 150 ppm (equivalent of $CaCO_3$) will be subsequently tested. The solutions pH will be adjusted at 8.5 using OAKTON pH-meter by addition of sodium hydroxide 0.1M.

b) Experimental unit

The tests will be carried out in a closed loop, depicted schematically in Figure 1. A 50L Polyvinyl Chloride (PVC) reservoir (**A**), a recycling pump, and the ClearWave electromagnetic unit (**B**) constitute the loop. The assays will be carried out in a batch recirculation mode using a stainless steel pipe (20” x ¾”) with a flow of 3 and 7 GPM induced by the centrifugal pump.

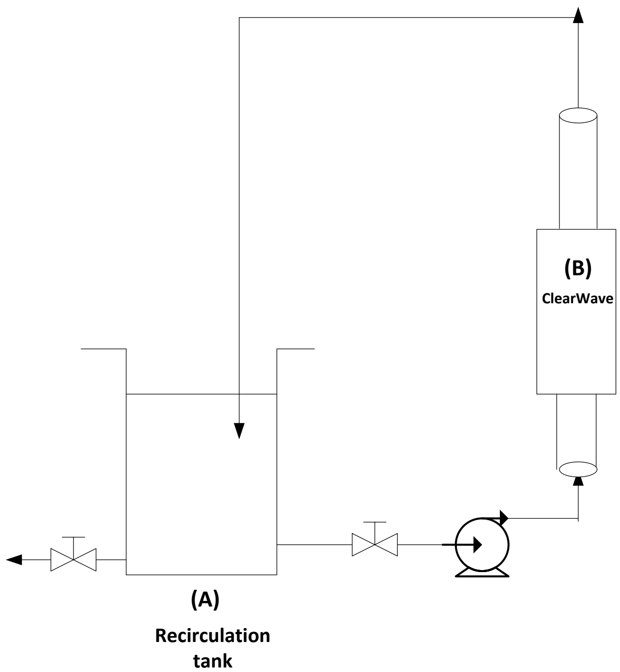

Figure 1: Schematic view of the installation of the ClearWave unit

Figure 2: Experimental unit used to evaluate the effectiveness of the ClearWave unit against scale formation.

c) Analytical methods

The characterization of carbonate deposits will be performed using scanning electron microscopy (SEM) observations with incident electron beam energy of 15KV. Finally, the energy-dispersive X-ray spectroscopy (EDX) coupled with *X-ray diffraction* (XRD) will be used to quantify the percentage of each allotropic forms of calcium carbonate (i.e. calcite, aragonite, vaterite). Bragg-Brentano X-ray diffraction will be carried out on the electrodeposited compounds with a Bruker D8 diffractometer using Cu Kα radiation. A

0.6 mm slit introduced at the detector was already found to be the best configuration for a good signal to noise ratio. The broadening of the experimental spectra can be corrected by subtracting the instrument broadening measured with a NIST LaB6 standard powder.

It is worth noting that, contrary to the Goebel's configuration, the Bragg Brentano's configuration does not create asymmetric peaks, especially at low angle, that may be associated to microstresses. This configuration allows for better accuracy with Rietveld refinement. Finally, the inductively coupled plasma (ICP) will be used in order to determine the concentration of calcium and magnesium in the hard water before and after electromagnetic treatment.

IV. RESULTS AND DISCUSSION

IV.1. Temperature effect on the efficiency of ClearWave unit against scale formation

The objective of this first set of tests was to demonstrate the effectiveness of the ClearWave unit to avoid scale formation in water pipes at different temperatures. Two temperatures (5ºC/41ºF and 70ºC/158ºF) were tested using hardness water of 150 ppm and 400 ppm, respectively, and flow rate of 3 GPM. During this study, different parameters were measured such as: total Hardness, Alkalinity (M), and residual Ca^{2+} and Mg^{2+} concentrations.

Figure 3 (a, b, c and d) shows the results obtained for the tests under the following operating conditions: Water hardness of 400 ppm, 3GPM, 24 hours of treatment time, temperature of 5ºC and 70ºC, respectively.

The results show clearly that when the ClearWave unit is turned off, the total hardness drops initially from 420 ppm to 198 ppm and 395 ppm at 5ºC and 70ºC, respectively, after 24 hours of treatment time. These results mean that 52% and 27% of total hardness have been deposited on the wall of the pipe either at 70ºC or 5ºC, leading to the scale formation inside the pipe. According to these results, it can be concluded that scale formation is highly dependent on the working temperature (52% against 27%) of initial hardness were respectively removed from water for the temperatures imposed of 70º and 5ºC (when ClearWave was turned off). These results were confirmed by the analysis of alkalinity and residual calcium concentrations against time. When the system was turned off, the alkalinity dropped from 250 ppm to 134 ppm (that represented 43% of alkalinity removal) for a temperature imposed of 70ºC. However, when the temperature was fixed at 5ºC, the alkalinity dropped from 250 ppm to 183 ppm (that represented 27% of alkalinity removal). Simultaneously, Ca concentrations dropped from 148 ppm to 71 ppm (52% of Ca removal) for a temperature imposed of 70ºC, whereas residual Ca concentrations passed from 148 ppm to 102 ppm (31% of Ca removal) when a temperature of 5ºC was imposed. However, Mg concentrations remain unaffected during scale formation. This phenomenon can be explained by the effect of pH. According to Dirany et al., 2016 [1] a higher pH than 9.3 is required for $Mg(OH)_2$ scale formation.

On the other hand, we can see clearly that the concentration of total hardness, Ca and Alkalinity were maintained constant when the ClearWave system was turned-On independently on the temperature of water. These results confirmed the effectiveness of the ClearWave unit to avoid scale formation independently on the temperature imposed.

