

## Effect of Magnetic Treatment on Temporary Hardness of Groundwater

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The magnetic treatment devices for water have been in use for scale prevention several decades ago. Although, the effect of magnetic treatment on the chemical and physical properties of water is not fully understood and needs to make a lot of research effort to be clarified. This work aims to investigate the effect of the magnetic treatment on the temporary hardness of the groundwater. A sample of groundwater was passed twice under the influence of perpendicular magnetic strength 0.5 Tesla with a flow rate of 10 L/h. The temporary and permanent hardness as well as scale formation test were measured before and after the magnetic treatment. The scale was analyzed by XRD and SEM techniques. The temporary hardness and the weight of scales were reduced after the magnetic treatment by 39.1 and 22.3 %, respectively. The decrease of temporary hardness after the magnetic treatment of groundwater may be attributed to that the magnetic field reduces both the dissolved CO<sub>2</sub> content and surface tension, both of which reduce the amount of temporary hardness. The SEM micrographs illustrate that the magnetic treatment modified the shape and size of crystals of CaCO<sub>3</sub> scales to prevent its adhesion to the substrate forming hard scales. The XRD patterns prove that the magnetic treatment of groundwater enhances the crystallization of amorphous CaCO<sub>3</sub> favouring the formation of calcite.

**Keywords:** Groundwater, Magnetic treatment, CaCO<sub>3</sub> scales, Temporary hardness, XRD, SEM, Aragonite, Calcite.

### INTRODUCTION

The temporary hardness is regarded to the presence of dissolved calcium bicarbonate and magnesium bicarbonate that can be removed by heating where these soluble salts are deposited in form of CaCO<sub>3</sub> which precipitates as hard scales. The deposition of hard scales can cause serious problems, for example; (1) it significantly reduces heat-transfer efficiency, (2) lead to partial or even complete blockage of water flow systems, (3) it increases operating and maintenance costs of water systems, (4) it increases the energy consumption and corrosion of pipelines [1]. Therefore, an effective water treatment is necessary which should be cost-effective while ensuring the minimum environmental pollution. Chemical treatment of water by using scale inhibitors changes the chemical composition of water and is in a long-term detrimental for the environment and can be harmful to the human health if such water is used in drinking water. The magnetic water treatment devices have been in use for scale prevention several decades ago. It is assumed that the water after being treated with the magnetic field loses

its ability to precipitate the salts on the hot surfaces. The real understanding of the influence of the magnetic field in water treatment and reduction of scale deposits begins first by knowing the effect of the magnetic field on the water molecule. The externally applied magnetic field interacts with the circular current elements of the hydrogen bonded clusters [2]. These magnetic interactions change the magnetic flux over water molecules and produce significant changes in various properties and functions of water [3]. Water molecules do not lose the magnetic properties after removing the external field. The magnetic memory of water is the period in which water molecules can sustain their magnetization properties after being exposed to a magnetic field of a certain intensity. The effects of magnetic memory on particles were recorded over time periods up to 6 days after the exposure of solution to a magnetic field [4]. The effect of magnetic field on properties of distilled water involves the variations in the flow rate of water, electric conductivity and dielectric constant. Increasing the strength of the magnetic field decreases the rate of flow. Hence, both the electric conductivity and the dielectric constant of water increase [5].

