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Effects of Magnetic Fields on The Properties of Water Treated by Reversed Osmosis

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Abstract: The current study focused on reviewing the rapid growing of using magnetic water in different fields of science and measure the influence of several intensities of magnetization on the chemical and electrical properties of tap water treated by reverse osmosis. The work includes circulation of water for 24 hrs. in magnetic fields of intensity 500, 1000, 1500, and 2000 G. The magnetization of water causes increasing some positive and negative ions in water such as (Mg, K, Na, Cl^-, Alkaline and SiO_2) and decreasing some positive and negative ions (Ca and SO_3). In the near future, the application of concepts of sustainability development in civil engineering have the to produce structures in harmony with these concepts through using of high-performance materials with less impacts on the environmental and have low cost. The main application of using magnetic water is improvement the geotechnical properties of soil through precipitation of calcite which increases the bond between soil particles and then strength of soil.

Keywords: magnetic field; intensity; chemical; electrical properties; osmosis water.

1. Introduction

Water (H_2O) is the polar molecule composed of a V-shaped order of dipoles (two hydrogen nuclear poles of positive charge). Magnetic water is defined as raw or treated water passed through magnetic field of different intensity and different circulation period. Water properties have been developed magnetic sensitivity and when subjected to a magnetic field these properties will start to change. The changes could be of negative or positive impacts according to the purpose of using the magnetic water. Water meniscus is not homogeneous and Nano scale and depended on the applied pressure and temperature. The two powers-controlled the chemical hydrogen bond and Vander Waal's forces, where magnetization can break down the structure of water and reduced the linkage angle and increased the solubility [1, 2].

Iwasaka and Ueno [3] and Lee et al. [4] found the magnetic field changes the size of the water clusters which changes the physical properties of water. Increasing the intensity of magnetic field causes decreasing the surface tension of tested water samples, which causes reducing the capillary rise of water [5]. The magnetic field application in wastewater treatment. The magnetic field applications

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have improved the physical and biological properties performance in terms of solid-liquid separation largely through aggregation of colloidal particles and improvement of bacterial activity [6]. The compression strength of concrete prepared with magnetic water is increased by10-23% more than that of the concrete mixture prepared with tap water samples [7]. Al Najm [8] explained the effects of magnetic field (2000 G) on raw salt water, where treatment of water increased the cations (K, Mg, Na, and Al) and decreased anions (Cl^- and SO_3). The results of treatment of irrigation water by magnetic field treatments have beneficial effects on the germination of seeds, plant growth and development, the ripening and yield of field crops.

Rajput et al. [9] investigated the effects of magnetization on the ability of magnetite (Fe_3O_4) nanoparticles synthesized by chemical co-precipitation in removing the metal ions from water. This ability characterized using several techniques such as XRD, SEM-EDX, FT-IR, VSM, zeta potential, and surface area measurements. As-prepared Fe_3O_4 nanoparticles were successful for aqueous Cr^{6+} and Pb^{2+} removal. The nanoparticles of magnetite (Fe_3O_4) are promising potential adsorbents and exhibited remarkable reusability for removal of metal ions from water and wastewater. Sheikholeslami et al. [10] studied the effect of magnetic field dependent (MFD) viscosity on free convection heat transfer of a nanofluid in an enclosure considering Brownian motion, where the bottom wall has constant flux of heating. The theoretical modeling of problem used control volume based finite element method is applied to simulate the effects of viscosity parameter, Hartmann number and Rayleigh number. The results showed that Nusselt number is an ascending function of Rayleigh number and volume fraction of nanoparticle, but it is descending function of viscosity parameter and Hartmann number.

Hachicha, et al. [11] explained significant decrease a soil of salinity (EC, Na, and Cl contents) irrigated with saline water treated by magnetization in comparison to the soils irrigated with saline water. In contrast, compared to both behaviors, it created non-significant effects on Mg^{2+} and HCO_3^-. The deficiency or high cost of potable water pushed framers to use saline water in the irrigation, but the saline water needs to be treated before using in the irrigation. The results of tests showed that salt contents in soil increased with increasing the depth in the column of soil treated with magnetic water where the salts moved deeper during the treatment process. The top layer of soil is very important in agriculture which considered appropriate for growing of vegetables and grass [12]. Andrianov and Orlov [13] studied the influence of magnetization of water on the rate of calcite precipitation and formation on the membranes of reverse osmosis process. The tests were conducted on tap water using a module of spiral wound with reverse osmosis membranes. The results of study did not show any effect for magnetization on the precipitation and formation of calcite.