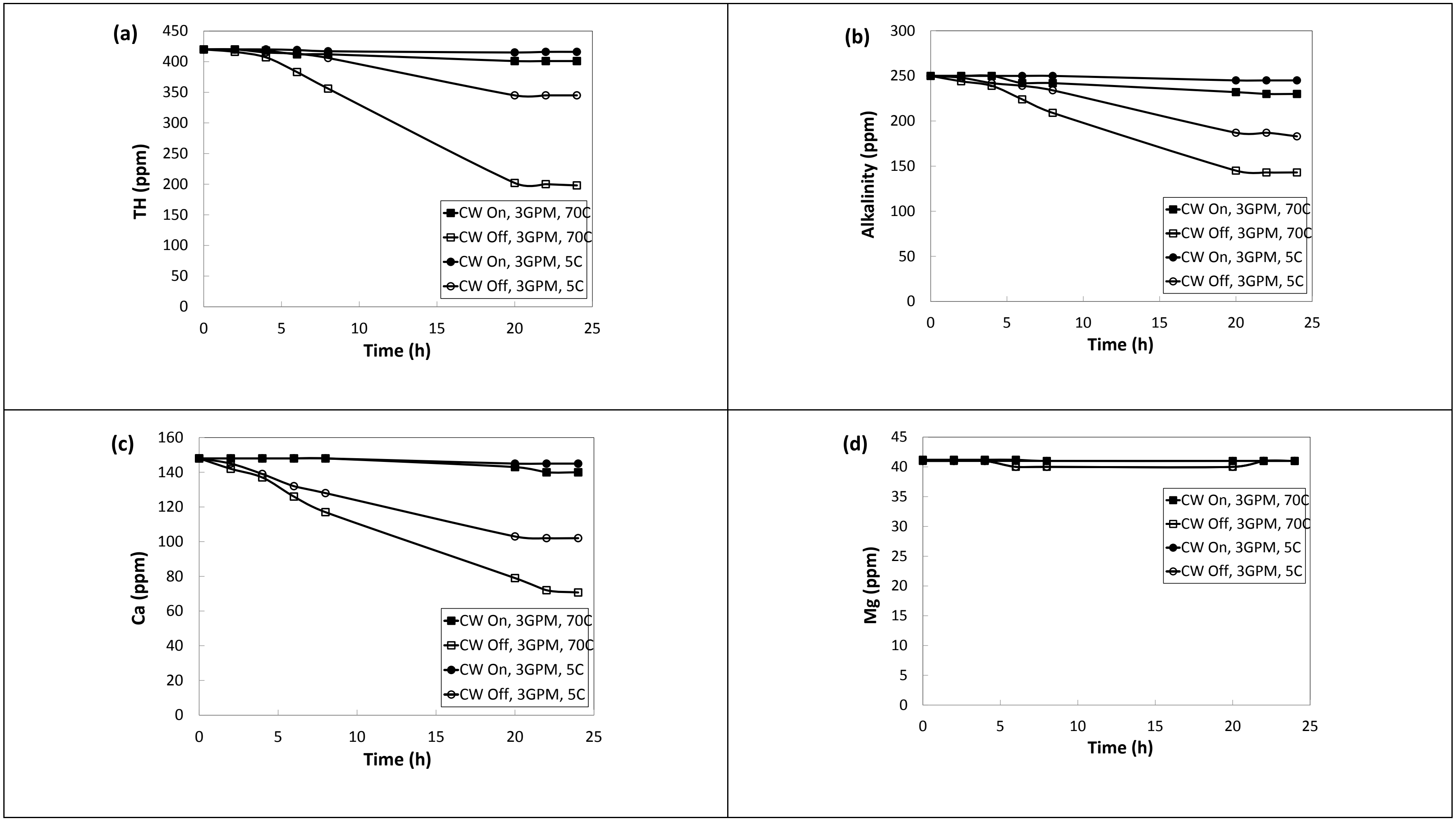

Figure 3: **Variation of total hardness (a), Total alkalinity (b), Ca concentration (c) and Mg concentration (d) with and without ClearWave (CW) system operated under the following conditions: Initial water hardness of 400 ppm, a recycling flow rate of 3GPM, a period of treatment time of 24 hours, the temperature imposed of 5ºC and 70ºC, respectively.**

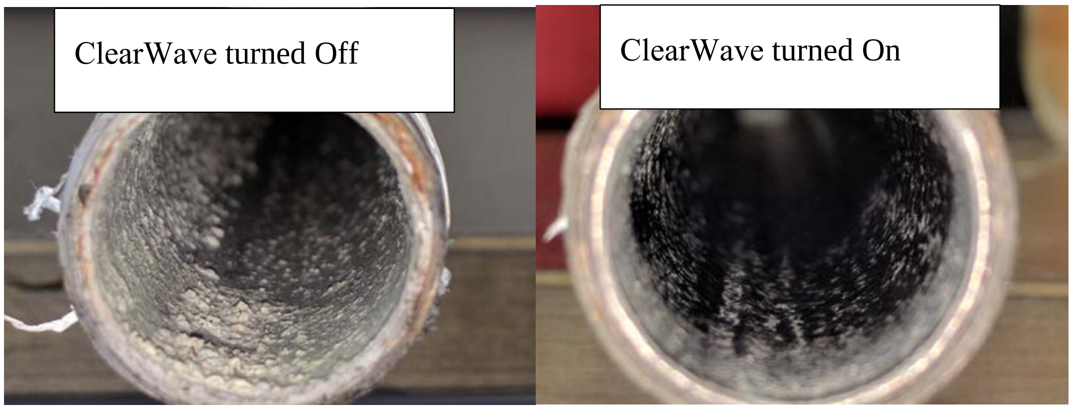

Figure 4: Inside stainless steel pipe (with and without ClearWave turned Off and turned On) under the following operating conditions: Water hardness of 400 ppm, 3 GPM, 24 hours of treatment time and 70ºC.

