

An-Najah National University

Faculty of Graduate Studies

**Optimization of Calcium Sulfate Scale
Reduction Using Magnetic Field.**

By

Nahed Thabet Yousef Sawaftah

Supervised

Prof. Shehdeh Jodeh

**This Thesis is Submitted in Partial Fulfillment of the
Requirements for the Degree of Master of Chemistry, Faculty of
Graduate Studies, An-Najah National University,
Nablus-Palestine.**

2017

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This thesis was Defended successfully on 26/3/ 2017, and approved by:

Defense Committee Members

Signature

1. Prof. Shehdeh Jodeh / Supervisor

.....

2. Prof. Ibrahim Kayali / External Examiner

.....

3. Dr. Iyad Saadeddin / Internal Examiner

.....

Dedication

Every challenging work needs self efforts as well as guidance of
elders

I dedicate my humble effort with a special feeling of gratitude to my
loving parents who gave me the strength and support to continue
without hesitation

To my beloved brother and sisters

To my fiancé and life partner

To all of my friends who encouraged me, along with all hard
working and respectful teachers

To all the martyrs of Palestine

Acknowledgement

Praise be to Allah, the lord of the worlds and peace and blessings of Allah be upon the noblest of the Prophets and Messengers, our Prophet Mohammad.

Foremost, I would like to express my sincere gratitude to my advisor Prof. Shehdeh Jodeh for his professional advice, guidance, and continued support throughout this project. I would like also to express my gratitude and appreciation to Dr. Iyad Saadeddin for his advice in some aspects of my work.

Many thanks to Middle East Desalination Research Center (MEDRC) who funded my project through the Palestinian Water Authority whom our thanks go as well to them for their follow up the project.

I would like to thank all the technicians and staff of the chemistry department at An-Najah National University, especially Mr. Omair Al-Nabulsi and Mr. Nafiz Dweikat for their help.

I would like also to express my thanks to all friends in the master program for the great and lovely time that we spent together.

Last but not the least, I would like to thank my family: my parents Dalal and Thabet Sawaftah, for giving birth to me at the first place and supporting me spiritually and financially throughout my life.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Optimization of Calcium Sulfate Scale Reduction Using Magnetic Field.

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يُقدم لنيل أية درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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List of Abbreviation

Symbol Abbreviation

MT	Magnetic Treatment
[Ca]	Concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water before MT
[Ca][*]	Concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water after one circulation in magnetic field
[Ca]^{**}	Concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water after five circulations in magnetic field
EC	The electrical conductivity of aqueous $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ before MT
EC[*]	The electrical conductivity of aqueous $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation in magnetic field.
EC^{**}	The electrical conductivity of aqueous $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations in magnetic field.
%R	The percentage of reduction under the influence of the magnetic treatment.
%R_[Ca]	The percentage reduction in the concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water under the effect of the magnetic treatment
%R_{EC}	The percentage reduction in the electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water under the effect of the magnetic treatment
pH[*]	pH of aqueous $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation in magnetic field.
pH^{**}	pH of aqueous $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations in magnetic field.
TSS	Total Suspended Solids
X	Parameters for untreated solutions after five circulations

X**	Parameters for magnetically treated solutions after five circulations
S	Standard deviation for non-magnetized $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solutions. n=3
S*	Standard deviation for $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solutions after one circulation in the magnetic field. n=3
S**	Standard deviation for $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solutions after five circulations in the magnetic field. n=3

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Abstract**

Scale formation is caused by impurities being precipitated out of the water directly on pipe surfaces or by suspended matter in water settling out on the metal and becoming hard and adherent. One of the most commonly encountered scale deposits is calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), which is known as gypsum.

In this study, magnetic treatment of water was used as a method to minimize the calcium sulfate dihydrate deposition on the pipe walls using a self-assembled magnetic device in a dynamic fluid system.

The efficiency of the magnetic treatment was evaluated by measuring the concentration, electrical conductivity, pH, and TSS (Total Suspended Solids) of the magnetically treated solutions and comparing the results with untreated solutions.

The efficiency of the magnetic treatment was measured via the percentage reduction in concentration, electrical conductivity, and calcium sulfate dihydrate deposition in the pipeline. The efficiency of the magnetic treatment increases as the percentage reduction increases.

Variations in the efficiency of the magnetic treatment were studied for different calcium sulfate dihydrate solution concentrations; 0.086g/50ml, 0.1291g/50ml, 0.172g/50ml, and 0.2151g/50ml. The efficiency of the treatment was also studied when the number of circulations was changed from one to five circulations in the magnetic device. Different ranges of pH, basic (10-12), acidic (2-4) and neutral (6-7) were used to find the most effective pH medium. Finally, different magnetic field configurations (regular and irregular) were used to figure out which configuration had the highest efficiency. And finally different pipe materials were studied.

The results obtained showed that the efficiency of the magnetic treatment improved when the amount of calcium sulfate dihydrate dissolved was increased. Different results were obtained when the number of circulations was changed from one to five, in which the five circulations had the higher percentage reduction and hence higher efficiency. The magnetic treatment had almost no effect on the pH of magnetically treated solutions. Although, the efficiency was changed when the pH range used was changed. A neat improvement in the efficiency of the magnetic treatment was noticed for irregular configuration when compared with the regular configuration. It was also obtained that the magnetic treatment was more effective when the pipe was made of conducting material such as stainless steel when compared with insulators like glass and polyethylene.

Chapter One

Introduction

1.1. Overview.

Scale deposits by natural water often lead to numerous technical and economical problems in industrial plants and domestic equipment by limiting heat transfer in heat exchangers or blocking the flow of water in pipes.¹

Scale formation on pipe walls and heat exchange equipments is considered a serious problem in almost all water processes. The commonly occurring scales are calcium carbonate, calcium sulfate, magnesium hydroxide, barium sulphate, calcium phosphate, calcium oxalate, etc.²⁻⁶

Being the most common crystal phases of calcium sulfate and calcium carbonate, gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and calcite (CaCO_3) are two major potential scalants. Calcite scaling can be prohibited by lowering the pH level (e.g., $\text{pH} = 5.6$) of the solution, while gypsum is not as sensitive as calcite to the pH values.⁷

Calcium sulfate is one of the most commonly encountered scale deposits and occurs in three different crystalline forms; calcium sulfate dihydrate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$; calcium sulfate hemihydrate (plaster of Paris), $\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$; and calcium sulfate anhydrite (CaSO_4).⁷

The precipitation of calcium sulfate hydrates is of particular interest because of their importance in many scale/ deposit control applications such as geothermal, oil production, cooling water and reverse osmosis-based systems.⁸⁻¹⁰

1.2. Background.

The precipitation and deposition of calcium sulfate dihydrate on brass heat exchanger surfaces from aqueous solutions have been studied using highly reproducible techniques. It has been found that gypsum scale formation takes place directly on the surface of the heat exchanger without any bulk or spontaneous precipitation in the reaction cell.³

With increasing temperature, the solubility of all calcium sulfate forms decreases. This is the cause of calcium sulfate scale formation on heat transfer surface.¹¹

The scale will decrease the cross-sectional area of the pipe and reduce the flow quantity of the water, even block up the channel and reduce the heating/cooling effect as a result.

In general, the scale has a great influence on the industrial process, environment safety, and economic benefits. Hence, it is of vital importance to establish appropriate methods to study this phenomenon and find effective ways to prevent or combat it.¹²

Over the years, several chemical scale reduction techniques have been proposed, including the use of acid, chelant, ion exchanger, or inhibitors. Such techniques are effective, but they could be expensive and can substantially change the water chemistry.¹³

The inhibition efficiency performance of chemical scale inhibitors could be significantly affected by a number of factors such as the changes in environmental conditions like pH, temperature, fluid hydrodynamics, and the presence of other chemicals and brine composition. Factors such as brine super saturation and the presence of divalent cations, such as Ca^{2+} and Mg^{2+} ions or even Zn^{2+} , can lead to incompatibility between the brine system with the chemical, hence reducing its concentration in solution and its scale inhibition performance.¹⁴⁻¹⁷

Also, due to various environmental and health related problems, strict international laws were imposed. Reducing their use and therefore increasing the need for the development of other environmentally friendly methods to supply the lack in this area.¹⁸

Physical water treatment methods do not change the potability of water. So they could be used safely. One such method involves subjecting the process fluid to a magnetic field.²

It is generally believed that subjecting a fluid to a magnetic field eliminates or minimizes deposit formation on heat transfer surfaces.¹³

Also, many studies stated that the magnetic treatment of fluids does seem to affect the scale precipitation; in terms of effects on nucleation and growth. Positive results indicate effects on (a) colloidal systems where aggregation is generally enhanced and (b) crystallization where larger hydrophilic crystals, usually with modified crystal growth, are generated.¹⁹

However, reported magnetic treatment (MT) effects are sometimes not consistent or not reproducible. This is probably due to variations in water composition, differences in the course of the treatment and due to the processes complexity.²⁰

In this study, aqueous solutions of calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) were subjected to a magnetic field produced by a self-assembled magnetic device, to study the effect of the magnetic field with different intensities on calcium sulfate dihydrate precipitation and solubility.

