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# Analysis of Calcium Carbonate Scales in Water Distribution Systems and Influence of the Electromagnetic Treatment

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**Abstract:** The formation of calcium carbonate scale in pipes and devices in water supply networks poses serious problems. Electromagnetic treatment (EMT) is a technology that can prevent the formation of these scales without the need to add chemical reagents, reducing maintenance costs in the installations. In this work, the types of crystals commonly found in water distribution systems are studied, with emphasis on the different techniques that allow their characterization (TGA, XRD, SEM), and the effects that EMT produces on their morphology. Laboratory trials have been carried out with synthetic water prepared from a calcium carbonate solution to study the crystals obtained at different temperatures, with and without EMT. High temperatures cause the production of aragonite instead of the stable form (calcite), as was observed in the samples from the heater resistors. In contrast, in the samples taken in lower temperature zones, a majority presence of calcite was observed. These results have been corroborated with a laboratory-scale evaporation trial, obtaining an increase in the aragonite/calcite ratio with increasing temperature and with the treatment applied, generating crystalline phases that exceed 70% aragonite (needle shape). It is highlighted that the EMT limits the reversion of aragonite to calcite and decreases the formation of scale.

**Keywords:** electromagnetic treatment; calcium carbonate scales; calcite; aragonite; water distribution systems

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## 1. Introduction

The formation of carbonate scale in pipes and systems that work with water causes great economic losses in domestic and industrial systems due to technical problems, such as clogged drains and reduced heat transfer that increase maintenance and energy costs [1]. For an open system in which both pH and partial pressure of $CO_2$ of the air remain constant, the precipitation of calcium carbonate salt has a different tendency to that of other minerals because at a higher temperature, the lower its product solubility [2], producing the precipitation of carbonate.

There are three main mineral forms in which calcium carbonate occurs, depending on the conditions of the environment and the presence of other elements. These minerals are the polymorphs in order of stability: calcite, aragonite, and vaterite. Calcite is the most stable mineral under normal conditions; on the other hand, aragonite is formed mainly under conditions of high pressure and temperature, although it is also metastable under normal conditions, with a very slow transformation of kinetics into calcite [3]. Aragonite has a higher density than calcite and is less prone to form hard scales [4]. Finally, vaterite is also metastable precipitating as a precursor under conditions of high supersaturation and transforming into a stable phase in hours or days [5]. In the process of formation of these crystals, Ostwald's rule describes the formation of polymorphs. This rule indicates that the less stable polymorph crystallizes first as a pre-crystal because it more closely resembles the state in solution and therefore has kinetic advantages. This crystal will later transform into a more stable phase [6,7].

Due to the problems caused by calcium carbonate scales, there are alternative non-intrusive techniques that do not alter water quality and do not generate waste, such as the application of magnetic and electromagnetic fields to the water [8]. This type of technique has been used for many years, originally applying permanent magnets made of elements such as neodymium to prevent carbonate scale. For this, some authors [9] have proposed different placement configurations of these magnets to improve their efficiency. Magnetic techniques have gradually given way to the application of electromagnetic fields to avoid scale, although magnetic techniques have never disappeared and are still being used and studied [10].

Electromagnetic techniques have been used in many cases as a more effective way of applying magnetic treatments to water. These techniques are supported by numerous studies that have verified the effects they generate on water and the experiences of the users of this type of system [11,12]. There are different configurations for the application of electromagnetic fields, one of the most common designs being a solenoid to which an electric current is passed [13].

Despite multiple studies in which the influence of electromagnetic fields on water has been determined [14–16], the phenomenon through which scale formation is prevented is not fully understood. Two main theories can be found to explain these physicochemical processes. One of them states that the treatment promotes the formation of crystals within the fluid, thus avoiding the formation of scale on the surface of the pipes [8]. On the other hand, some studies affirm that electromagnetic treatment (EMT) modifies the mineral phase in which calcium carbonate precipitates. In the absence of treatment, precipitation occurs in the form of calcite (rhombohedral structure), while applying electromagnetic fields favors the crystallization of calcium carbonate as needles of aragonite [4,17]. The latter authors observed in their experiments that the aragonite crystals transformed to calcite after some time, and the effect of the treatment on the crystals could last for more than 200 h before reversion occurred. Botello-Zubiate et al. [18], in a similar study, obtained less lasting treatment effects, attributing the differences to the chemical composition of the water since their samples contained higher amounts of $Na^+$, $Ca^{2+}$, and $K^+$, and the concentrations of $Fe^{2+}$, $Mn^{2+}$, and $Zn^{2+}$ were also different from those of Coey and Cass [4]. All these works indicate the influence of the chemical composition of the water and the time elapsed since exposure to EMT on the crystals formed.

Electromagnetic treatment (EMT) is a technology that has been used for years to prevent scale formation in water distribution systems; however, there is no clear scientific evidence to support these effects. The preferential formation of aragonite compared to calcite in systems with this treatment is the main objective of this study. To analyze the types of crystals commonly found in water distribution systems, various analytical techniques will be used to characterize the scales and determine if the EMT equipment is functioning efficiently. Additionally, the study aims to investigate the appearance of aragonite crystals when applying EMT and identify conditions that could modify existing crystalline structures. For this purpose, laboratory tests have been conducted with synthetic water prepared from a supersaturated calcium carbonate solution to obtain crystals under different temperature conditions with and without EMT, allowing for the analysis of its effect on the formed crystals. Other technologies require continuous maintenance and the use of environmentally harmful chemical reagents. Demonstrating the effectiveness of this technique in specific systems could promote a broader application of the technology, with consequent environmental and economic benefits.

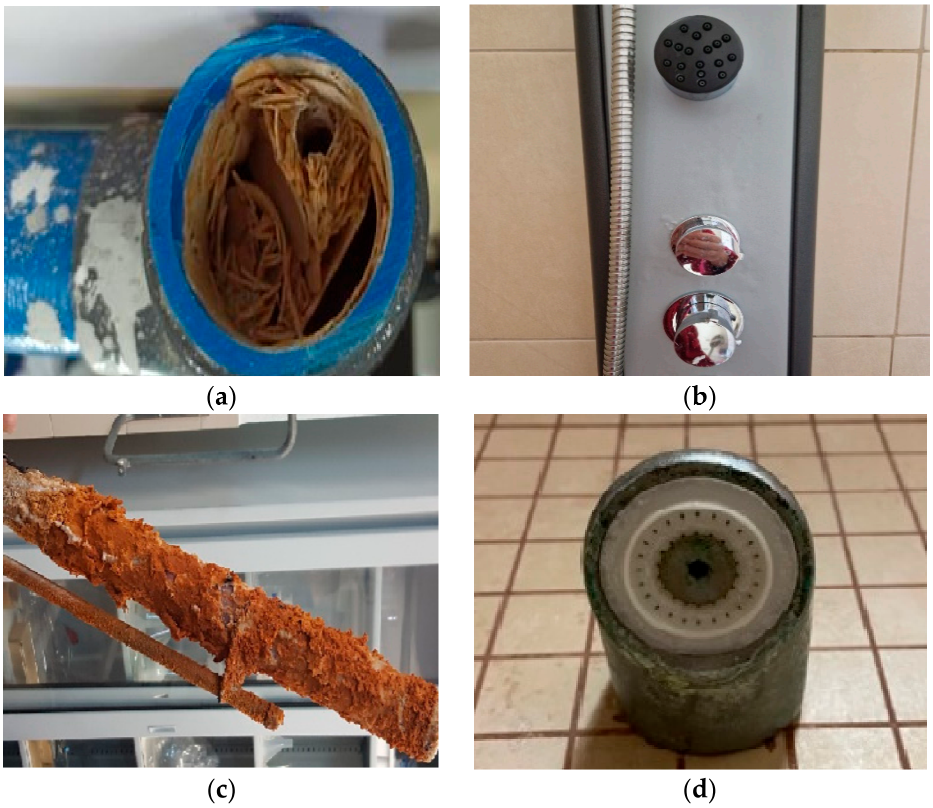
## 2. Materials and Methods

### 2.1. Reagents

The reagents used were $CaCO_3$ (99% Fisher Chemical, Waltham, MA, USA), $Co(NO_3)_2 \cdot 6H_2O$ (99% Fisher Chemical), and bi-osmotic water (<2 $\mu S\,cm^{-1}$).

