The Effect of Magnetic Treatment on Retarding Scaling Deposition

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Abstract: The magnetic treatment method has been applied as a scale deposition controlling and/or preventing tool for several decades in the domestic and industrial water systems. However, most of the scientific communities have remained skeptical about the viability of this water treatment method. However, the attention paid to magnetic treatment has increased during the last years as a prevention method.

Hence, a literature review was carried out to seek both positive and negative results. However, a review of the available literature is rather confusing. An experimental laboratory study on the effect of magnetic treatment method was conducted at the Kuwait Institute for Scientific Research's (KISR's) Doha Laboratory for reverse osmosis plant to investigate the effect of magnetic treatment in preventing and/or retarding scaling. Thus, the effect of magnetic treatment in retarding calcium carbonate, calcium sulfate and barium sulfate scaling was investigated within two different configurations (open and closed loop) and by using different techniques at ambient temperature. The current paper summarizes the literature survey and expresses the results of experimental work. The results showed that the magnetic treatment was effective in increasing the retention time required for scaling. Nonetheless, further investigation is recommended to optimize magnetic power, flow rate and operating temperature.

Key Words: Barium sulfate ($BaSO_4$), Calcium Carbonate ($CaCO_3$), Calcium Sulfate (Ca SO_4), Magnetic Treatment.

Introduction

Magnetic water treatment (MWT) is a proposed method of water treatment. The manufacturers of water treatment devices have claimed that powerful magnetic fields can affect the properties of solutes passing through the magnetic field, therefore, eliminating the need for chemical treatment agents as softening or antiscalant agents. Although the magnetic treatment has been applied as a scale-deposition controlling/preventing tool for the several decades in the domestic and industrial water systems, most of the scientific communities have remained skeptical about the viability of this water treatment method.

The first commercial device to be used for magnetic treatment was patented in Belgium in 1945 and used in a hot water system; in the United States of America the use of magnetic water treatment devices has been wide spread since 1975.

In 1985, Kronenberg was the first physicist who reported anecdotal evidence to the pseudoscientific theory that magnetic water treatment could prevent the formation of scale even after the magnetic field is removed.

Since the magnetic treatment is a controversial matter, a literature survey was conducted to investigate the viability and reliability of magnetic treatment in retarding the scaling deposition for membrane process.

Several scientific journals supporting magnetic treatment were found and reported positive scientific results.

Martynova et. al. (1967) found that in the presence of oxides of iron, in the industrial water and circulation process, the magnetic treatment of water enlarged the center of the crystals of a certain type of salt after the magnetic treatment of the water solutions. Biochenko et. al. (1977) also found that the effectiveness of magnetic treatment depends on several parameters such as temperature, type of salt, flow rate, and magnetic intensity.

In 1984, Grutsch and McClintock demonstrated a deposit control by using magnetically treated water where they conducted an extensive literature review on magnetic treatment and concluded that those who approved of the viability of magnetic treatment based their approval on proper application or specific experimental procedures. They added that the failure of previous researchers to see the effect of magnetic treatment could be due to the improper use of magnetic equipment such as magnetic intensity, polarity, material and others. They also found that the magnetic treatment equipment could successfully control salt deposition during the circulation of alkaline cooling (tower) water solutions and the treatment has positive control over calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$) scale. They indicated that the proper parameter such as water velocity (6 m/s) could yield a positive scale control.

Busch et. al. (1986) were the first who suggested that the changes in voltage and current of conducting solutions passing through the field of magnetic treatment devices might be due to the effect of Faraday's law. He applied several precise magnetic field experiments using the commercial magnetic devices with normal stainless steel and plastic pipe housing. He found that the voltage and the current were both produced when the water solution was passed through an orthogonal magnetic field. He also postulated that insoluble iron produced from the magnetic material might be the center for $CaCO_3$ crystals which they believed might be the reason for suspension of $CaCO_3$ on the solution rather than depositing it on the plumbing surfaces.

A saturated solution of calcium sulfate ($CaSO_4 \cdot 2H_2O$) was tested in the magnetic field of a nuclear magnetic resonance spectrometer by Ronald et. al. (1995). Five replicates were performed for each experiment. The experiments were conducted using a magnetic device of 4.75 T and 1200 rpm. Results showed that the magnetic treatment indeed had a significant effect on the precipitation of $CaSO_4$ crystals. Conductivity, soluble Ca, and Zeta potential (ζ) all decreased, whereas the total suspended solid (TSS) increased. A transfer of Ca from the soluble to the solid phase (crystal as $CaSO_4 \cdot 2H_2O$) was confirmed using mass balance calculations. Thus, the results are consistent with claims in literature that magnetic water treatment can induce precipitation of inorganic crystals from solution, and could possibly prevent scaling by avoiding the precipitation of these salts onto solid surfaces.

A similar positive result was reported by Baker et al. (1997). The test was performed in a flow through the test ring; scale precipitation was induced by controlling a dosing of 0.1-M sodium hydroxide (NaOH) into a flowing solution of calcium chloride and sodium carbonate, the pH was adjusted to 6.5 using 37% HCl. Different strengths and configurations of magnetic fields were tested. The contact time, temperature and velocities (0.8, 1, 2 m/s) were also varied for a five-hour operation. After each experiment, the scale precipitated on the test tube section and wire loops were quantified and analyzed by a scanning electron microscope. The experiments were conducted under flow through reverse osmosis (RO) (open loop) and in a reticulated RO (closed loop) and the run continued until a sufficient flux decline occurred. On the open loop, no reproducible change was found in the nature or in the quantity of the scale adhered to the wire loops, but the physical differences were reported in the nature of the deposit when a magnetic field was applied to a supersaturated solution. The scale from untreated water formed a fine-grained uniform covering the pipe, while magnetically treated scale formed coarser-grained covering of the pipe in two different crystalline forms. The first form was calcite, and the other form was a cauliflower-type structure (aragonite). The author emphasized that these two forms of scale were not apparent when an undersaturated solution was used. But, in the closed loop the flux and the rejection were significantly improved especially at a low flow rate (10-12 l/h). The result of analysis confirmed that the magnetic treatment produced a deposit (aragonite) which was less compact and more amenable to chemical cleaning than that formed under normal conditions.