The present article focused on reviewing the applications of magnetized water in different field of science, especially in water treatment and improvement of the chemical and geotechnical properties of soil. Also, the influence of magnetic field of several intensities on the chemical and electrical properties of water treated by reversed osmosis and ozone have been investigated. This water prepared to be used in improvement the geotechnical properties of swelling soils.

2. Applications of Magnetic Water

The magnetized water has many applications in the different fields of science and industry especially in development of green technology. The circulation of water in magnetic field could change some of its important properties. These changes may be useful in industries associated with the

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important properties of water such as pH value, surface tension, electrical resistivity, viscosity, and scale formation inhibition. The pH and viscosity of magnetized water mostly increased, but the surface tension decreased. The magnetized water as green technology has many applications which considered environmentally friendly fluid in remediation of contaminated soils and water. In addition, the magnetized water used as injection fluid the oil recovery areas for producing oil [14].

2.1. Water Purification

The treatment of water can be classified according to the source of water as domestic, natural, and wastewater. According to the quality of water, a specific plan of action for reuse, treatment, or disposal. The treatment of water depends on the type of influent and the required specifications of effluent. The available techniques of water purification are adsorption, catalytic processes, biotechnology, membrane treatment, ionizing radiation, and magnetization processes. High gradient magnetic separator (HGMS) is a technique commonly used in separation of particles [15-18]. The application magnetic field across a column of water, will produce a magnetic gradient along the column will attract magnetized particles to their surfaces and help to trap these particles, so the collection of particles depends on the magnetic gradient, size of particle, and may be the shape of particles.

2.2. Wastewater Treatment

There are many chemical, physical, and biological techniques used for treatment of wastewater. The quantity of wastewater is mainly related to the size of population and the level of development, where the rapid development of industry and growing of population produce different types of wastewater which requires different types of technologies to reuse such wastewater. The magnetic field have been used in treatment process of wastewater for several processes. The technology of treatment using magnetic field had been used for the removal of colors, heavy metals, suspended solids and turbidity, organic compounds, and toxic chemicals [19-21]. However, more research required in this field of treatment to fill the deficiency of data required to improve these promise technologies.

2.3. Formation of Calcite ($CaCO_3$)

The formation of $CaCO_3$ has the attention of many researcher in different fields of science because of its wide range of applications in engineering processes as cementing agent, adsorbent material, and brightener filler [22-26]. The sedimentation of $CaCO_3$ causes damages and operational problems such as blocking of pipes, clogging of membranes, and efficiency decay in heaters. Several methods have been used to prevent precipitation of $CaCO_3$ (scaling) such as water decarbonization through electrochemical processes and addition of acid and chemical inhibitors. The chemical treatment may be harmful to biomass and especially human health. Therefore, the physical techniques have been developed to avoid using the chemical additives to prevent scaling, one of these techniques is the magnetic treatment of hard water [26-27].

Donaldson [28] proved the precipitation of different types of crystals under the existence of a magnetic field, where $CaCO_3$ is considered the most thermodynamically stable crystals at standard temperature and pressure and form thick layers that are difficult to be removed mechanically. The magnetic field accelerate the rate of precipitation of $CaCO_3$, therefor two methods have been

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developed to address the influence of magnetic field on precipitation of $CaCO_3$: (1) the direct effects on the dissolved ions and (2) the magnetic effect on particulates [29]. Higashitani et al. [30] investigated the properties of $CaCO_3$ crystals formed during the magnetization process magnetically treated and from chemical reactions of calcium chloride and sodium carbonate.