### 2.2. Samples of Scale from Water Distribution Systems

To analyze the crystalline phases that form the incrustations present in water distribution systems, several points susceptible to producing this type of deposits in domestic systems were selected. The selected points are presented in Figure 1.



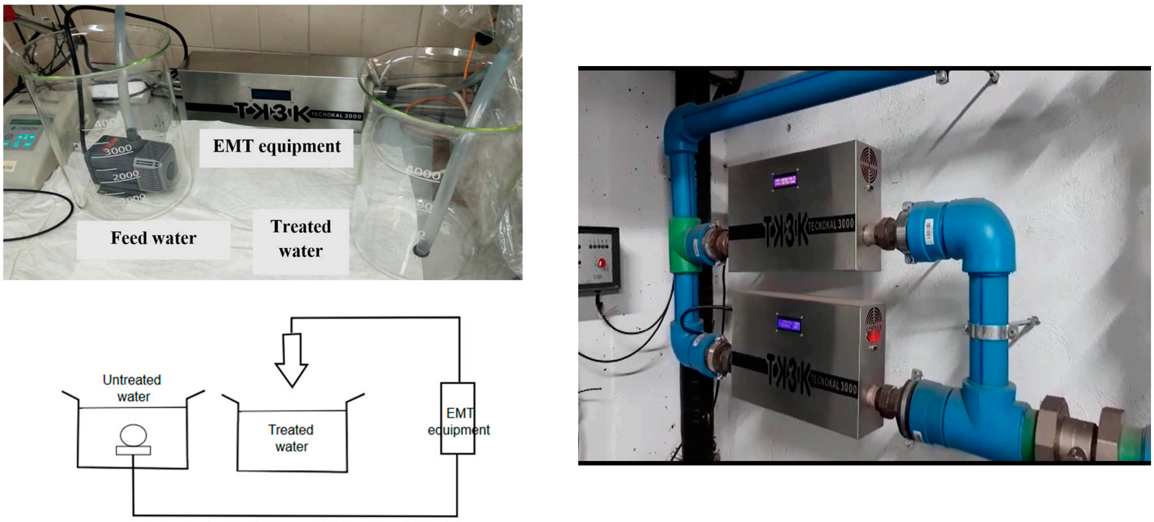
(**a**) (**b**)

(**c**) (**d**)

**Figure 1.** Sampling sites for scaling in water distribution systems: (**a**) pipe; (**b**) tap; (**c**) heater resistance; (**d**) hot water shower.

### 2.3. EMT Equipment

Figure 2a shows a photograph and flow diagram of the EMT device used in the laboratory tests. The technical characteristics of this equipment can be found in previous works developed by our research group [12,19]. The magnetic flux density of this treatment equipment is about 0.012 T in the central part, which is the point of greatest influence of the magnetic field. This equipment contains an internal pipe through which a PVC tube (non-toxic, 13 mm in diameter) was inserted, connected to a pump (EPSA Decor 08, maximum flow rate 800 L/h), which pumps water from a beaker containing the feed water to another beaker, passing through the equipment. This treated water is then used to prepare synthetic water by dissolving calcium carbonate at a determined concentration. In industrial systems (Figure 2b), the internal pipe of the equipment allows it to be connected directly to the water distribution system.



(**a**) (**b**)

**Figure 2.** Electromagnetic equipment used in the testing of (**a**) laboratory and (**b**) real installations.

### 2.4. Preparation of the Synthetic Water to Obtain Precipitates

For the preparation of synthetic water, 2 g of $CaCO_3$ was added to 4 L of bi-osmotic water, then bubbled with $CO_2$ until complete dissolution of the carbonate (≈ pH 6) to form $H_2CO_3/HCO_3$ (Figure 3). A total of 500 mL of the mixture was taken and evaporated in the oven to dryness at different temperatures. Temperature was determined with a VWR TD10 digital thermometer (±0.1 °C). For pH, a VWR pHmeter model pHenomenal 1100 L with a pHenomenal 221 662-1161 electrode was used.

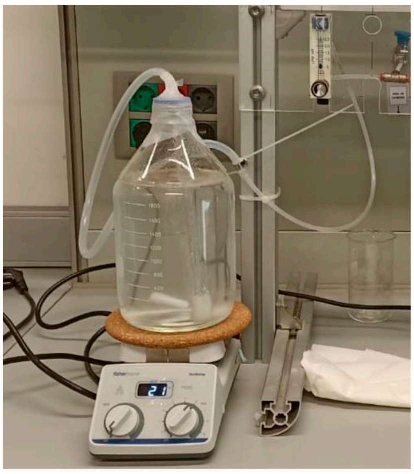


**Figure 3.** Assembly used in sample preparation.

### 2.5. Methods of Analysis and Characterization of Precipitates

The precipitates were analyzed by different techniques. The microscopy techniques used were scanning electron microscopy (SEM) (Hitachi S3000N, Tokyo, Japan) and polarized light optical microscopy (OPTIKA NP-400T, Ponteranica, BG, Italy). On the other hand, Bruker D8-Advance (Bruker, Germany) equipment was used for X-ray diffraction (XRD) analysis. For the study of the thermal decomposition of solids, the thermogravimetric analysis equipment (TGA) TGA/DSC 1 of the Mettler Toledo brand (Columbus, OH, USA), STARe system model, connected by a flexible transfer line to a BRUKER Tensor 27 Fourier (Markham, ON, Canada) transform infrared spectrometer (FTIR).

During the course of this work, the adaptation of the Meigen test method to samples from calcareous incrustations was carried out. This is a classic test in mineralogy used to distinguish the mineral calcite from the mineral aragonite, the two most common natural crystalline forms of $CaCO_3$, with rhombohedral and orthorhombic crystal structures, respectively. When applying this test, the rhombohedral crystals remain white and the orthorhombic structures turn purple. The adaptation and optimization of the Meigen test were performed on calcite and aragonite mineral samples provided by the Department of Earth Sciences and Natural Resources of the University of Alicante. The influence of various parameters on phase determination was studied: temperature and reaction time, concentration of the cobalt nitrate solution, amount of sample, and crystal size. Once the process was optimized, the adaptation of the Meigen test for calcium carbonate precipitates was defined in the following steps (Figure 4).

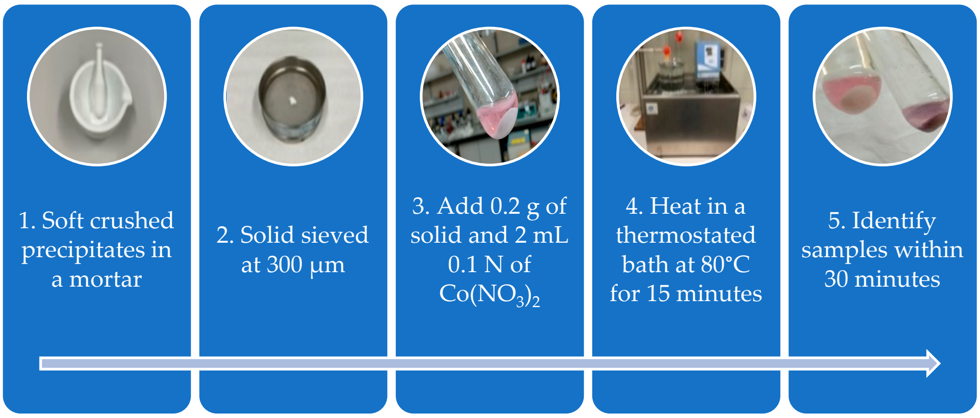


**Figure 4.** Steps for the application of the Meigen test.

The crystals can be obtained through filtration to facilitate their identification (Figure 5). If the time exceeds 30 min, the precipitate darkens because the $Co^{2+}$ ($CoCO_3$, purple) reagent used is oxidized to $Co^{3+}$ ($Co_2O_3$, dark brown).