The effect of the magnetic field was studied in different conditions including; treatment-pH (acidic, basic and neutral mediums), different treatment time corresponding to single and multiple circulations through the magnetic field, different concentrations of calcium sulfate dihydrate and different pipe materials. Volumetric and gravimetric analysis of scaling species were used to evaluate the efficiency of the magnetic treatment.

1.3. Objectives

1.3.1. General Objective

Generally, this project aims to study the effect of the Magnetic field treatment on calcium sulfate dihydrate solubility and its ability to minimize the calcium sulfate dihydrate deposition on the pipe walls

1.3.2. Specific Objectives

- ❖ Study the effect of magnetic field on calcium sulfate dihydrate concentration and solubility
 - a. When different amounts of calcium sulfate dihydrate were dissolved in water using self-assembled magnetic device.
 - b. When the number of circulations was changed from one to five circulations in the magnetic device.
 - c. When the pipe material was changed.
- ❖ Study the effect of magnetic field on calcium sulfate dihydrate deposition on the pipe walls in state of different water pH, and different intensities of the magnetic field.

1.4. Overview of Thesis

Chapter two will consist of a literature review of previous research on the subject. Chapter three will provide a detailed explanation of the procedures used for the thesis's experiments. The following chapter, will consist of the results, and data analysis obtained from the lab work, and a discussion of what has been derived from these

results. A conclusion to the study and an insight into further research that could be continued in this field.

Chapter Two

Literature review

2.1. Scale Formation.

Scale formation is the deposition of sparingly soluble inorganic salts from aqueous solutions. Scale can deposit on almost any surface so that once a scale layer is formed, it will continue to get thicker unless treated. Mineral scale is one of the leading problems in the oil and gas industry.

Next to corrosion and gas hydrates, scale is probably one of the biggest water-related production problems, and for some fields, scale control can be the single biggest operational cost. It can block pore throats in the near well bore region or in the well itself causing formation damage and loss of well productivity. It can form a layer on well equipment surfaces, such as electric submersible pumps or sliding sleeves, manifold, causing malfunctions. Mineral scale can occur anywhere along the production conduit narrowing the internal diameter and blocking flow, scale can also form in production and processing facilities. Similar complications are observed in seawater desalination processes or industrial wastewater treatment. The type of scales depends on the chemical composition of water, for instance, in oil field formation water the concentration of Ca^{2+} , Ba^{2+} , Sr^{2+} , Fe^{2+} , HCO_3^- and SO_4^{2-} ions is frequently higher than that in seawater.^{19,21,22}

Scale precipitation occurs whenever process conditions lead to the creation of super saturation with respect to one or more of the sparingly soluble

salts. This difficulty is encountered in both evaporation and membrane desalination processes. Unless preventive measures are undertaken, the concentration effect involved in every desalination process induces precipitation of sparingly soluble salts such as CaCO_3 and CaSO_4 .²³

Scale formation comprises complex phenomenon involving both crystallization and transport mechanisms. Thermodynamically, crystallization or precipitation becomes feasible when the activity of ions in solution is above their saturation limit and the solution is supersaturated.

In addition to super saturation conditions, kinetics of precipitation should also be considered as it is a key determinant of the severity of scaling. When super saturation exceeds a critical value, nucleation of scale formation on particle surfaces induces growth of crystals, and low concentration of nucleation sites slows crystallization kinetics. Scale formation was reported to occur by two crystallization pathways, surface (heterogeneous) crystallization and bulk (homogeneous) crystallization.²⁴⁻²⁶

Scaling in pipe systems is a combination of these two extreme mechanisms and is affected by process conditions in the pipe. Surface crystallization occurs due to the heterogeneous crystallization of the scale deposit on the pipe surface, resulting in pipe blockage. Bulk crystallization arises when crystal particles are formed in the bulk phase through homogeneous crystallization and may deposit on pipe surfaces as sediments/ particles to form a cake layer that leads to flux decline. In addition, supersaturated scale forming conditions leads to scale growth and agglomeration.^{5, 27}

2.1.1. Scale Forming Mechanism

The mechanism of scale formation may be summarized in the following steps.

2.1.1.1. Aggregation.

The most important factor determining the intensity of scaling is the super saturation level of the deposit-forming species. After a super saturation system is established first, cationic and anionic species, such as Ca^{+2} and $\text{CO}_3^{-2}/\text{SO}_4^{-2}$, collide to form ion pairs in solution. These pairs then go on to form micro-aggregates which are small centers of crystals, embryos, micro-nuclei or seeds.

2.1.1.2. Nucleation.

Some of these micro-aggregates go on to become nucleation centers for crystallization which leads to the formation of micro-crystals. Their formation is facilitated by the presence of a deposition surface so that in all practical systems nucleation can be assumed to be of a heterogeneous nature.

2.1.1.3. Crystal growth.

Microcrystals are formed in solution, which agglomerate and/or absorb to surfaces to grow into larger microcrystals and eventually fuse to form adherent macrocrystals.

2.1.1.4. Agglomeration.

These macrocrystals continue to grow through the adsorption of additional scaling ions from solution and eventually form the beginning of a scale film on a surface. Once an initial scale film is formed, subsequent deposition is facilitated.²⁷

Growth of a crystal layer on a flow surface involves several consecutive processes:

1. Diffusional transport of the crystal-forming ions towards the crystallizing layer.
2. Incorporation of the ions on growth sites of the crystal lattice.
3. Adhesion and removal processes.²³

Various operating conditions such as pH, temperature, operating pressure, permeation rate, flow velocity, and presence of other salts or metal ions can influence scale formation.²⁸

2.2. Calcium Sulfate Scale.

2.2.1. Calcium Sulfate Dihydrate (Gypsum).

Calcium sulfate minerals (CaSO_4) precipitates in three crystallographic forms: gypsum or calcium sulfate dihydrate form, plaster of Paris or calcium sulfate hemihydrates and calcium sulfate anhydrite.^{11, 28}

calcium sulfate dihydrate, ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is the most abundant natural sulfate. It is widely present in the earth crust and plays important roles in various geological (for instance crustal deformation dynamics) and environmental (for instance the global distribution of Ca^{2+} and SO_4^{2-}) processes. Gypsum is also heavily used in industry, mainly in cement industry as a conditioning agent. The setting time of cement is controlled by the addition of gypsum to the clinker during the grinding process.

The hydrated gypsums have many beneficial properties, such as heat and sound insulation, fire resistance, waterproof ability, etc. Due to these magnificent properties, gypsums are being used in plaster, plaster boards, dental models, surgical casts, and paint fillers. Gypsum plaster is predominantly used in building construction for pastes, mortars, masonry blocks, ceiling boards, and decorative elements. Moreover, gypsum is used as a fertilizer to supplement calcium and as a ground material to improve alkaline soil.^{29, 30}

Gypsum is also obtained as a by-product of various chemical processes. The main sources are from processes involving scrubbing gases evolved in burning fuels that contain sulphur, such as coal used in electrical power generating plants, and the chemical synthesis of chemicals, such as sulfuric acid, phosphoric acid, titanium dioxide, citric acid, and organic polymers.²⁹

2.2.2. Calcium Sulfate Dihydrate Scale Formation.

Calcium sulfate dihydrate or gypsum is the most common scale among the non-alkaline scales. Calcium sulfate scaling is a major issue in applications such as desalination, geothermal energy production, and petroleum engineering.³⁰

Large quantities of gypsum are produced as a byproduct in the production of phosphoric acid. Gypsum is also the most unwelcome scalant in the production of oil and gas, in water cooling towers, in hydrometallurgical processes, etc. This type of scale can cause severe plugging of equipments and producing formations; it creates the necessity of costly remedial work.^{31, 32}

Calcium sulfate scale formation may have several disadvantages: in particular, when scales crystallize on heat transfer surfaces, they offer a resistance to the heat flow and can accumulate in pipelines, orifices and other flow passages seriously impeding the process flow. Moreover, calcium sulfate scales, together with calcium carbonate scales, are the major cause of fouling in reverse osmosis membranes, resulting in a continuous decline in desalted water production thus reducing the overall efficiency and increasing operation and maintenance costs.²⁹

2.3. Scale Reduction Techniques.

Scale deposition may be prevented by, controlling pH, using chelating agents, and using the “threshold effect” to prevent nucleation. Control of pH is limited to disposal wells, injection wells and surface equipment where acid can be used to lower the pH of the injection water. This type of treatment stabilizes the bicarbonate and bisulfate by lowering the pH. However, lowering the pH tends to establish a corrosive environment.

