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Magnetic water treatment for scale control in heating and alkaline conditions

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ABSTRACT

Magnetic water treatment (MWT), an alternative solution for scale control, is discussed with emphasis on the construction of the magnetic devices and the mechanism of MWT influence on the scale formation. Two applications in high-temperature and high-pH conditions are presented. The treatment noticeably reduced the scale thickness on the heating spiral and removed preciously precipitated scale from hot tap-water outlet pipe; on the walls in the zone with heated alkaline water, instead of hard scale, only thin, brittle coating was formed. The morphology analyses showed the acceleration of aragonite nucleation and raised formation of fine suspended particles.

Keywords: Scale control; Magnetic sater treatment; Crystallization

1. Introduction

In industrial water processing, the supplied water usually needs to be pre-treated to prevent the precipitation of sparingly soluble salts. The most common scalant is calcium carbonate, precipitating on susceptible regions of temperature and pH rise or of pressure drop, resulting in reduction in heat transfer in heating systems, flow capacity of pipes, and transfer through filters, and causing other technological problems [1,2].

Besides well developed chemical treatments for scale control [3,4], a magnetic water treatment (MWT) is available as an alternative solution. Since 1960, former Soviet Union designed different industrial devices with strong electromagnetic coils, which gave in high-temperature water systems—high energy savings. In the USA, one of the first applications of such devices was in oil refinery. In three of the biggest columns of Amoco Oil Company in Texas, where high concentrations of environmental charging scale-control additives were required for cooling water, an installation of MWT devices yielded more than two-times lower waste-water outlet and an operational cost reduction for about \$0.60 per m^3 of water [5].

The industrial reports about high energy savings, reduced cleaning and process down-time costs by the applications of such magnetic devices in different technological systems—including heat exchangers and cold-water pipelines, relatively low investment costs, easy installation and long life time of the devices, with minor maintenance and low or no energy consumption, motivate us for further exploration of this phenomenon.

The treatment does not change the composition of the water, it only changes the way of the precipitation. Having very little influence on the composition of the water, it is also convenient for food industry and drinking water supplies.

Laboratory examinations showed that crystals formed from magnetically treated waters are modified in structure and size, in majority with raised portion of aragonite. There are many evidences about different influence of weak magnetic fields on:

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1. The crystallization, either nucleation and crystal growth [6–15], and
2. The colloidal stability, i.e. zeta potential, [13,17].

The mechanism is complex, depending on water composition and working conditions, and has not been established completely. It is rather of kinetic than of equilibrium nature, and hypothetically comprises at least two phenomena:

1. Magnetically modified hydration of ions and solution/solid interfaces (the changes in water structure due to H-bond distortion) [18–21], and
2. Lorentz-force action on dissolved ions and dispersed particles (the shifts of ions in the electric double layer) [22–25].

Micro-particles, micro-bubbles and ions carry an electrical charge, e, and are surrounded by the electric double layer. During the water flow (with a velocity v) through a magnetic field (of density B), they can be shifted upon Lorentz force, F_L: $\vec{F}_L = e(\vec{v} \times \vec{B})$. The vector product is the highest when the magnetic field is orthogonal to the water-flow direction, $F_L = evB$.

Both the modified hydration and Lorentz-force action can have influence on the crystallization process.

Commercial MWT devices are available in various configurations by numerous manufacturers, some using electromagnets and others using single magnets or arrays of permanent magnets.

Considering the theoretical fundaments and practical experiences, the following shall be taken into consideration when choosing or constructing the device:

1. The velocity of water flow through the gap of the device is commonly 0.5 to 2 m/s.
2. The orientation of magnetic field is commonly perpendicular to the water flow.
3. The required magnetic field density is relatively low and depends on the type of the device. The pulsating and alternating magnetic field is more effective than the static homogenous [26]. The dynamic type of magnetic treatment can be effective at field densities as low as 0.05T [9,27], while the exposition of static water to a homogeneous magnetic field can give noticeable results at stronger, but still relatively weak fields, such as 0.3T [6,9].
4. The required residence time of water in the gap is at least 0.1 s at dynamic treatment [26], and can be prolonged by a re-circulation loop or by increasing the number of magnets. At static exposure, longer times are needed, for instance 10 min at 0.3T [6].

