

# Influence of magnetic water treatment on the calcium carbonate phase formation and the electrochemical corrosion behavior of carbon steel

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## Abstract

A study of the influence of magnetic water treatment on the calcium carbonate phase formation and the electrochemical corrosion behavior of carbon steel was carried out. The water was exposed to a magnetic field of 1 T with a speed of flow through the magnet of 0.77 m/s (1.56 ml/s). The observations demonstrated that the calcite is the main form of calcium carbonate, and became aragonite by action of the magnetic field. The aragonite content, expressed in wt.% with respect to the total calcium carbonate content, grew constantly with respect to the water without magnetic treatment up to 30 h of incubation time (18 wt.% of aragonite for water without magnetic treatment and 38 wt.% for water with an incubation time of 30 h). For incubation times greater than 30 h and up to 200 h the aragonite content fluctuated about 35 wt.%.

The electrochemical corrosion behavior was evaluated using polarization curves (ASTM G5-94). The polarization curves showed that the rate of corrosion increase with the magnetic water treatment.

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## 1. Introduction

It is believed that magnetic water treatment decreases the hardness of water and avoids scale formation and that it is good health. It is also possible to find different kind of magnet-based magnetic water treatment devices in the market. Magnetic water treatment becomes an alternative to resolve the scale formation problem in pipes and hot-water systems. Magnetic water treatment devices consist of one or more magnets clamped onto or installed inside the incoming residential water supply line. However, there is relatively little scientific literature on magnetic water treatment [1–3] and almost nothing about the influence of magnetic field on the corrosion behavior of carbon steel. The efficacy of magnetic treatment is reported to last from tens of minutes to hundreds of hours [4], and Coey and Cass [5] reported that drawing water through a magnetic field increases the aragonite/calcite ratio in the deposit with a 99.9% probability level and that

memory of magnetic treatment extends beyond 200 h. A magnetic water treatment device prototype was constructed for testing in a pilot plant and the results look very promising for reducing the need for chemically treated water [6].

Calcite and aragonite are two common natural forms of  $\text{CaCO}_3$ . Calcite is usually associated with hard scale formation whereas aragonite is less prone to form hard scale.

## 2. Experimental

Water was exposed to a magnetic field of 1 T with a speed of flow through the magnet of 0.77 m/s (1.56 ml/s). It was stored for incubation times from 0, 15, 30, 100, 150 and 200 h before heating in 500 ml open beakers at 80 °C to form limescale. Scale was collected on microscope slide at the bottom of the beaker.

Inductively coupled plasma-optical emission spectrometry (ICP-OES) determined the chemical composition of the water. The morphology was observed by scanning electron microscopy with EDAX analysis. The relative content of aragonite and calcite was determined by X-ray diffraction.

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The aragonite ratio  $A$  was evaluated from the X-ray diffraction patterns by measuring the ratio of three X-ray reflections in the region  $25^\circ < 2\theta < 30^\circ$ . The Miller index of the calcite peak is (1 0 4), the Miller index of the aragonite peaks are (1 1 1) and (1 0 2). The ratio  $A$  is calculated by [5]

$$A = \frac{(I_{111} + I_{012})}{(I_{104} + I_{111} + I_{012})}$$

The corrosion behavior was evaluated using electrochemical polarization curves according to the standard ASTM G5-94, for voltages in the range of  $\pm 900$  mV with a scanning speed of 10 mV/min.

### 3. Results and discussion

The chemical analysis for the untreated water is shown in Table 1.

Table 1  
Untreated water (mg/l) analyses

Elemental chemical analysis	
Al	1.4278
Ba	0.138
Ca	228.64 [232.839]
Cu	0.5426
Fe	0.3244
K	12.1596
Mg	10.936
Mn	1.2464
Mo	0.1074
Na	163.38 [171.789]
Si	27.1
Sr	1.7254
Zn	0.9456

The changes after magnetic treatment are shown in square brackets. pH = 8.37 and  $\sigma = 503 \mu\text{S}$ .