Chemical methods of scale control or water softening involve either the pre-precipitation of scale causing ions (a homogenous nucleation/coagulation in bulk water) into fine suspended particles that later in critical regions, the addition of scale inhibiting reagents or the replacement of the scale former with soluble ions by ion exchange.

All of these methods, though effective in scale control, substantially change the solution chemistry. Many chemicals that will prevent scale deposition will not remain in the formation long enough to make them economically feasible as inhibitors and can be prohibitively expensive. The environmental concerns have led to the development of alternative physical means for hard-scale prevention: by the usages of permanent magnets, electromagnetic coils, electrodes, and ultrasonic pre-treatment.^{19,33}

2.4. Magnetic Treatment.

Magnetism is a unique physical property that independently helps in water purification by influencing the physical properties of contaminants in

water. In addition, its combination with other processes enables an improvised efficient purification technology.³⁴

This physical treatment helps to avoid the use of chemicals such as polyphosphates corrosive substances, which are expensive and can be harmful to human life or disruptive to the environment.³⁵

Magnetic field has been used as aids for many purposes, such as in plant growth development.^{36,37} It was also found that when water was magnetized and used in concrete instead of normal water, the compressive strength of concrete was increased considerably.^{38,39} Other studies were more concentrated on the enhancement of biological treatment of wastewater by magnetic field,^{40,41} and advanced oxidation process.^{42,43}

Magnetic treatment methods have been studied and have been available for the past few decades as an alternative to chemical methods to prevent and control scale formation. In 1873, A.T. Hay received the first US patent for a water treatment device that employed a magnetic field. Today, many of these devices are commercially available.⁴⁴

The simplest unit may consist of no more than one magnet externally mounted around a water pipe. In some, the magnet is located inside the pipe through which the treated water flows.⁴⁵

Commercial magnetic treatment devices (MTD's) are available in various configurations from numerous manufacturers, some using electromagnets and others using single or arrays of permanent magnets with many different

orientations of magnetic field. Some MTD's are intrusive (i.e. plumbed in, and therefore have to satisfy relevant legislation) or non intrusive (i.e. clamped on) and the cost of the unit varies with size up to thousands of pounds. Some units employ a field that is orientated approximately orthogonal to the direction of flow whilst others employ a mostly parallel field.¹⁹

2.4.1. Magnetization and Exhibition of Magnetic Field

Particles or molecules can be categorized as positively charged (positive χ) or negatively charged (negative χ), where χ is their magnetic susceptibility. Their magnetization M can be expressed as

$$M = \chi v \cdot H \quad \text{Eq(1)}$$

Where H is an applied magnetic field in emu/cm³, M is magnetization of a particle after exposure to H , and χv is a measured magnetic susceptibility of the molecules' electrons due to the magnetization.

Molecular substances can also be classified as polar or nonpolar. Both polar and nonpolar molecules are illustrated in Figure 2.1. In the absence of magnetic field, polar molecules are positioned randomly.

However, when the samples are exposed to a magnetic field of certain intensity, the polar molecules are easily aligned in accordance with their positive and negative charges. Meanwhile, nonpolar molecules in the absence of a magnetic field move continuously at random because the positive and negative charges coincide in the centers of molecules. This

inhibits coagulation. However, under the influence of a magnetic field, the positive and negative charges can be separated. The molecules are aligned in accordance with the direction of the magnetic field. With the resulting alignment, as shown in Figure 2.1, the molecules are in an orderly arrangement, causing the particles to coagulate and aggregate. In addition, the number of dipoles pointing in the direction of the field increases with increasing field strength. This makes it more likely that the particles coagulate and that uncommon or unnecessary particles or pollutants can be removed.³⁵

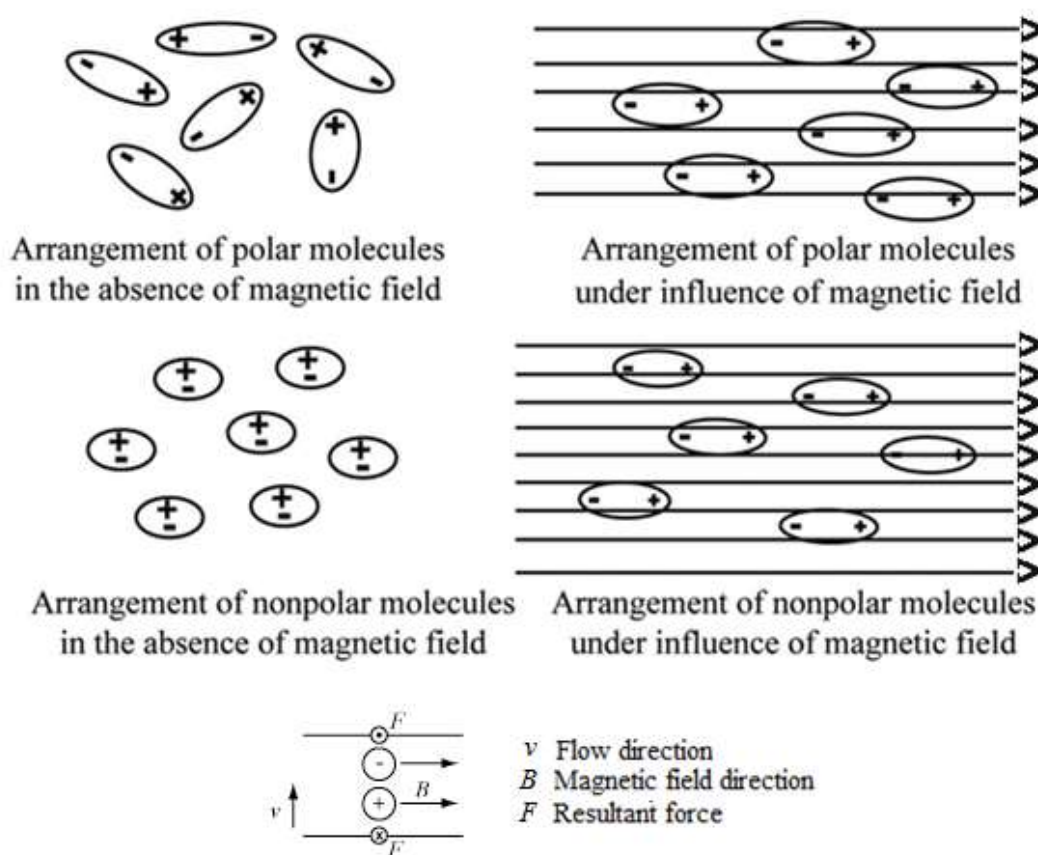


Figure 2.1: Effect of a magnetic field on polar (top) and nonpolar (bottom) molecules.³⁵

2.4.2. The mechanism of Magnetic Water Treatment.

The principle of operation of existing magnetic devices is based on the influence of the exposed magnetic field to the dissolved hydrated metal cations that leads to a change in the rate of electrochemical coagulation and aggregate stability of dispersed charged particles in a liquid stream and to formation of multiple nucleation sites on the particles of fine dispersed precipitate consisting of crystals of substantially uniform size.

Several processes occur during the magnetic water treatment:

- Enhancement in the nucleation rate of the dissolved salts in water.
- Changing in precipitation and deposition rates of dispersed particles in the solution treated by the magnetic field.
- As a result, the dissolved salts will lose their ability to form a dense deposit.