In 1998, a laboratory experiment was undertaken by Barrett and Parsons to assess the effects of magnetic treatment on $CaCO_3$ precipitate. Static test solutions of calcium chloride, $CaSO_4$ and sodium carbonate were placed in a magnetic field. $CaCO_3$ was magnetically treated and the changes in precipitation were recorded. The results of this study support earlier work which indicates that magnetic fields may influence the formation of $CaCO_3$ by the suppression of nucleation and acceleration in crystal growth. The magnetic effect is maintained for at least 60 h after exposure and magnetic exposure exerts a greater effect on $CaCO_{3.}$ Results indicate that the magnetic field suppresses the formation of $CaCO_3$ nucleation and crystal growth.

Gabrielli et al. (2000) tested magnetic treatment by measuring the remaining ionic calcium at the output of the device by means of ion-selective electrode. The scaling power of the treated water was estimated through an electrochemical scaling test. Chroamperometric curves and chronoelectrogravimetric curves were plotted to obtain the scaling time and nucleation time of scale deposition. Finally, an empirical equation was proposed, relating the efficiency of magnetic treatment to the length and flow velocity. The efficiency of the magnetic treatment through different types of pipe material polyvinyl chloride (PVC), stainless steel (SS) and Copper (CU) were also tested and it was concluded that copper is the most powerful material that can be penetrated through magnetic treatment, followed by SS and finally PVC. The inversion of polarity was found to improve the efficiency of the magnetic device. The scaling time was doubled when a magnetic device was used without inversion; however, that time would be increased to triple if inversion polarity were used in the magnetic device. The power of magnetic treatment was found to be greater when increasing the length of treatment or the number of polar pieces used in the treatment. The experiment was carried out in a control condition and totally confirmed the effect of magnetic treatment.

Freitas et al. 2000 investigated the effect of magnetic field on the crystallization of zinc sulfate in a series of controlled batch cooling experiments. Zinc sulfate solutions were exposed to magnetic fields of different intensities from 0.3 up to a maximum of 0.7 T (B). A clear increment of saturation temperature, growth rate, and average crystal size was found. However, a decree in the metastable zone width was also reported.

Kobe et al. 2001 and 2002 published many studies on the influence of magnetic field on the crystallization of $CaCO_3$. He concluded that the applied magnetic field can successfully prevent the hard calcite scaling; the main purpose of his work was to understand the mechanism of the beneficial influence of the magnetic treatment. However, his result also confirmed that magnetic treatment has altered the morphology of crystals forming 90% calcite and 9.6% aragonite without magnetic treatment to 28% calcite and 70% aragonite under a magnetic field of 1.22 T. Hence, the influence of the applied magnetic field on nucleation and further crystallization of $CaCO_3$ in hard water was confirmed.

Knez and Pohar (2005) conducted a laboratory study on the effect of magnetic field on the polymorph composition of $CaCO_3$ that precipitated from carbonized aqueous solutions in a closed loop. The experimental work was repeated in different magnetic flux densities, different intervals and flow velocity. The most important conclusion that was drawn from the Knez experiments was that the magnetic field clearly favors and/or promotes the precipitation of aragonite instead of calcite when nonmagnetic treatment was applied.

Saban et al. 2005 investigated the influence of static magnetic field of strength 0.75 T on the nucleation of $CaCo_3$ crystals using the particle size analysis and number of $CaCO_3$ particles formed. The experiment was conducted using 10-ml sodium bicarbonate ($NaHCO_3$) solution in a test-tube under magnetic field. The calcium chloride solution was taken from a vertical burette positioned above the test tube and mixed to a slow flow rate, drop by drop. One of the major findings was that the magnetic field can reduce the size of high percentage number of particles formed and also compress the particle size.

Kney and Parsons (2006) conducted a laboratory-based study to test the effect of treating solutions and particulate of $CaCO_3$ through magnetic treatment. Reproducible results were observed, but only when $CaCO_3$ particulates were exposed to magnetic fields, and not when a solution of sodium carbonate ($NaCO_3$) was exposed to magnetic fields. The result of the experiment was based on mixing the solution of sodium carbonate and calcium chloride in a test cuvette, and then absorbance measurements were taken at seven-s intervals over 30-min period.

Alimi F. et al. (2007) conducted a series of experiments on the effect of magnetic field on the calcocarbonic pure water containing calcium, carbonate, and bicarbonate ions only under 0.16-T magnetic field. A magnetic device consisting of five pairs of permanent magnets with north and south faces facing each other was used; the solution was flowed into a 150-mm plastic tube with a sectional area of 0.38 cm^2. The test tube was immersed in a water bath to control the temperature for 90 min. the tested solution was heated to a desired temperature Then, the concentration of dissolved calcium was measured before and after heating every 10 minutes. The difference in calcium ion concentration represents the amount of $CaCO_3$ precipitated. The influence of the applied magnetic field on the nucleation and precipitation of calcium carbonate was confirmed.

Lipus in 2007 evaluated the effectiveness of the magnetic field by the amount of scale precipitated in boilers and pipes during a three-week run using tap water, which contained (Mg^{2+}) and (Fe^{3+}) ions in a concentration exceeding the thresholds for calcite inhibition. All of the scales were identified to be aragonite, but in the case of magnetic treatment, the scale occurred in much smaller amounts. The scale on a heating copper-pipe was 2.5 times thinner due to magnetic water treatment, and the zinc-coated steel pipe occurred as a very thin powder–like coating, while in the line without treatment, abundant hard lining was formed.

Magnetic treatment recorded a revolution in solid-liquid separation as reported by Nirschl (2009), where he confirmed that he could separate between two inorganic components using magnetic field in a magnetic filter. The author also reported in another study that the magnetic field effects influence the filtration process positively.