Figure 4 shows inside the stainless steel pipe (with and without the treatment by the ClearWave unit). These pictures show the efficiency of the ClearWave unit to avoid the scale formation inside the pipe and confirm the analysis results of total hardness, alkalinity and Ca concentrations.

During this study, the calcium carbonate layer formed when the ClearWave unit is turned Off was examined by SEM analysis. No major difference was recorded between 5º and 70ºC (Figure 5).

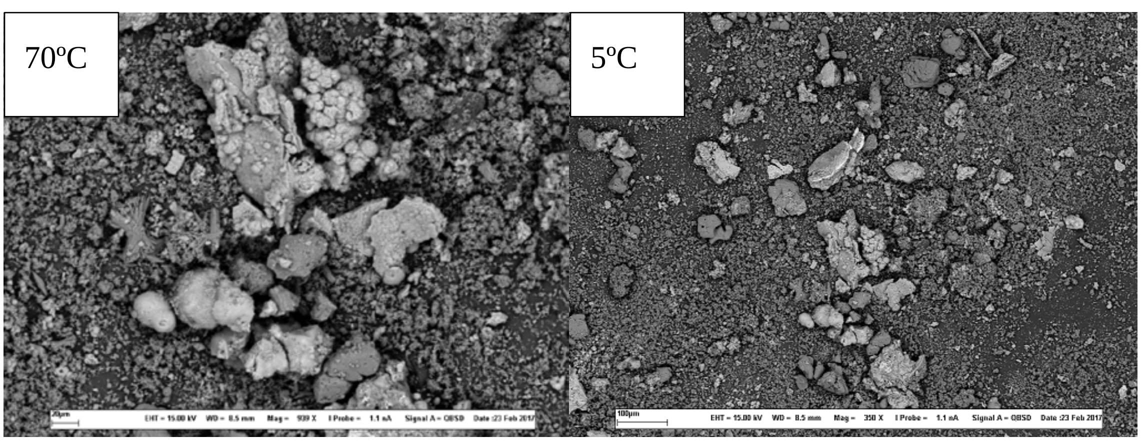

Figure 5: SEM pictures of calcium carbonate samples deposited inside the pipe while imposing the temperatures of 5ºC and 70ºC, respectively, (without ClearWave) under the following operating conditions: Water hardness of 400 ppm, 3 GPM, 24 hours.

The same test was carried out at 5º and 70ºC by changing the initial hardness concentration of water from 400 ppm to 150 ppm. The results are presented in Figure 6.