Anti-scale effect under the magnetic water treatment depends on the composition of the treated water, the magnetic field strength, rate of water movement. It also depends on the state of the scaling solution, static or dynamic, and the duration of its stay in the magnetic field.^{35,46-48}

A number of mechanisms have been proposed to explain magnetic field (MF) effects on aqueous solutions and particle dispersions. Although it is almost certain that there are influential factors that are

unrecognized. At the present time, the majority of the researchers have suggested that the main mechanism in the dynamic state is magnetohydrodynamic “MHD” phenomena in which Lorentz force effects on ions and dispersed particles.^{46,47,49,50}

2.4.3. Lorentz Force.

Lorentz force affects charged particles moving through a magnetic field. The force increases linearly with particle charge, the particle velocity, and the orthogonal vector component of the magnetic field strength.¹⁹ As shown in Figure 2.2, when charged particles flow in the direction perpendicular to the direction of the magnetic field in the same plane, they produce a Lorentz force that is also perpendicular to the direction in which the charged particles flow and the magnetic field direction.^{19,35,51} The Lorentz force has been proven to promote enhancement of water-related mechanisms, including dissolution enhancement, crystallization nuclei formation, stabilization of coordinated water, and double layer distortion.^{35,46,54}

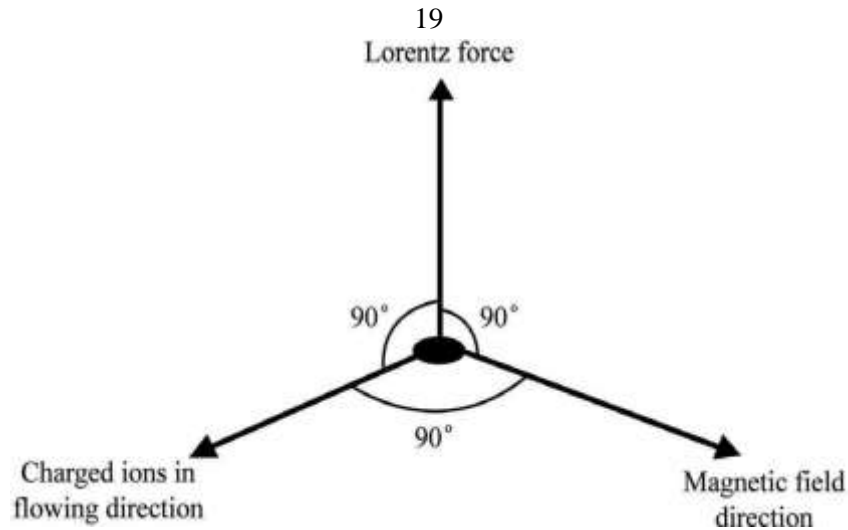


Figure 2.2: The Laplace-Lorentz force on a moving charged ion is at right angle of both the ion flowing direction and the magnetic field direction.³⁵

Lorentz force is commonly exemplified by the phenomenon of electrical generators as shown in Figure 2.3. This figure indicates that when a wire carrying an electrical current I is placed in a magnetic field B , each of the moving particle charges comprising the current can experience the Lorentz force F . Lorentz force is generated when charged particles moving through the magnetic field. The magnitude of this force is defined as follows:

$$|F_L| = q|v \times B| = qvB \sin \theta \quad \text{Eq(2)}$$

where, F_L is the Lorentz force, q is the quantity of charged species, v is the velocity of particles, B is the magnetic field, and θ is the angle between v and B vectors. 53

The induced Lorentz force creates a macroscopic force on the wire that is responsible for the motional electromotive force (EMF), the force underlying many electrical generators. When a conductor is moved through a magnetic field, the Lorentz force tries to push electrons through the wire, creating the EMF. This phenomenon has been applied in the development

of a magnetic treatment device (MTD) in water applications to inhibit lime scale deposition on pipe wall.^{35, 46, 53}

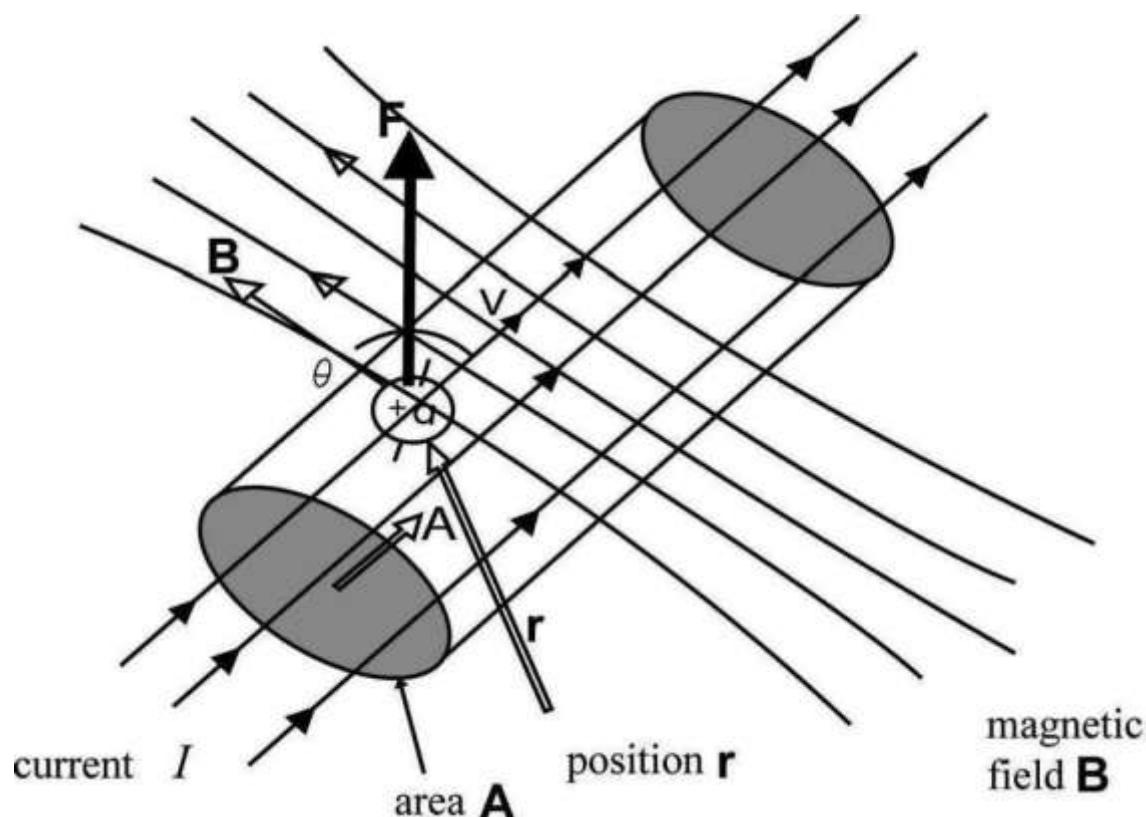


Figure 2.3 an electric wire with cross-section A flown by a current I is submitted to a force F when placed into a magnetic field B .³⁵

2.5. Types of Magnets

The intensity of magnetization of a separator can be enhanced by variation in magnet type used. There are three categories of separators based on magnet type: permanent magnet-based, electromagnet-based and superconducting magnet-based.

Permanent magnets have been prepared from ferromagnets of iron-based, nickel-based, cobalt-based or rare earth element-based compounds. Traditionally permanent magnets were considered weak intensity magnetic forces generating fields of less than 1 T. However with the advancement in

materials development and shape design parameters information; high intensity magnetic field strengths could be generated.⁵⁴⁻⁵⁷ In this regard multipole magnets find considerable advantages since it can generate fields greater than 2 T per unit length. The developments in this field helps to offer reduction in operational cost related to other types of magnets since no electricity would be utilized for generation of magnetic field.

In case of electromagnets, there is a solenoid of electrical conducting wires which generate magnetic field within their cavity on passage of electric current.^{58,59} the space of solenoid for linear, annular and different shape designs have been developed depending on the application. The electromagnets generate maximum field of 2.4 T.