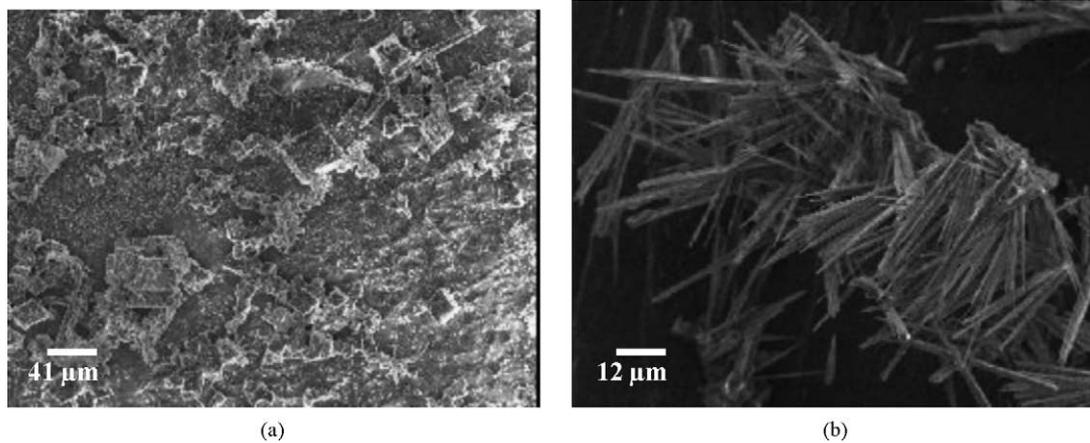


Fig. 1. (a) Calcite agglomerates of equiaxial crystals and (b) aragonite needle aggregates.

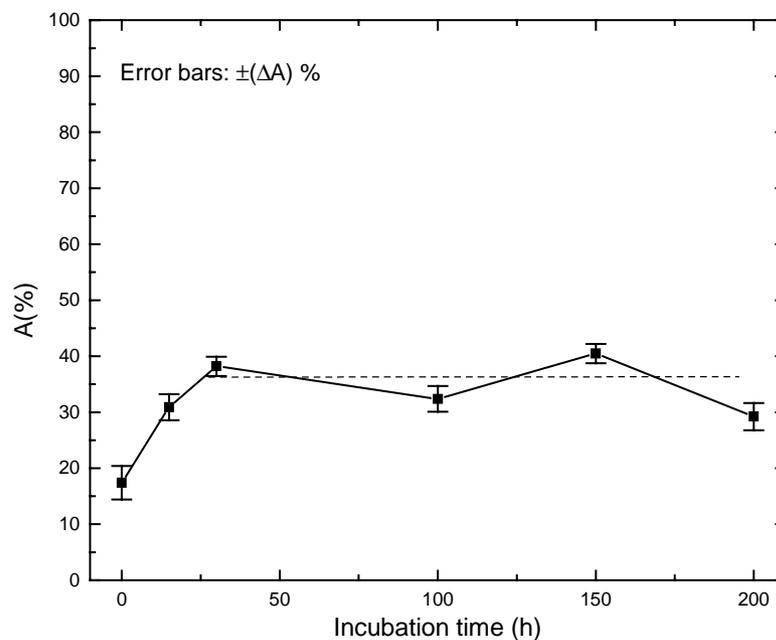


Fig. 2. Evolution of the aragonite ratio  $A$  with incubation time in magnetic treated water.

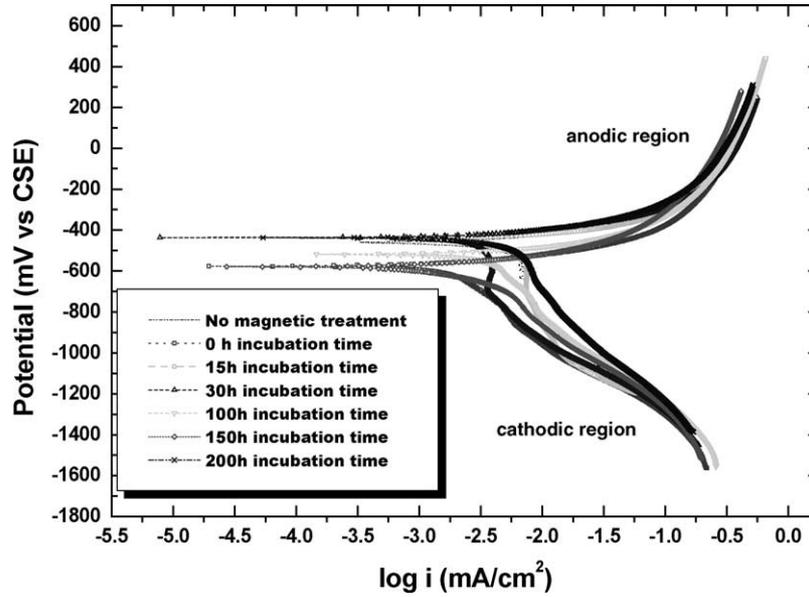


Fig. 3. Polarization curves for different incubation times in magnetic treated water.