2.4. Synthesis of Polyhydroxyalkanoates (PHAs) from Biomass Sludge

The application of magnetic field on the bacteria medium enhanced bacteria growth [31-33], which depends on the gradient of magnetic field and the type of existing microorganisms. There are many studies investigated the effects of magnetization on the growth of microorganisms have been published, the synthesis of polyhydroxyalkanoates (PHAs) under a magnetic field has not been investigated in details. The high cost is considered the main obstacle to the application of PHAs for production of biodegradable plastic, either poly-3-hydroxybutyrate (PHB) or poly-3- hydroxyvalerate (PHV) [34]. Also, the carbon waste such as activated sludge can be used to reduce the cost of processing [35-37]. Yu and Wang [38] demonstrated that using acetate of concentration more than 200 Cmmol/l can prevent cell growth and formation of PHA. Therefore, magnetization treatment can be used to enhance the production of PHA under unfavorable conditions.

2.5. Magnetic Water In Agriculture

The magnetization of water changes its chemical and physical properties and these changes will affect the soil-water-plant-system. The irrigation and leaching of soil with magnetic water will increases the available alkaline such as Na, K, Mg significantly in the depth of plantation. The magnetic susceptibility of nutrients will determine its behavior under magnetic field. Generally, the molecules comprising nonmagnetic water are in loose state, but the molecules clusters together due to attraction force. These forces may help pollutants especially the toxic ones to move inside the water molecule cluster. Also, the large structure of water molecule clusters or toxic molecules can clog the membrane when they pass through the cell membrane [39-41]. The magnetization of water will prevent the toxic agents from entering the structure of water, therefor, the magnetic water considered a bio friendly fluid for biomass. Using the magnetic water in agriculture will help to increase the crop yield and benefit to the health of biomass. Also, using magnetic water in irrigation process will improve water quality and increase the productivity of farms. Using magnetic water will help to conserving the fresh water supplies for the expected water crisis [39, 40, 42].

2.6. Soil Improvement and Remediation

Improvement and remediation of soil is considered one of the important fields in geotechnical engineering. The application of magnetic field to the water passes through weak or contaminated soils help to build bonding between particles of soil through precipitation of calcite in pores of soil. These bonds depend mainly on the quantity of calcite precipitated in the pores and the ability of calcite in absorbing the contaminants from soil.

3. Used Materials and Testing Procedure

The pure water as dipolar and associative liquid can alter its intermolecular bonds under the application of magnetic field and transform to a metastable state [43]. The magnetic field will affect both physical and chemical processes of crystallization and dissolution of water molecules [44]. There

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are two main different types of magnetic field effects. The direct field which effect on the biochemical reactions and the indirect field which effect on the surroundings [45]. The first type of magnetic field, the concern might be the possible genetic influence on the living organisms, but the second type of magnetic field can be considered of secondary effects such as temperature, pressure, or mechanical stirring. Generally, the magnetic water treatment method is passing water through the device at a certain velocity, where alternating magnetic fields (preferably orthogonal to water flow direction) are created. After such treatment, water loses its ability to deposit hardness salts in the form of scale, and these salts are crystallized as fine sludge easily carried away by the water flow.

In the present study, a water container made from plastic fiber (acrylic) material. The used pump of water has the properties: power is 25 w, head is 18 m, flow rate is 1000 l/h, and AC220 V/50 Hz) and the provided magnetic fields are (500, 1000, 1500. and 2000 G) with plastic tube of diameter 12 mm. All these parts are connected together in a basin of water contains 10 liters of water treated by reversed osmosis (RO) as shown in Figure 1.

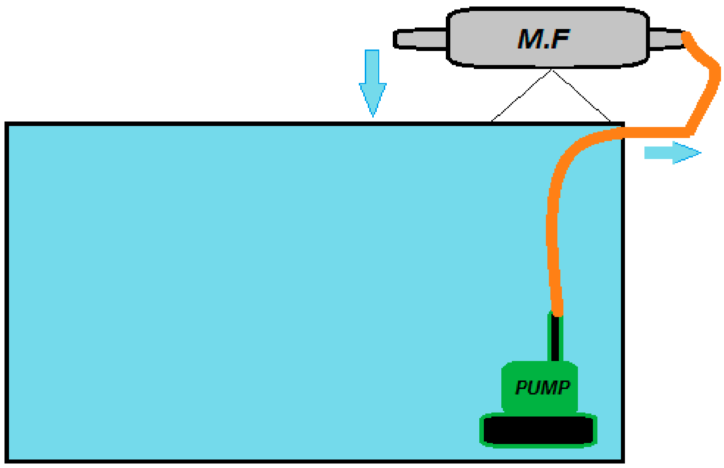

Figure 1. Schematic diagram of magnetization system.