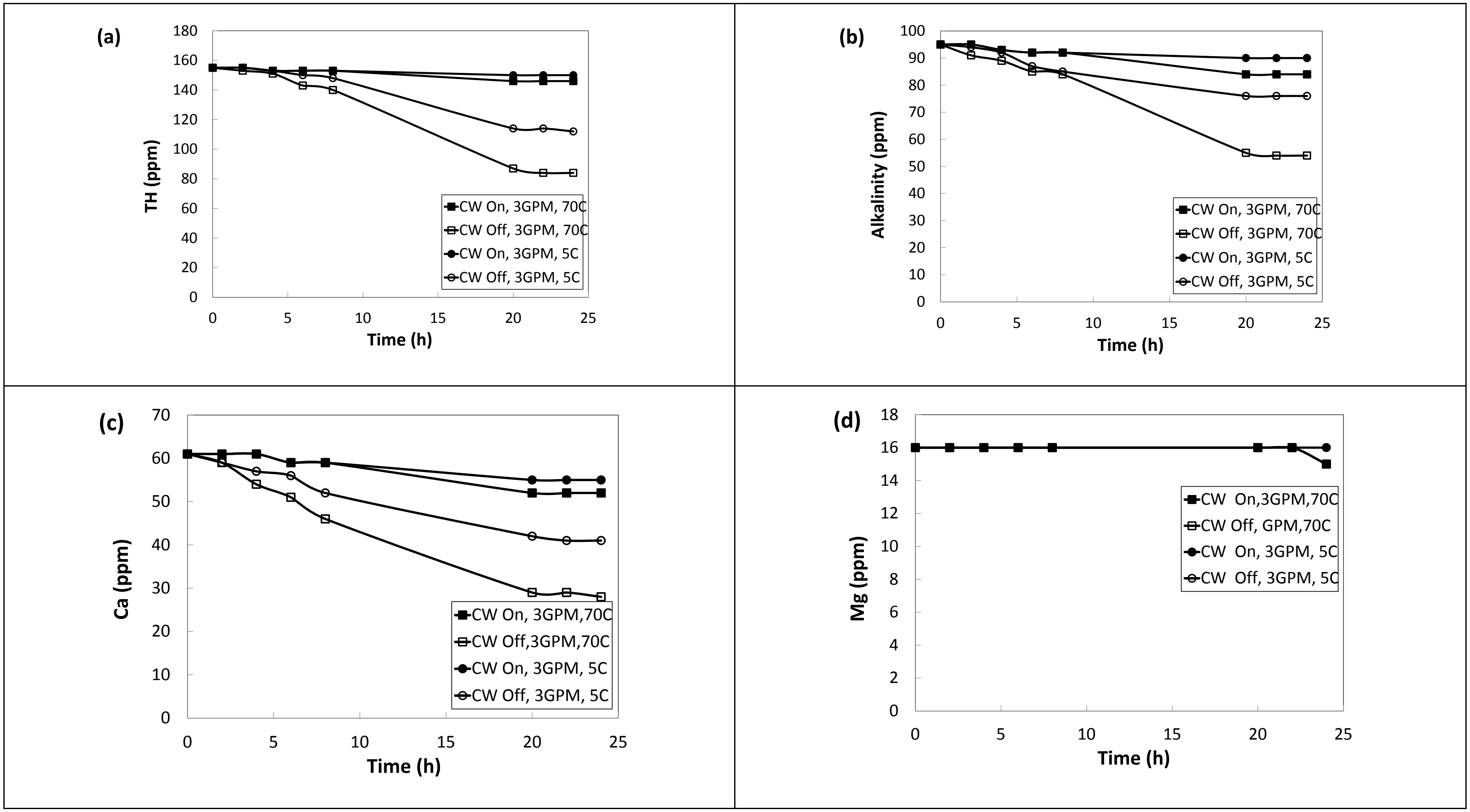

Figure 6: Variation of total hardness (a), Alkalinity M (b), Ca concentration (c) and Mg concentration (d) (with and without the ClearWave (CW) unit) under the following operating conditions: Water hardness of 150 ppm, a recycling flow rate of 3GPM, a treatment time of 24 hours, temperature imposed of 5ºC and 70ºC respectively.

The results obtained during this test using water hardness concentration of 150 ppm were consistent with those recorded for water hardness concentration of 400 ppm.

It can be seen that the ClearWave unit avoids scale formation when a low hardness concentration was imposed. The total hardness, alkalinity and Ca concentrations remained constant when the system is turned On. Without ClearWave unit, the total hardness dropped from 150 ppm to 84 ppm and 155 ppm to 112 ppm respectively at 70ºC and 5ºC. During this test, there was not enough amount of $CaCO_3$ (solid) for SEM analysis.

IV.2. The flow rates effects on the efficiency of ClearWave unit against scale formation

The objective of this second set of experiments was to demonstrate the effectiveness of the ClearWave unit to avoid scale formation in water pipes at different flow rates. Two recycling flow rates of 3 GPM and 7 GPM were tested by imposing the following conditions: a hardness water of 150 ppm and 400 ppm, respectively, and a temperature of 70ºC. During this study, different parameters were measured such as: total Hardness, alkalinity, and residual Ca and Mg concentrations. Figure 7 (a, b, c and d) shows the results obtained for the test under the following operating conditions: water hardness of 400 ppm, 70ºC, 24 hours of treatment time, the recycling flow rates of 3 GPM and 7 GPM, respectively. The results show that when the ClearWave unit was turned off, the total hardness decreased from 420 ppm to 198 ppm for a recycling flow rate of 3 GPM, whereas the total hardness passed from 420 ppm to 179 ppm for a recycling flow rate of 7 GPM after 24 hours of period of treatment time. These results mean that 52% of total hardness was deposited inside the pipe irrespective of the recycling flow rate. These results were consistent with the alkalinity measurements and residual calcium concentrations. When the ClearWave unit was turned off, the alkalinity decreased from 250 ppm to 143 ppm and from 250 ppm to 139 ppm respectively at 3 GPM and 7 GPM.

Simultaneously, the calcium concentration decreased from 148 ppm to 70 ppm and from 148 ppm to 59 ppm respectively at 3 GPM and 7 GPM. According to these similar results, it can be concluded that scale formation did not depend on the recycling flow rates. On the other hand, it can be seen that the concentration of total hardness, Ca and alkalinity were maintained constant when the ClearWave unit was turned on independently on the recycling flow rate. These results confirmed the effectiveness of ClearWave unit to avoid scale formation independently on the flow rate.