Fig. 1 shows the difference in morphology of the sediments observed by scanning electron microscopy. Fig. 1a corresponds to untreated water with  $A = 18\%$ , while Fig. 1b corresponds to water with 150 h of incubation time after magnetic treatment and  $A = 40\%$ . Fig. 1a shows mainly calcite agglomerates of equiaxial crystals. Fig. 1b shows aragonite needle aggregates.

Fig. 2 shows the dependence of the aragonite ratio  $A$  as a function of the incubation time. The aragonite ratio increases up to 38% at 30 h of incubation time, and maintains a value of 30–40% up to 200 h of incubation time. Error bars for the determination of the  $A$  ratio are smaller than the variations of the  $A$  ratio with the incubation time. Therefore, the variations

of the  $A$  ratio with the incubation time are due to statistical variations in the samples. Changes of the peak intensities due to some preferential orientation of the aragonite needles could influence the determination of the  $A$  ratio.

Fig. 3 show plots of electrode potential against  $\log I$ , for the cathodic and anodic reactions, respectively. From polarization curves, it was observed that the rate of corrosion tend to increase with the magnetic water treatment, and the cathodic behavior of the carbon steel 1018 in the presence of this water indicates a higher polarization by concentration in the water with a incubation time of 15 h, falling down for an incubation time of 200 h. All the anodic curves show an activation behavior. Cathodic curves like anodic curves

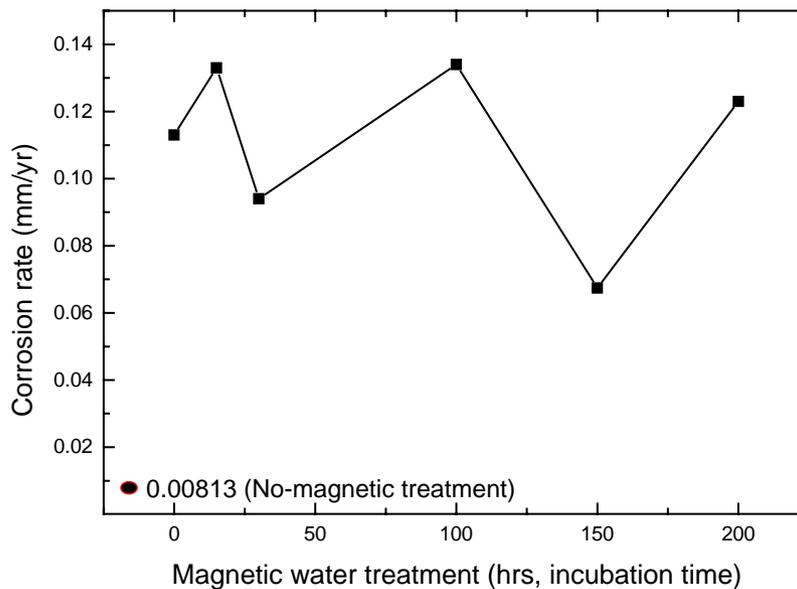


Fig. 4. Corrosion rate for different incubation times in water magnetic treated and untreated water.

show largest demand of current with respect to the untreated water, that means largest corrosion rate.

Fig. 4 compares the corrosion rates of the steel in water without and with magnetic treatment for different incubation times. In spite of the fluctuations of the corrosion rates due to statistical variations in the samples, one can clearly observe the increase of the corrosion rates due to the magnetic treatments.

#### 4. Conclusions

Qualitatively similar effects of the magnetic treatment on water behavior to those reported by Coey and Cass [5] were observed. However, our results differ in magnitude, and the effect after 200 h of incubation time is lower than that reported by Coey and Cass. These differences are related to the chemical composition of the samples, since our samples contain larger amounts of Na, Ca and K than those reported by Coey and Cass. Also, Fe, Mn and Zn the concentration were different. The influence of Fe, Mn and Zn in the magnetic water treatment has been reported elsewhere [7,8]. This

work demonstrates that the effects of magnetic treatment on water depend on the water chemical composition and on the store time after magnetization. This work also establishes a magnetic effect on the corrosion behavior, that is, corrosion rate increase when the water is magnetically treated.

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