The magnetization device of water is supplied for water treatment by reverse osmosis (RO) from local factory. The water treated with reverse osmosis will be referred as reference water for comparison. The procedure of magnetization of water can be easily described by putting 10 liters of reference water in glass box. The box supplied with submersible pump and magnetization equipment fixed on the top of box. The submersible pump connected to the magnetization equipment by tube of 12 mm in diameter. The circulation of water in magnetic field continued for five days, but mostly the chemical and electrical properties of water are approximately constant after 24 hrs. The practical use of water systems magnetic treatment is based on certain changes in their physical and physiochemical properties. Intensification and stabilization of small initial changes in properties can occur with the help of intermediate mechanisms increasing many times these changes. In the most cases, such intensification is inherent to heterogeneous systems and their phase transitions. For example, the slightest stimulation of crystal formation can cause avalanche irreversible bulk crystallization, with all the process consequences. A slight decrease in hydration degree of solid particles surface under certain conditions can lead to their mass coagulation, as well as significant improvement in filtration, etc. The tested chemical and electrical properties of water are listed in Table 1.

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Table 1. Methods and specifications of tested properties of water.

Parameter	Symbol	Specification
pH	pH value	ASTM, D1293
Electrical conductivity	Ec	ASTM, D1125
Total alkaline	Alkaline	ASTM, D1067
Total dissolved salts	TDS	ASTM, D5907
Silicon dioxide	SiO_2	ASTM, D859
Chloride content	Cl^-	ASTM, D512
Sulfate	SO_4	ASTM, D516
Magnesium, Calcium	Mg, Ca,	ASTM, D511
Sodium	Na	ASTM, D4191
Potassium	K	ASTM, D4192

4. Results and Discussion

Several studies demonstrated that magnetic water treatment influences the molecular and physicochemical properties of water that alter the quality of water. The effects of magnetic treatment on irrigation water include increasing the number of crystallization centers and altering the free gas content [46]. The factors affecting the magnetization process are the flow rate, time of circulation, intensity of magnetic field, carbonate water hardness of more than 50 mg/l, and the concentration of hydrogen ions in water at pH value > 7.2. To determine the influence of intensity of magnetic field on the properties of water, several intensities ranging from 500 to 2000 G as differential field conditions produced by common lab devices and procedures. Moreover, the circulation of water in magnetic field continued for 24 hrs. Experimental studies have shown that magnetic treatment can increase the number of crystallization and modulates the free gas content of the solution [47]. Magnetic treatment on water plays important roles in different procedures influencing a crystallization process such as association, dissociation and nucleation rates [46, 48, 49].

4.1. Effect of magnetization on pH value

The pH value is a scale used to specify the state of a water-based solution, which can be classified as acidic solutions when have a lower pH and basic solutions when have a higher pH value. The pure water is considered neutral and has a pH value of 7 at room temperature (25 °C), where the amounts of H^+ ions and OH^- ions are equal. Water becomes more volatile as a result of magnetic processing due to the weakening of the hydrogen bonds between water molecules [50]. The magnetic process can change the pH of water samples which depends on the quality of water and the impurities in the treatment device [51]. The decrease in pH value is belong to the formation of calcite nuclei resulted from the liberation of H^+ ions.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \tag{1}$$

$$H_2CO_3 = H^+ + HCO_3^- \tag{2}$$

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$$Ca^{2+} + HCO_3^- \longrightarrow CaCO_3 + H^+ \quad (3)$$

Figure 2 shows the variation of pH value with different intensity of magnetic fields. When water passes through a magnetic field, the pH value increased by 6 to 34.34% when the magnetic field intensity increased from 500 to 2000 G under constant flow rate of 1000 L/h, when the flow rate higher than 2160 L/h, the pH value will be stability under different magnetic fields [52]. According to the results, the pH value increases with increasing the intensity of magnetic field, it means the absorption of H^+ ions and increasing the number of OH^- ions in the water. These finding confirmed by previous studies, but with increasing percentage 0.53 to 5.6% [53-55], this difference is mainly due to the quality of the water used and these physicochemical parameters.