Fig. 1 presents basic schemas of magnets' arrangements that produce perpendicular or radial magnetic field. The first type (Fig. 1a) with rectangular cross-section can be constructed with permanent magnets and used for low water-flow capacities. Higher capacities, up to few-ten m^3/h, can be achieved by parallel systems of these units.

The second type with annular gap (Fig. 1b) is more convenient for coils inserted into the kernel. They can be used for high water capacities, commonly present in the industrial water processes.

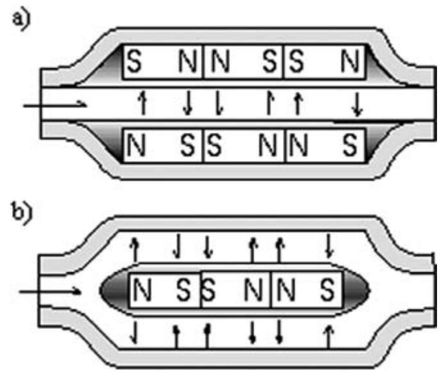


Fig. 1. Basic schemas of MWT devices: (a) perpendicular (parallel arrangement of permanent magnets), (b) radial (kernel of electromagnetic coils inserted into ferromagnetic tube).

2. Scale-control results in water heaters

The influence of magnetic water treatment on scale control in water heater with copper heating spiral was observed. The comparison of scales was done on two parallel identical pipeline systems, described in [28].One line was supplied by untreated tap water (16 °C, pH = 7.5, Table 1) and heated to 70 °C, in the another line the water was magnetically pre-treated.

The magnetic device consisted of three pairs of permanent magnets, with 0.5 cm gap thickness (Figs. 1a and 2), and the water flow velocity through the gap was 1.25 m/s.

MWT noticeably reduced the scaling on the heating surface and prevented scale formation in the outlet (hot water conducting) pipe. Later the outlet pipe was switched off with the scaled one (from the line without MWT) and after one week operation with magnetically

Table 1
The input water composition

Cations	c (mmol/l)	Anions	c (mmol/l)
Ca^{2+}	1.80	Cl^-	0.61
Mg^{2+}	0.71	SO_4^{2-}	0.10
Na^+	0.04	NO_3^-	0.34
K^+	0.02	HCO_3^-/CO_3^{2-}	2.12

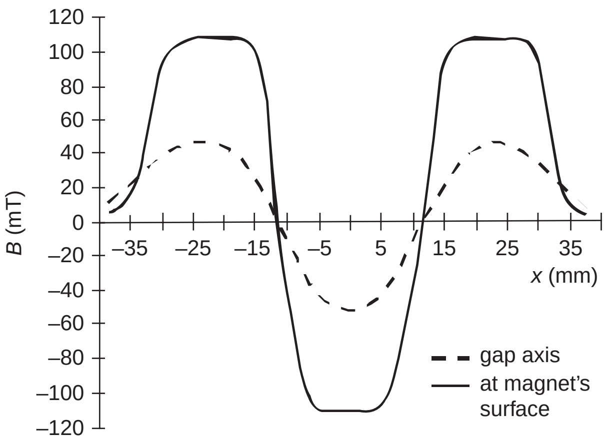


Fig. 2. The magnetic flux distribution in the rectangular gap between two rows of alternately arranged NiFe magnets (2 cm long and separated with 0.5 cm wide segments).