Although Prisyazhniuk in 2009 explained different methods that are used for preventing scaling in heat exchanger, only the magnetic method was tested on his study. A predictive equation was also proposed in the study, relating the increase of power consumption to the degree of saturation of $CaCO_3$ on the surface and adjoining layer.

Purified potable water was then circulated at a constant flow rate in a magnetic field by Cai et al. (2009). Then, the physicochemical properties of water were measured; a decrease of surface tension and an increase of viscosity over the treatment time were observed. The correlation time (τ_c) was calculated in terms of spin–lattice relaxation time of proton, which verified that the rotational motions slowed down after the magnetic treatments. A two-phase model was set up to prove that the proportion of free water molecules was reduced. The results suggested that the average size of water clusters have become larger through magnetic treatments.

On the other hand, many other researchers reporting negative results such as Eliassen et al. in 1985 reported that no positive results were achieved when the magnetic treatment was applied in preventing scaling.

Hasson and Bramson in (1985) found that the magnetic treatment failed to suppress the scale formation of $CaCO_3$. In addition, Limpert and Raber (1985) reported that the magnetic treatment device failed to prevent scale formation in a heat exchanger system. Sohnel and Mullin in 1988 believed that the magnetic treatment has no hard scientific evidence to improve the performance of tested system.

The most obvious example of the negative result was reported by Al-Qahtani in 1996, where several samples of seawater (43,000 mg/l) were circulated through a high magnetic field intensity of 7,000 gauss for several hours at fixed temperature, flow rates, and nitrogen concentration. The pH and conductivity of all of the samples were increased during the circulation time. Using RO, both the treated and untreated solutions were desalinated in a seawater RO unit at several pressures. No significant difference was seen between circulated and uncirculated solution.

Smothers et. al. (2001) tested the effect of three different magnetic devices on the type and the quantity of scaling mineral deposit on the three shell and tube heat exchangers using potable water as supplied water. The results did not indicate any clear advantage for any of the three devices tested versus a control for the inhibition of mineral scale formation or the corrosion of copper. The amount of mineral scale formed for the control versus device heat exchange tubes was relatively constant. The scale formed was found to be a type of calcite ($CaCO_3$) and had the same crystalline structure for each heat exchange tube. There was no effect on the crystalline structure of the scale formed by any of the tested devices. On the other hand, many other researchers also reported a positive result and proposed a model to explain the effect of magnetic treatment as given below.

Mergen et al., (2008) tested the magnetic ion-exchange resin treatment for the removal of natural organic material using a bench scale method in a continuous operation. Treatment shows a high percentage removal. Tai et al. (2008) used permanent magnets of different intensities to investigate its effect on the crystal growth of calcite in a fluidized bed using the constant composite technique. The result confirms that the calcite growth rate in the presence of a magnetic field was lower than those in the absence of magnetic field. Alimi F. et al. (2009) investigated the influence of the material of the pipe on calcium carbonate precipitation under magnetic treatment. The result of the experiments proved that magnetic water treatment affects calcium carbonate crystallization by favoring its formation in bulk solution, instead of its incrustation on the wall. Stuyven B. et al. (2009) offered a new explanation for the mechanism of magnetic treatment's ability to prevent scale. The results of the experimental work prove that water contains suspended micron size particles that can be fragmented by application of orthogonal magnetic field on a turbulent flow, which results in size-reduction by two to three orders of suspended salt particles and increases the surface area of these particles by four to six orders. So precipitation will occur in the larger surface area present that could explain why the precipitation will increase in the bulk solution instead of the surface area of the container or pipes.

Gryta M. (2011) investigated the effect of using magnetic water treatment to reduce calcium carbonate deposit during membrane distillation. The result confirmed that the flow of water through the magnetic field has a considerable influence on the morphology of $CaCO_3$ precipitation during the thermal decomposition of bicarbonates. Bin et al., (2011) investigated the effects of magnetic field on sodium, magnesium and calcium ions in chloride solutions. He concluded that magnetic treatment leads to an increase of diffusion coefficients of magnesium, sodium and calcium and a decrease of chloride ions. The result confirms that magnetic treatment is beneficial for the separation process of brine water from seawater. Madsen (2004) reported that the calcium carbonate crystal formed from mixing calcium chloride solution with sodium carbonate solution under magnetic treatment, results in the crystal-size decrease with increasing strength of the magnetic field.

Cefalas et al., (2008) used the x-ray diffraction analysis to analyze the effect of 1.2 T magnetic fields on the calcium carbonate precipitated crystal form. The magnetic field was found to increase the precipitation of aragonite and decrease the formation of calcite. Cefalas et al. also proposed a quantum mechanical model which stated that, magnetic fluctuation inside the liquid can be amplified by exchanging energy with the magnetic field through an angular momentum of the water molecular rotors and with the macroscopic angular momentum of the turbulent flow. The gain is higher if the magnetic fluctuation is in resonance with the rotational frequencies of the molecular rotors or low frequencies of the turbulent flow. The authors added that, at low external magnetic field, the formation of aragonite takes place when a vacuum state electromagnetic mode is trapped, amplified and sustained in a coherent antisymmetric state, which is created by an ensemble of individual molecular rotors which are excited coherently by the external magnetic field. The amplified magnetic mode will not decay to the ground symmetric state of the ensemble of water molecular rotors due to the forbidden nature of transition between the antisymmetric and the symmetric state. The ensemble of water molecular rotors is then driven to a higher, free-energy state for a longer period of time, allowing thus the $CaCO_3$ precipitants to be crystallized as aragonite. Furthermore, the existence of the coherent antisymmetric state, elucidate the memory effects observed previously in water solutions. Coey and Stephen also reported an increase in aragonite and/or calcite ratio in the deposit when using a magnetic field of 0.1 T, and the authors also confirmed that the memory of magnetic treatment can last up to 200 hrs. Szczes et al. (2011) reported that, when an electrolyte solution was exposed to a weak static magnetic field (MF) generated from a stack of magnets (B = 15 mT) at the flow rate of 1.4 ml/s, a change in the electrolyte conductivity was recorded. it was found that the changes in electrolyte conductivity depended on the kind of electrolyte and the magnetic exposure time and are related to the thermodynamic function of hydration. The magnetic treatment was founded to increase the amount of evaporated water. The literature review showed that the effect of magnetic treatment was tested in numerous scientific journals, which obviously showed that the attention to this treatment method has been increasing in recent years. However, a review of the available literature is rather confusing due to the often contradictory results that are reported. The main drawback in the literature is that a part from many conventional theories, the effect of magnetic field on the physical and chemical properties of water, was recently interpreted on the basis of quantum field theory which was proposed by Cefalas et al., (2008) in agreement with previous work. Moreover, there is difficulty in getting reproducible results on a laboratory scale. However, it can be said that the available literature generally agrees on some principles of operating conditions for such devices given as follows:

