

# Reducing Formation of CaCO<sub>3</sub> Scales of Groundwater by Magnetic Treatment

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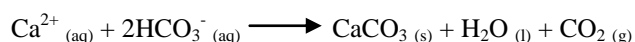
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**Abstract**— The aim of this paper is to investigate the effect of magnetic treatment on the ability of groundwater to form scales. Sample of groundwater was provided from well located at Ghamid Al Zanad district and used in this study. Magnetic treatment process was carried out using a laboratory made magnetic treatment system using three neodymium magnets of total magnetic strength of xxx tesla. Groundwater sample was treated by passing it through the magnetic treatment system with a rate of 10 liters per hour. The treatment was repeated twice. The ability of scale formation of groundwater was assessed by measuring scale weight, hardness, total dissolved solids and pH measurement as well as x-ray diffraction and scanning electron microscope analyses. It was concluded that the amount of temporary hardness causing ions (Ca<sup>2+</sup> and HCO<sub>3</sub><sup>-</sup>) as well as the weight of scales were markedly reduced after magnetic treatment of groundwater by about 39.13 and 22.2 % respectively. As a result, the pH of treated water increases. In the other hand, the amount of permanent hardness causing ions (Ca<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and NO<sub>3</sub><sup>-</sup> ions) as well as total dissolved solids were slightly reduced. Magnetic treatment enhances the growth of calcite, vaterite and aragonite crystals. Large aragonite needle crystals that was formed from magnetic treated groundwater may be characterized with a rather weak adhesion to the substrate and could be carried away by the liquid flow, in contrast to calcite which are difficult to remove mechanically.

**Keywords**— Groundwater, CaCO<sub>3</sub> scales, magnetic treatment, neodymium magnets, hardness, total dissolved solids, pH, XRD, SEM, aragonite, calcite.

## I. INTRODUCTION

Hard water contains high concentration of dissolved calcium and magnesium bicarbonate (temporary hardness) in addition to calcium and magnesium chloride, sulphate and nitrate salts (permanent hardness). Dissolved aluminium and iron salts can contribute to hardness, however their presence is less critical [1]. Calcium carbonate precipitates in form of lime scale from hard water even in cold weather according to the following reaction:



Lime scales consist of mainly calcium carbonate plus calcium sulfate, calcium phosphate, magnesium hydroxide, iron hydroxides, sand, clay, silt and corrosion products, dependent on the geographical area and chemical composition of water. Precipitation of scales causes problems in industry and domestic users in hard water areas. Scale deposits increases the costs of operation and maintenance and energy consumption by lowering the water flow rate and lowers the

thermal transfer coefficient in heat exchangers. Scale can clog pipes and fittings. Scale deposits can also increase corrosion of metal pipes and fittings. Hard water can be treated by chemical and physical methods to reduce the total dissolved solids of water and scale. The chemical method such as soda-lime softening, cation exchange and complexing agents are very effective however employs chemical product harmful to the environment and human health [2]. The magnetic treatment of water involves the use of magnetic field from strong magnets to intercept the water flow path. Magnetic field may affect the orientation of random polar water molecules as well as hydrated dissolved salts [3,4].

Numerous studies have claimed significant effects and proposed possible mechanisms for the observed decrease in water scale formation [5]. Some of these mechanisms were summarized as follows. Magnetic fields modifies the shape of solute lime molecules leading them to precipitate as easily dislodged spherical or round scales rather than sheets or platelets of hard scales [6]. Magnetic field reduces the surface charge on small suspended scale particles, leading them to coagulate as large particles that stay with the flow rather than depositing as hard scale [7,8]. Magnetic treatment causes the smaller water cluster to be more reactive, hydrates the calcium and carbonate ions more effectively and cause a surface and/or orientation effects on the growing crystals [7]. Magnetic treatment causes water containing minerals to favor formation of aragonite that is more soluble form of calcium carbonate rather than calcite [9,10]. Magnetic treatment encourages aragonite nucleation rather than calcite that is harder prone to form hard scales on pipe surfaces [11, 12]. However, the literature is somewhat confused whether aragonite crystals are less prone to form hard scale on surfaces or not [13]. Magnetic treatment inhibits the thermodynamic transformation of aragonite into calcite [14]. In contrast, aragonite formed in magnetic field eventually changes to calcite [15]. Magnetic treatment changes the dielectric constant of water and in turn decreases the conductivity and dissolution properties i.e. total dissolved solids of water [8].