Since the chemical composition of raw water is complex as it contains a variety of dissolved ions and gases as well as suspended matter. Therefore, the effect of magnetic treatment on raw water will be complicated, contradictory and its mechanism of action on the whole chemical and physical properties of water is not fully understood due to the interference of materials included. As a result, the review of the literature regarding the beneficial effect of water magnetic conditioners is rather confusing due to the often contradictory results that were reported. Hence, the effect of the magnetic field on raw water depends on many factors such as the field strength [6], the direction of the applied field [7], the duration of the magnetic exposure [4], the flow rate of the solutions [8], the additives present in the system [9], the pH [10]. In particular, the published data concerning the regarding the effect of water magnetic conditioners on water hardness is relatively few, rather confusing due to the often-contradictory results. Some researchers confirmed that the magnetic field affected water quality and reduced water hardness [11-15]. While others reported that the magnetic field has no effect on the hardness of water [16-21]. Tantawy *et al.* [11] measured the scale formation test, total hardness, TDS and pH of groundwater after being treated by mild magnetic field (0.5 Tesla) with a flow rate 10 L/h with repeating twice. The temporary hardness and weight of scales were markedly reduced, the permanent hardness and TDS were slightly reduced, whereas, pH increased. The magnetic treatment enhanced the growth of calcite, vaterite and aragonite crystals. Banejad and Abdosalehi [12] measured hardness of water after subjection to a magnetic field (0.05, 0.075 and 0.1 Tesla) with different flow rate (4 and 30 L/h). It was concluded that the magnetic field affected the water quality and that production of magnetic water reduces water hardness until 51 %. Rameen *et al.* [13] measured the TDS and pH of four different water samples (suction sump water, normal tap water and salt water) after subjection to some commercial magnetic water conditioners (1.12 Tesla) for 2 h. Although harness has not been measured, measuring TDS can be considered equivalent because, the higher the level of TDS, the higher the degree of hardness. As it was concluded that TDS decreases, it is certain that the hardness decreases. The same situation has been repeated in the research article by Hasaani *et al.* [14] measured the TDS, pH, thermal conductivity, viscosity and surface tension of water from different sources after being treated by strong magnetic field (6.56 Tesla) for a very short period (2 min). They found that the TDS and electrical conductivity decreased but pH of the water was increased. Surface tension, viscosity and thermal conductivity were decreased. Hence, it is certain that the hardness decreases. Coey and Cass [15] measured the water quality of groundwater and commercial mineral water after subjection to a magnetic field (0.1 Tesla). The only decrease in Fe and Mn content of the groundwater water was observed after magnetic treatment. It is also certain that the hardness decreases because  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  contribute to the hardness of water.

In contrast, Khater and Ibraheim [16] measured the majority of physical and chemical properties of tap water after being treated by very weak magnetic field (1.8 m Tesla) for long period (1 and 7 days) and then left for recovery after 7 days. The important result is that the magnetic field has no effect on the TDS.

Taking into consideration that they used water with TDS equal 200 ppm, which is considered slightly hard water. Accordingly, the magnetic treatment has not been expected to affect the hardness of such a water sample. Kotb [17] measured the pH, TDS and hardness of tap water after being treated by weak magnetic fields of different commercial magnetic water conditioners (110-170 m Tesla) in a closed loop of circulation for different times up to 820 min. It was concluded that the magnetic water conditioners have no effect on the water pH, TDS and hardness. Kotb and AbdelAziz [18] measured the pH, TDS and hardness of tap water after being treated by weak magnetic fields of different commercial magnetic water conditioners (170 m Tesla) in an open loop for unknown time. The pH increased where TDS and hardness of water are not affected by magnetic water conditioner. Duffy [19] measured the hardness of tap water after being treated by a magnetic field of an unknown strength for an unknown time. It was concluded that the magnetic treatment has no effect on the hardness of water or the formation of scales on pipes. Gruber and Carda [20] measured the physical and chemical properties of tap water after being treated by a magnetic field of unknown strength for an unknown time. It was concluded that there was no change in the physico-chemical properties or the calcium ion concentration of water treated with the devices. Alleman [21] measured the specific conductivity, surface tension, boiling point of depression, pH, alkalinity, total hardness and calcium concentration of tap water after being treated by a magnetic field of an unknown strength for unknown time. It was concluded that no significant variation in the measured parameters between the control and the treated water. It can be concluded that the extent of the effect of magnetic treatment on the proportion of hardness depends on the quality of water as the previous studies have confirmed that the magnetic treatment only reduces the proportion of hardness of harder water while not affect that of softer water. The main objective of this study is to explain why the magnetic treatment does reduce the hardness of water. This has been accomplished by measuring the temporary and permanent hardness as well as scale formation test before and after the magnetic treatment.