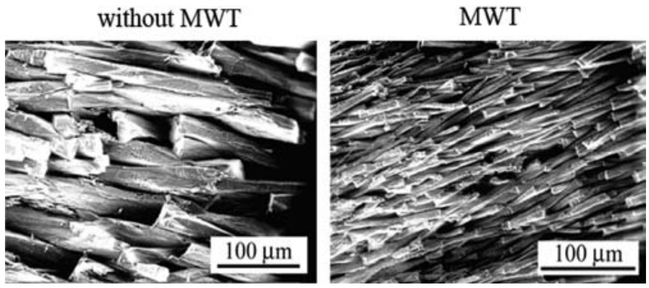


Fig. 3. Micrographs of scales on the heating spiral [28].

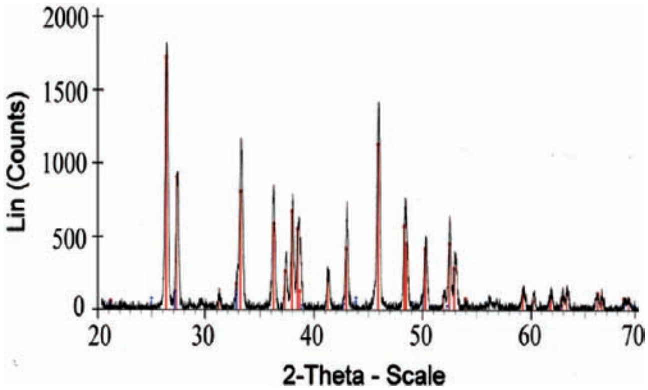


Fig. 4. X-ray diffraction spectrograph of particles dispersed in outlet hot water, identifying the sample as aragonite.

treated and heated water, the old scale vanished. The scales on heating copper spirals were in both lines aragonite and consisted of parallel crystal needles, but in the case of MWT, the scale was 2.5 times thinner and the needles were four times thinner (Fig. 3).

The outlet hot water was filtered and solid residue was analyzed with AXS-Baker/Siemens/D5005 X-ray Powder Diffractometer and with FEI–QUANTA 200 3D environmental scanning electron microscope. Both samples consisted of well formed spherical particles and were identified as aragonite (Fig. 4). In the case of MWT, particles were smaller, with a diameter from 10 to 20 nm, while the particles from untreated water had a diameter from 50 to 180 nm (Fig. 5).

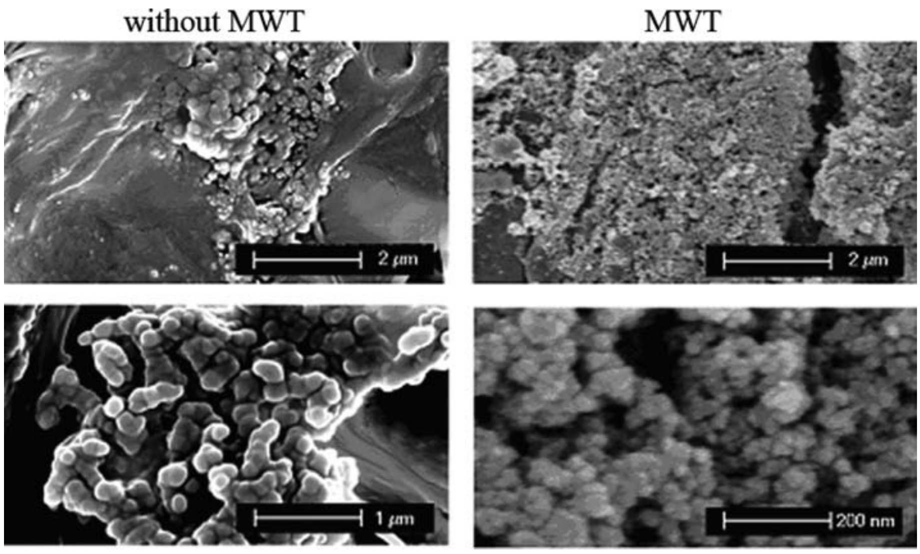


Fig. 5. The comparison of particles dispersed in outlet hot water.