Numerous works study different parameters that affect the efficiency of magnetic treatment of hard water. The direction and variation of the magnetic field was found to affect the efficiency of magnetic treatment of hard water [15]. Increasing strength of the magnetic field was found to decrease the crystal size of scale deposits [16]. Recirculatory magnetic treatment systems, with prolonged magnetic exposure, give

more supportive results over single treatment [17]. Magnetic treatment appears to be enhanced by prolonged or repeated magnetic exposure [13]. The presence of dissolved oxygen was found to be important for the production of the magnetic effect for formation of aragonite rather than calcite [18] and for initiation of scale deposition [19]. The pipe material was found to affect the efficiency of magnetic treatment. The magnitude of the effect depends on pipe conductivity and surface roughness [20].

There are a lot of benefits to use magnetic treatment of water, although there is still considerable debate as to its efficacy. Biological benefits claimed include; increased earliness of crops growth, increased yield; increased flowering of fruit as well as increased vitamin C, sugar and total acid content [21,22]. Applications of magnetic treatment of water are abundant in industry where it is used to prevent scaling on the inner walls of pipes conveying fluids, especially water [23]. The oil industry has recently had success in preventing calcium carbonate scaling [24]. The use of magnetic field prevent hydrocarbon deposits in pipes.

## II. MATERIALS AND EXPERIMENTAL METHODS

Sample of about 20 liters of groundwater was provided from well located at Ghamid Al Zanad district and used in this study. Location map of the groundwater well was illustrated in Figure (1).

Magnetic treatment process was carried out using a laboratory made magnetic treatment system as illustrated in Figure (2). The system consists of a 2 liters capacity-separating funnel joined in its outlet with a 0.25 inch diameter rubber pipe strengthened with 0.125 inch diameter plastic pipe from inside. Three strong neodymium magnets isolated from damaged computer hard disks with total magnetic strength of 1.4 tesla were used as the source of magnetic field. The magnets were fixed along the strengthened rubber pipe making the magnetic field vertical on the water flow direction. The valve opening of the separating funnel was adjusted to make the water flow rate about 10 liters per hour. The magnetic treatment process was repeated twice.