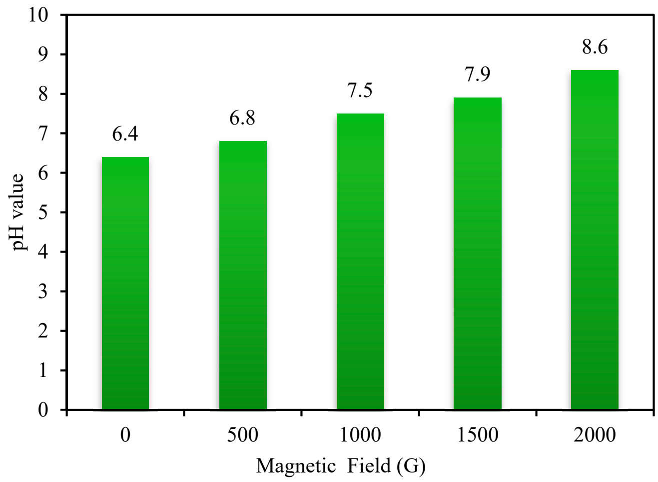

Figure 2. Concentration of pH with magnetic field.

4.2. Effect of magnetization on alkaline content

The alkaline metal are basic that dissolves in water which have pH value greater than 7.0. Generally, the water forms more carbonate without magnetization which accelerate the precipitation of calcite. It shows magnetic field inhibits decrease the precipitation of bicarbonate, and then inhibits formation of calcite precipitation, but the magnetization increases the precipitation of sodium, potassium, and magnesium. Mostly, the alkaline metals increased with increasing the intensity of magnetic field. Also, the magnetic field induces faster transfer of proton from hydrogen carbonate to water due to the inversion spin of protons in the diamagnetic field of salts. Figure 3 shows the concentration alkaline with different intensity magnetic field, during water reference pass through magnetic field increased alkaline value from 238 to 450% when the magnetic field increased from 500 to 2000 G. The results of tests demonstrated significant increase in the concentration of alkaline minerals with increasing the intensity of the magnetic field, but the alkaline may be affected by flow velocity. The intensity of magnetic field did not affect the alkaline content at the highest flow velocity, but have significant effects on the content of alkaline at low flow velocity [56].

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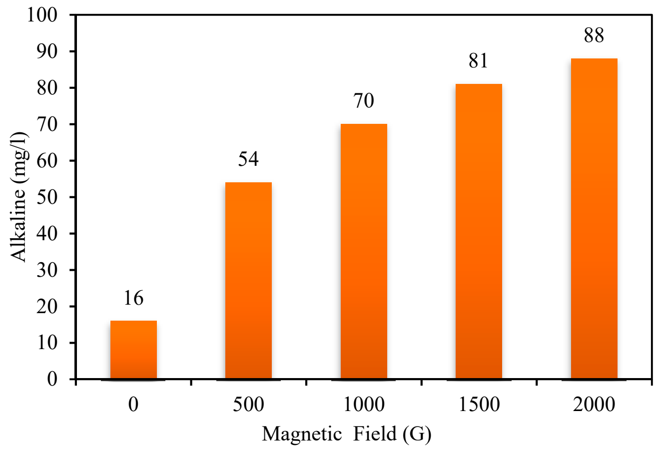

Figure 3. Concentration of Alkaline with magnetic field.

Figure 4 shows the variation of concentration of alkaline minerals: magnesium (Mg), calcium (Ca), sodium (Na), and potassium (K) with different intensities of magnetic fields. The magnesium is a shiny gray solid chemical element has atomic number 12. The content of Mg water increased significantly by 28.5, 41.4, 52.8, and 67.14% with increasing the intensity of magnetic field by 500, 1000, 1500, and 2000 G respectively. The potassium is soft silvery-white alkaline metal and has an atomic number of 19. Potassium have a single valence electron in the outer electron shell, which can be easily removed to create a cation. The potassium in nature is oxidizes rapidly in air and strongly reacts with water producing a heat that sufficient to burn hydrogen resulting from the reaction [57]. The concentration of K increased by 20, 78, 110, and 150% for intensity of magnetic field 500, 1000, 1500, and 2000 G respectively.