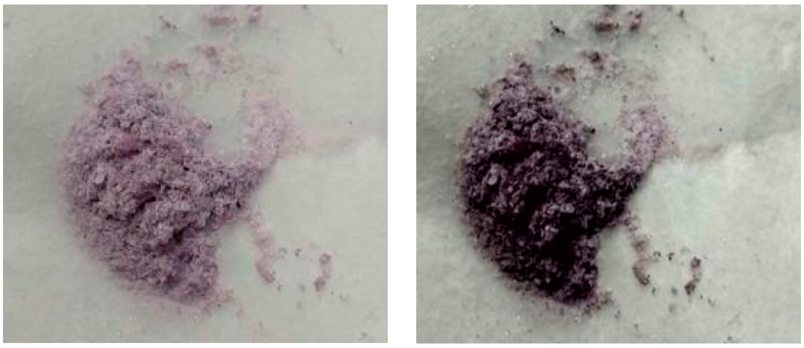

(**a**) (**b**)

**Figure 5.** Application of Meigen test to aragonite mineral: (**a**) before 30 min; (**b**) after 30 min.

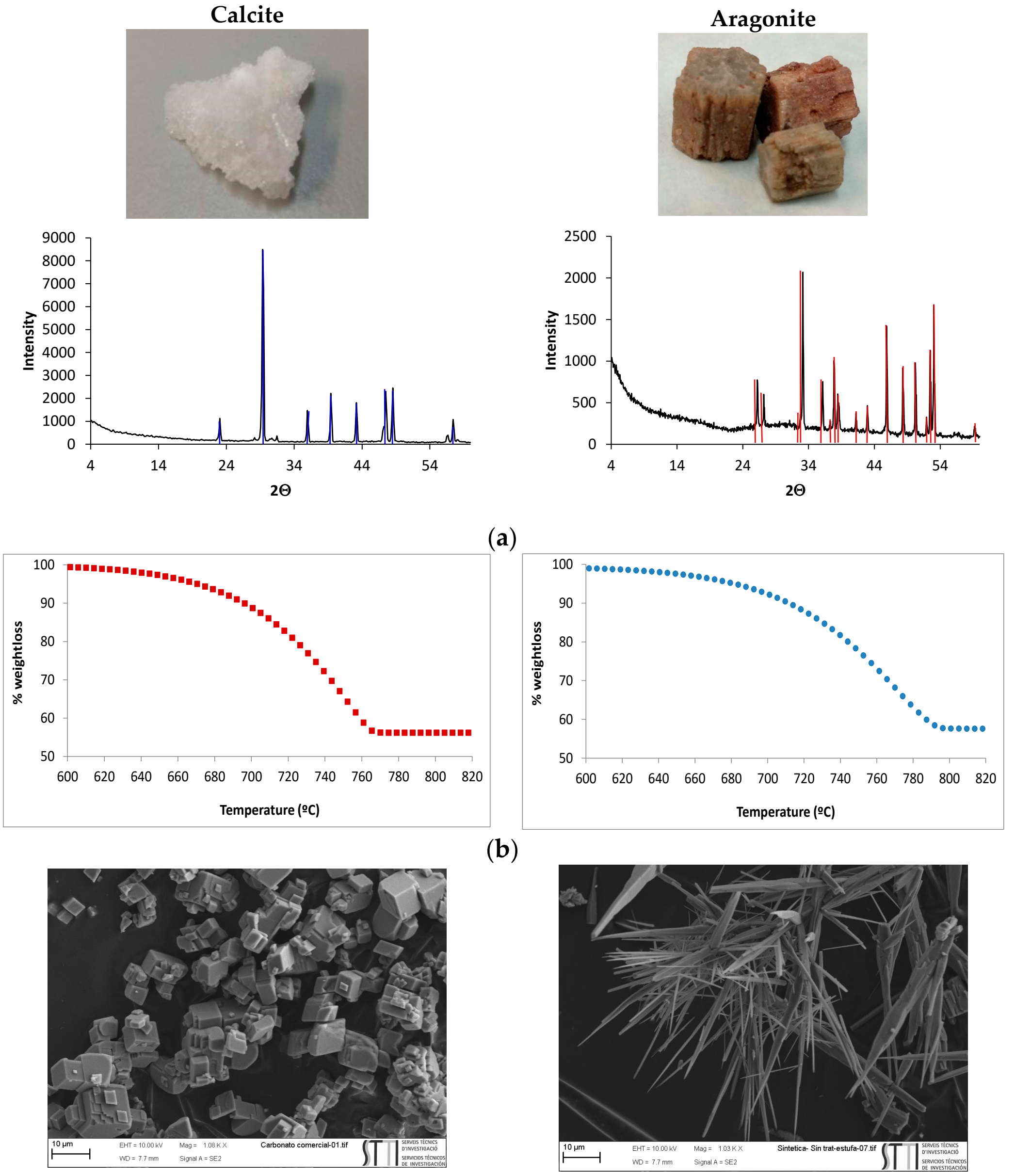
In this research, this test is applied to scale obtained from water distribution systems. It is a simple way to identify calcite and aragonite in solids or evaporated water samples without the use of instrumental equipment.

## 3. Results and Discussion

As mentioned in the introduction, previous research indicates that EMT modifies the crystallization form of calcium carbonate between calcite and aragonite. In this sense, a study of the scales present in drinking water distribution systems was carried out using different techniques. In addition, a study of the scales collected in an installation subjected to EMT, after two years of its application, was carried out. Evaporation studies have also been carried out in a temperature-controlled laboratory.

### *3.1. Characterization of Calcite and Aragonite Minerals*

Different techniques allow distinguishing between calcite and aragonite, such as XRD, TGA, SEM, optical microscopy, and Meigen test. Figure 6 shows the results obtained for pure minerals. It should be noted that these minerals were obtained from the sample base of the Department of Earth Sciences and Natural Resources (University of Alicante, Alicante, Spain).