- The magnetic treatment can lead to the formation of $CaCO_3$ particles in the bulk of scaling solution, instead of precipitating on the internal surface, and these particles are carried away by the water flow.
- The result of experimental research confirmed that homogenous nucleation increased in the presence of magnetic treatment, resulting in the formation of crystals that are greater in numbers with smaller sizes
- Furthermore, it has been reported that the fluid must be orthogonal with respect to the direction of the applied magnetic field (Busch et al., 1986). However, some studies have mentioned that a magnetic field

strength of at least 0.05 T is required for successful treatment, although this would depend on the composition of water and the type of device.

Testing the Magnetic Treatment at Doha Reverse Osmosis Plant (DROP)

The magnetic treatment methods have been tested at KISR for a different client at DROP. Different types of experiments were conducted on the magnetic treatment but with different objectives. The first experiment studied the effect of magnetic treatment on the quality of feed water (chemical-physical and biological effect) using a stagnant magnetic field. The second experiment was conducted at DROP to test the effect of magnetic treatment on the operation parameters of RO system as salt passage, salt rejection, recovery, and differential pressure in an open cycle system. The result of both the experiments proved to be negative, except for a few physical parameters showing a little difference, as TSS and turbidity, and the effect of magnetic treatment were considered to be invisible. However, when a further research was conducted to investigate the previous research done on magnetic treatment, it was found that the pH, conductivity, salt passages, chemical compositions are not suitable tools for evaluating the efficiency of magnetic treatment. Similar treatment methods used by many other researchers also yielded a negative result, since the effect of magnetic treatment is visible only when there are suspended particles or during the formation of scale particles. The magnetic treatment was found to have a positive effect only when either the morphology of crystals formed or the number and size of crystals formed was studied. In addition, the magnetic treatment showed a positive effect on the retention time required for scale formation.

Therefore, the effects of magnetic treatment on different types of scaling compounds were tested in KISR at DROP using other tools for evaluation. $CaCO_3$, calcium sulfates ($CaSO_4$) and barium sulfates ($BaSO_4$) were tested in two identical operating conditions with magnetic treatment and without magnetic treatment.

Experimental Details

The magnetic unit used in the experiments consisted of three pairs of permanent magnets with north and south poles facing each other. Each polar piece is the assembling of two rectangular permanent magnets. Fixed at steel frame 14 mm apart (The induction of the magnetic field (B) is 0.16 T in the air gab, for each pair of magnet device. The magnetic effect on the formed scaled was tested under an ambient temperature at DROP (22°C). The effect of the magnetic treatment on retarding scaling deposition was tested using three different synthesis-saturated scaling solutions.

Each solution was saturated with one type of scaling compounds such as BaSO4, CaCO3, or CaSO4. The prepared saturated solution in the feed water tank will flow to the test tank, through a magnetic device oriented orthogonally to the direction of flow as shown in the tested unit in Fig 1. First NaCO3 solution will be circulated through the magnetic device without mixing with CaCl2 solution for 24 hours before starting the experiment. Then the zero time will be considered exactly as the time of mixing CaCl2 solution with NaCO3 solution, and then a sample will be drawn from the test tank every one minute for analyzing the scaling species. Turbidity and concentration of scaling species were used for evaluation the magnetic treatment. Turbidity was measured continuously using a dipping turbidity meter as shown in the tested unit. Dipping turbidity meter is able to display an automatic reading for turbidity. All of the proposed test solutions were tested under the same magnetic field's strength and at stagnant condition. The turbidity and concentration of soluble scaling ions versus time used as indicators for scaling precipitation versus time. Whereas, when the initial concentration of the scaling compounds in the tested solution decreased, the precipitation of the scaling compound is indicated. However, if the magnetic treatment is effective in retarding the precipitation of the scaling compounds, the concentration of the scaling species will be constant for a period equal to the retention time. Then, the concentration of scaling species will be plotted versus time and the evaluation of magnetic treatment will be based on these graphs.