Sodium (Na) is soft has silver-white color and considered highly reactive alkaline metal. Na has an atomic number of 11 and has a single electron in its outer shell. This electron is easily donated and transform to Na^+ cation. The sodium metal does not occur freely in nature and prepared chemically from compounds. Sodium is an important constituent of a number of silicate materials, such as sodalite, feldspars, micas, and rock of salts. The sodium salts are highly soluble in water. The concentration of Na increased significantly by 43, 96, 143.75, and 225% for different intensity of magnetic fields of 500, 1000, 1500, and 2000 G respectively. The pH value almost increases with increasing the intensity of magnetic field and the concentration of calcium ion begins to decrease. In other words, the high precipitation of $CaCO_3$ will make a significant drop in the calcium content. The magnetic field inhibits growth of crystal particle and can be explained by electrical double layer near the charged surface of particles [56]. The concentration of Ca is decreased with increasing the intensity of magnetic field by 14.7, 26.5, 38, and 50% for intensity of magnetic field 500, 1000, 1500, and 2000 G respectively.

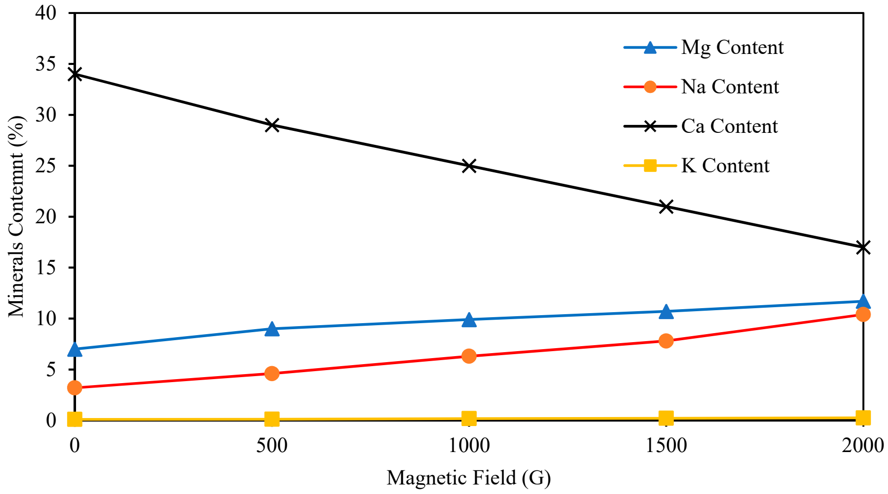

Figure 4. Concentration of Mg with magnetic field.

4.3. Effect of magnetization on chloride content

The chloride (Cl^-) is anion formed when the chlorine element gains an electron or when a compound such as hydrogen chloride is dissolved in water or other polar solvents. Chloride salts such as sodium chloride are often very soluble in water. Figure 5 shows the variation of Cl^- concentration with different intensities of magnetic fields during the circulation of reference water in this field. The concentration of Cl^- increased by 20, 45, 75, 100% for magnetic field intensity of 500, 1000, 1500, and 2000 G respectively as shown in Figure 5.

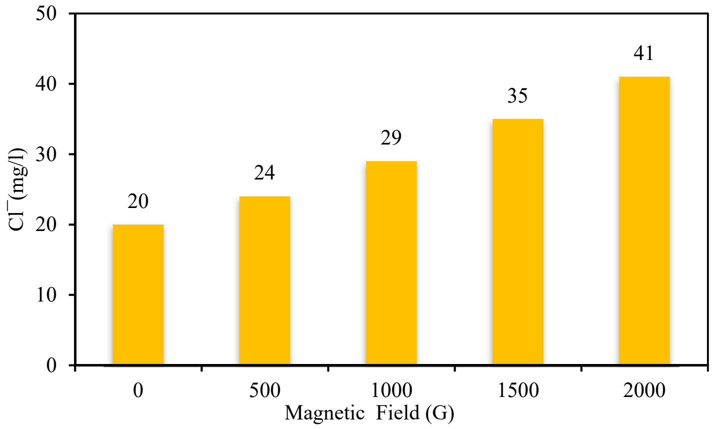

Figure 5. Concentration of Cl^- with magnetic field.