Table 2
The input water composition

Cations	c (mmol/l)	Anions	c (mmol/l)
Ca^{2+}	1.55	Cl	0.73
Mg^{2+}	0.86	SO_4^{2-}	0.35
Na^{+}	0.35	NO_3^{-}	0.25
K^{+}	0.12	HCO_3^{-}/CO_3^{2-}	1.60

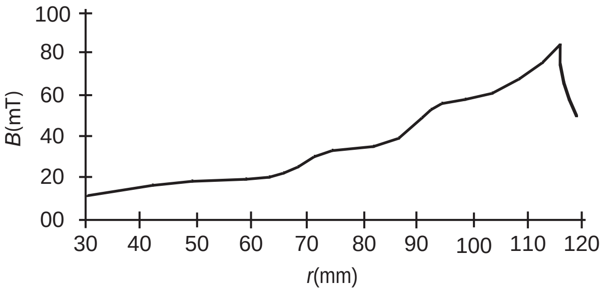


Fig. 7. The magnetic-field density distribution in the gap along the radius of inner plate in MWT device with flat coil.

3. Scale-control results in a bottle-washing machine

A bottle-washing machine was supplied with local ground water (Table 2). Bottles are cleaned with hot NaOH solution. In the washing zone the alkaline water attains 70°C and pH = 10.5. The scale is formed on the walls of the machine in this zone. The presence of Fe^{2+} ions (0.9 μmol/L, exceeding the threshold 10^{-8} mol/L for calcite inhibition [29]) and high temperature retards the calcite formation.

In this case of higher water flow capacity, a device with a flat coil was used (Fig. 6). A ferromagnetic plate is inserted in the center of the coil, so, the water enters at the top of the device, overflows the inner plate in radial directions, passes the plate edge into the lower zone and flows out at the bottom.

The device is supplied by rectified 220V input and generates the pulsating magnetic field with magnetic lines that cross the water flow perpendicularly. The magnetic field in the gap is the strongest at the edge of the inner plate; the efficiency requirement $B > 0.05$T is satisfied in half of the plate area (Fig. 7). The device is constructed on the way that along the increasing radius, r, of the inner plate the gap, h, is thickening to provide proper water velocity. The water flow was adjusted to the water-velocity requirement ($v = 0.5$ to 2 m/s) and to the retention-time requirement 0.1 s.

Scale samples were collected from the heating surface in the washing machine before the installation of the magnetic device and after a month long run with magnetically pretreated water.

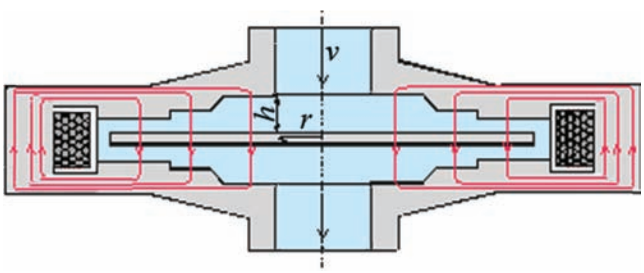


Fig. 6. MWT device with flat coil.

The scale from untreated water was compact and strongly adhered to the surfaces. The scanning electron microscopy showed three types of morphology in the samples collected from the surface: agglomerate regions (Fig. 8a), plate-dendrite particles (Fig. 8b) and aragonite regions (Fig. 8c–e). The needles had various thicknesses; from 10 to 150 nm. X-ray powder diffractometry identified the samples as monohydrocalcite (Fig. 9a). Small portions of calcite and aragonite can be also seen from the specter.

From the magnetically treated water, a thin coating was formed, brittle and easy to wipe away. The scanning electron microscopy of aragonite showed more dendriform structure (Fig. 8f,g). Needles were bigger, from 200 to 300 nm in thickness, and covered with 10 to 20 nm small seeds (Fig. 8h, 3.8-times magnified detail from Fig. 8g). The predomination of aragonite can be also seen from SEM (Fig. 9b).