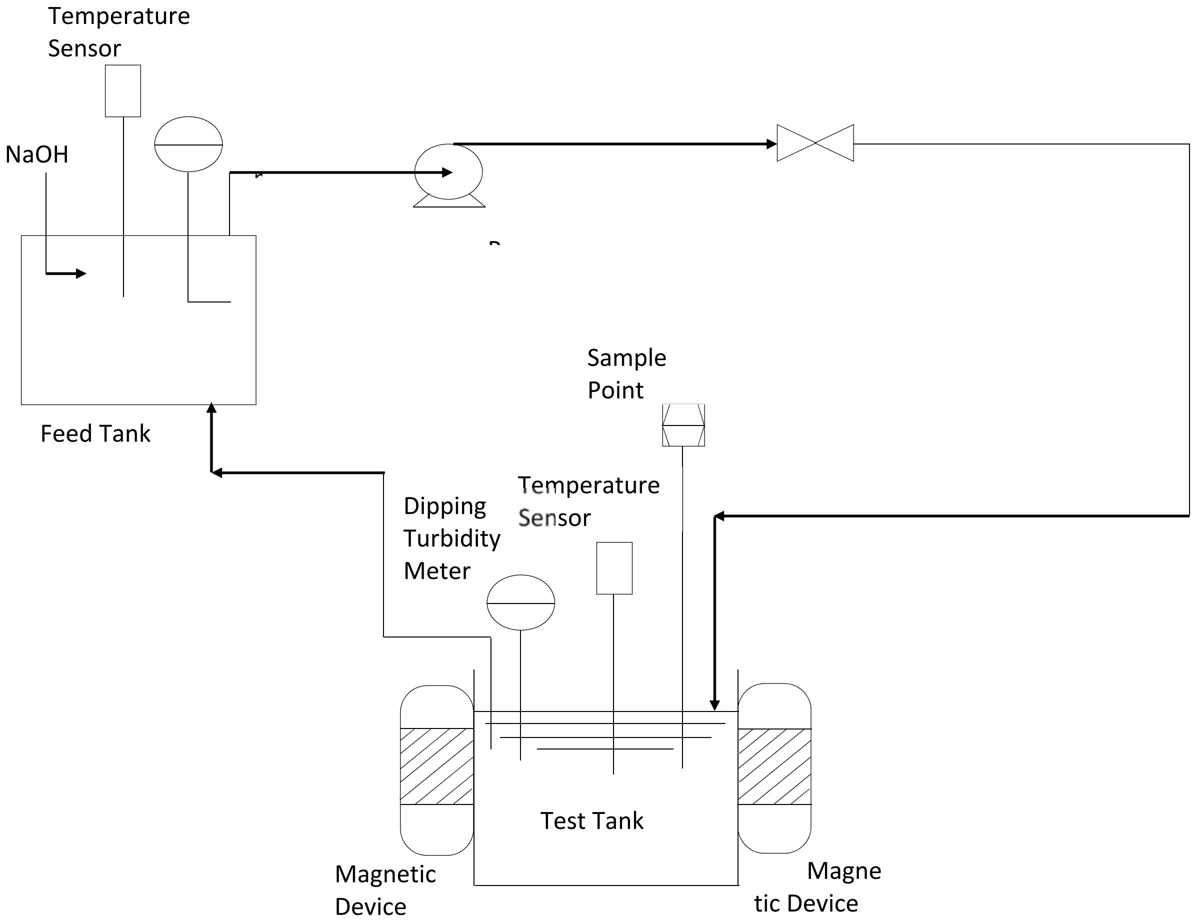

Fig. 1. The schematic of the experimental test plant.

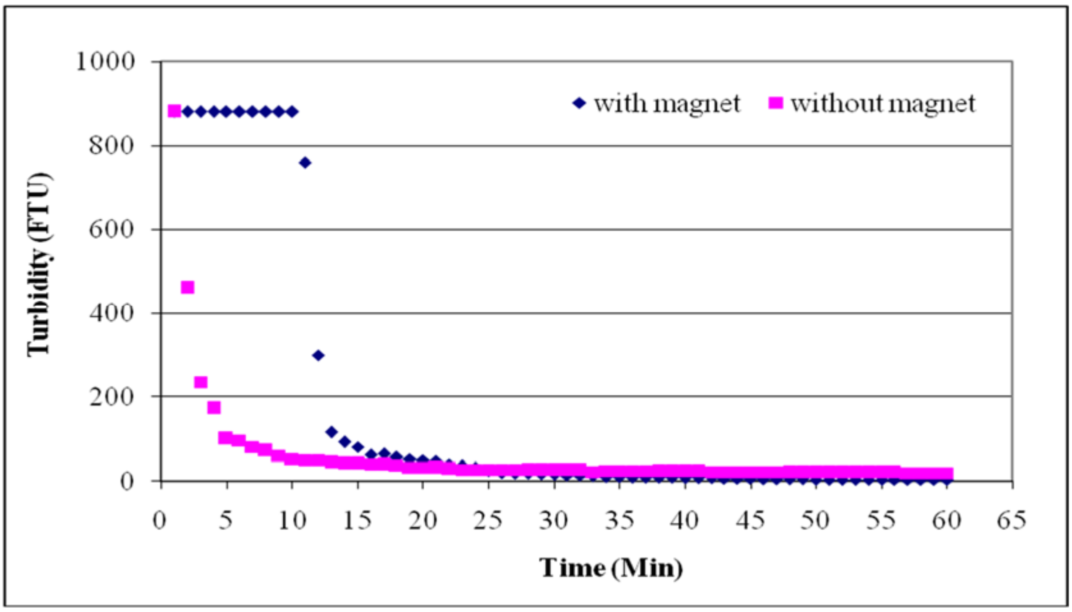

Fig. 2. Turbidity of $CaCO_3$ solution under stagnant condition versus time.

The Effect of Magnetic Treatment on Calcium Carbonate Scaling

Calcium carbonate ($CaCO_3$) solution was prepared by mixing 0.5 M of calcium chloride ($CaCl_2$) with 0.5-M sodium carbonate ($NaCO_3$) in the feed tank. When applying a magnetic treatment, the $NaCO_3$ solution was treated with the magnetic unit for about 24-h before mixing. Then turbidity of the solution was measured immediately after mixing in the tested tank. The turbidity of the mixed solution, which contained $CaCO_3$ particle solution was measured every one minute; the first solution under the magnetic treatment, the second solution without magnetic treatment. The measurement of the turbidity was continued for about 60 min. Fig. 2 shows the effect of magnetic treatment on a solution containing $CaCO_3$ particles in a stagnant condition. The effect of the magnetic treatment on the $CaCO_3$ scale particles was confirmed. Hence, the magnetic treatment succeeded in keeping the particles of $CaCO_3$ formed in a suspension state for almost 10 min. Furthermore, without any treatment, the turbidity of $CaCO_3$ solution decreased after one minutes of mixing from 800 FTU to 500 FTU. The decreasing trends continued until it reached 100 FTU after 6 min of mixing.

Zero turbidity was reached after about 13 min of mixing. Under the magnetic treatment, the turbidity of the CaCO3 solution reached the 100 FTU turbidity after about 16 min instead of six min without magnetic treatment. However, figure 2 shows that the effect of magnetic treatment was almost negligible after 16 min of CaCO3 formation. The second experiment was conducted using similar conditions as the previous experiment, but the dissolved calcium ion was analyzed before mixing and after mixing every 10 s to three minutes, then the analysis was conducted every one minute for almost one h. The decrease in Ca2+ ion from the initial concentration represented the precipitated salt as CaCO3 scale.