The third category of magnetic separators is based on superconducting magnets which generate the highest intensity magnetic field.^{60,61} Superconducting magnets are capable of generating magnetic field from 2 to 10 T.³⁴

2.6. Application of Magnetic Treatment on Scale Causing Minerals

CaCO₃ scale deposition causes damages and operational issues such as pipe blocking, membrane clogging, and efficiency decay in heaters or heat exchangers. Various methods have been used to prevent scaling, which include water decarbonization through electrochemical processes, seeding or acid addition, and the addition of chemical inhibitors. However, these chemical are deleterious to human health, and their use is forbidden in

drinking water. Therefore, physical methods have been developed to avoid the addition of these chemicals; magnetic treatment of hard water is one of the methods currently used to prevent incrustation by these mineral salts.⁴⁹

Previous studies showed that the Magnetic treatment (MT) affects calcium carbonate crystallization, precipitation type (homogeneous and heterogeneous) and solubility by increasing the total precipitate quantity and by favoring its formation in the bulk solution instead of its incrustation on the walls. And it increases the amount of aragonite in the carbonate deposits.^{49,61,63}

Experiments conducted on calcium carbonate solutions after being affected by the magnetic field showed that the efficiency of the magnetic treatment differentiate according to calcium carbonate water concentration, treatment-pH, the pipe material, the surface roughness, water flow rate, and the length of treatment in the magnetic field.^{1,50,64,65}

Magnetic scale prevention may include several mechanisms, depending on the state of the scaling solution, static or dynamic. the majority of the researchers have suggested that the main mechanism in the dynamic state is magnetohydrodynamic “MHD” . For this mechanism to be used, the magnetic field should be perpendicular to the flow of the solution, the fluid should flow as fast as possible, and the space between magnets should be as narrow as possible.

Till now, most of the investigations were interested in how the magnetic fields affect the calcium carbonate (CaCO_3).^{49,62,63} This is not surprising

since CaCO_3 is one of the two most commonly encountered scale-causing salts, the other being CaSO_4 .

Previous Study on the effect of magnetic field on calcium sulfate crystal morphology suggested that subjecting a magnetic field affects the direction of the crystal growth, possibly increasing the growth rate in one direction and suppressing it in the other directions. This may lead to weaker crystals that may easily be swept away by fluid shear forces. Alternatively, the large surface area may promote bulk crystallization providing preferential sites for crystal growth. The overall result is a reduction in scale formation on heat transfer surfaces.¹³

Another study was published in early 1995 which used a nuclear magnetic resonance spectrometer to produce a magnetic field of 4.75 T intensity, and 1200 rpm rotation speed. Results showed that the magnetic treatment indeed had a significant effect on the precipitation of CaSO_4 crystals. Conductivity, soluble Ca, and ζ -potential all decreased, whereas TSS increased. A transfer of Ca from the soluble to the solid phase (crystal as $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) was confirmed by mass balance calculations. Thus the results are consistent with claims in the literature that magnetic water treatment can induce precipitation of inorganic crystals from solution, and could possibly prevent scaling by avoiding precipitation of these salts on to solid surfaces.⁶⁶

This study will concentrate on the effect of the magnetic field on the solubility and crystal deposition of calcium sulfate dihydrate on the

pipe walls via changing the amounts of calcium sulfate dihydrate dissolved, and also by changing the pH and the magnetic field intensity used.

Chapter Three

Experimental Part

3.1. Chemicals and Materials

All the chemicals in the experimental part were used with no further purification. $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (from Sigma-Aldrich, purity more than 99%). The solvent used was distilled water. For pH adjustment, 0.1M NaOH and 0.1M HCl were used.

In the volumetric analysis, EDTA (Ethylenediaminetetraacetic acid) and $\text{ZnSO}_4 \cdot 8\text{H}_2\text{O}$ were used for standardization; solid Eriochrome Black T and Hydroxyl naphthol blue were the indicators. 1M KOH and ammonia solution were used as buffers. The instruments used were glassware, pH meter (model: 3510, JENWAY), conductivity meter (model: 3130, JENWAY), digital gaussmeter (model: DGM-102), hotplate, magnetic stirrer, desiccators, balance, oven (model: LDO-060E, LabTech).

3.2. Preparation of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Solutions.

To prepare $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution, different weights (0.086g, 0.129g, 0.172g, and 0.215g) of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ were dissolved in 50ml of deionized water in pH range 6-7 at ambient temperature.

Each solution, unless specified, contained calcium sulfate dihydrate only, in order to avoid any side effect from foreign ions.

3.3. Assembling of the Magnetic Treatment Device.

The magnetic device used, consisted of a series of five pairs of permanent magnets with north and south poles facing each other to produce an alternating constant magnetic field. A stainless steel pipe, total length 130 cm, and 6mm diameter was placed in the middle of the magnetic field as shown in Figure 3.1.

$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution was circulated through the pipe inserted between the polar pieces. In this configuration, the magnetic induction is perpendicular to the solution flow. Each polar piece was assembled of rectangular permanent magnets (40-20 mm² and 2 mm thick). The magnetic field intensity was controlled by the number of magnets used in each side of the polar pieces; the magnetic field intensity increased as the number of magnets used increased.

The magnetic circuit of all of the pairs of magnets were partially closed by U-shaped piece of mild steel, to close the magnetic field in the gap. The various pairs were separated by 12 mm.

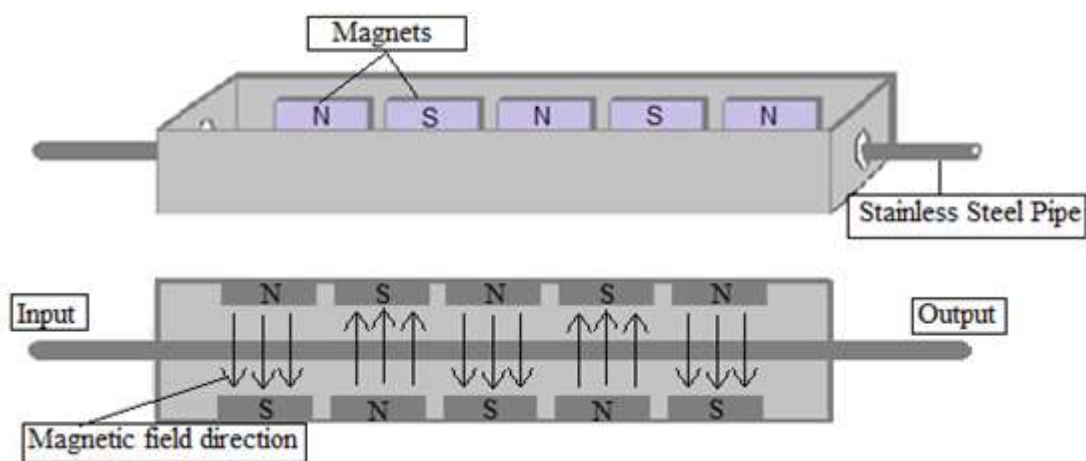


Figure 3.1: Scheme of the magnetic device with alternated polar pieces.

The effectiveness of the magnetic treatment was tested through the volumetric analysis of the concentration of calcium $[Ca]^{2+}$, electrical conductivity and TSS with and without the magnetic treatment, number of circulation in MT device, pH of the medium, and the intensity of the magnetic field.

For the magnetic field to be effective, the concentration $[Ca]^{2+}$ electrical conductivity (EC) and the deposition of calcium sulfate dihydrate (measured by the TSS) on the pipe walls must decrease.

The effect of the magnetic treatment was measured through the following equation.

$$\%Reduction = \frac{[x]^* - [x]}{[x]} \times 100 \quad \text{Eq.(1)}$$

Where $[x]^*$ and $[x]$ refers to the concentration, electrical conductivity and total suspended solids of $CaSO_4 \cdot 2H_2O$ in presence and absence of magnetic field respectively.

Eq.(1) was used in all the experiments to find the efficiency of the magnetic treatment.

3.4. Effect of the Magnetic Treatment After One Circulation.

Measurements were carried out the magnetic intensities shown in Figure 3.2, pH range 6-7 and ambient temperature.

Each $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution was circulated one time through the magnetic device. The flow speed for each solution was 0.201 L/s. For each solution, the pH value, electrical conductivity (EC), and calcium concentration $[\text{Ca}]^{2+}$ were measured. In the same manner, similar solutions were passed through the pipe without being affected by the magnetic field.

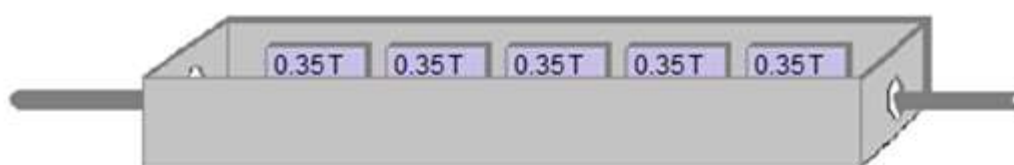


Figure 3.2: Scheme of the MT device with the intensities of the polar pieces used in parts from 3.4 to 3.6.