4.4. Effect of magnetization on silicate dioxide content

Silicon dioxide (SiO_2) is a chemical compound extensively found in quartz, sand, and in various living organisms. This compound is not very reactive due the polarity of molecule is zero. The silica is the major compound of sandy soils in the world. Silicon dioxide is one of the most complex and most abundant families of materials and has many uses in chemical, electronic and pharmaceutical industries. Figure 6 shows the concentration SiO_2 with different intensities of magnetic field, during

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water reference pass through field magnates increased SiO_3 value from 28 %at 500 G, 57% at 1000 G, 76% at 1500 G and 95% at 2000 G than those of reference treatment.

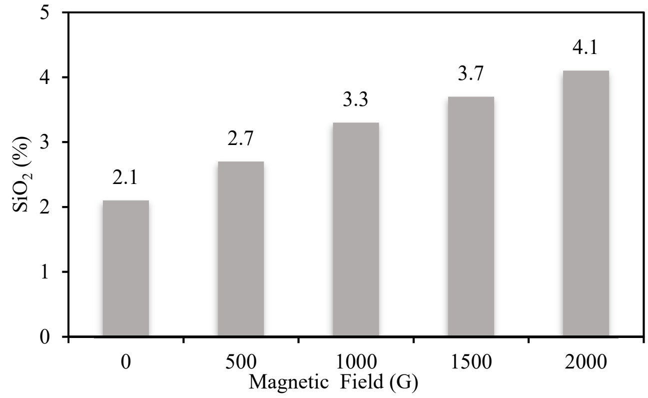

Figure 6. Concentration of SiO_2 with magnetic field.

4.5. Effect of magnetization on sulfate content

The sulfate (SO_4) is a polyatomic anion which almost found in all natural water. The sulfate compounds are resulted from the oxidation of sulfite ores, the presence of shales, and the industrial wastewater. Also, sulfate is considered one of the major dissolved salts in rainwater. The salts and acid derivatives of sulfate are used in industry. Figure 7 shows the concentration of SO_4 with different intensities of magnetic field, where the circulation of water in a magnetic field causes decreasing the content of SO_4 from 8 to 48% with increasing the intensity of magnetic field from 500 to 2000 G.

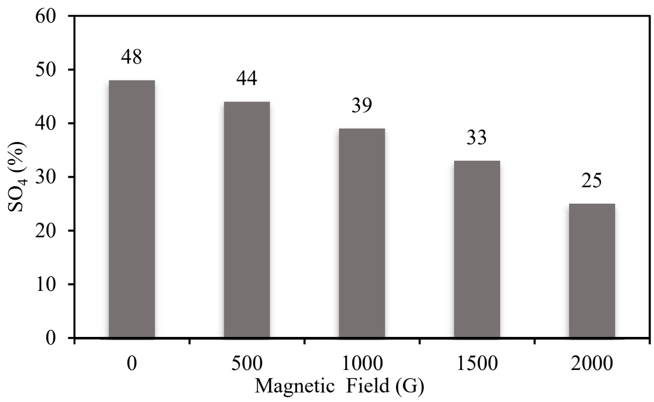

Figure 7. Concentration of SO_4 with magnetic field.

4.7. Effect of magnetization on total disolved salts (TDS)

Total dissolved solids (TDS) is a measure of the dissolved inorganic and organic substances present in a liquid in molecular, ionized or micro-granular suspended form. The specific types of TDS mainly include calcium, magnesium, potassium, sodium, bicarbonates, chlorides, iron, lead and sulfates. The common sources of dissolved solids in water are come from weathering of rocks and erosion of earth's surface. Many minerals are soluble in water, so high contents will be accumulated over time through the constantly reoccurring process of precipitation and evaporation. The groundwater usually has high contents of TDS than surface water, due to long duration of contact

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with the underlying rocks and sediments. TDS can consist of inorganic components and organic components such as decaying organisms, surface runoff of water, and effluent from municipal and industrial activities. Figure 8 shows the variation of TDS content with different intensities of magnetic fields. The content of TDS in magnetized water increases with increasing the intensity of magnetic field, where TDS increased from 38 mg/dL for reference water to 155 mg/dL for water passes through magnetic field of intensity 2000 G.

