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MICROSCOPIC OBSERVATION OF CALCIUM CARBONATE PARTICLES: VALIDATION OF AN ELECTRONIC ANTI-FOULING TECHNOLOGY

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ABSTRACT

It is hypothesized that an electronic anti-fouling (EAF) technology precipitates dissolved mineral ions through solenoid-induced molecular agitation. In order to investigate the hypothesis of the EAF technology, the present study conducted microscopic observation of calcium carbonate crystallization process from both untreated and treated water samples by the EAF technology as the water samples underwent drying process. The untreated water sample showed a large number of small crystals within a range from 1 μm to 10 μm in diameter, whereas the treated water sample by EAF technology showed large crystals ranging from 10 μm to 20 μm in diameter. © 1997 Elsevier Science Ltd

Introduction

Hard water is the culprit of the precipitation fouling problem. Hard water can be described as water containing excessive amounts of dissolved ions beyond the saturation limit of each ion, hence becoming very "unstable." When the supersaturated water enters heat transfer equipment, the solubility of dissolved mineral ions changes. Subsequently, the mineral ions come out of the water, precipitating and adhering to the heat transfer surface. The solubility changes primarily due to the changes in temperature, pressure, and pH of the water. The solubility decreases with increasing temperature for calcium carbonate, one of the most common scales.

Once scales build up in a heat transfer surface, at least two problems associated with scales occur. The first problem is the degradation in the performance of the heat transfer equipment due to small thermal conductivity of scales. The second problem is that a small change in tube diameter substantially decreases the flow rate or increases the pressure drop across the heat transfer equipment [3].

The traditional method of preventing scale or fouling in heat transfer equipment is to use scale-inhibiting chemicals or water treatment equipment. As an alternative, the present study investigates the feasibility of using a new electronic anti-fouling (EAF) technology which does not require the use of any chemicals or water treatment equipment. EAF technology uses a solenoid coil wrapped around a pipe, and a time-varying current signal is being driven through the solenoid coil. Further information of EAF technology is given elsewhere [4, 5].

EAF technology uses a square-wave current signal which produces an oscillating electric field inside a pipe, a phenomenon known as Faraday's law. The oscillating electric field provides molecular agitation to dissolved mineral ions, converting them into insoluble mineral salt crystals through improved collision process. Once water is treated by EAF technology, there is a much lower number of dissolved mineral ions in the water. In other words, the supersaturation ratio (or Langelier index) is significantly reduced by the EAF treatment. Subsequently, the EAF treated water behaves almost like saturated water, thus precipitation fouling will be significantly reduced or prevented on a heat transfer surface.

The critical process in the operation of EAF technology is the nucleation of dissolved mineral ions by solenoid-induced molecular agitation and subsequent crystallization. Theoretical descriptions of the nucleation and crystallization phenomena initiated by EAF technology are given elsewhere by Cho et al [5]. The above-mentioned hypothesis of the improved collision efficiency by the EAF technology needs to be verified experimentally. However, since the collision occurs at molecular levels, it may not be possible to prove this experimentally in engineering laboratory. Therefore, the present study attempts to provide indirect experimental proof that EAF technology indeed produces the precipitation of the dissolved mineral ions through molecular agitation.

Methods

In the present study artificial hard water was prepared in a laboratory by adding $CaCl_2$ and $NaHCO_3$ to tap water available at Philadelphia. In order to make hard water with a total hardness equivalent to 500 ppm as calcium carbonate, 0.005 M $CaCl_2$ (40 Mesh, technical grade) and 0.01 M $NaHCO_3$ (99.7%, A.C.S. reagent grade) were mixed up and dissolved in tap water.

Figure 1 shows a schematic diagram of a once-through flow system used in the present study. The flow system consisted of a water tank, a pump, a flow meter, and a test section with an electronic anti-fouling unit. Two water sampling ports were located before and after the test section. The reservoir tank had a capacity of 50 liters where we prepared hard water. In order to test the effect of EAF technology on the crystallization of $CaCO_3$, we wrapped two sets of coils of 60 turns each around a copper tube (1.27 cm OD) as shown in Fig.2. There was a 0.1 m gap between the two coils. The second water sampling port was some distance away from the second coil, which is indicated by letter "L" in Fig. 1.

In the present study we investigated the effect of EAF technology on the crystallization of $CaCO_3$ by comparing the crystal growth characteristics in water samples obtained with EAF treatment and without EAF treatment. For this purpose, water samples were collected from the second sampling port while the EAF unit was turned off and on, and these water samples were used for comparison. Water samples collected at the first sampling port were also analyzed as a reference.