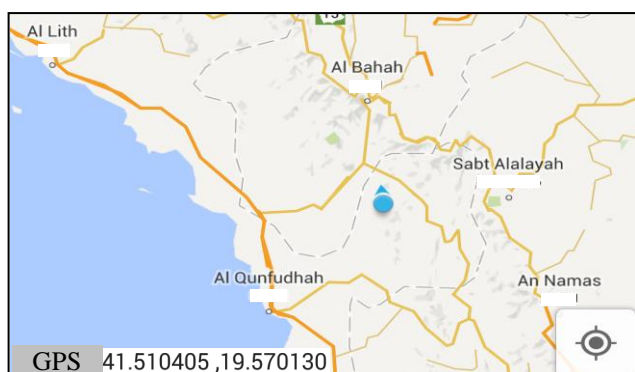


Fig. 1. Location map of the groundwater well



Fig. 2. Magnetic treatment system

The ability of scale formation of groundwater was assessed by measuring scale weight, hardness, total dissolved solids and pH measurement as well as x-ray diffraction and scanning electron microscope analyses. Scale formation test was determined by heating 600 ml of groundwater in 1 liter beaker on a hot plate to the temperature range of 93-97°C. The beaker was removed before excessive bubbling starts. The beaker was shaken while pouring the heated water out to removed the suspended scales. Heating was repeated 10 times while each time a new water sample was used to obtain an appreciable weight of scales. The weight of dry scales was calculated from weight difference of the beaker before and after the test and expressed in unit of mg per liter of  $\text{CaCO}_3$  [25]. The scale reduction percentage was calculated. Temporary hardness was determined by titrating known volume of water against standardized HCl solution in presence of methyl orange indicator until reaching a reddish end point. The temporary hardness was expressed in unit of mg per liter of  $\text{CaCO}_3$  [25]. Total hardness is determined by adding known amount of standardized EDTA solution to known volume of water and titrating the excess EDTA against standard  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  in presence of eriochrome black-T indicator and ammonia buffer pH 10. Total hardness was expressed in unit of mg per liter of  $\text{CaCO}_3$  [25]. Permanent hardness was determined from the difference between total and temporary hardness and expressed in unit of mg per liter of  $\text{CaCO}_3$ . Total dissolved solids content was measured using calibrated electrical conductivity meter (model EC 215 conductivity meter, HANNA Instruments). The electrical conductivity value was measured and converted to TDS expressed in unit of mg per liter. pH was measured using calibrated pH meter (model pH 212 micro processor pH meter, HANNA Instruments). X-ray diffraction analysis was carried out by Philips x-ray diffractometer PW 1370, Co. with Ni filtered  $\text{CuK}_\alpha$  radiation (1.5406 Å). Scanning electron microscope analysis was investigated by Jeol-Dsm 5400 LG apparatus.

### III. RESULTS AND DISCUSSION

The weight of scales, hardness, total dissolved solids and pH as well as their reduction percentage for raw and magnetic treated water were tabulated in Table (1) and were graphically represented in Figures (3-7).

TABLE I. THE WEIGHT OF SCALES, HARDNESS, TOTAL DISSOLVED SOLIDS AND pH AS WELL AS THEIR REDUCTION PERCENTAGE FOR RAW AND MAGNETIC TREATED WATER

Measurement	Raw water	Treated water	Reduction percentage, %
Weight of scales, mg	36.6	30	22.3
Temporary hardness, mg/L	190.2	136.8	39.13
Permanent hardness, mg/L	529.65	518.86	2.08
Total hardness, mg/L	719.85	655.66	8.92
Total dissolved solids, mg/L	1529.6	1491.2	2.58
pH	7.4	7.6	-

It was observed that the amount of temporary hardness ( $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  ions) and accordingly, the weight of scales were markedly reduced in case of treated water. As a result, the pH of treated water increases. This may be due to that magnetic treatment causes water containing  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  ions to favor formation of a more soluble form of calcium carbonate (aragonite rather than calcite) [9, 10]. In the other hand, the amount of permanent hardness ( $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  ions) and total dissolved solids were slightly reduced in case of treated water. It was observed that magnetic treatment of groundwater lead to an observable reduction in the amount of temporary hardness and scales by 39.13 and 22.2 % respectively. In the other hand, magnetic treatment of groundwater does not affect the amount of permanent hardness and total dissolved solids.