## EXPERIMENTAL

The magnetic treatment system is illustrated in Fig. 1. A 2 L capacity separating funnel was filled with groundwater. The funnel is joined in its outlet to rubber pipe that was surrounded by a set of three neodymium magnets with magnetic strength 0.5 Tesla in a manner that the magnetic field is perpendicular to the water flow direction. A patch of 20 L groundwater is passed through the system twice with a water flow rate 10 L/h.

The temporary and permanent hardness as well as scale formation test were measured before and after the magnetic treatment. The scale formation test was performed by heating 600 mL of groundwater in 1 L beaker on a hot plate to the temperature range of 95 °C. The beaker was removed before excessive bubbling starts. The beaker was shaken while pouring the heated water out to remove the suspended scales. The weight of dry scales was expressed in the unit of mg per liter of  $\text{CaCO}_3$

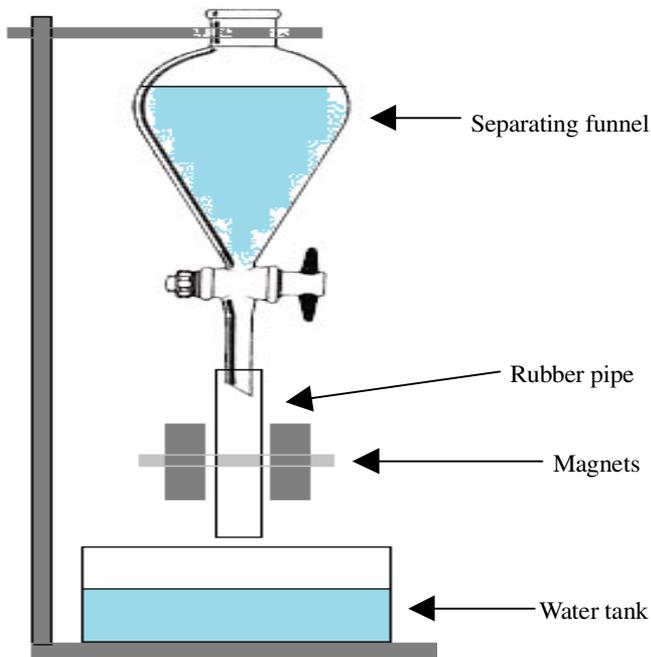


Fig. 1. Magnetic treatment system

[22]. The temporary hardness was estimated by titrating sample of water with HCl solution in presence of methyl orange indicator to a reddish end point [22]. Total hardness was estimated by back titration of EDTA solution with a  $ZnSO_4 \cdot 7H_2O$  solution in presence of eriochrome black-T indicator and ammonia buffer pH 10 to a wine red end point [22]. Permanent hardness was estimated from the difference between total and temporary hardness. Hardness was expressed in the unit of mg/L  $CaCO_3$ . The scales obtained from the scale formation test were analyzed by the X-ray diffraction XRD and scanning electron microscope SEM techniques. XRD analysis was performed by Philips X-ray diffractometer PW 1370, Co. with Ni-filtered  $CuK\alpha$  radiation (1.5406 Å). SEM analysis was performed by Jeol-Dsm 5400 LG apparatus.

## RESULTS AND DISCUSSION

The weight of scales, temporary and permanent hardness, as well as their reduction percentage for raw and magnetically treated water, were tabulated in Table-1. The reduction percentage of scales, temporary and permanent hardness was illustrated in Fig. 2. The temporary hardness and the weight of scales were markedly reduced after the magnetic treatment. On the other hand, the permanent hardness was slightly reduced after the magnetic treatment, while the pH increases. On other words, the magnetic treatment of groundwater reduces

TABLE-1

WEIGHT OF SCALES, TEMPORARY AND PERMANENT HARDNESS AS WELL AS THEIR REDUCTION PERCENTAGE FOR RAW AND MAGNETICALLY TREATED WATER