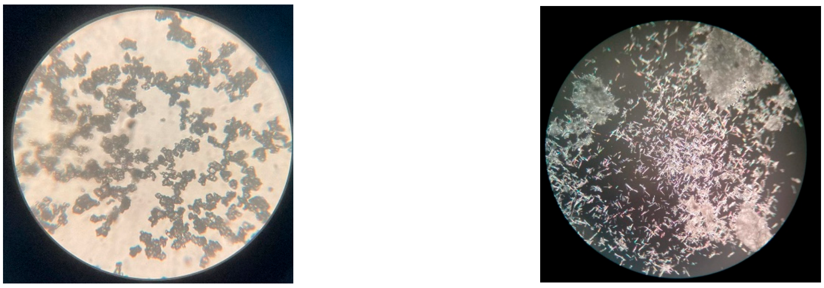


(**a**)

(**b**)

(**c**)

**Figure 6.** *Cont.*

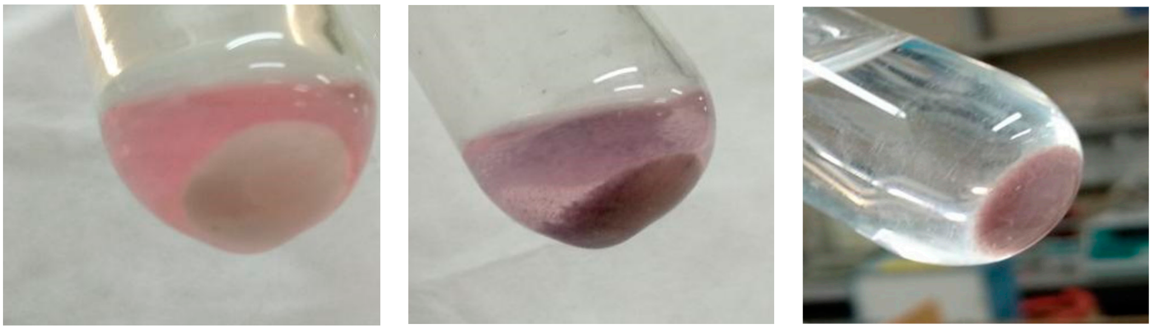


(**d**)

**Figure 6.** Characterization of calcite and aragonite minerals: (**a**) XRD patterns; (**b**) thermal stability (TGA); (**c**) scanning electron microscope (SEM); (**d**) optical microscope.

These techniques allow distinguishing between the two mineral phases that are generally present in water distribution facilities and that can be affected by EMT. The XRD technique shows diffractograms identical to those corresponding to the database for both minerals and also coincides with previous studies on the crystal structures of these materials [20]. The TGA showed a higher decomposition temperature for aragonite than for calcite and the SEM images show rhombohedral morphological structures for calcite and orthorhombic for aragonite (needle-like). Optical microscopy can also be used to see these structures when there is a small amount of sample and it is not possible to apply any of the above-mentioned analysis techniques. In this case, the same crystalline forms as above are observed. The above results corroborate the referential characteristics of calcium carbonate polymorphs in both precipitated and biomineral samples [21,22]. Under this approach, Kezuka et al. [23] analyzed the properties of calcium carbonate powder and obtained rhombohedral and needle-shaped morphologies for calcite and aragonite, respectively; while in thermal decomposition, they obtained weight losses up to 45% at temperatures close to 800 °C, which agrees with the decomposition temperature obtained for aragonite.

On the other hand, the Meigen test allowed the identification of the crystalline phases of calcium carbonate, where white color is shown in the case of calcite and purple coloration in the case of aragonite. Figure 7 shows the results obtained with the test for directly sieved mineral samples. Figure 7a corresponding to calcite shows white crystals, but in Figure 7b the purple color of the aragonite is not seen, showing a certain brownish color coming from the mineral itself. After washing the precipitate with distilled water, the purple color appears (Figure 7c).



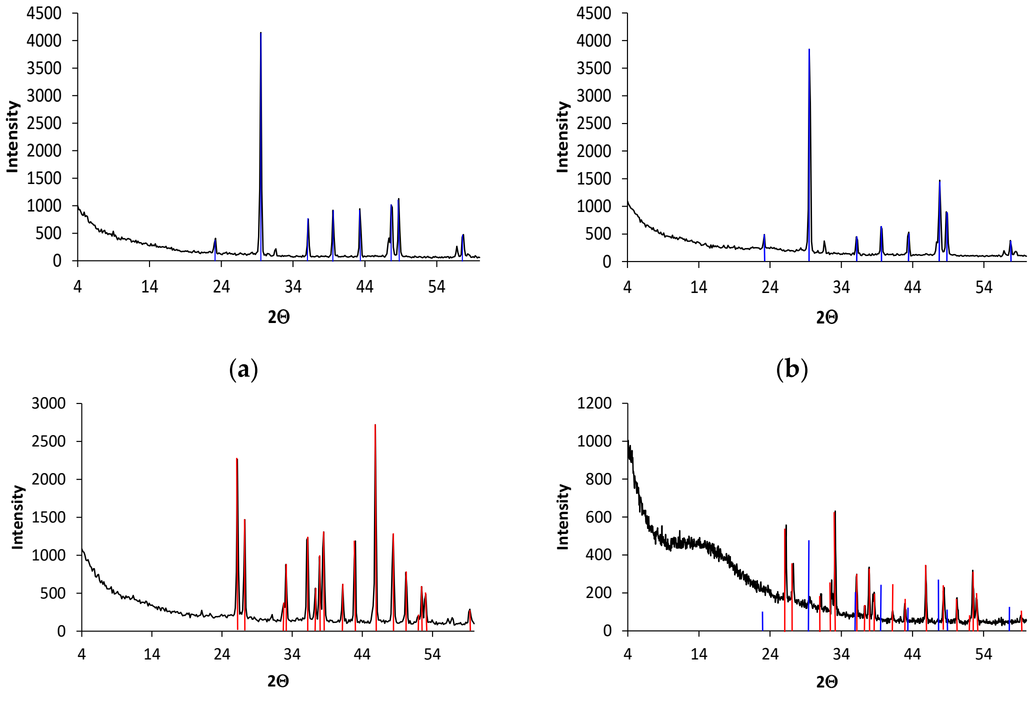
(**a**) (**b**) (**c**)

**Figure 7.** Images of the applied Meigen test: (**a**) calcite; (**b**) unwashed aragonite; (**c**) washed aragonite.

## *3.2. Characterization of Scales in Water Distribution Systems*

### 3.2.1. System without EMT

The characterization techniques discussed above were used to identify the mineral phases in the scale collected in the water distribution systems. The results obtained in water distribution systems without EMT are presented below. Figure 8 presents the diffractograms of the analyzed scales.



(**a**) (**b**)

(**c**) (**d**)

**Figure 8.** XRD patterns in the analyzed samples: (**a**) pipe; (**b**) tap; (**c**) heater resistance; (**d**) hot water shower. (Blue: calcite, red: aragonite).

As can be seen in Figure 8, the scales present in the pipe and tap are calcite, while those found in the heater resistance, where temperatures are higher, are aragonite. In the case of the shower, where hot water is also used, both mineral phases appear. Temperature seems to favor the formation of aragonite. Temperature is a key parameter in the formation of crystals derived from the precipitation of calcium carbonate. It has been established that the binding of water molecules at temperatures above 45 °C causes dipole moments across the carbonate ions [24], which favor the formation of aragonite crystals.

Figure 9 shows the TGA of the calcite and aragonite minerals together with those of the samples taken from the heater resistance and pipe. The tap and shower samples could not be analyzed as they were too few in quantity. It is observed how the incrustation of the resistance matches the mineral aragonite, while that of the pipe does not match the calcite. This fact has been verified in different samples (not included in this work), which may be due to, among other things, the different morphology of the crystals formed, as can be seen in the SEM images (Figure 10). The microscopy techniques show how the scale that has remained in the pipe for a sufficient time (Figure 10a) presents a much more organized structure with more compact crystals than a scale obtained from a tap filter (Figure 10b), where the scale generally has less time to form. This behavior modifies the weight losses and makes TGA not a good technique to differentiate these real incrustations.