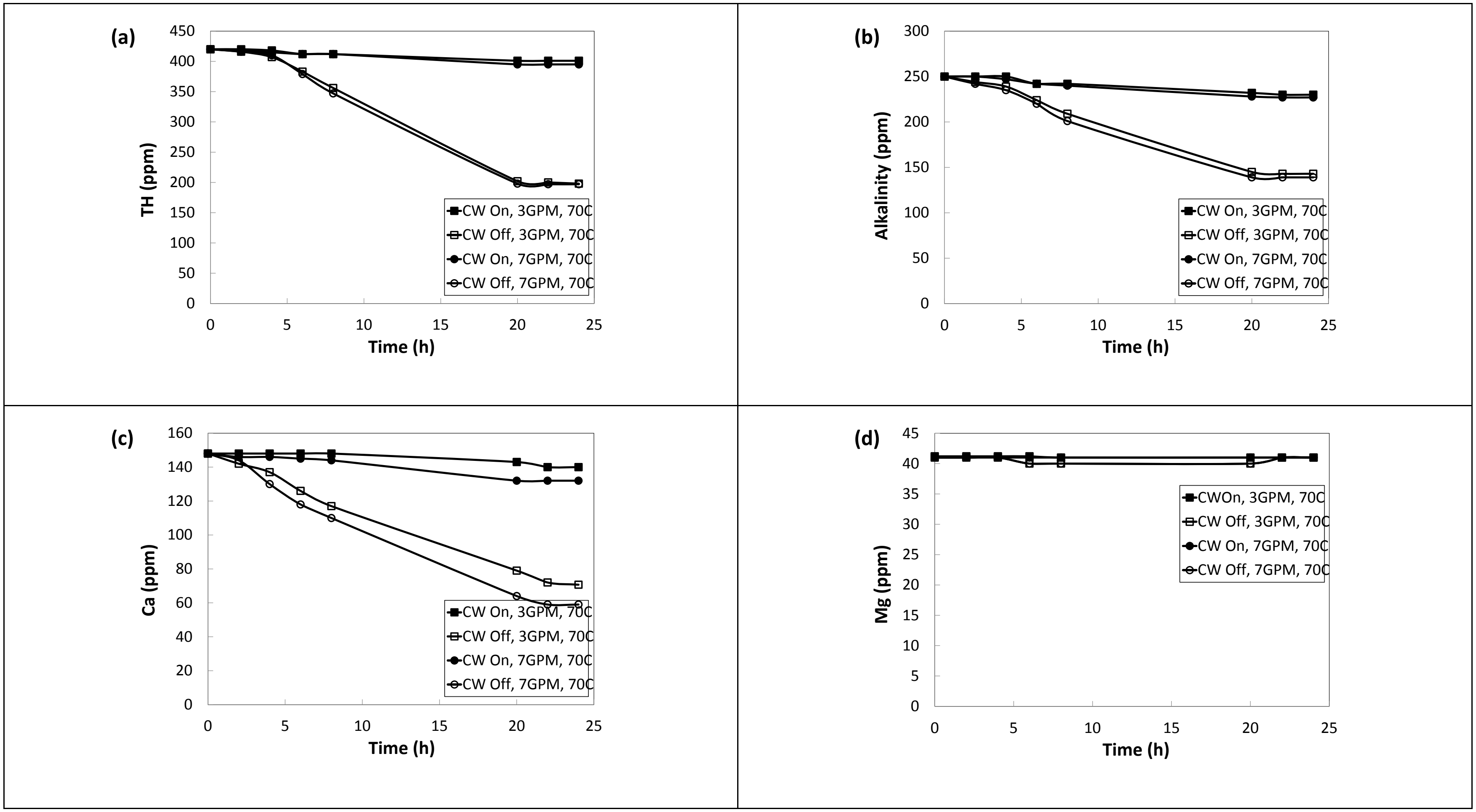

Figure 7: Variation of total hardness (a), Alkalinity M (b), Ca concentration (c) and Mg concentration (d) (with and without ClearWave (CW) unit) under the following operating conditions: Water hardness of 400 ppm, a temperature of 70ºC, a treatment time of 24 hours, recycling flow rates of 3 GPM and 7 GPM.

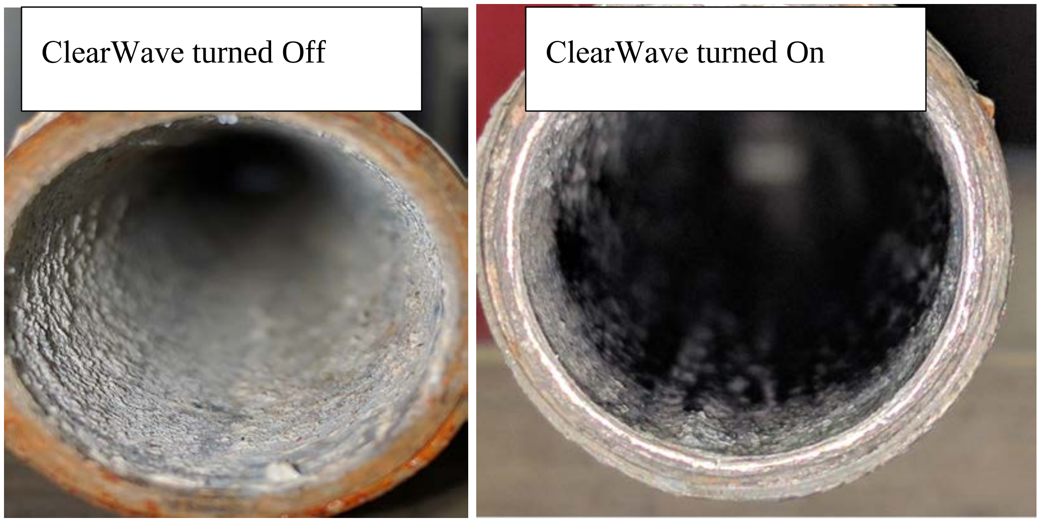

Figure 8: **Inside stainless steel pipe (with and without ClearWave turned Off and turned On) under the following operating conditions: Water hardness of 400 ppm, 7GPM, 24 hours of treatment time and a temperature of 70ºC**

Likewise, during this study, no major difference between the calcium carbonate layers was recorded between 3 GPM and 7 GPM. See Figure 9.

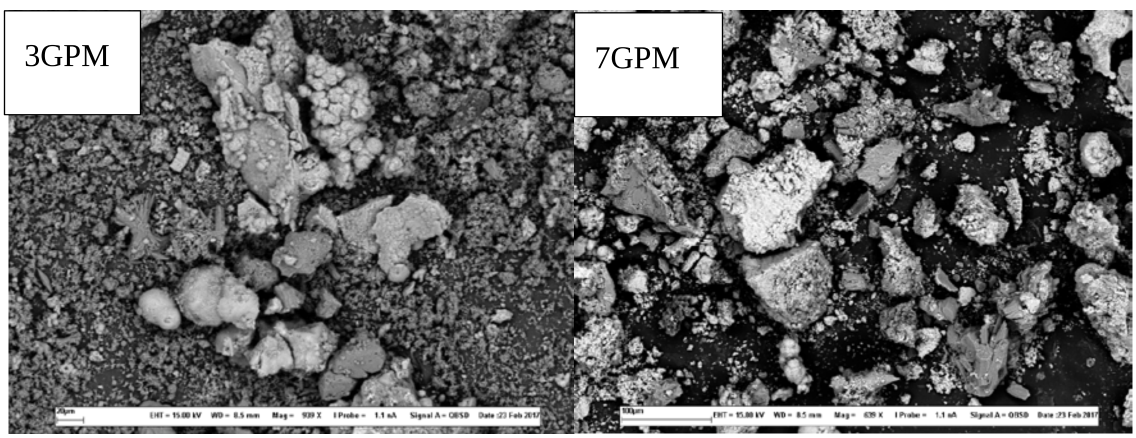

Figure 9: **SEM pictures of calcium carbonate samples deposited inside the pipe for the recycling flow rates of 3 GPM and 7 GPM (without ClearWave) under the following operating conditions: Water hardness of 400 ppm, 24 hours of treatment time and a temperature of 70ºC.**

The same test was carried out at 3 GPM and 7 GPM by changing the initial hardness of water from 400 ppm to 150 ppm. The results are presented in Figure 10.