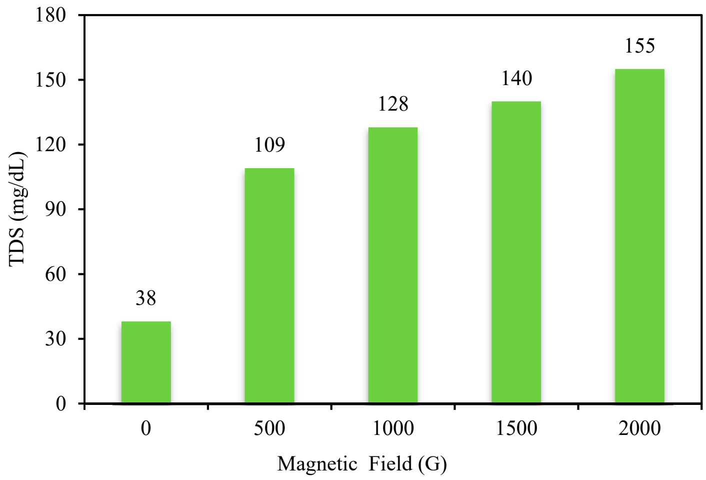

Figure 8. Concentration of TDS with magnetic field.

4.8. Effect of magnetization on electric conductivity

Electrical conductivity is the reciprocal of electrical resistivity. It represents a material's ability to conduct electric current. Figure 9 shows the change in electrical conductivity for different intensities of magnetic flux at a flow rate of 1000 L/hr, where Ec increased from 56 to 264 with increasing the intensity of magnetic field from zero to 2000 G. The flow rate does not have a significant effect on the electrical conductivity which continues to increase with increasing intensity of magnetic field [56]. The electrical conductivity depends on the content of ions, where the precipitation of silicate will change the electrical conductivity. It is observed decreasing the content of Ca with increasing the intensity of magnetic field which causes increasing the electrical conductivity [56].

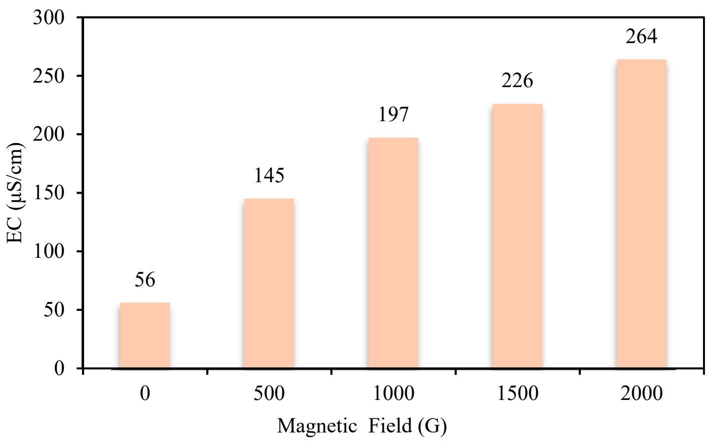

Figure 9. Variation of EC with magnetic field.

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5. Conclusions

The results of present study showed that the circulation of water in a magnetic field increases the pH value which indicates increasing the alkalinity of water with increasing the intensity of magnetic field. The nucleation of alkaline content increased from 16 mg/l for reference water to 88 mg/l for water treated with magnetic field of intensity 2000 G. Also, the magnetic treatment reduces the nucleation of calcium mineral and sulfate content in water. The common results from this research are focused on the influences of magnetic fields of different intensity on the chemical and electrical properties of water treated by reversed osmosis. The experiments could change the content of ions in water as follows:

- Water properties after use of magnetic treatment, pH, EC and TDS increased with increasing the intensity of magnetic field.
- Increased some positive and negative ions (Mg, K, Na, Cl^-, Alkaline and SiO_2).
- Decreased some positive and negative ions (Ca and SO_4).
- The strength of soil could be improved by this method while without chemical additives to the soil through precipitation of calcite. The amounts of sulfate in magnetic field has been decreased, it is useful to protect concrete from erosion, but the magnetization causes increasing the content of chloride in water which attach reinforcement steel of foundation and causes corrosion.

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Conflicts of Interest: The authors declare no conflict of interest

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