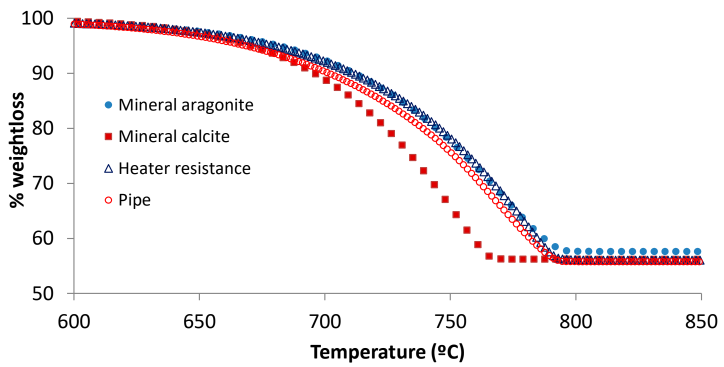


**Figure 9.** TGA of calcite and aragonite minerals along with the resistance and pipe samples.

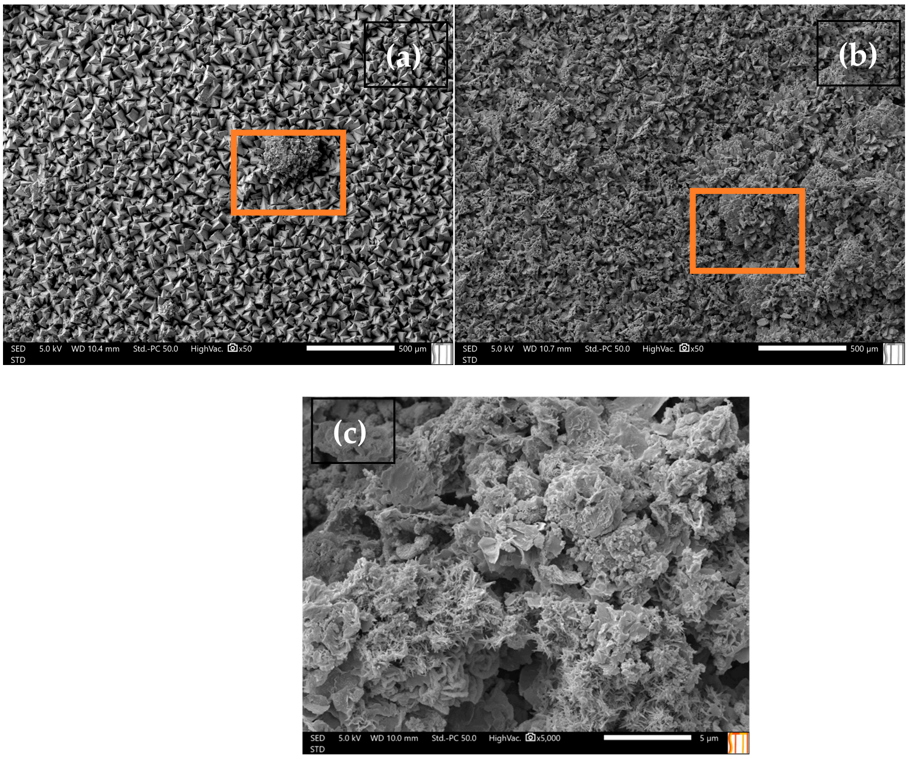


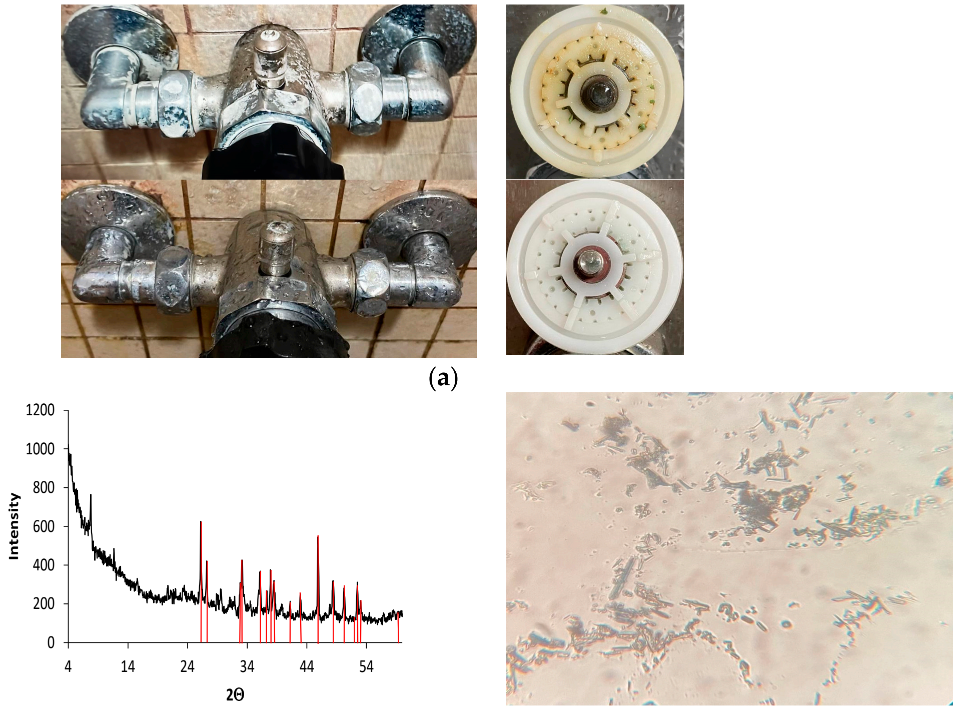
**Figure 10.** Samples of scales analyzed by SEM: (**a**) in pipe; (**b**) in tap; (**c**) in heater resistance. The orange frame shown agglomerated crystals in scales with shapes not well-defined.

The SEM images also show many agglomerated crystals in scales of water distribution systems (marked areas in Figure 10a,b) that are not well-defined, making identification difficult. These agglomerates are related to the nucleation and growth phenomena of crystalline phases [25,26], which can alter the particle size distribution and crystal shape, as observed in some of the samples analyzed in our investigation. However, needle-shaped structures can be distinguished in systems exposed to high temperatures, such as heater resistance, corresponding to aragonite (Figure 10c). In areas of lower temperature where growth has occurred slowly, the crystals exhibit a rhombohedral shape corresponding to calcite (Figure 10a). The formation of crystals derived from calcium carbonate precipitation has also been evaluated in boron coprecipitation studies [27], determining typical rhombohedral crystal structures for calcite and needle-shaped structures for aragonite. In some cases, these forms can create agglomerates that depend on factors such as pH, temperature, and precipitation rate.

When the Meigen test is applied to scale from water distribution systems, in terms of color, the results are identical to those shown in Figure 7a,c (pure minerals) and corroborate those obtained with the more expensive instrumental techniques (Figures 8 and 10). Therefore, the Meigen test is suitable for identifying calcite and aragonite in the scale of water distribution systems, highlighting that this test is simple and fast to identify the calcium carbonate scale.

### 3.2.2. System with EMT

In the sports hall of the University of Alicante, EMT equipment was installed (Figure 2b) to observe its effect in a real installation. Figure 11a shows a shower tap and shower head sprinkler (corresponding to the hot water shower, Figure 1d) before and two years after the installation of the EMT, where a decrease in limescale can be observed. As a result of installing the equipment, maintenance tasks in this section have been significantly reduced, and there is minimal calcium carbonate scale formation in this part of the water distribution system of the sports hall. In Figure 11b, the diffractogram of a few scales found in the system with EMT shows only the presence of aragonite, unlike the scales collected from the distributors of the hot water showers without EMT (Figure 8d), where both calcite and aragonite were found.



(**a**)

(**b**) (**c**)

**Figure 11.** Effect of EMT on scale formation: (**a**) tap and shower head sprinkler before and after 2 years of EMT; (**b**) XRD patterns of scale; (**c**) image with an optical microscope when needle shapes can be observed.

After two years of EMT, very few scales were found, making analysis through SEM impossible. Therefore, the sample was observed using an optical microscope (Figure 11c), where separated crystals and aragonite needles were observed. Temperature and EMT promote the formation of aragonite. Han et al. [28] proposed that treatment with electromagnetic fields produces very small aragonite needles that can easily flow in water [29]. In this regard, it is concluded that EMT has a direct effect on the precipitation profile of calcium carbonate and the morphology of the resulting microcrystals, promoting efficient particle separation and consequently preventing scale formation in water distribution systems.