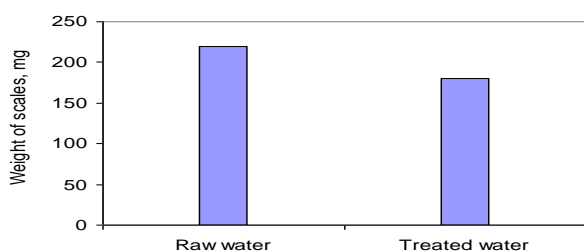


Fig. 3. The weight of scales for raw and magnetic treated water

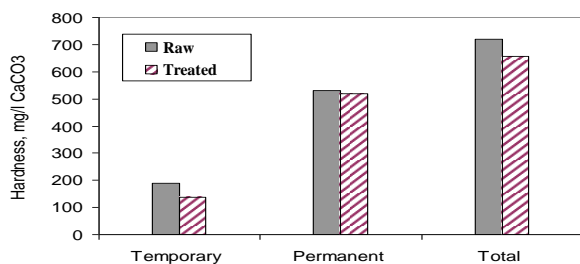


Fig. 4. The hardness of raw and magnetic treated water

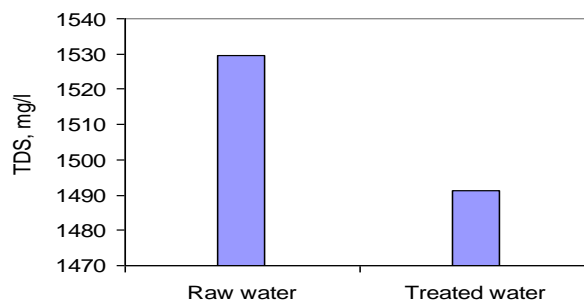


Fig. 5. The total dissolved solids for raw and magnetic treated water

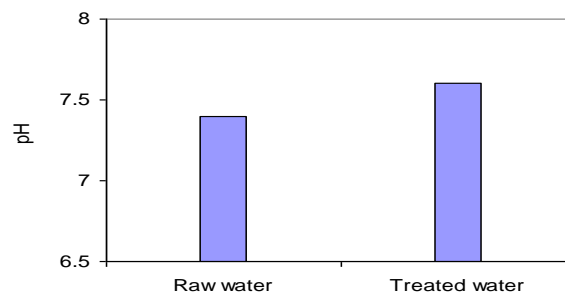


Fig. 6. The pH for raw and magnetic treated water

Figure (8) illustrates the SEM micrographs of scales formed from raw groundwater and magnetic treated water. SEM micrographs show the existence of different polymorphs of  $\text{CaCO}_3$  in scales formed from raw and magnetic treated groundwater. Hexagonal platelets and spherical particles are attributed to vaterite, cubic crystals are attributed to calcite mineral and needle crystals are attributed to aragonite [26]. Among these phases calcite is thermodynamically the most stable at ambient temperature and atmospheric pressure and usually prevails in the precipitation from pure  $\text{Ca}(\text{HCO}_3)_2$  solutions [27,28]. Aragonite and vaterite are kinetically favorable and may appear as a first form, recrystallizing to calcite during the aging of the precipitate. Vaterite is the least stable anhydrous polymorph [29]. Aragonite is quite stable when precipitates from hot waters [27]. Aragonite may result from the transformation of metastable vaterite nuclei [30]. Aragonite is dominant because it is usually formed above  $60^\circ\text{C}$  instead of calcite [31]. It was also observed that the growth of calcite, vaterite and aragonite crystals was enhanced in case of scales formed from magnetic treated groundwater.

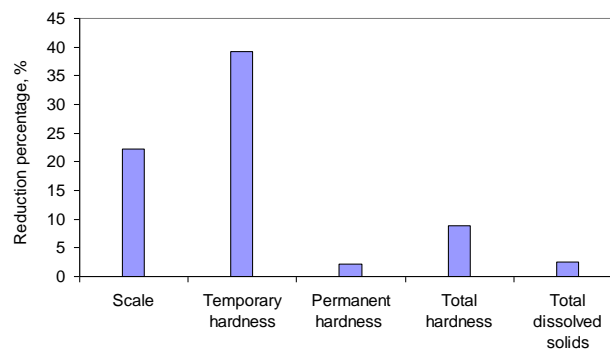


Fig. 7. The reduction percentage of scales, hardness and total dissolved solids of magnetic treated water