The distance "L" between the second coil and the second sampling port was varied from zero to 22.0 m. The results of calcium carbonate crystallization obtained at four different distances of L (i.e., 0.9 m, 1.8 m, 3.6 m, and 5.5 m) are reported in the present study because the results obtained at L greater than 5.5 m were almost identical to those obtained at L = 5.5 m.

Microscopic observations of $CaCO_3$ crystals were carried out using a polarized microscope. The procedure of the observation of the crystals is as follows: first, we collected a water sample from the second sampling port, then using a pipette, we dropped 1 ml of the water sample on a clean glass slide and observed the crystallization process of $CaCO_3$ in the polarized microscope. As the water sample dried due to evaporation, we continuously counted the numbers of crystals of different sizes as a function of time. The crystals were grouped into four different sizes: less than 1 μm, between 1 and 10 μm, between 10 and 20 μm, and between 20 and 50 μm. By recording the changes in the numbers and sizes of the crystals at different times, the rate of the crystal growth of $CaCO_3$ was estimated. We observed consistently the same area including an edge, bounded by the x and y axes of the eye piece of the microscope, such that the numbers of crystals counted from one water sample were comparable to those counted from the other.

Results and Discussion

Tables 1 and 2 present the results from the microscopic observations with untreated and EAF treated water samples, respectively. For consistency, both water samples were taken downstream of the second coil at L = 0.9 m. The numbers of the four different size $CaCO_3$ crystals are reported as a function of time (e.g., at t = 0, 5, 10, 15, and 20 min.). A magnification of 100X was used for observations.

As shown in Table 1, the number of crystals consistently decreases with increasing crystal size both during drying and in dried water samples for the untreated water case. In other words, the untreated water generates a large number of small crystals. The crystal sizes observed from the treated water sample shown in Table 2 are in the range of 1-10 µm at t = 5 min., but as time progresses, the crystals grow to 10-20 µm size and eventually to 20-50 µm size at t = 20 min.

TABLE 1

Number of Crystals Observed from Untreated Water Sample
at Various Time Stages through Microscope with a Magnification of 100X

	Crystal Size (µm)			
Time (min.)	0-1	1-10	10-20	20-50
0	0	0	0	0
5	0	21	0	0
10	0	38	10	0
15	0	34	16	0
20	0	40	16	1

TABLE 2

Number of Crystals Observed from EAF Treated Water Sample
at Various Time Stages through Microscope with a Magnification of 100X

	Crystal Size (µm)			
Time (min.)	0-1	1-10	10-20	20-50
0	0	0	0	0
5	3	40	0	0
10	0	28	20	0
15	0	20	25	5
20	0	20	30	5

TABLE 3

Number of Crystals Observed from EAF Treated Water Samples through Microscope with a Magnification of 100X. Observations were made when they are completely dried.

	Crystal Size (μm)			
Distance L (m)	0-1	1-10	10-20	20-50
0.9	0	20	30	5
1.8	0	5	25	7
3.6	0	7	29	5
5.5	0	12	35	5

Table 3 shows the distance effect on the crystallization characteristics of $CaCO_3$ in the treated water sample. The distance between the second sampling port and the second EAF coil changed from 0.9 m to 22 m. The results given in Table 3 were from the EAF treated water samples and observed at a magnification of 100X after the samples were dried for 20 minutes. It is of note that the results obtained at L larger than 5.5 m were almost identical to those obtained at L = 5.5 m, thus not shown here.

When we compare these results obtained with EAF treatment with those without EAF treatment, there is a considerable difference between the two. The untreated water sample shows a large number of small crystals mostly in a range of 1 to 10 μm in diameter. The EAF treated water sample gave predominately large crystals in a range of 10 to 20 μm in diameter. The results in Table 3 clearly indicate that the EAF treatment of hard water makes the calcium carbonate crystals in water grow into larger ones than those in the untreated water sample.

When we calculated the precipitated mass of calcium carbonate from dried water samples (i.e., at $t = 20$ min.) from the untreated and treated water as shown in Tables 1 and 2, respectively, it became 475 and 725. Based on these numbers, we can conclude that the EAF treatment produced approximately 53% more precipitation in the treated water sample.