### *3.3. Evaporation Studies to Obtain Scales with Controlled Conditions*

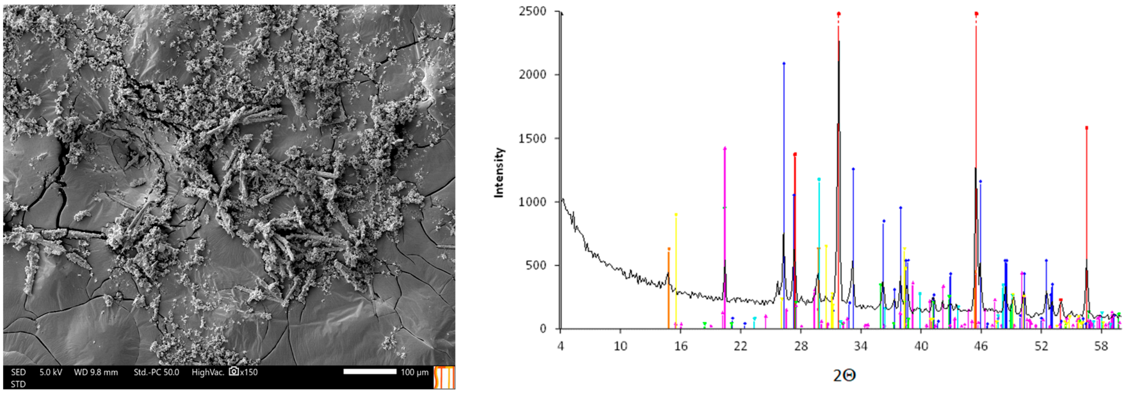
#### 3.3.1. Analysis of Precipitates Obtained via Evaporation of Real Water

To test whether the presence of aragonite in the scale is due to EMT, temperature, or a combination of both, laboratory trials were conducted under controlled conditions. We started by studying the evaporation of real water in an oven at 105 °C. The majority of cations and anions in these waters are shown in Table 1

**Table 1.** Characterization of tap water used in evaporation studies.

| Parameters | Tap Water |
|---|---|
| pH | $8.26 \pm 0.05$ |
| Conductivity (µS/cm) | $970 \pm 10$ |
| $Ca^{2+}$ (mg/L) | $75 \pm 1$ |
| $Mg^{2+}$ (mg/L) | $30 \pm 1$ |
| $Na^{+}$ (mg/L) | $100 \pm 5$ |
| $K^{+}$ (mg/L) | $3 \pm 0.1$ |
| $HCO_3^{-}$ (mg/L) | $165 \pm 5$ |
| $SO_4^{2-}$ (mg/L) | $85 \pm 1$ |
| $Cl^{-}$ (mg/L) | $215 \pm 5$ |
| $NO_3^{-}$ (mg/L) | $7 \pm 0.1$ |

The product obtained shows a large agglomeration of salts together with precipitated calcium carbonate, as seen in Figure 12. The SEM does not reveal a clear crystalline structure, and the diffractogram shows the presence of calcite and aragonite along with halite, magnesian calcite, magnesium chloride, and copper chloride, among others. Therefore, it was not possible to perform an optimal identification of the mineral phases present in the samples, nor a comparison between treated and untreated conditions. It was also not possible to study these samples with TGA for the precipitates obtained using tap water since the high presence of salts in the sample holder caused problems in the measuring cell. As previously mentioned in Section 3.2.1, if the morphology of the calcite crystals already affects the TGA, the presence of additional salts would make their interpretation much more difficult. For this reason, this technique was dismissed for these real samples.



(**a**) (**b**)

**Figure 12.** Characteristics of the sample from the 105 °C evaporation of tap water: (**a**) SEM image; (**b**) XRD patterns.

On the other hand, when the Meigen test is applied to tap water evaporated in the oven, different shades appear depending on the ions present, due to the composition of the water. Figure 13a shows the purple color of the aragonite, contributed by the cobalt carbonate, compared to the precipitate obtained from tap water (Figure 13b), where the tetrachlorocobalt (II) ion, which appears when the water has a high concentration of chloride ion, gives the precipitate a blue color. Certainly, the variable composition of tap water and the presence of chemical elements make it difficult to characterize the crystalline phases of calcium carbonate in precipitates from real water samples [8,30], so it is necessary to carry out experiments with synthetic water.

(**a**) (**b**)

**Figure 13.** Meigen test applied to tap water containing: (**a**) aragonite; (**b**) tetrachlorocobalt (II) ion.

### 3.3.2. Analysis of Precipitates Obtained through Evaporation of Synthetic Waters. Study of the Reversion of Aragonite to Calcite

As seen in the previous section, the techniques applied to precipitates obtained from tap water do not allow the formation of calcite and aragonite to be adequately distinguished due to different problems such as agglomeration of salts, the presence of interferents, etc. To distinguish if EMT generates any effect on the crystalline phases, studies were carried out with synthetic waters prepared only with calcium carbonate.

The synthetic waters, treated and untreated with EMT, were prepared by dissolving reagent-grade calcium carbonate in osmosed water with $CO_2$ bubbling. Once prepared, they were evaporated in an oven at different temperatures (40, 70, 105 °C) and the precipitates obtained were analyzed via TGA, SEM, XRD, and adapted Meigen test.

Figure 14 shows that the analyzed samples are between the two mineral phases. The crystalline phases of the treated waters move at higher temperatures, both for crystals obtained at room temperature and those obtained at 105 °C, which would indicate a higher percentage of aragonite in them; this percentage being higher in the higher temperature samples. The untreated samples present a decomposition temperature more similar to calcite. Regarding the thermal decomposition of the precipitates, it is confirmed that the EMT generates a greater tendency towards the formation of aragonite, which is catalyzed by high temperatures [31].

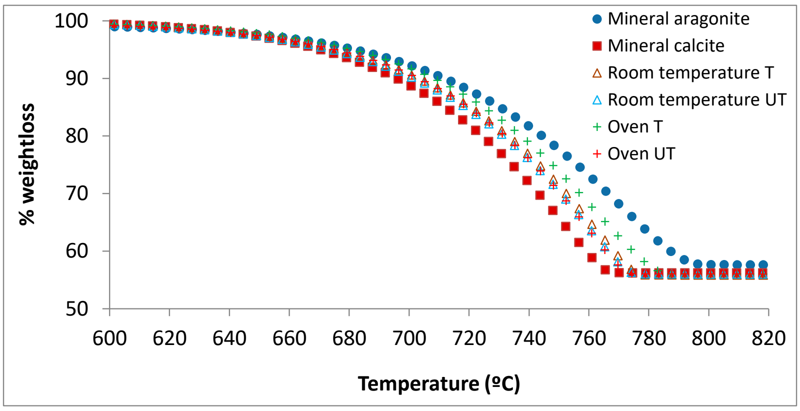


**Figure 14.** Thermal decomposition of calcite and aragonite mineral crystals and crystals from evaporation of treated and untreated samples at room temperature (23 °C) and in oven (105 °C).

The XRD patterns (Figure 15) and SEM images (Figure 16) corroborate the results shown above since they show the coexistence of the two mineral phases (calcite-aragonite) in the scale. However, it is shown that as the evaporation temperature of the sample increases, the proportion of aragonite increases; this is more evident in the samples that received EMT. The efficiency of this type of magnetic device has also been tested in water systems in electric heaters [32], demonstrating that this technology can reduce the thickness of scale on surfaces heated at high temperatures if the treated water is heated up to approximately 75 °C.