Measurement	Raw water	Treated water	Reduction (%)
Weight of scales (mg)	36.6	30	22.3
Temporary hardness (mg/L)	190.2	136.8	39.1
Permanent hardness (mg/L)	529.65	518.86	2.1
Total hardness (mg/L)	719.85	655.66	8.9

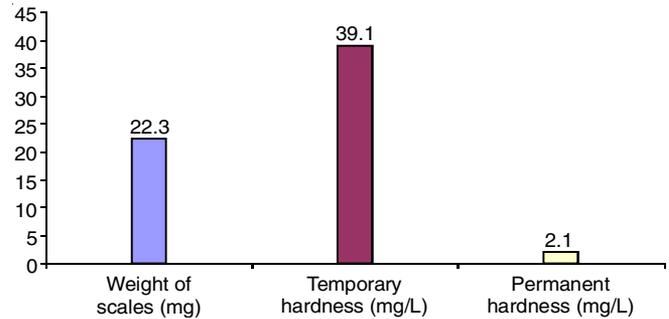
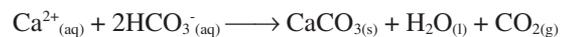


Fig. 2. Reduction percentage of scales, temporary and permanent hardness of magnetically treated water

the temporary hardness and scales by 39.1 and 22.3 %, respectively.

The scale formation test measures the amount of  $CaCO_3$  that is precipitated when water is heated to near boiling and adhere to the vessel wall while the sediments that did not stick are poured and carried away with the water stream flow. The amount of adhering scales decreases due to the magnetic treatment of water. This proves that the  $CaCO_3$  scales formed after the magnetic treatment of groundwater has weak adhesion to the substrate. Regarding the following reaction:



It was observed that the temporary hardness is related to the amount of dissolved calcium and magnesium bicarbonates. According to a previous study [11], it was observed that the amount of dissolved  $CO_2$  decreases after the magnetic treatment of water without being recovered. As  $CO_2$  being removed from the water as a result of the magnetic treatment, the previous reaction will be directed to the right, *i.e.*, the amount of dissolved calcium bicarbonate will convert to  $CaCO_3$  that precipitate out from the water. Accordingly, the temporary hardness decreases due to the magnetic treatment of water.

On the other hand, it has been established that the addition of dissolved salts affects the surface tension of the solution. Surface tension is generated due to the attractive forces present in a liquid-gas interface. The attractive forces in pure water are weaker hydrogen bonding between the O end of one water molecule with the H end of another water molecule. As a soluble salt is added, it gets dissociated into cations and anions which lead to much stronger attraction of water molecules around these ions by hydration. Where H ends of water molecules are arranged around anions and O ends are arranged around cations. As the net attractive forces increase between the hydrated charged species with the addition of salts, the net surface tension increases, too [23]. In the same context, it was found that the presence of hardness salts leads to a significant decrease in surface tension of water [24]. According to Amor *et al.* [25], it was observed that the surface tension decreases after the magnetic treatment of water. Decreasing the surface tension after the magnetic treatment of water, lead to an increase in the rate of dissolution of a scale. Accordingly, the temporary hardness decreases after magnetic treatment.

Fig. 3 illustrates the SEM micrographs of scales formed from raw groundwater and magnetically treated water. It was established that hexagonal platelets and spherical crystals are attributed to vaterite, the cubic crystals are attributed to calcite