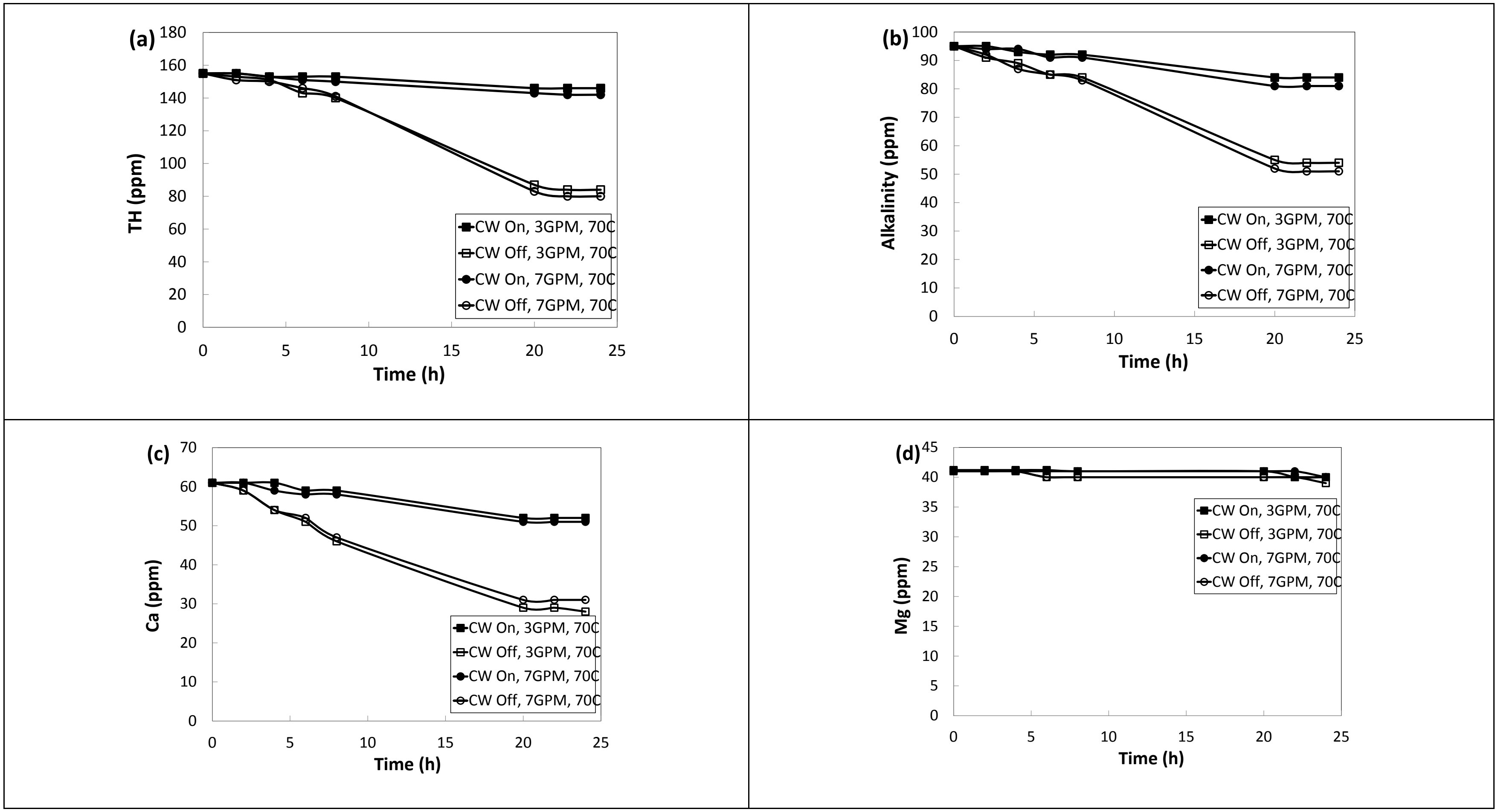

Figure 10: Variation of total hardness (a), total alkalinity (b), Ca concentration (c) and Mg concentration (d) (with and without ClearWave (CW) unit) under the following operating conditions: Water hardness of 150 ppm, a temperature of 70ºC, treatment time of 24 hours, recycling flow rates of 3 GPM and 7 GPM.

It can be seen that the ClearWave unit avoids scale formation when a low hardness concentration of water was imposed, irrespective of the recycling flow rates (3 GPM and 7 GPM). The total hardness, alkalinity and Ca concentration remain constant when the ClearWave unit was turned on. Without the ClearWave the total hardness dropped from 155 ppm to 84 ppm for a recycling flow rate of 3 GPM, whereas the total hardness passed from 155 ppm to 80 ppm for a recycling flow rate of 7 GPM. During these experiments, there was not enough amount of calcium carbonate deposited inside the pipe to carry out SEM analysis's.

IV.3. Demonstration of the performance of the ClearWave unit to remove calcium carbonate initially deposited inside the pipe.

These experiments were carried out to evaluate the effectiveness of the ClearWave unit to remove calcium carbonate deposited inside the pipe. During the first step of the treatment (24 hours of treatment), the ClearWave unit was turned off in order to deposit the maximum of calcium carbonate layer inside the stainless steel pipe. After this first step, the ClearWave unit was turned on for the next period of 24 hours (second step) by keeping the same water in the recycling tank. The ultimate aim of this test was to demonstrate the ability of the ClearWave unit to remove the layer of calcium carbonate initially deposited inside the pipe. This experiment was carried out under the following operating conditions: Water hardness of 400 ppm, 3 GPM, 24 hours of treatment time and temperature of 70ºC. The results are presented in Figure 11.