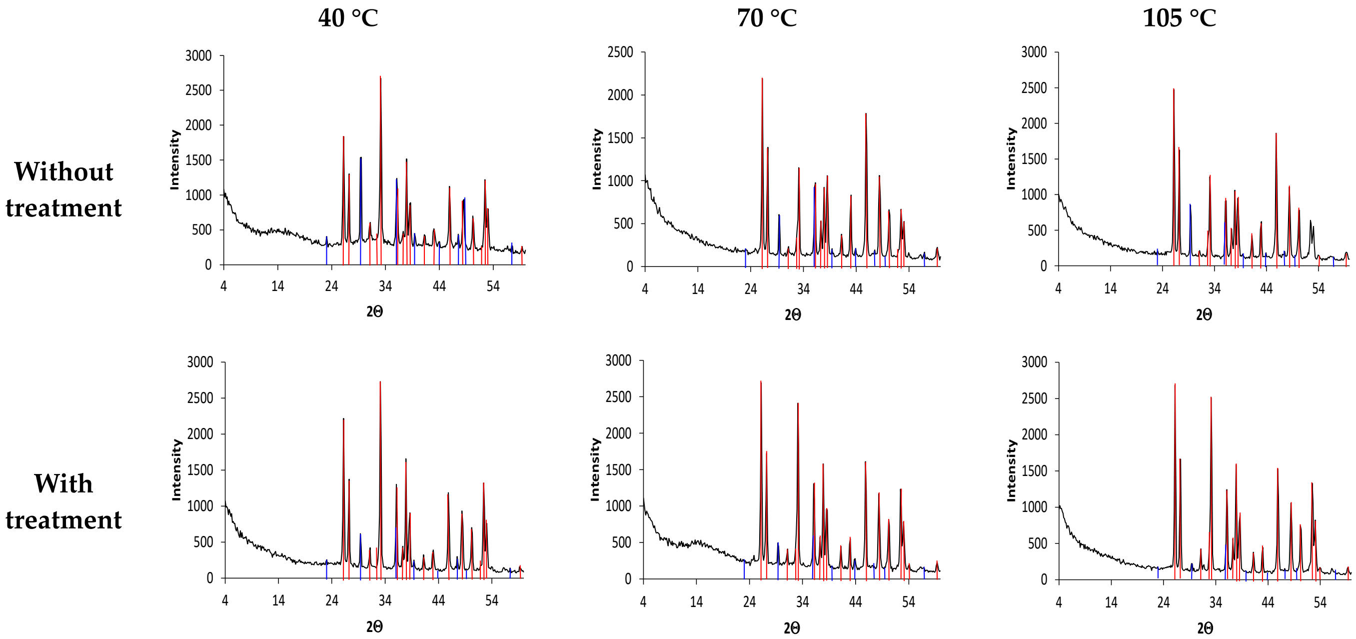


**Figure 15.** Diffractograms of crystalline phases obtained in synthetic water samples (with and without EMT) evaporated in the oven at 40, 70, and 105 °C (red: aragonite, blue: calcite).

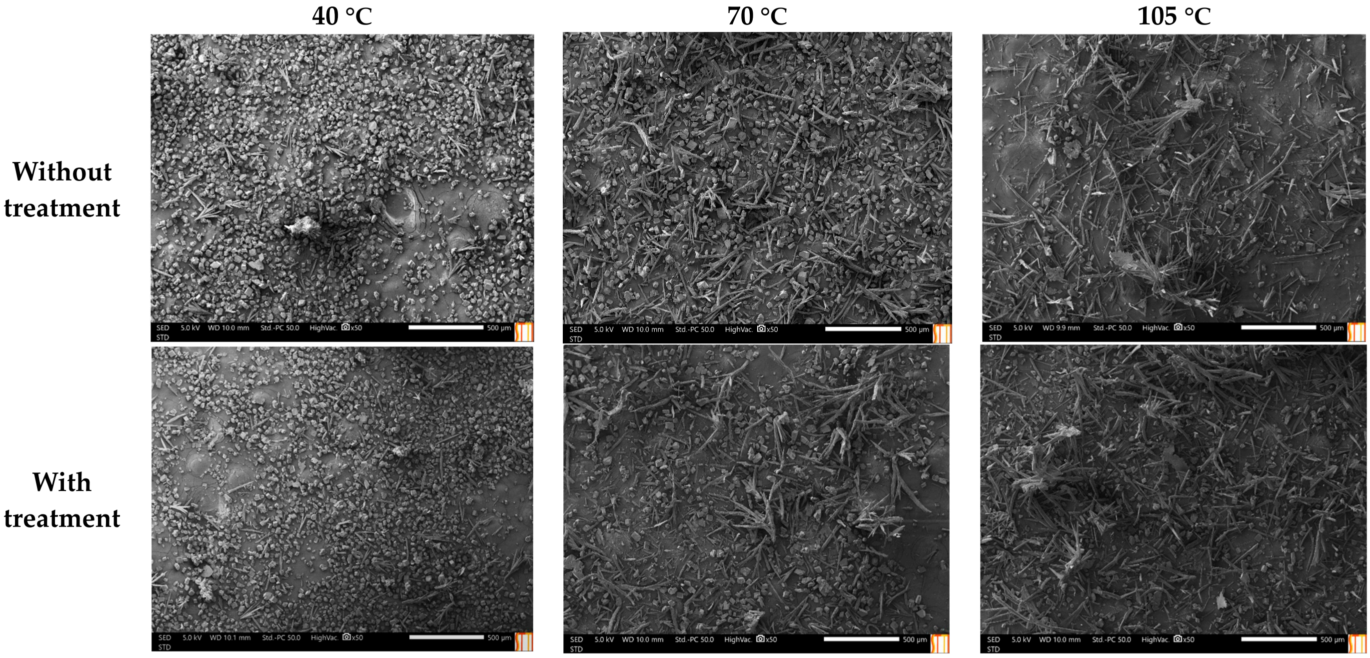


**Figure 16.** SEM images of crystalline phases obtained in synthetic water samples (with and without EMT) evaporated in the oven at 40, 70, and 105 °C.

Figure 17 shows the percentage of calcite and aragonite calculated from the X-ray diffraction results. It is visualized that EMT increases the aragonite composition at all evaporation temperatures evaluated, so the physicochemical mechanism by which EMT operates is closely linked to an increased composition of low-size and density aragonite crystals (needle-like), which can be easily transported in the aqueous medium and slow down scale formation in the systems through which the water flows. In addition to the technical and economic advantages of reduced fouling in EMT-connected systems, this technology shows stability at different temperatures, which can reduce operating costs and make EMT applications feasible in areas with variable thermal conditions.

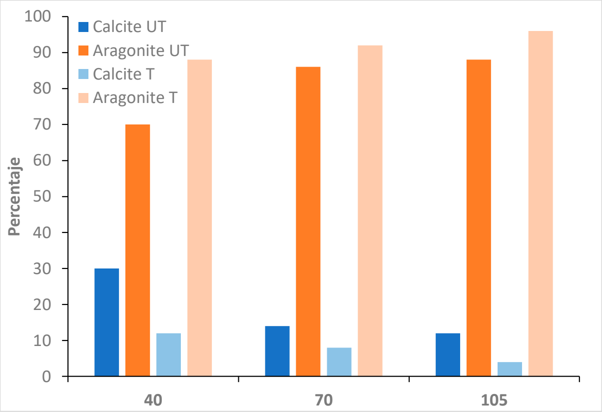


**Figure 17.** Percentage of calcite and aragonite in precipitates obtained at different temperatures from untreated (UT) and treated (T) synthetic waters.

About the Meigen test (Figure 18), since aragonite is present in all the samples, a purple hue appears in all the precipitates analyzed, increasing slightly in intensity as the proportion of aragonite present increases.