Figures 3(a) and 3(b) show close-up views of the crystals from both untreated and EAF treated water samples, respectively, under a magnification of 250X. These pictures were taken from the eye piece of the polarized microscope using a Nikon camera with a special adapter for fitting. The untreated water sample shows a number of small size crystals, whereas the EAF treated sample shows large crystals whose sizes are within 20 to 50 μm in diameter. Of note is that the diagonal line crossing the upper right corner is the edge of water sample.

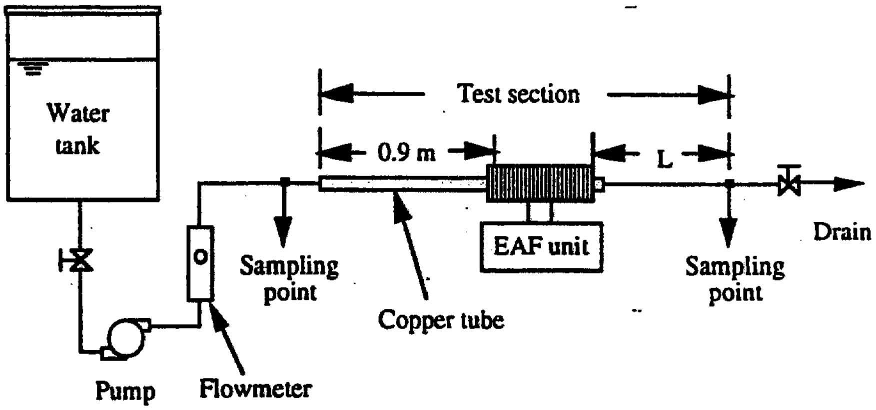


FIG. 1
Sketch of flow system with an EAF unit. L is the distance between EAF coil and water sampling port, which varied from 0.9 m to 22m. Flow rate was fixed at 2 gpm.

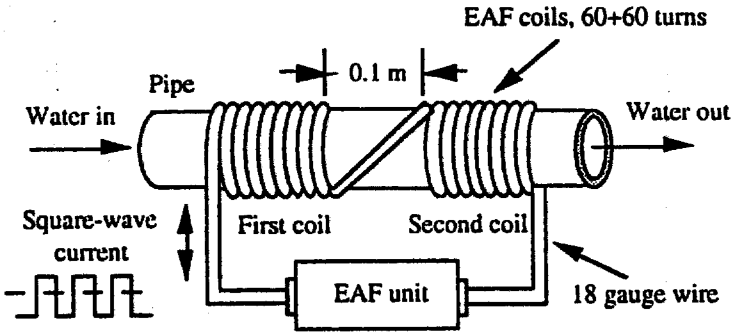


FIG. 2
Sketch of EAF coils wrapped around pipe.

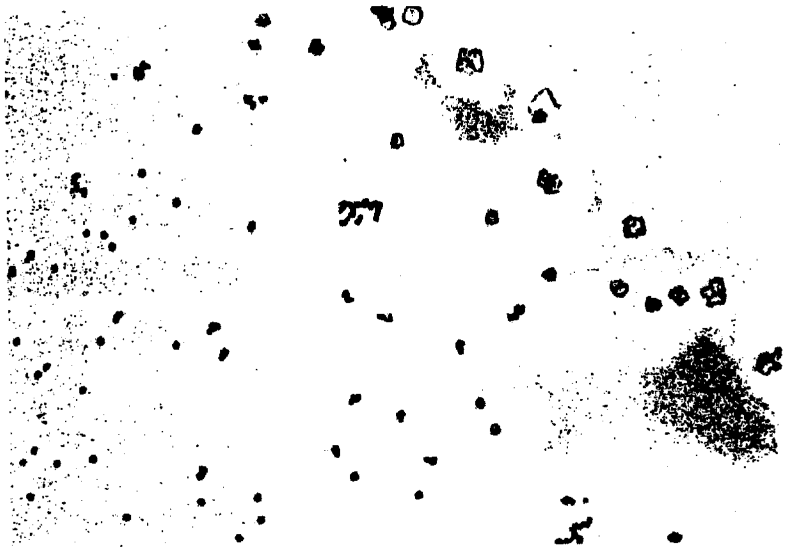


FIG. 3(a)

Photograph of water sample from untreated water sample. Magnification 250X. The upper right corner is the outside of the sample.