3.5. Effect of the Magnetic Treatment after Five Circulations.

Measurements were carried out at constant magnetic field intensity shown in Figure 3.2, pH range 6-7 and ambient temperature.

Each $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution was circulated five times with a flow speed of 0.201 L/s for each circulation with the configuration shown in Figure 3.2. For each solution, the pH value, electrical conductivity (EC), and calcium concentration $[\text{Ca}]^{2+}$ were measured. In the same manner, similar solutions were passed five times through the pipe without being affected by the magnetic field.

Each experiment was repeated six times, three under magnetic exposure and three without exposure. A comparison was made between the one and five times circulated solutions to obtain the relation between the number of circulation and the efficiency of the magnetic treatment (MT) in reducing the concentration and the electrical conductivity of calcium sulfate dihydrate solutions.

The concentration and the number of circulation that showed the highest efficiency were determined, and used in the following experiments.

3.6 Effect of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Electrical Conductivity Versus Time.

$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution was prepared, circulated five times in the magnetic device shown in figure 3.3 with a flow speed of 0.201 L/s for each circulation, the electrical conductivity was measured every 5 minutes until both magnetically treated and untreated solutions had reached the same value. The electrical conductivity of soluble ions versus time is used as an indicator for scaling deposition versus time.

3.7 Effect of the pH value on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Deposition on Pipe Walls under the Magnetic Treatment.

The previous experiments were used to define the weight that showed the highest reduction in the concentration and electrical

conductivity. After that new solutions were prepared at different pH values and circulated in the magnetic field.

Only 0.215 g/50ml solution was studied, since it showed the highest reduction. The magnetic field was produced using the configuration shown in Figure 3.3. Since the electrical conductivity results were affected by the ions of HCl and NaOH used to adjust the pH. The electrical conductivity measurements were higher when compared with the previous results.

Each solution was circulated in the magnetic field five times, filtered, its pH, EC, and $[Ca]^{2+}$ were measured.



Figure 3.3: scheme of the regular magnetic device used to study the efficiency of the magnetic treatment in different pH values

For the TSS to be measured the filter paper was kept to dry over night, weighed, dried in the oven at 90 C° for 30 min, cooled in the desiccators and weighed again, this part was repeated multiple times until constant weight was reached then TSS was calculated using the following equation.

$$mg \text{ total suspended solids}/L = \frac{(A - B) \times 1000}{\text{sample volume (L)}}$$

Where:

A = weight of filter + dried residue, mg, and

B = weight of filter, mg.

3.7.1. Effect of Neutral Medium.

0.215 g/50ml was prepared in neutral medium using distilled water. After that, the solution was treated by the magnetic device, filtered and its pH, EC, $[\text{Ca}]^{2+}$, and TSS were measured and compared with solutions that were not affected by the magnetic field. The pH was in the range 6-7.

3.7.2. Effect of Acidic Medium.

0.215 g/50ml was prepared in acidic medium using 0.1 M HCl to adjust the pH. After that, the solution was treated by the magnetic device, filtered and its pH, EC, $[\text{Ca}]^{2+}$, and TSS were measured and compared with solutions that were not affected by the magnetic field. The pH was in the range 2-4.

3.7.3. Effect of Basic Medium.

0.215 g/50ml was prepared in acidic medium using 0.1 M NaOH to adjust the pH. After that, the solution was treated by the magnetic device, filtered and its pH, EC, $[\text{Ca}]^{2+}$ and TSS were measured and compared with solutions that were not affected by the magnetic field exposure. The pH was in the range 10-12.

3.8 Effect of the Magnetic Treatment in State of Variance Magnetic Field Intensities.

In this part, the magnetic field intensity was changed and a comparison was made between the irregular magnetic field intensity

used before with another regular configuration. The intensity of the magnetic field was changed via changing the number of magnets used. The chosen magnetic intensities are shown in figure 3.4.

3.9 Effect of the Material of the Pipe.

So far, only stainless steel pipe was used to test the efficiency of the magnetic treatment. However, changing the material of the pipe could change the treatment efficiency.

In this section, a comparison was made between stainless steel, glass, and polyethylene pipes.

For each one of these pipes 0.215g/50ml solutions were prepared and circulated five times in the magnetic device illustrated in figure 3.4.C. For each solution the concentration and the electrical conductivity were measured and compared find the most effective material.

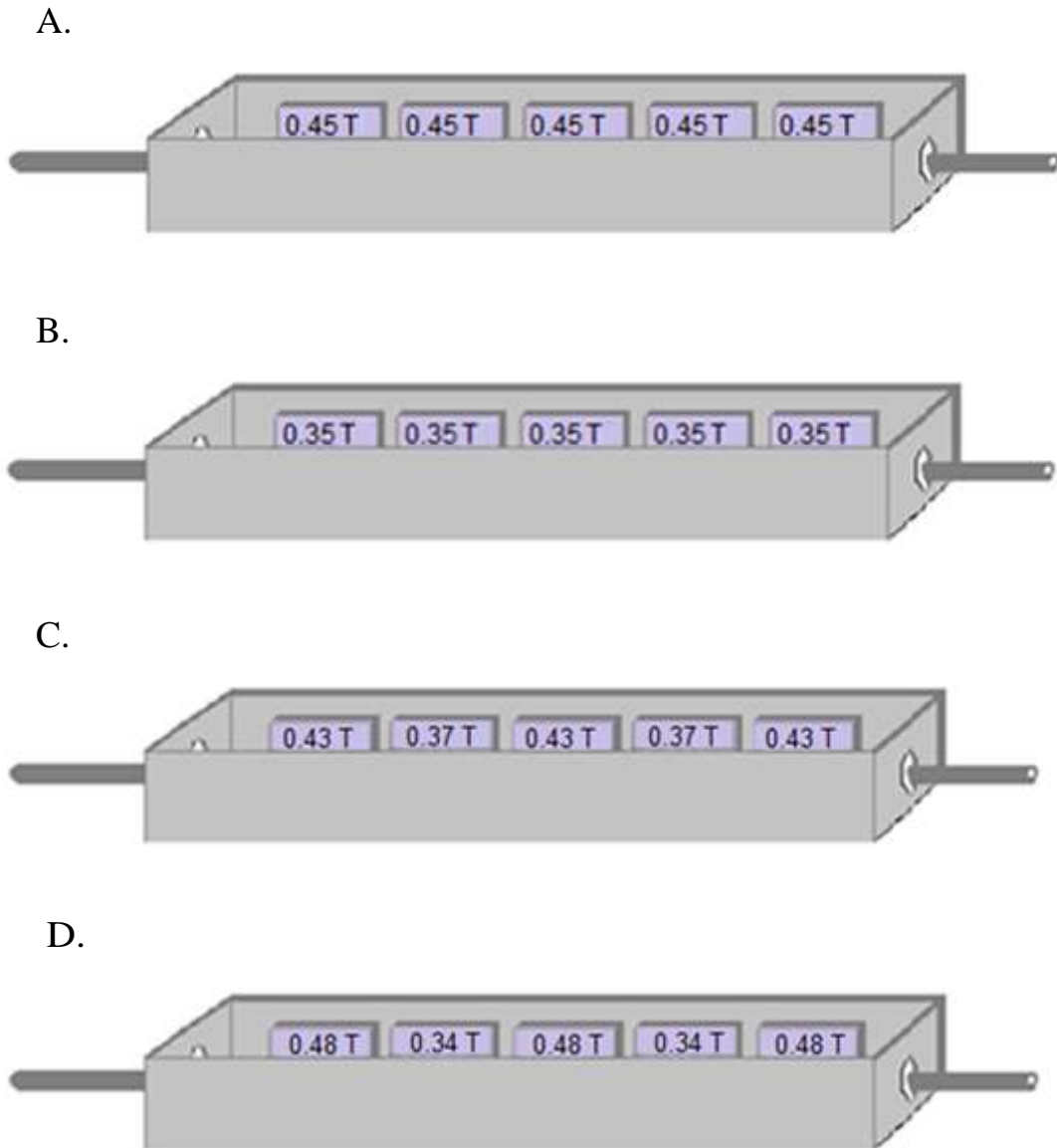


Figure 3.4: **A.** The configuration of regular magnetic device with a steady magnetic intensity of 0.45T. **B.** The configuration of regular magnetic device with a steady magnetic intensity of 0.35T. **C.** The configuration of irregular magnetic device which starts with 0.43T and followed by 0.37T. **D.** The configuration of irregular magnetic device which starts with 0.48T and followed by 0.34T

Chapter Four

Results and Discussion

4.1 Efficiency of the Magnetic Treatment for Different Aqueous Solutions of Different $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Concentrations.