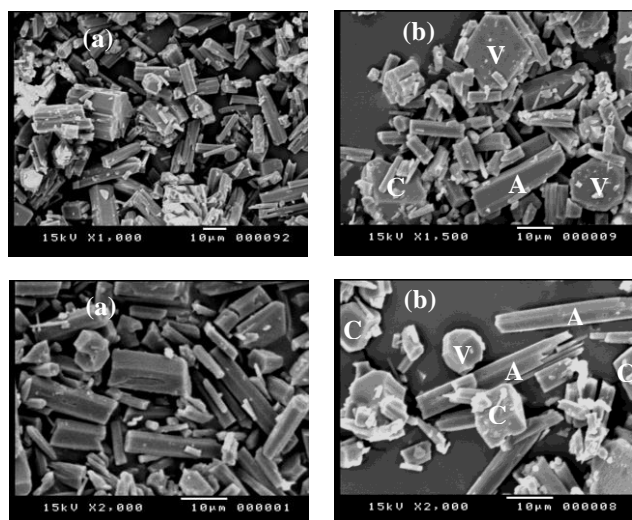


Fig. 8. The SEM micrographs of scales formed from (a) raw groundwater and (b) magnetic treated water

This is because magnetic treatment would tend to reduce the rate of nucleation and to accelerate the crystal growth [32]. Large aragonite needle crystals that was formed from magnetic treated groundwater may be characterized with a rather weak adhesion to the substrate. Therefore, they could be carried away by the liquid flow [33]. On the contrary, calcite forms dense and tenacious layers, which are difficult to remove mechanically. Figure (9) illustrates the x-rays diffraction patterns of scales formed from raw groundwater and magnetic treated water. Figure (19) illustrates the standard XRD patterns of calcite and aragonite. The amorphous heap at 12-25  $2\theta$  may be attributed to the hydrated amorphous calcium carbonate formed during crystallization of calcium carbonate. The unstable hydrated amorphous calcium carbonate can be considered as the precursors of the three usual anhydrous polymorphs; namely calcite, vaterite or aragonite [34]. The intensity of amorphous heap attributed to the hydrated amorphous calcium carbonate was reduced after magnetic treatment of groundwater. This proves that magnetic treatment of groundwater enhances the crystal growth of anhydrous calcium carbonate polymorphs.

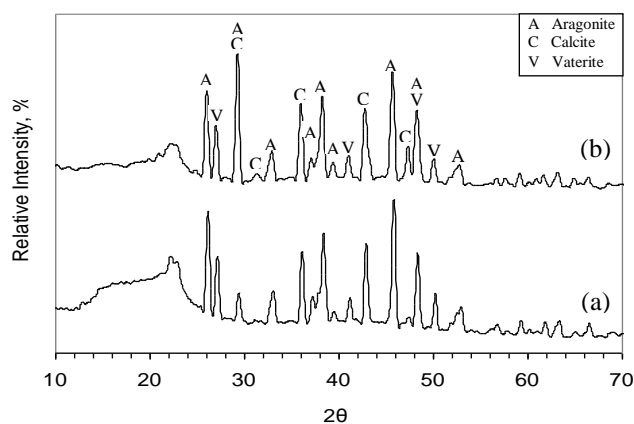


Fig. 9. The XRD patterns of scales formed from (a) raw groundwater and (b) magnetic treated water

It was observed that calcite, aragonite and vaterite minerals present in case of scales formed from raw water and magnetic treated water. The main difference is that the intensity of calcite peaks increases in case of scales formed from magnetic treated water. Because calcite is the thermodynamically stable crystal form of  $\text{CaCO}_3$ , there is the possibility that, after precipitation and deposition in an experiment, the other crystal forms such as aragonite may transform to calcite before the samples can be analyzed [35]. This proves that magnetic treatment reduces the rate of calcite formation.

## CONCLUSIONS

It was investigated that the amount of temporary hardness ( $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  ions) and the weight of scales were markedly reduced in case of treated water. As a result, the pH of treated water increases. In the other hand, the amount of permanent hardness ( $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  ions) and total dissolved solids were slightly reduced in case of treated water. It was observed that magnetic treatment of groundwater lead to an observable reduction in the amount of temporary hardness and scales by about 39.13 and 22.2 % respectively. Magnetic treatment enhances the growth of calcite, vaterite and aragonite crystals. Large aragonite needle crystals that was formed from magnetic treated groundwater may be characterized with a rather weak adhesion to the substrate and could be carried away by the liquid flow, in contrast to calcite which are difficult to remove mechanically.

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