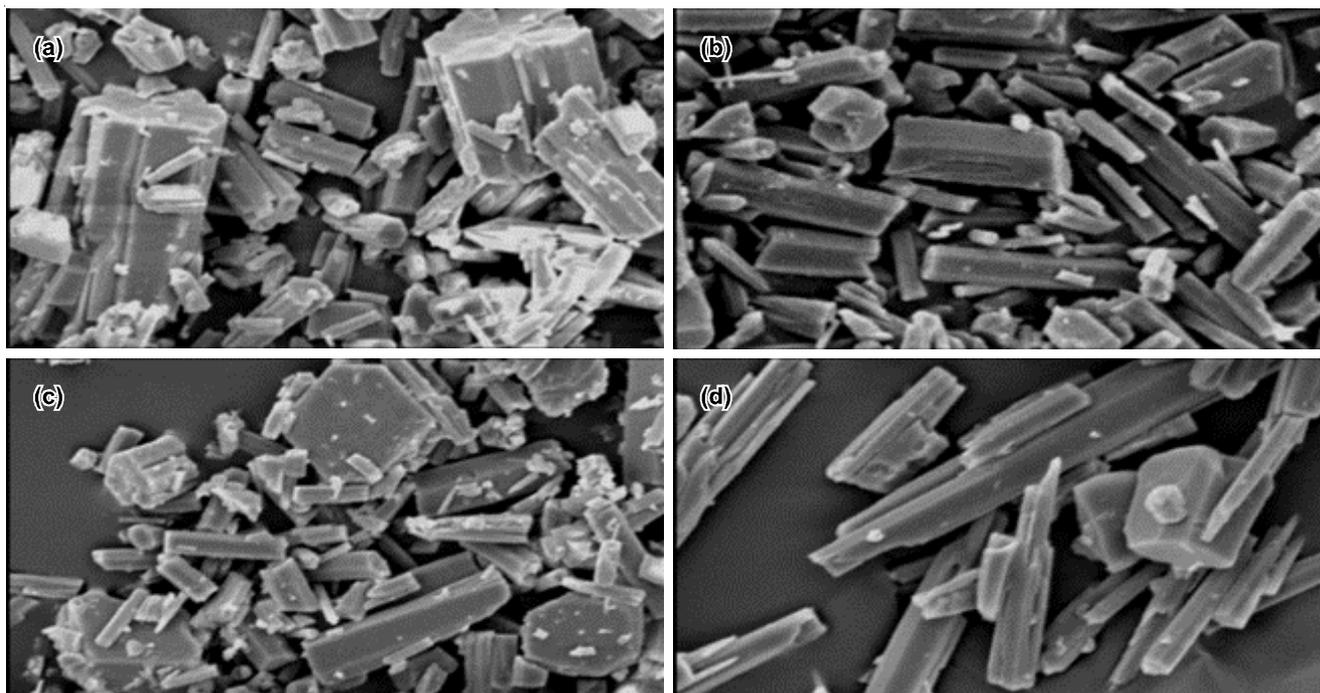


Fig. 3. SEM micrographs of scales formed from raw groundwater (a, b) and magnetically treated water (c, d) (the magnification x1500 for a and c as well as x2000 for b and d respectively)

and the needle crystals are attributed to aragonite [26]. Obviously, the three polymorphs can be easily identified in the scales obtained either before or after the magnetic treatment. The difference is that there is a clear homogeneity in the size and consistency in the shape of crystals of scales obtained from the scale formation test for the raw groundwater. In contrast, there is a clear diversity in the size and shape of crystals obtained from the scale formation test for the magnetically treated groundwater. The appearance of long prismatic, cubic as well as flat crystals after the magnetic treatment of groundwater proves that the magnetic treatment enhances the growth of scale crystals. This is because magnetic treatment would tend to reduce the rate of nucleation and to accelerate the crystal growth [27]. The ability of some crystals before the magnetic treatment to stick together is evident, while crystals after the magnetic treatment are isolated and far apart. The long prismatic, cubic, as well as flat crystals formed after the magnetic treatment may be characterized with a rather weak adhesion to the substrate. Therefore, they could be carried away by the liquid flow [28]. It does not matter whether the magnetic treatment favours the formation of calcite or aragonite scale, but what must be emphasized is that the magnetic treatment modified the shapes and sizes of crystals of  $\text{CaCO}_3$  scales and prevent its ability to stick together to form hard scales.