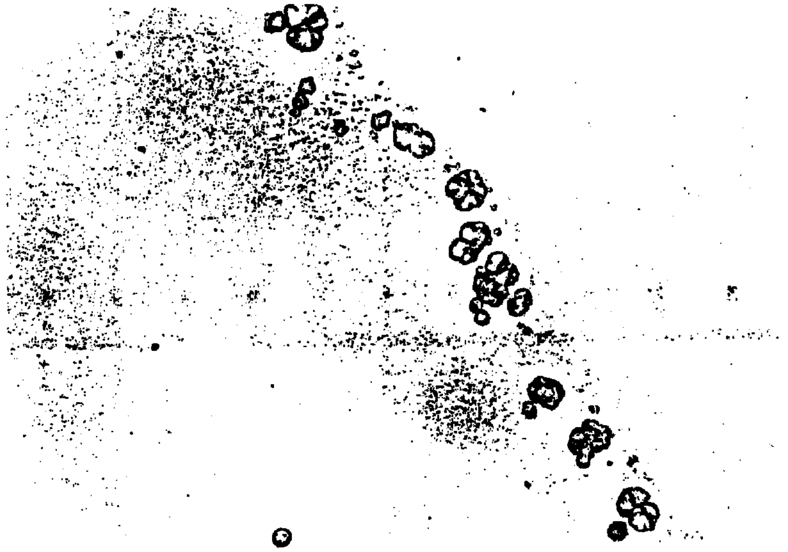
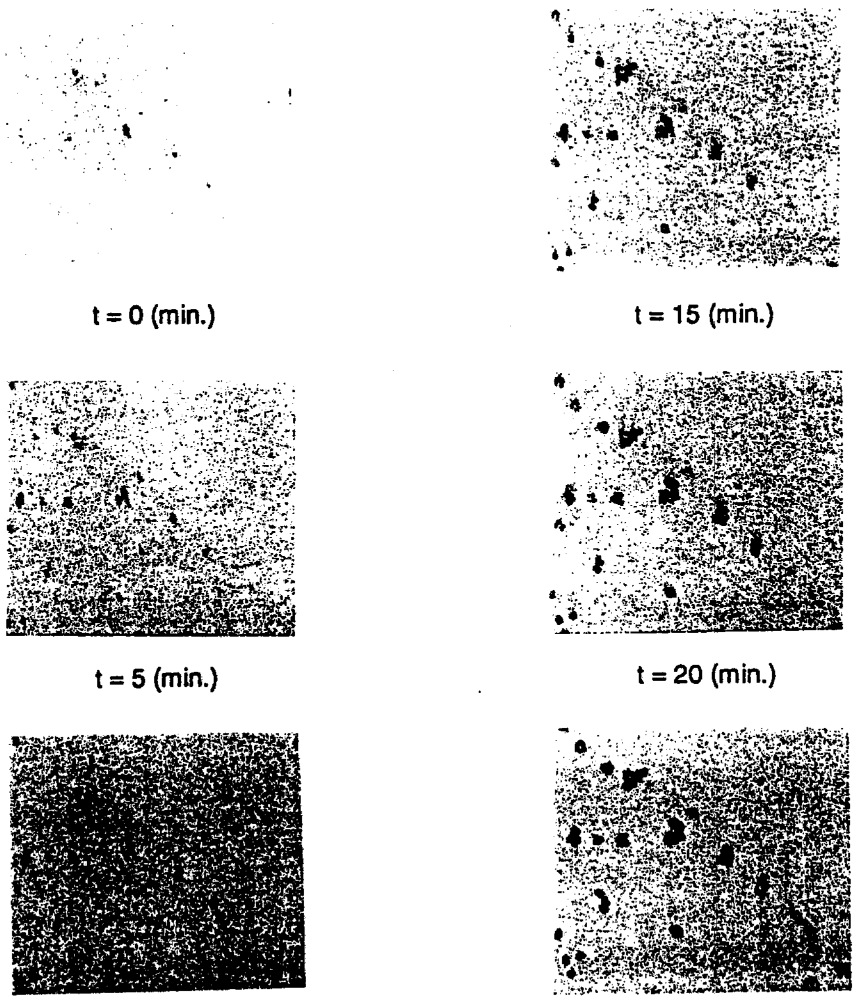


FIG. 3(b)

Photograph of water sample from EAF treated water sample. Magnification of 250X. The upper right corner is the outside of the sample.



t = 0 (min.)

t = 15 (min.)

t = 5 (min.)