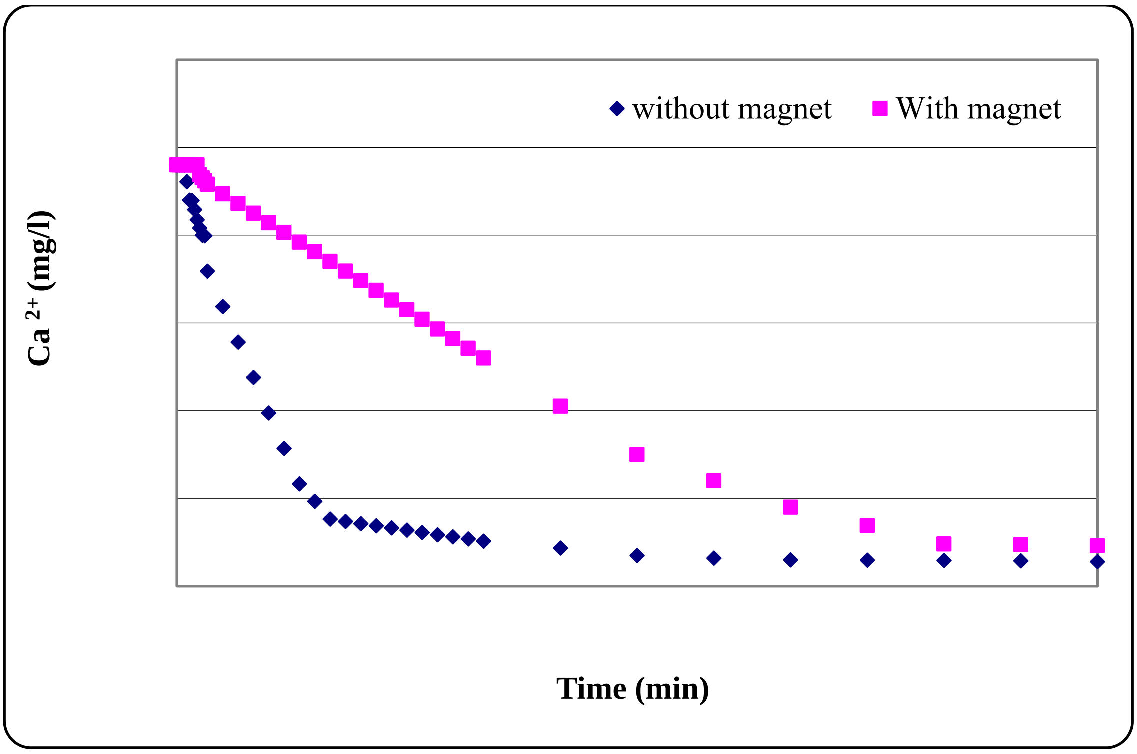

Fig. 3. Calcium ion analysis of $CaCO_3$ solution in flowing condition versus time.

Figs. 3 shows the analysis of Ca^{2+} ion in a flowing solution directly after the formation of $CaCO_3$ particles. The effect of magnetic treatment on the Ca^{2+} ions was found to be stronger than the effect of magnetic on the turbidity of $CaCO_3$ solution. Hence, a higher concentration of Ca^{2+} in the solutions would mean a higher prohibition for scale formation.

In other words, as the concentration of calcium ions becomes constant for a longer time (suspended), the scale precipitation would be lower and the scale prevention would be stronger. Fig. 3 shows that the magnetic treatment up to 25 min has succeeded in keeping the concentration of Ca2+ ions two and half times more than the concentration without magnetic treatment. This implies that the inhibition of CaCO3 precipitation was increased through the magnetic treatment by two and half times than that without any treatment. However, the effect of magnetic treatment was also negligible after 50 min of treatment (Fig. 3) It is worthy to mention that the Ca2+ was not prevented totally from decreasing, indicating precipitation of CaCO3, although in fewer times than without treatment.

The Effect of Magnetic Treatment on Calcium Sulfate Scaling

Calcium sulfate was formed by mixing 0.5-M NaSO4 and 0.5-M CaCl2 in the same procedure as described for CaCO3. Figs. 4 and 5 show the effect of magnetic treatment on CaSO4 solution directly after the formation of CaSO4 particles. It is worth noting that, the magnetic treatment was found to have a strong effect during the first five minutes after the formation of CaSO4. However, the effect of magnetic treatment on CaSO4 decreased gradually until 40 min after mixing when the magnetic effect was hardly noticeable. However, during the first four min, the magnetic treatment succeeded to keep the turbidity of the $CaSO_4$ solution above 400 FTU. Whereas, the turbidity of the same solution was found to be less than 100 FTU after only one minute of $CaSO_4$ formation without treatment. Therefore, the inhibition was almost four times compared to the solution without any treatment during the first four minutes.