The calcium concentration $[\text{Ca}]^{2+}$, electrical conductivity, and the pH value for different calcium sulfate dihydrate solutions were measured in presence and absence of Magnetic Treatment, to provide information about the efficiency of the magnetic treatment in state of variance amounts dissolved.

4.1.1 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Concentration after One Circulation.

Experimental results shown in Figure 4.1 illustrate the magnetic treatment effect on the solubility of calcium sulfate dihydrate in water. Under the effect of the magnetic treatment, $[\text{Ca}]^{2+}$ decreased when the amount of calcium sulfate dihydrate dissolved increased. Whereas the concentration increased with increasing the amount of calcium sulfate dihydrate dissolved when no magnetic field was applied.

The decrease in the concentration of calcium indicates a decline in the solubility of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water, and increase in the rates of nucleation instead of crystal growth which cause the precipitation of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

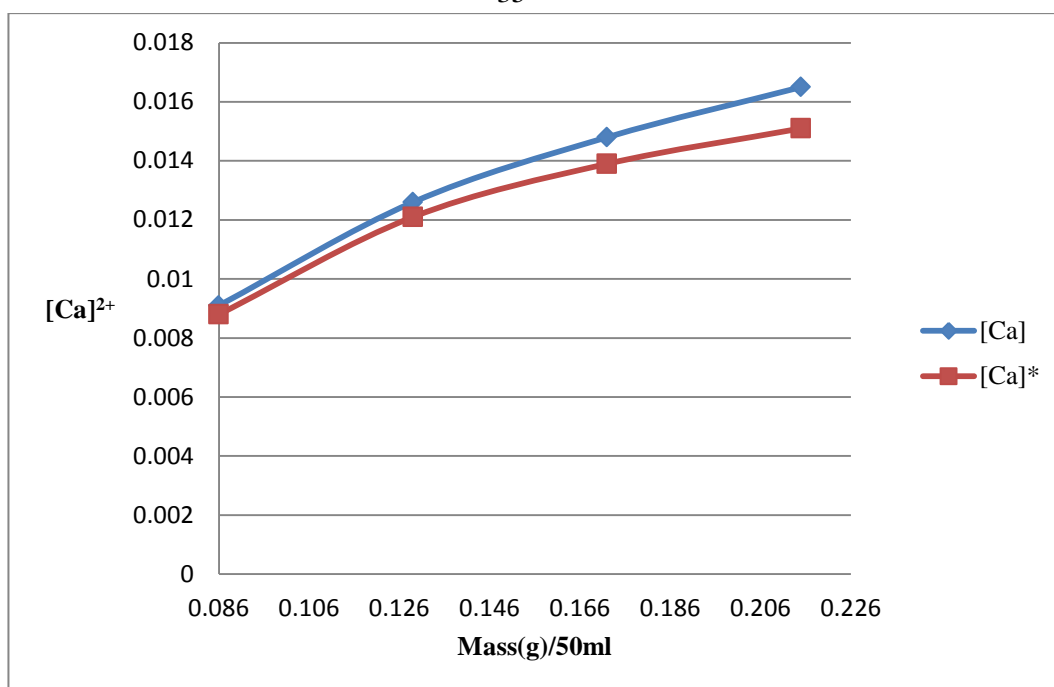


Figure 4.1: The effect of the magnetic treatment on $[\text{Ca}]^{2+}$ of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation. $[\text{Ca}]^*$ and $[\text{Ca}]$ are the concentrations of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation with and without the magnetic field treatment respectively.

Table 4.1 shows that the efficiency of the magnetic treatment increased from 3.29% to 3.97% when the calcium sulfate dihydrate mass was doubled from 0.086g to 0.129g, respectively. And the highest efficiency obtained was 8.98% when 0.215g was dissolved in 50ml of water. Such results indicate that the efficiency of the magnetic treatment increased with increasing the amount of calcium sulfate dihydrate suspended in water.

Table 4.1: Efficiency of the magnetic treatment on $[\text{Ca}]^{2+}$ after one circulation.

Mass(g)/50ml	[Ca]	[Ca] [*]	%R _[Ca]
0.086	0.0091	0.0088	3.29
0.129	0.0126	0.0121	3.97
0.172	0.0148	0.0139	6.08
0.215	0.0165	0.0151	8.48

[Ca]^{*}: Concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation in magnetic field %R_[Ca]: The percentage reduction in the concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ under the effect of the magnetic treatment

4.1.2 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Electrical Conductivity after One Circulation.

Figure 4.2 illustrates the difference in the electrical conductivities of magnetized solutions when compared with non-magnetized solutions. The figure shows that non-magnetized solutions had higher electrical conductivities, which means that the number of ions dissolved in untreated water is higher than in magnetized solutions.

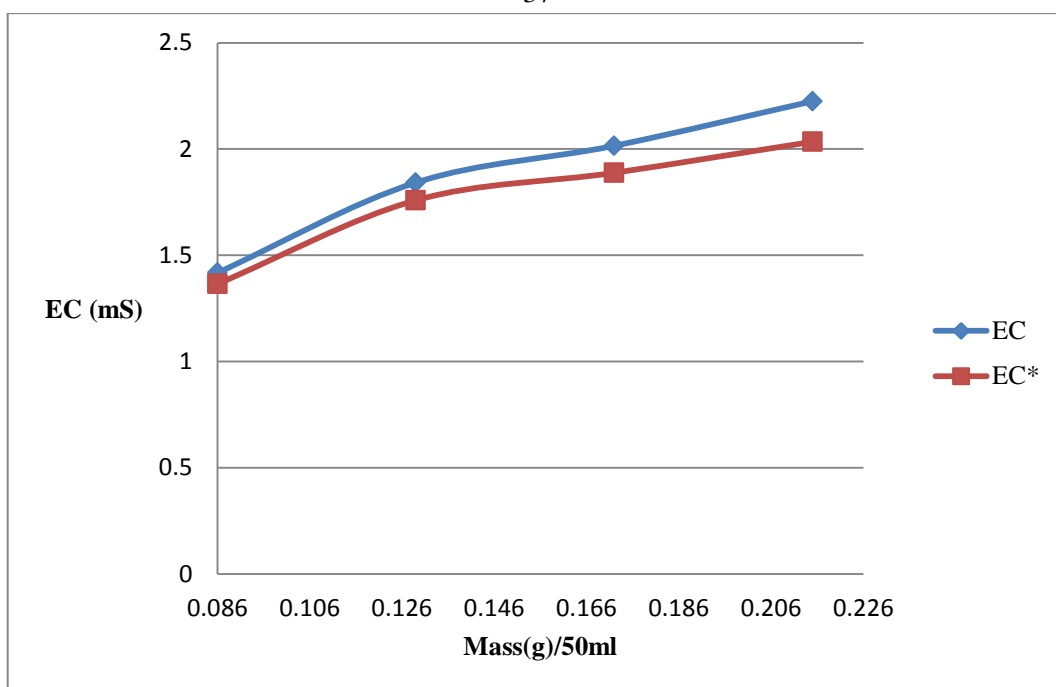


Figure 4.2: The electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ for magnetically treated and untreated solutions after one circulation. EC^* and EC are the electrical conductivities of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation with and without the magnetic field effect respectively.

Results shown in table 4.2 illustrate the efficiency of the magnetic treatment on the electrical conductivity of different solutions of calcium sulphate dihydrate. The efficiency of the magnetic treatment increased from 3.67% to 4.51% when the amount dissolved was doubled from 0.086g to 0.129g respectively. The highest efficiency was 8.58% and it was obtained when 0.215g of calcium sulphate dihydrate dissolved in 50ml of deionised water.

Table 4.2: Efficiency of the magnetic treatment on EC of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation.