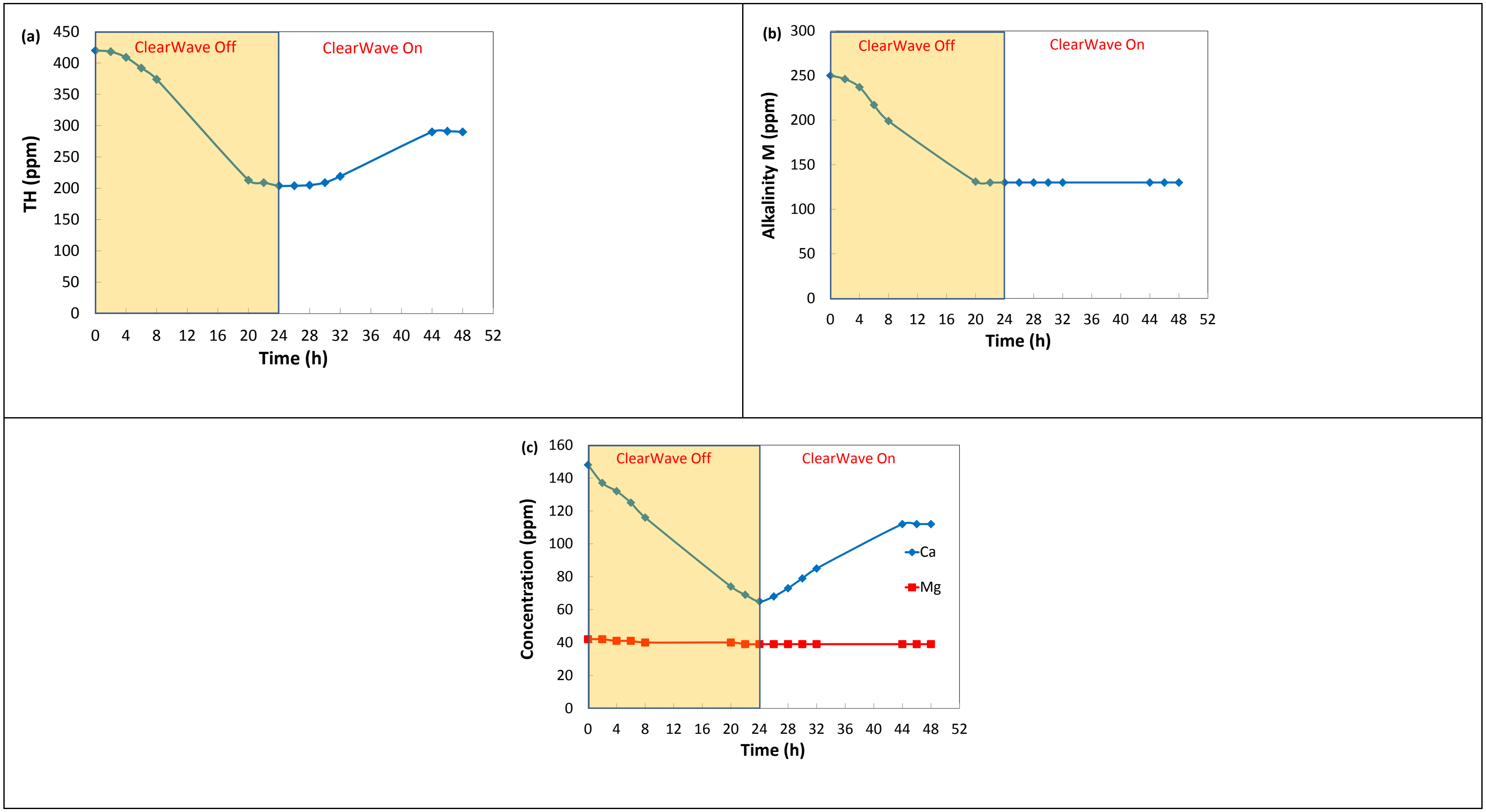

Figure 11: Variation of total hardness (a), total alkalinity (b), Ca and Mg concentrations (c); ClearWave was turned off during 24 hours of operation (first step), following by 24 hours of operation with ClearWave turned On (second step). Operating conditions: Water hardness of 400 ppm, a flow rate of 3 GPM and a temperature imposed of 70ºC.

According to the results, it can be seen that for the first 24 hours (when ClearWave was turned off), the total hardness dropped from 420 ppm to 204 ppm. This means that 51% of total hardness has been deposited as scale inside the stainless steel pipe. Simultaneously, the alkalinity and Ca concentration decreased from 255 ppm to 130 ppm and 148 ppm to 65 ppm, respectively. On the other hand, when the ClearWave unit was turned on, the concentration of the total hardness gradually increased from 204 ppm to reach 290 ppm for the next 24 hours. These results mean that more than 30% of $CaCO_3$ was released in the water. This can be confirmed by the measurements of Ca concentrations in solution. When the ClearWave unit was turned on, Ca concentration increased from 65 ppm to 112 ppm after 24 hours. In the case of alkalinity, its concentration remained constant when the ClearWave unit was turned on. Why? The total alkalinity represents the hydroxyl (HO^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions in water. The calcium carbonate released in water in form of solid (non-ionic) when the ClearWave unit was turned on, so that carbonate concentration could not be measured by the volumetric titration used. Finally, this study confirms the effectiveness of the ClearWave unit.

The difference between the first 24 hours (ClearWave unit on) and the last 24 hours (ClearWave unit off) is seen in Figure 12.