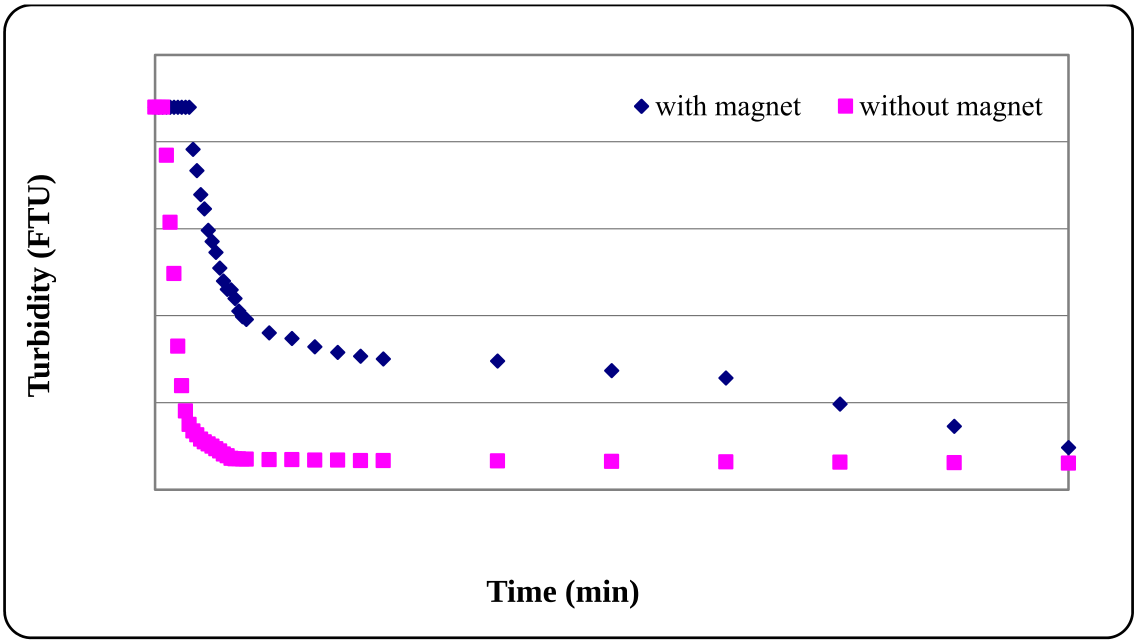

Fig. 4. Turbidity of solution of $CaSO_4$ in a stagnant condition versus time.

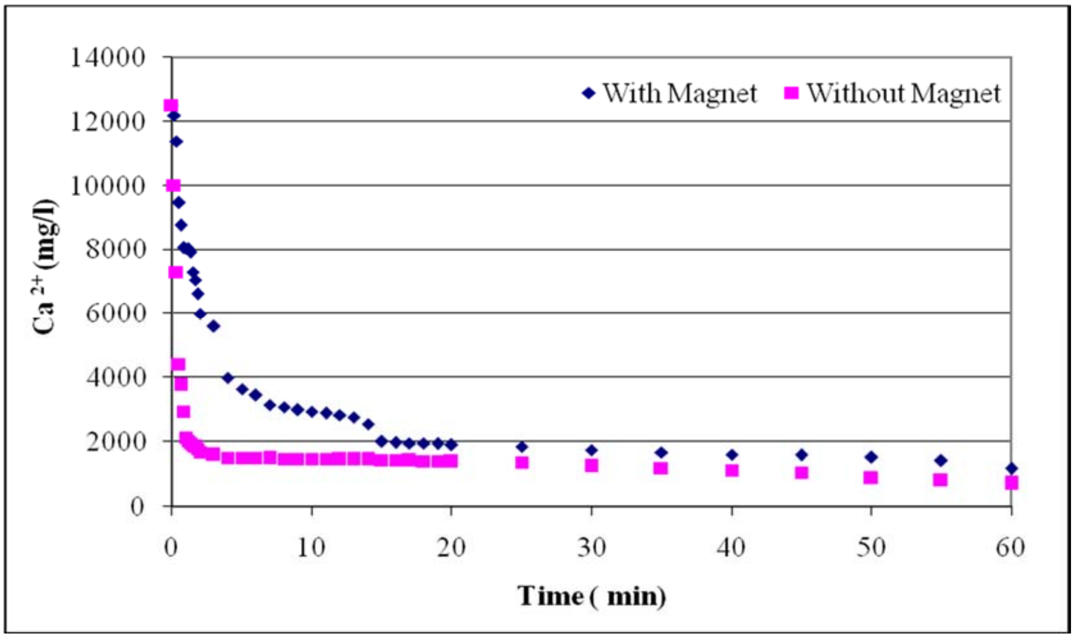

Fig. 5. The concentration of calcium ion of CaSO4 in stagnant condition.

The effect of magnetic treatment on the Ca^{2+} was also studied and illustrated in Fig 5. The same theory was applied to the Ca^{2+} precipitation. If the Ca^{2+} ion's concentration decreased with the tested solution, this indicated a precipitation of $CaSO_4$ particles.

The concentration of Ca^{2+} ion decreased from 12000 mg/l to 4000 mg/l during the first minute of $CaSO_4$ formation without any treatment, while the concentration of Ca^{2+} ion decreased to 8000 mg/l when given magnetic treatment (Fig. 5). After two minutes, the magnetic treatment succeeded in keeping the concentration of Ca^{2+} within the range of 6000 mg/l, while the concentration was below 2000 mg/l, without magnetic treatment and in stagnant conditions. The same behavior was noticed in the flowing condition, where the magnetic treatment affected the concentration of Ca^{2+} strongly during the first 10 minutes. However, this effect decreased as time increased and became almost negligible after 20 min of $CaSO_4$ formation (Fig. 5).

The Effect of Magnetic Treatment on Barium Sulfate

$BaSO_4$ was prepared by mixing barium chloride with $NaSO_4$. The effect of magnetic treatment on the turbidity of $BaSO_4$ solution is shown in Figs. 6 . It is worth mentioning that the figure shows that for almost 6 to 7 minutes, no changes or differences were seen directly after mixing $BaCl_2$ and $NaSO_4$, and whether the tested solution was magnetically treated or not.

The turbidity of BaSO4 solution was 450 FTU for about 10 min with the magnetic treatment, decreasing to 250 FTU after 11 min and continued to decrease to 100 FTU after 12 min of mixing. However, the turbidity of the same solution decreased from 450 FTU to 250 after 7 min of BaSO4 formation and reached zero FTU after only 8 min of mixing (Fig.6).