4. Conclusion

Industrial experiences with MWT applications have shown that in the cases of hard coatings in cold-water conducting pipelines and in heat exchangers with output water temperature below 40 °C, MWT devices, when properly designed, can completely prevent scale formation and even an old hard scale can be removed in relatively short time after the installation of such a device. Even in hot alkaline water, MWT gives some good results: thinner linings are formed and can be easily removed. The presented tests, with the water heater and the bottle-washing machine, proved the reduction in scale formation in heating and alkaline conditions. The scale on the spiral heater was 2.5-thinner, which means essentially higher heat transfer. On the walls in the washing zone of the machine, instead of hard scale, only a thin coating was formed, and could be wiped away easily.

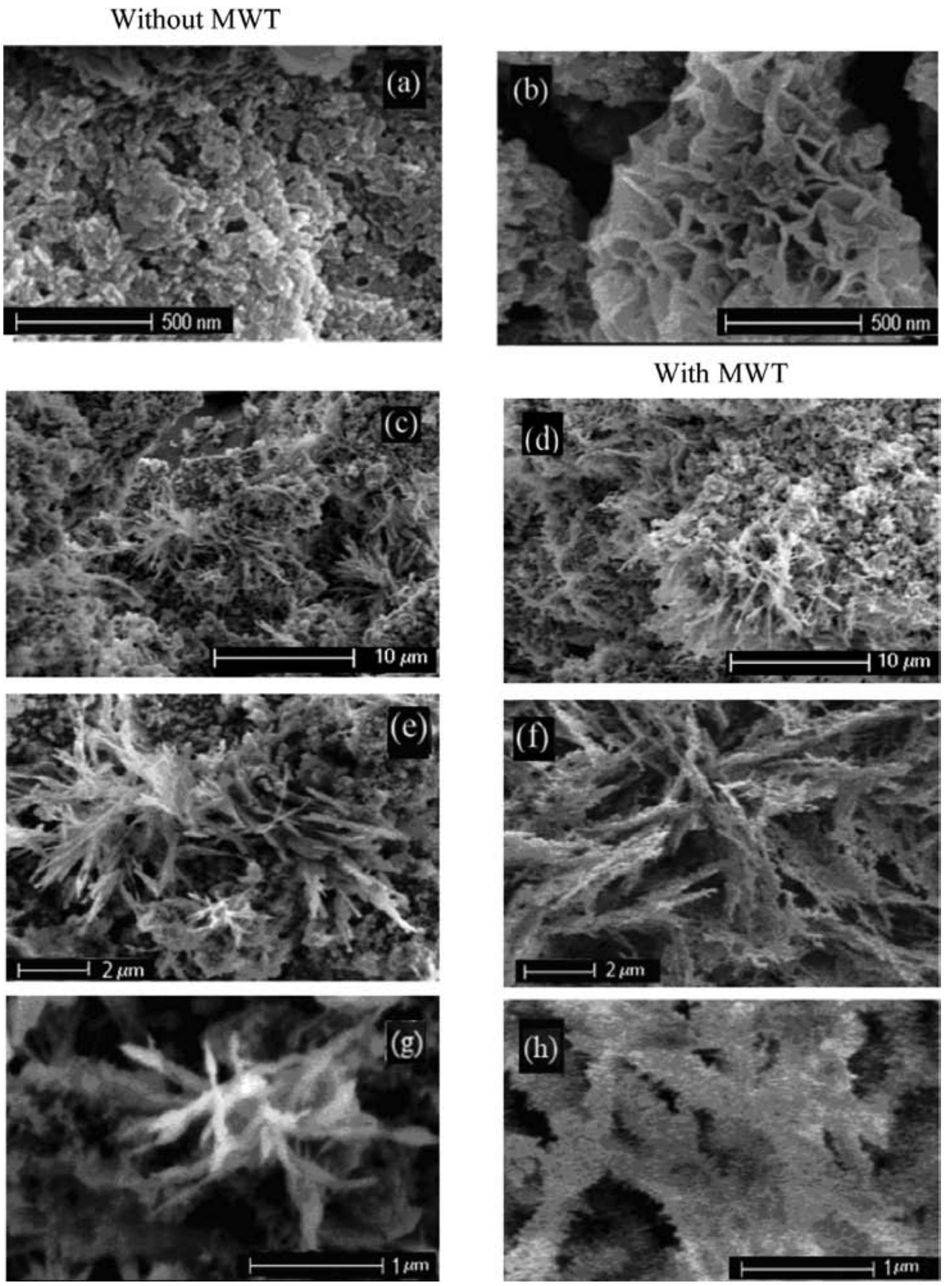
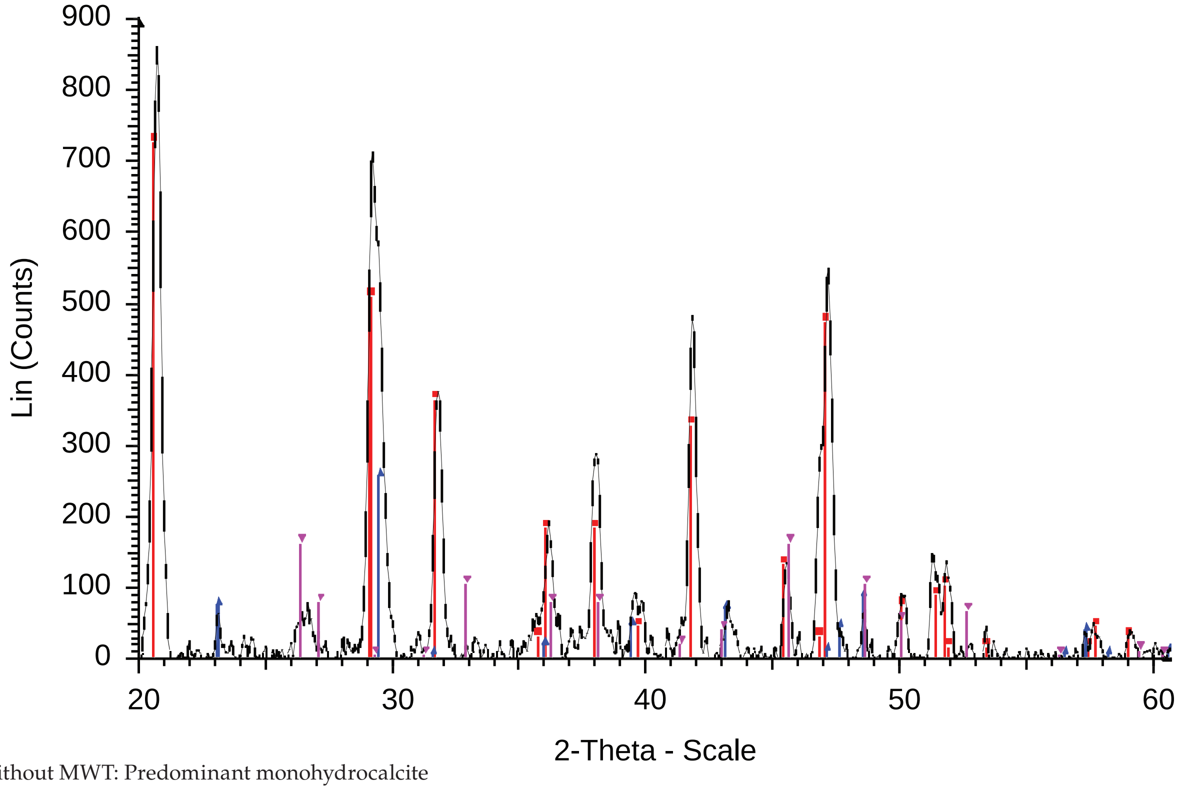
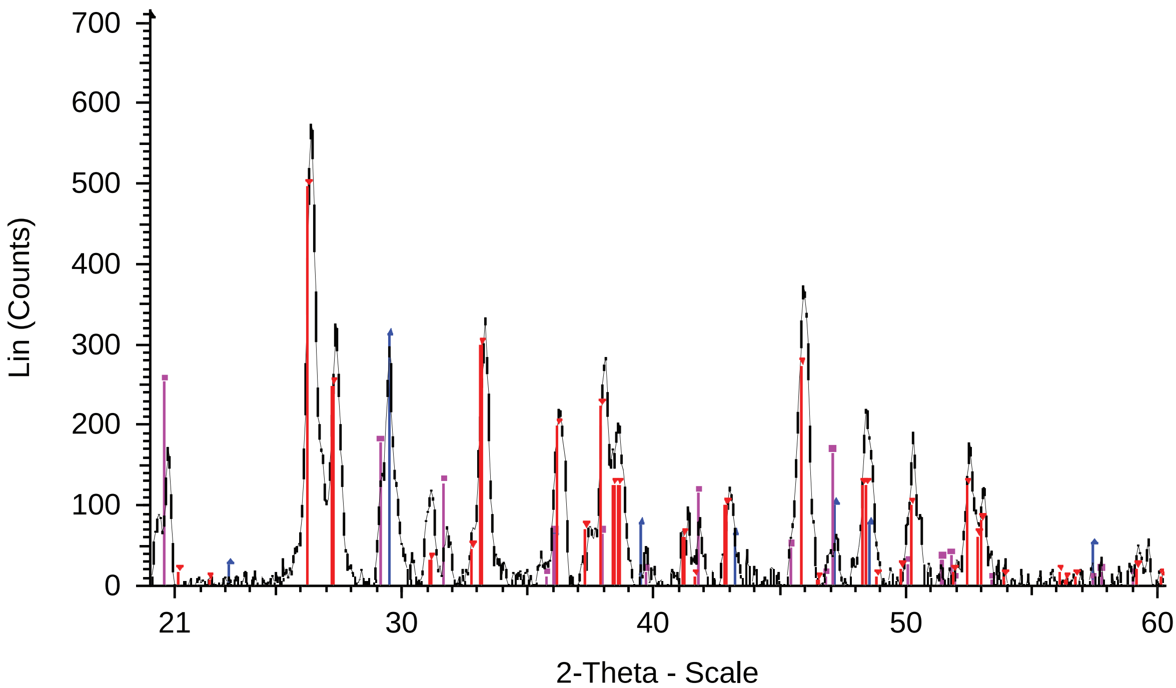


Fig. 8. Micrographs of the scale from the bottle-washing machine. (a–e) Sample from untreated water, (f–h) Sample form magnetically treated water.

A possible explanation for the reduction of hard scale is that the finer particles are formed in the bulk of the solution and that they remain suspended and carried from the system with the water flow. The analyses of the samples from both tests showed the formation of smaller aragonite particles. The needles in the scale from the heating spiral were four times thinner and the suspended spherical particles from hot outlet water were 5 to 10-times smaller than in the case without the magnetic treatment. In the bottle-washing machine, instead of predominantly hard scale, the dendrite structure of aragonite was formed and needles were covered by seeds along the whole surface. The results in both cases can be explained with the enhanced nucleation of aragonite.



(a) Without MWT: Predominant monohydrocalcite



(b) With MWT: Predominant aragonite

Fig. 9. X-ray diffraction spectrographs of the scales from the bottle-washing machine.(■)Monohydrocalcite, syn – $CaCO_3 \cdot H_2O$ – Hexagonal,(▼)Aragonite–$CaCO_3$ – Orthorhombic,(▲)Calcite – $CaCO_3$ - Rhombo. H. axes.

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