Desalination 369 (2015) 18–25

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Performance of physical treatment method and different commercial antiscalants to control scaling deposition in desalination plant

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HIGHLIGHTS

- A literature survey on magnetic treatment (MT) & scale controlling was conducted.
- The effect of MT on seawater/drinking water characteristics was examined.
- The effect of MT and four commercial antiscalants on scaling retention time (RT) was examined.
- MT succeeds in increasing RT of $CaSO_4$, $BaSO_4$ and $CaCO_3$ for 45, 20 and 10 min respectively.
- The performance of MT was found similar to the performance of antiscalants.

ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form 20 April 2015
Accepted 21 April 2015
Available online 29 April 2015

Keywords:
Barium sulfate ($BaSO_4$)
Calcium carbonate ($CaCO_3$)
Calcium sulfate ($CaSO_4$)

ABSTRACT

A literature survey was conducted at Kuwait Institute for Scientific Research (KISR), to investigate the effect of magnetic treatment method (MTM) on the water quality and controlling scaling deposition in RO plants. The result of the literature survey reported many positive experiments confirming the ability of MTM on retarding scaling deposition. So, two experiments were carried out at Doha reverse osmosis plant (DROP) to examine the effect of magnetic treatment method (MTM) on the chemical composition of two different solutions; potable water and seawater. The results show that MTM did not change the chemical composition, hardness, organic materials and trace metals. However, it was noticed that MTM affects clearly the turbidity and total suspended solids (TSSs) of tested water. A third experiment was conducted to investigate the effect of MTM in retarding calcium carbonate, calcium sulfate and barium sulfate scaling at ambient temperature and constant magnetic field (MF). The performance of MTM was compared to the performance of four commercial antiscalants in retarding the scaling deposition. The current paper summarizes the literature survey and expresses the results of experimental work. The results showed that the MTM was effective in increasing the retention time required for scaling.

1. Introduction

The reverse osmosis (RO) desalination plant suffers from scaling problem, which reduces the recovery of RO plant and increased the operating cost. Antiscalant was usually used to control scaling in RO plant, however antiscalants have many disadvantages, where they could increase the potential risk for biofouling. The manufacturer of magnetic field (MF) has claimed that MF devices can replace the antiscalant with lower operating expense. They claimed also that powerful magnetic fields can affect the properties of solutes passing through the MF unit and produce water with lower hardness. Furthermore, MF unit can disinfect water or reduce the biological contamination and finally control different types of scaling in any water system such as $CaCO_3$ and $CaSO_4$; thus, eliminating the need for chemical treatment agents as softening or antiscalant agents. So, a comprehensive literature review was conducted at KISR to investigate the effect of MTM on the quality of drinking water and controlling scaling deposition. Although the MTM has been applied as a scale-deposition controlling/preventing tool for 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 MTM 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 widespread since 1975. Fig. 1 shows different types of magnetic devices used in testing the magnetic treatment method.

In 1985, Kronenberg was the first physicist who reported that MTM could prevent the formation of scale even after the MF is removed. Several scientific journal research articles related to MTM were found and reported positive and negative scientific results. The failure of previous researchers to see the effect of MTM could be due to the improper use of

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http://dx.doi.org/10.1016/j.desal.2015.04.023