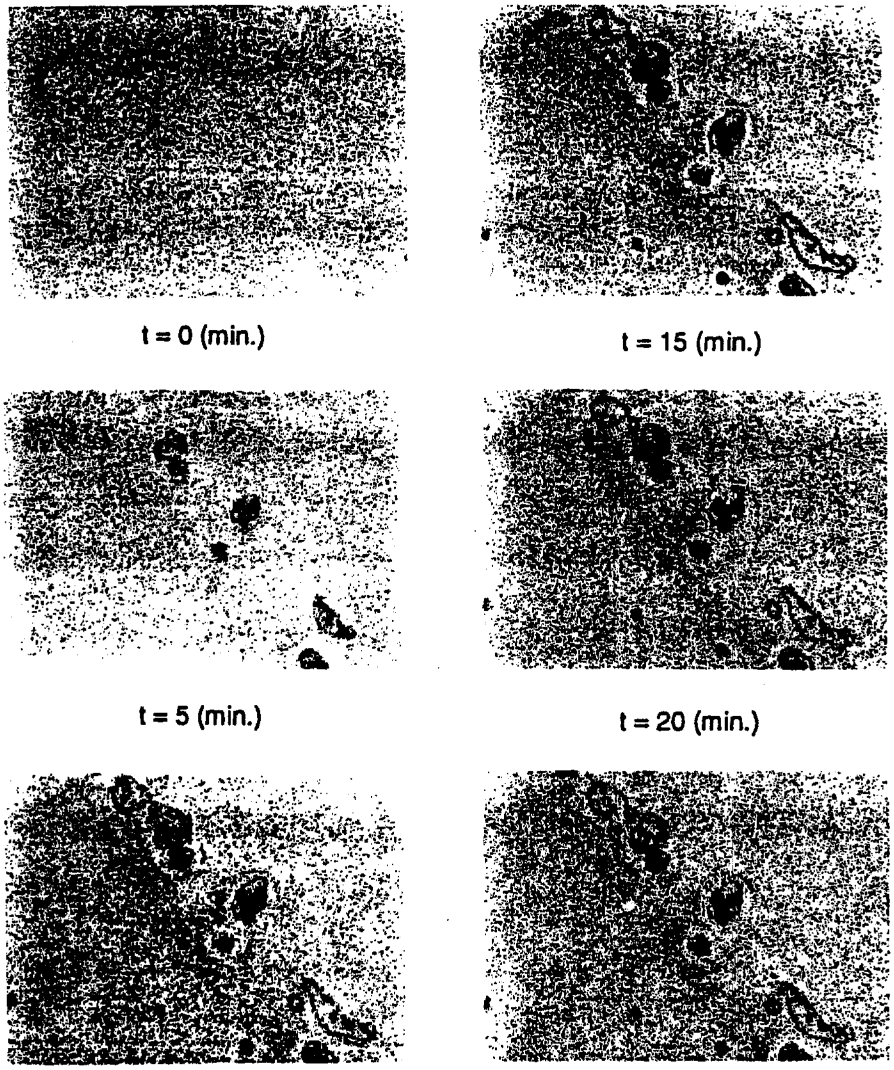
t = 20 (min.)

t = 10 (min.)

t = 30 (min.)

FIG. 4

Photographs of crystal growth of calcium carbonate taken during drying process from untreated water sample. Magnification of 100X.



t = 0 (min.)

t = 15 (min.)

t = 5 (min.)

t = 20 (min.)

t = 10 (min.)

t = 30 (min.)

FIG. 5

Photographs of crystal growth of calcium carbonate taken during drying process from EAF treated water sample. Magnification of 100X.

Figures 4 and 5 present photographs of crystal growth of calcium carbonate taken during the drying process from untreated and EAF treated water samples (both collected at L = 0.9 m), respectively. A magnification of 100X was used in the microscopic observation for both cases. As shown in Fig. 4, a large number of small crystals are found at the interior of the untreated water sample. For the EAF treated water sample shown in Figs. 5, there is a much lower number of small crystals at the interior area of the water droplet. If one compares crystals along the edge, the untreated water sample shows mostly small crystals whose sizes are within a range from 1 to 10 μm in diameter whereas the EAF treated water sample shows many large crystals with diameters ranging from 20 to 50 μm.

Conclusions

The crystallization process of calcium carbonate was observed in both untreated and EAF treated water samples, respectively. The EAF technology was found to produce large crystals of dissolved mineral ions. Some of the key observations are summarized as follows:

1. The untreated water sample shows a large number of small crystals mostly within a range from 1 μm to 10 μm in diameter. Small crystals were found both in the interior area and at the edge of dried water sample.
2. The EAF treated water sample shows large crystals mostly ranging from 10 μm to 20 μm in diameter. Some crystals grew up to 50 μm in diameter in the dried water sample.

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