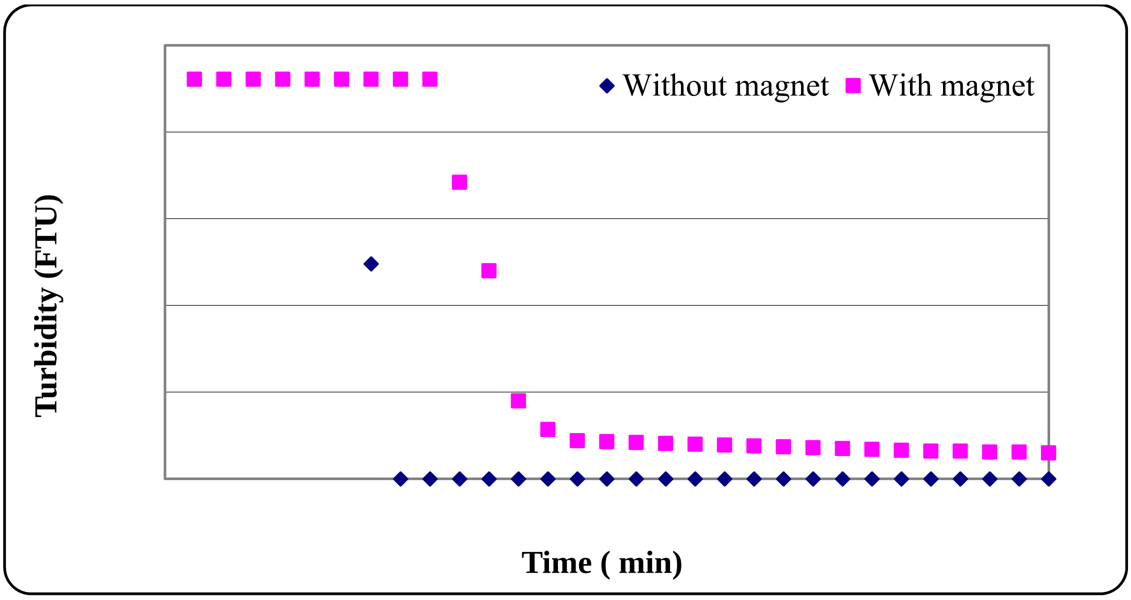

Fig. 6. Turbidity of $BaSO_4$ solution in a stagnant condition versus time.

Figs. 7 shows the concentration of SO_4^{2-} in a stagnant condition, in a $BaSO_4$ solution. The magnetic treatment succeeded in keeping the concentration of SO_4^{2-}at the same initial concentration (7000 mg/l) for 45 min (fig.7), while without magnetic treatment, the concentration of SO_4^{2-} was found to decrease to 6000 mg/l after only five minutes in a stagnant

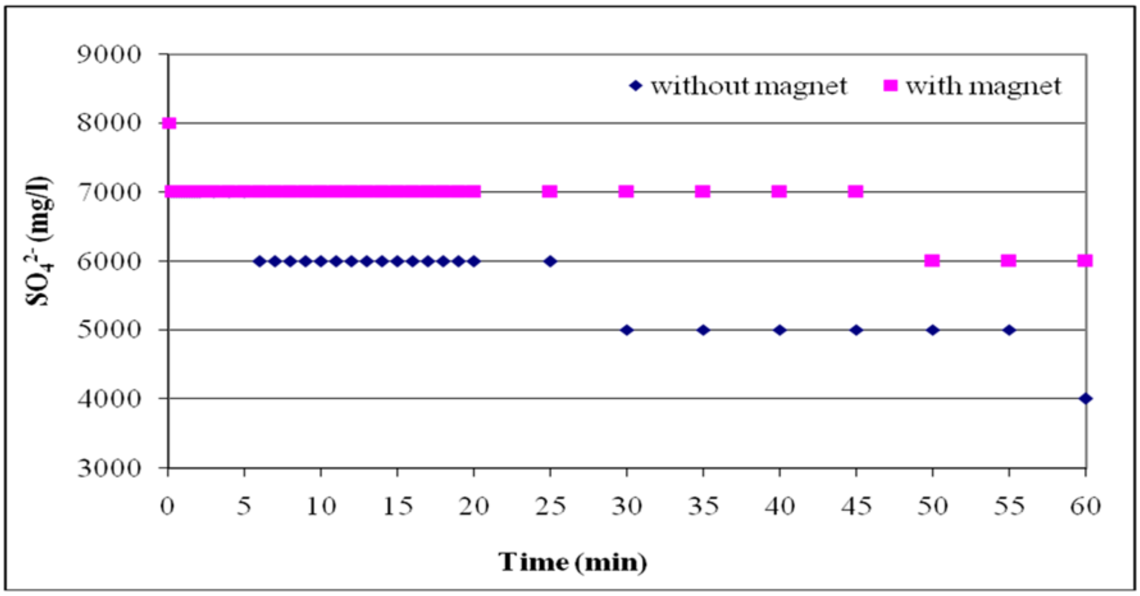

Fig. 7. The SO_4^{2-} concentration in $BaSO_4$ solution in stagnant condition versus time.

Conclusions and Recommendations

The literature survey and the results of the experimental investigation both confirm that the magnetic treatment could be effective in scale control, but the effect of the magnetic treatment on $CaCO_3$ was found to be stronger than the effect of the magnetic treatment on $CaSO_4$ or $BaSO_4$. Another major finding was that the magnetic treatment could not prevent the formation of $CaCO_3$, $CaSO_4$, and $BaSO_4$ scaling although it could reduce or retard the scale, where the experimental investigation showed that the magnetic treatment could keep the scale formed in a state of suspension long enough for it to be disposed along with the brine discharge even without any treatment. Since it is well-known that the time required for the feed water to enter and exit the desalination plant is not longer than 15 minutes. From the experimental investigation, the magnetic treatment succeeded in keeping the scale suspended for 45 min for $BaSO_4$, and 20 min for $CaCO_3$. On the other hand, the magnetic treatment inhibited the $CaSO_4$ from precipitation, for only 10 min. Thus, the effect of magnetic treatment proved to be different depending on the type of scale formed. However, in general, the effect of magnetic treatment in preventing scaling species from precipitation on the inside surface of pipes cannot be ignored. The result of the experimental investigation confirmed that the magnetic treatment depended on different parameters such as the magnetic power used, type of scale tested, and the condition of water, whether stagnant or flowing. Further investigation is recommended on this regard.

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