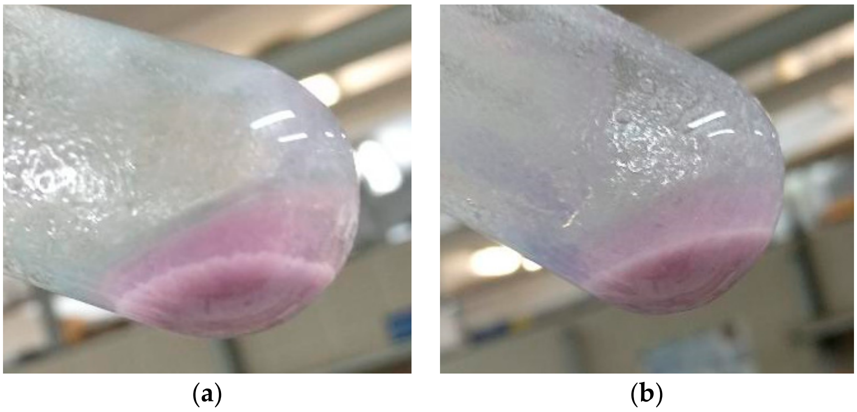

(**a**) (**b**)

**Figure 18.** Meigen test on precipitates obtained from synthetic waters evaporated at 105 °C: (**a**) untreated; (**b**) treated.

As mentioned, aragonite is an unstable phase and tends to revert to calcite; for this reason, a study was carried out by subjecting treated and untreated synthetic water to a heating process, in an oven at 80 °C for 3 h, followed by evaporation for one month at room temperature (23 °C). Aragonite was reported in both samples, but with a higher presence in the sample with EMT, as shown in Figure 19 with SEM images and diffractograms, suggesting that the aragonite formed in these samples reverts to calcite more slowly than the sample without EMT.

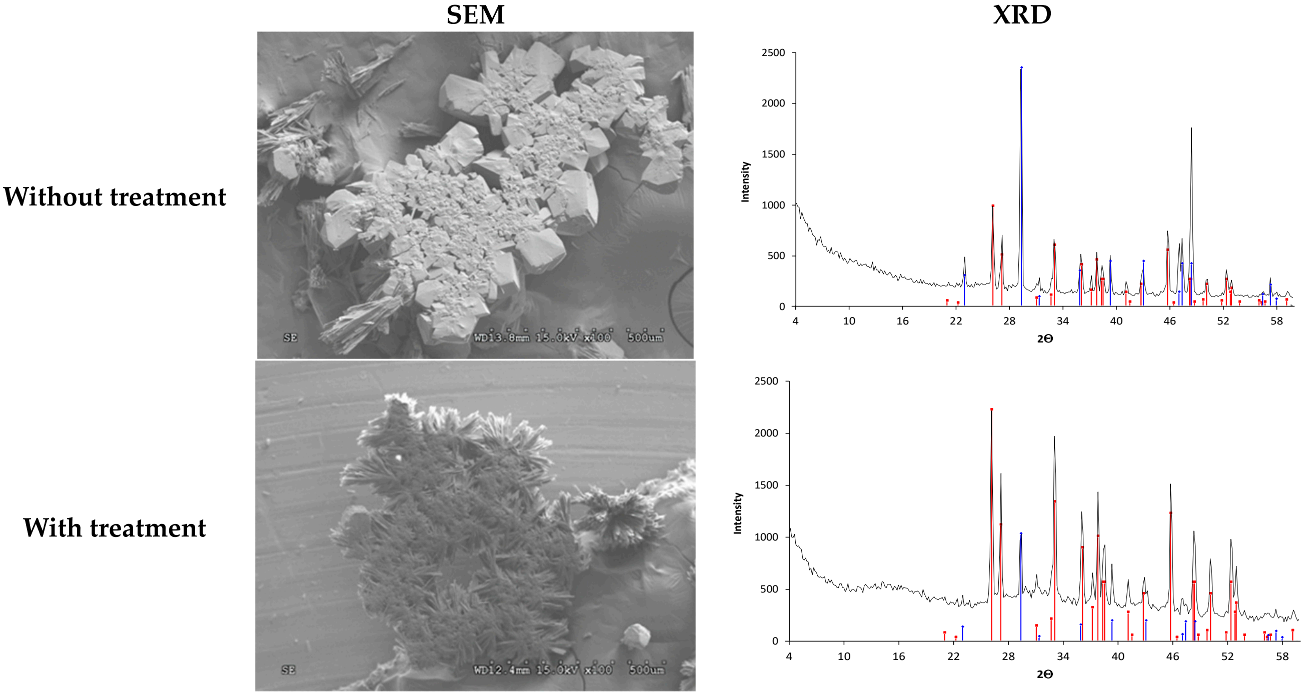


**Figure 19.** SEM and diffractograms of the crystalline phases were obtained in synthetic water samples with flash heating and one month of evaporation at 23 °C.

These results align with those observed in Figure 8d (corresponding to the diffractograms of the scale taken from the hot water distribution systems), where aragonite is present due to the effect of temperature but gradually reverts to calcite. For this reason, both mineral phases are visible in these samples. When aragonite reverts to calcite, the latter being more incrustating, cleaning and maintenance problems occur [33–35]. Concerning the samples subjected to EMT, the reversion of aragonite to calcite is delayed, and no incrustations are generated.

Once the results are seen, it is observed that both temperature and EMT favor the formation of aragonite. Additionally, EMT delays the reversion of aragonite to calcite, which, in real water distribution systems, will reduce scaling problems. Currently, EMT equipment is used with known benefits, and although there are no simple methods to measure the positive effects produced, we have demonstrated through laboratory tests that changes occur that affect crystallization and prevent scale formation.

Other technologies require continuous maintenance and the use of harmful chemical reagents, leading to high costs at both domestic and industrial levels, in addition to environmental damage. Systems usually applied to eliminate or avoid scale, such as acid treatments, water softening, reverse osmosis, etc. [8], use acids for cleaning, antifouling agents to prevent deposition in membranes, and sodium chloride to regenerate ion exchange resins, among others. All of these practices result in polluting discharges into the environment and involve various costs, especially in energy consumption. By contrast, EMT technology requires no maintenance or additional reagents, and its energy consumption is low, translating to economic and environmental benefits, making its application highly recommended.

## 4. Conclusions

The present investigation determined the significant influence of water temperature on the formation of the crystalline phase of calcium carbonate. High temperatures lead to the formation of aragonite instead of the stable form (calcite), as found in the samples from the heater resistance. On the other hand, in the rest of the samples taken from areas of the water distribution system where temperatures are lower, such as pipes, taps, and filters, a majority of calcite is present. EMT equipment is currently used, and its benefits are known, but its effective operation for scale inhibition depends on the density of the magnetic flux, operation time, and flow, among other factors. However, there are no simple methods to measure the positive effects produced in real water, making it necessary to carry out studies with synthetic water prepared only with calcium carbonate. These studies have corroborated the coexistence of the two mineral phases, with the proportion of aragonite increasing as the evaporation temperature rises. A higher proportion of aragonite also appears in the sample treated using electromagnetism at the same evaporation temperature. Regarding the stability of the crystals, it is concluded that aragonite reverts to calcite more slowly in the EMT-treated sample. The greater presence of aragonite and its slower reversion to calcite in EMT systems reduces the occurrence of scales in water distribution systems, leading to economic benefits such as less frequent replacement of pipes and valves, as well as the savings this technology provides by not requiring maintenance. From an environmental point of view, it avoids the use of chemicals for cleaning and softening, as well as consumables used in other treatment systems such as membranes, qualifying EMT as a low-cost and sustainable technology. For future research, it would be interesting to conduct this study with equipment that has variable flow intensity to investigate the influence of other operating conditions.

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