Fig. 4 illustrates the X-rays diffraction patterns of scales formed from raw groundwater and magnetically treated water. The heap at 12-25  $2\theta$  may be attributed to the hydrated amorphous calcium carbonate formed before crystallization of  $\text{CaCO}_3$  [29]. The intensity of the heap was reduced after the magnetic treatment of groundwater. This proves that the magnetic treatment of groundwater enhances the crystallization of amorphous  $\text{CaCO}_3$ . It is clear that the three polymorphs of  $\text{CaCO}_3$  are represented in the two patterns. Hence, the two patterns are somewhat identical, except for differences in mine-

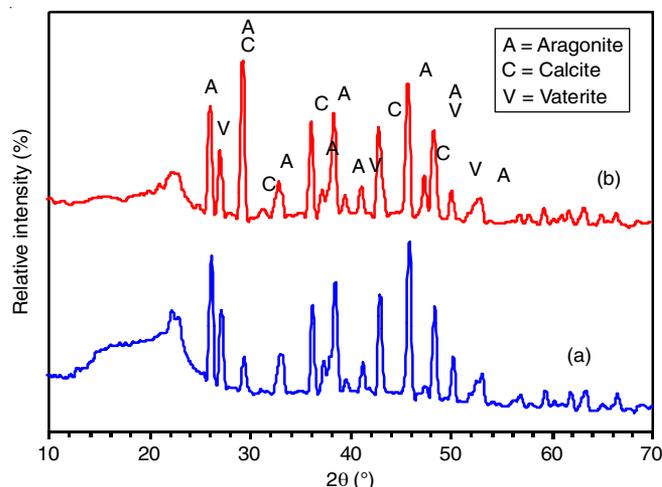


Fig. 4. XRD patterns of scales formed from (a) raw groundwater and (b) magnetically treated water

ral ratios. The percent of calcite increases after the magnetic treatment of groundwater. Because calcite is the thermodynamically stable crystal form of  $\text{CaCO}_3$ , or that aragonite may transform to calcite [30]. These results are consistent with SEM results. Whatever, the magnetic treatment favours the formation of calcite or aragonite scale, the most important conclusion is that the magnetic treatment modified the shapes and sizes of crystals of  $\text{CaCO}_3$  scales to be characterized with a rather weak adhesion to the substrate and could be carried away by the liquid flow.

### Conclusion

Temporary hardness is attributed to the presence of dissolved calcium and magnesium bicarbonates that can be removed by heating where these soluble salts are deposited in form of calcium carbonate which precipitates as hard scales causing

serious problems. Commercial magnetic treatment devices have been in use several decades ago as scale inhibitors. As the effect of the magnetic field on water is complex and depends on many factors, the literature concerning regarding the effect of water magnetic conditioners on water hardness is confusing due to the often-contradictory results. As a general conclusion concerning the effect of magnetic treatment on the hardness of water, the magnetic treatment only reduces the proportion of hardness of harder water while not affect that of softer water. The main objective of this study is to explain why the magnetic treatment does reduce the hardness of water. This has been accomplished by measuring the temporary and permanent hardness as well as scale formation test before and after the magnetic treatment.

The temporary hardness decreases may be due to decreasing the amount of dissolved CO<sub>2</sub> as a result of the magnetic treatment of water. As CO<sub>2</sub> being removed from water as a result of the magnetic treatment, the reaction will be directed to the right, *i.e.*, the amount of dissolved calcium bicarbonate will covert to CaCO<sub>3</sub> that precipitate out from water. The SEM micrographs of scales formed from raw groundwater and magnetically treated water prove that the magnetic treatment enhances the growth of scale crystals. The large crystals formed after the magnetic treatment may be characterized with a rather weak adhesion to the substrate. The XRD patterns prove that the three polymorphs of CaCO<sub>3</sub> are represented in the two patterns except for differences in mineral ratios as well as that the percent of calcite increases after the magnetic treatment of water.

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#### CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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