magnetic equipment. Furthermore, the effectiveness of MTM was found to depend on several parameters such as temperature, type of salt, flow rate, and MF intensity [10]. Grutsch and McClintock concluded that those who approved of the viability of MTM based their approval on proper application or specific experimental procedures. Busch et al. [11] were the first who connected between the changes in voltage or current of solutions passing through MTM devices and the effect of Faraday's law. He also concluded that MF is the reason for suspension of $CaCO_3$ on the solution rather than depositing on the inner surfaces. Martynova et al. [28] found that the MTM of water enlarged the center of the crystals of a certain type of salt. A saturated solution of $CaSO_4$ was tested by Ronald et al. [17] under MF. Results showed that the MTM indeed had a significant effect on the precipitation of $CaSO_4$ crystals, whereas the soluble calcium ion and Zeta potential decreased and the TSS increased. However, most of the experiment related to MTM effectiveness was conducted using a saturated solution of $CaCO_3$. Whereas, Barrett and Parsons [7] test the effectiveness of MTM using a saturated $CaCO_3$ solution and found that MTM accelerates the $CaCO_3$ nucleation crystal growth and yields a new form of crystal morphology, which is aragonite. Gabrielli et al. [18] evaluated the inhibition power of MTM in retarding $CaCO_3$ scaling by measuring the concentration of calcium ion, the scaling time (retention time) and nucleation time of scale deposition. The time required for scaling was found to increase to triple if MTM was applied, and empirical equation was proposed, relating the efficiency of MTM to the length and flow velocity. However, a decree in the metastable zone width was also reported. Kobe et al. [21,22] concluded that the MF can successfully prevent calcite scaling, where the result confirmed that MTM has changed the morphology of crystals forming 90% calcite and 9.6% aragonite without MTM to 28% calcite and 70% aragonite under a MF of 1.22 T. Furthermore, the main conclusion that was drawn from Knez and Pohar [23] experiments was that the MTM clearly promotes the precipitation of aragonite instead of calcite when MF was applied to $CaCO_3$ scaling. Madsen [29] reported that the $CaCO_3$ crystal formed from mixing $CaCl_2$ solution with Na_2CO_3 solution under MTM, results in the crystal-size decrease with increasing strength of the magnetic field. Saban et al. [35] investigated the influence of static 0.75 T MF on the nucleation of $CaCO_3$ crystals, the major finding was that the MF can reduce the size of particles formed, which supports Madsen [29] observations. Kney and Parsons [24] evaluate the MTM using the absorbance of saturated $CaCO_3$ scaling solution to prove the effect of MT in a reproducible result. Alimi et al. [4] confirm the effect of MF on the nucleation and precipitation of $CaCO_3$, through measuring the difference of calcium ion concentration. Permanent magnets of different intensities were used by Tai et al. [42] to investigate the effect of MF on the crystal growth of calcite. The result confirms that the calcite growth rate in the presence of a MF was lower than those in the absence of MF. Alimi et al. [5] proved that MTM affects $CaCO_3$ crystallization by favoring its formation in bulk solution, instead of precipitation on the wall. Stuyven et al. [39] support Alimi et al. hypothesis which refers to the MTM's ability to prevent scale, to its effect on crystal growth and aragonite formation. Furthermore Cefalas et al. [1], Gryta [19], Mwaba et al. [31] and Coey and Cass [13] investigate the morphology of the formed scale from saturated $CaCO_3$, and confirm that MTM promotes the formation of aragonite more than calcite. Lipus in 2007 used a boiler water saturated with $CaCO_3$ and contained magnesium (Mg^{2+}) and iron (Fe^{3+}) ions, to evaluate the effectiveness of MTM for a three-week run by measuring the type and amount of scale precipitated. All of the scales were identified to be aragonite, but in the case of MTM, the scale occurred in much smaller amounts. Ben Salah et al. [8] evaluated the performance of three physical treatment methods such as MTM, ultrasonic field and pulsed electrical field using synthesis brackish water and concluded that MF prevents scaling in desalination by favoring the homogenous precipitation which will precipitate in the bulk solution instead of membrane surfaces. Zinc sulfate solution was also used by Freitas et al. [15], in investigation of MTM effect on crystallization and precipitation. A clear increment of saturation temperature and crystal growth rate was found. Szczes et al. [40, 41] tested an electrolyte solution to prove the effectiveness of MTM in controlling scale, where the solution was exposed to a weak static MF from a stack of magnets (B = 15 mT), at a flow rate of 1.4 ml/s. It was found that the changes in electrolyte conductivity depended on the kind of electrolyte and the magnetic exposure time. Brine solution was also used in evaluating MTM, where Bin et al. [9] used the diffusion coefficient in the evaluation of MTM to prevent scaling deposition in brine solution containing Mg^{2+}, chloride (Cl^{1-}), calcium (Ca^{2+}) and sodium ions (Na^{1+}) in high concentration; the MTM was found to lead to an increase of diffusion coefficients of Mg^{2+}, Na^{1+} and Ca^{2+} ions and a decrease of Cl^{1-} ions. The result confirms that MTM is beneficial for the separation process of brine water from seawater.

The efficiency of MTM in controlling $BaSO_4$ and strontium sulfate ($SrSO_4$) was only reported by Silva et al. [36]. Whereas the efficiency of MTM in controlling the precipitation of $CaSO_4$, $BaSO_4$ and $SrSO_4$ under 25 l/h and a 1.0 T MF was compared and the effect of MTM on $SrSO_4$ was confirmed and a crystal formed was found smaller in size and has more stable dispersion and that effect was maintained for two days or destroyed after heating the solution at 60 °C. The MTM recorded a revolution in solid–liquid separation as reported by Nirschl [32,33], where he confirmed that he could separate between two inorganic components using MF in a magnetic filter. Mergen et al. [30] tested the MF using an ion-exchange resin for the removal of organic material, a high percentage removal was also found.

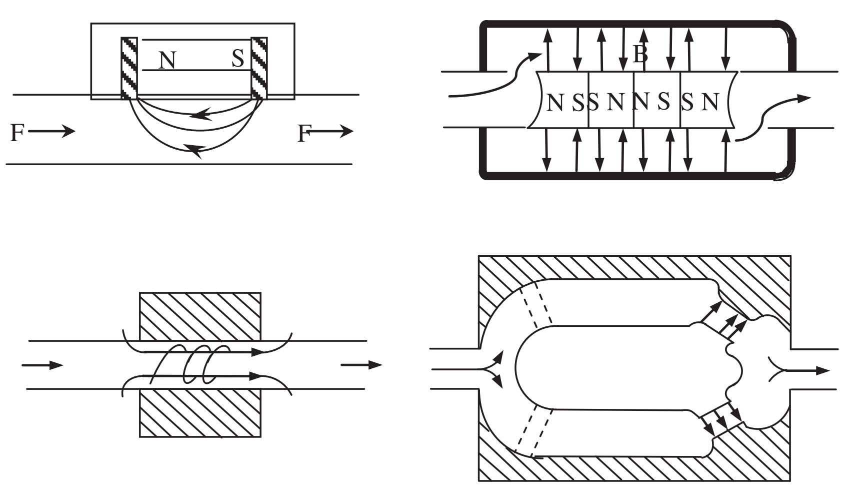

Fig. 1. Different types of magnetic devices used in testing the magnetic treatment method.