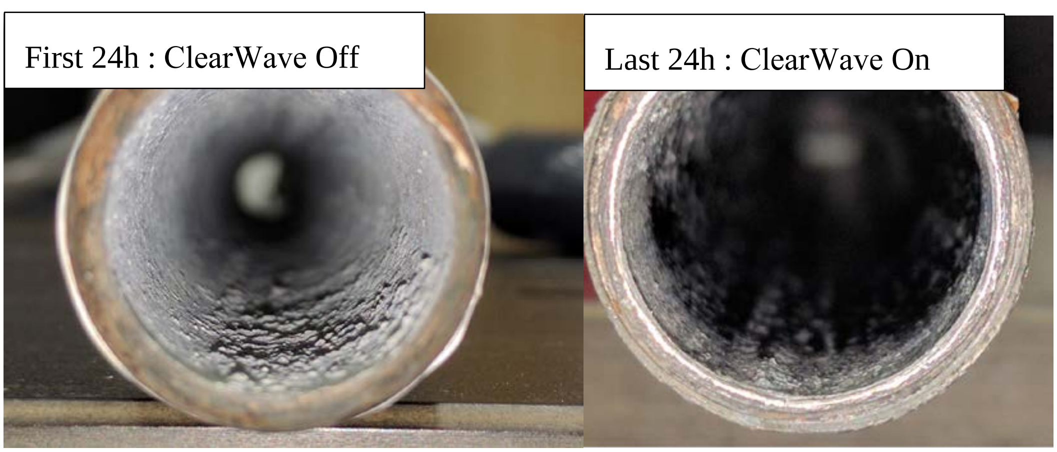

Figure 12 Inside stainless steel pipe (with and without ClearWave unit off and on) under the following operating conditions: Water hardness of 400 ppm, a flow rate of 3GPM, a treatment time of 48 hours and a temperature of 70ºC.

IV.4. XRD analysis

In this study, samples of calcium carbonate ($CaCO_3$) were examined by XRD analysis to determine the nature of different allotropic forms. Figure 13 presents the diffractogram of sample from the experiments under these operating conditions: water hardness of 400 ppm, a temperature of 70ºC, a period of treatment time of 24 hours, recycling flow rates of 3 and 3GPM.

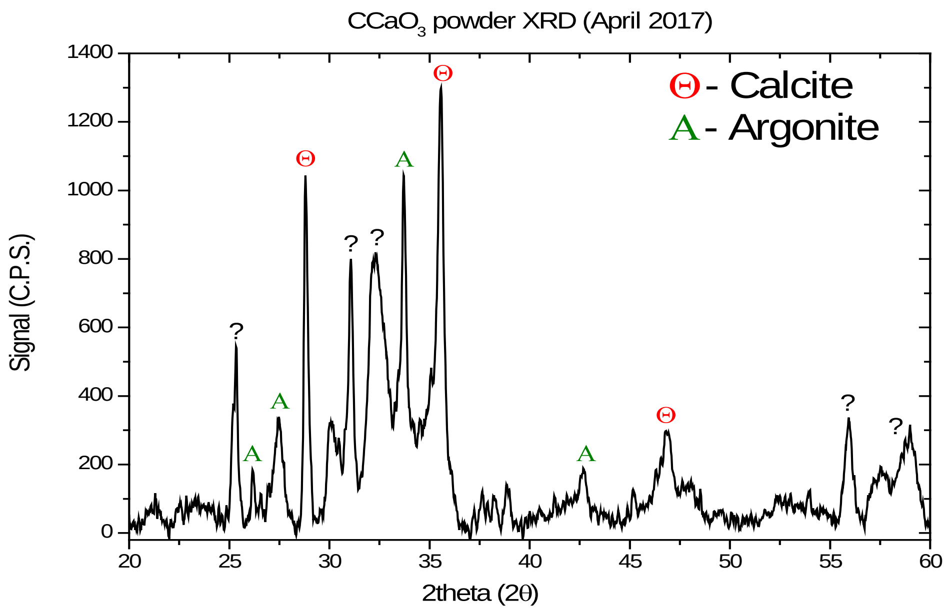

Figure 13 XRD analysis (Cu-Kα radiation) of calcium carbonate obtained without ClearWave unit and under the following operating conditions: Water hardness of 400 ppm, a recycling flow rate of 3GPM, a period of treatment time of 24 hours and a temperature of 70ºC.

According to the results recorded, it can be seen that the formation of two allotropic forms of $CaCO_3$ when the ClearWave unit was turned off. We have identified 3 pics of calcite form and 4 pics of aragonite form with higher signal of calcite. These types of results mean that calcium carbonate contained more calcite than aragonite when the system was turned off. According to Dirany et al., 2016 [1], calcite structure is more compact than aragonite. Once deposited on the wall of the pipe, calcite is more difficult to remove than aragonite. According to previous study, the presence of magnetic field increases the formation of aragonite form of $CaCO_3$ having a low adhesion compared to calcite form[2]. During this study (and after the water treatment by using the ClearWave unit), the amount of calcium carbonate deposited inside the pipe was negligible so that we did not have sufficient quantity of sample for XRD analysis. That means that ClearWave unit was very efficient against scale formation.

V. CONCLUSION

According to the results of different experiments, we can conclude that the ClearWave unit was very efficient to prevent and remove the scale formation irrespective of water hardness, water temperature and recycling flow rates.

References

1. Dirany, A., P. Drogui, and M.A. El Khakani, *Clean electrochemical deposition of calcium carbonate to prevent scale formation in cooling water systems.* Environmental Chemistry Letters, 2016. **14**(4): p. 507-514.
2. Gabrielli, C., et al., *Magnetic water treatment for scale prevention.* Water Research, 2001. **35**(13): p. 3249-3259.