Mass/50ml	EC(mS)	EC* (mS)	%R _{EC}
0.086	1.418	1.366	3.67
0.129	1.842	1.759	4.51
0.172	2.015	1.888	6.30
0.215	2.225	2.034	8.58

EC*:The electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation in magnetic field. %R_{EC}: The percentage reduction in the electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ under the effect of the magnetic treatment

The results shown in both Figure 4.2, and Table 4.2 corresponds to the results shown in section 4.1.1, since the electrical conductivities of magnetized solutions were lower than non-magnetized solutions when the same amount of calcium sulfate dihydrate were dissolved. Also the efficiency of the magnetic treatment increased with increasing the amount of calcium sulfate dihydrate dissolved in water.

Both of the concentration and electrical conductivity decreased after one circulation in the magnetic field. Such reduction is explained using the magnetohydrodynamic (MHD) mechanism. This mechanism is used to explain the effect of the magnetic field and its related to the condition at which the magnetic field is perpendicular to the flow of the treated solution on the dynamic state. In this mechanism, the magnetic treatment promotes the homogeneous nucleation in the bulk rather than heterogeneous nucleation in the

pipe wall which cause a reduction in the solubility of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ in water.

4.2 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after Five Circulations.

The effect of number of circulations on the efficiency of magnetic treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solutions was tested by multiplying the number of circulation to five. $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ concentration, electrical conductivity and pH values were measured and the magnetic treatment efficiency was compared with one circulation results.

4.2.1 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Concentration After Five Circulations.

The increase in the circulation number to five caused an improvement in the efficiency of the magnetic treatment when compared with solutions that were circulated one time in the magnetic device.

Figure 4.3 shows the difference in the concentration of five times circulated solutions in the magnetic device when compared with solutions that have had the same concentration but were circulated five times in the same pipeline without the use of any permanent magnets.

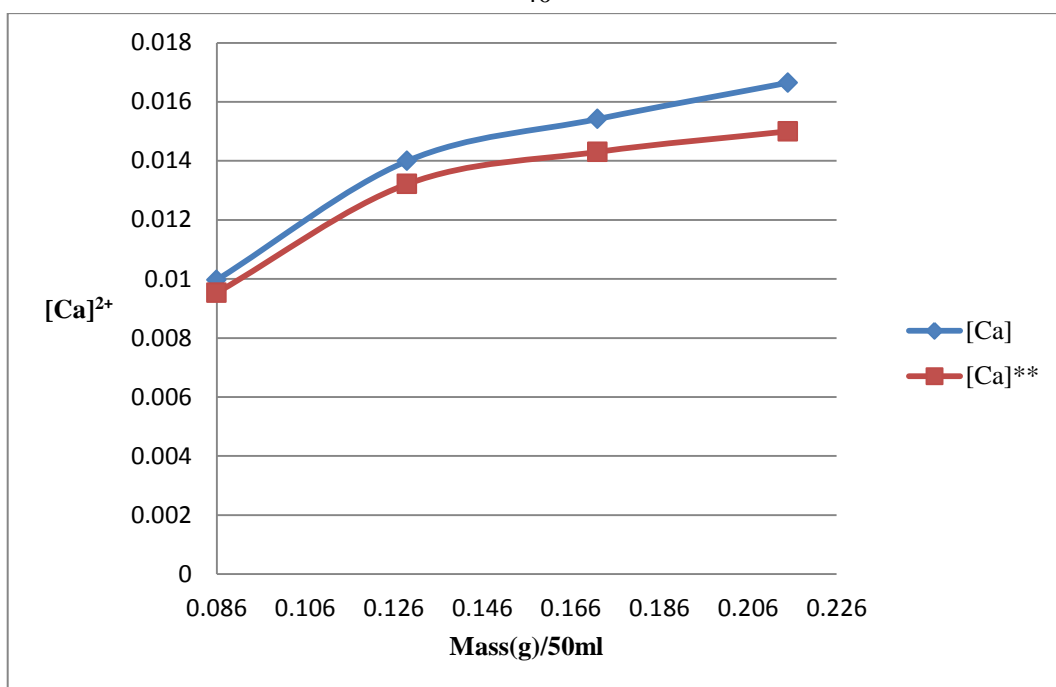


Figure 4.3: The effect of the magnetic treatment on $[\text{Ca}]^{2+}$ of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations. $[\text{Ca}]^{**}$ is the concentration of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations in magnetic field

Table 4.3 illustrates the efficiency of the magnetic treatment after five circulations in the magnetic device. The efficiency of the magnetic treatment was increased from 4% to 5.71% when the amount dissolved was doubled from 0.086g to 0.129g respectively. The highest efficiency obtained was for 0.215g/50ml and it was 9.64%.

Table 4.3: Efficiency of the magnetic treatment on $[\text{Ca}]^{2+}$ of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations.

Mass(g)/50ml	[Ca]	[Ca]**	% $R_{[\text{Ca}]}$
0.086	0.0100	0.0096	4.00
0.129	0.0140	0.0132	5.71
0.172	0.0154	0.0143	7.14
0.215	0.0166	0.0150	9.64

The efficiency of the magnetic treatment for 0.086g/50ml was 3.29% and 4% after one and five circulations, respectively. And for 0.1291g/50ml it was 3.97% and 5.71% for one and five circulations respectively. The same growth in the efficiency was noticed in 0.172g/50ml and 0.215g/50ml calcium sulfate dihydrate solutions.

Such results obtained from comparing the one and five circulations in the magnetic field shows that, increasing the number of circulation from one to five cause an increase in the efficiency of the magnetic treatment.

4.2.2 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Electrical Conductivity after Five Circulations.

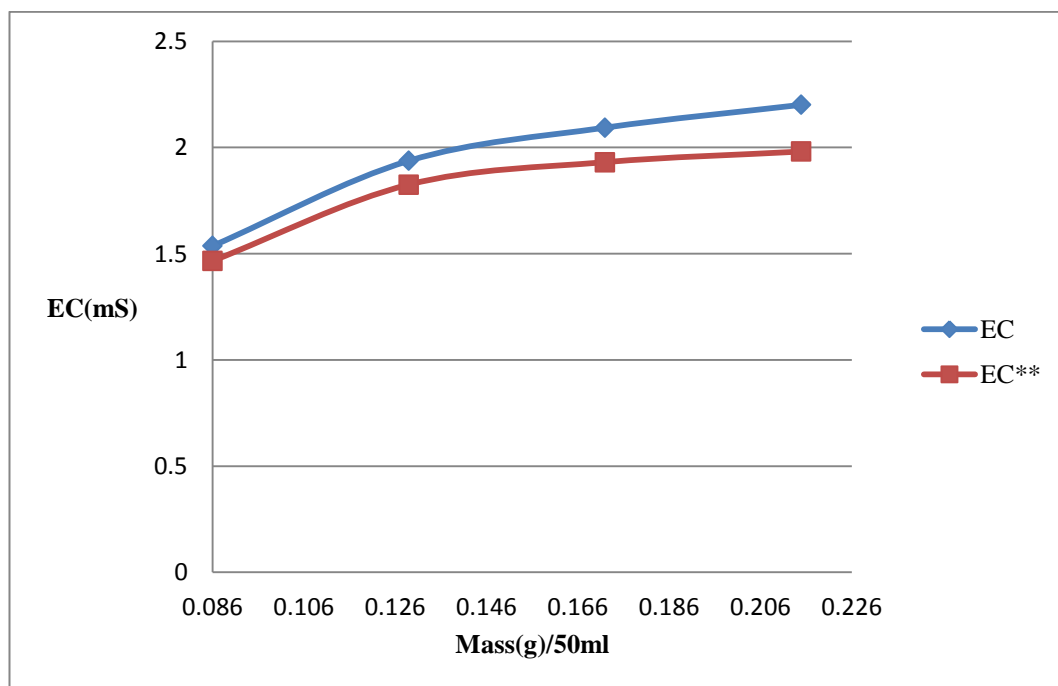


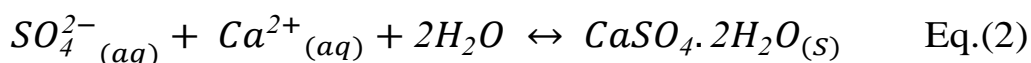
Figure 4.4: The electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ for magnetically treated and untreated solutions after five circulation. EC^{**} is the electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations in magnetic field.

Table 4.4: Efficiency of the magnetic treatment on EC of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations.

Mass(g)/50ml	EC(mS)	EC** (mS)	% R_{EC}
0.086	1.537	1.466	4.61
0.129	1.937	1.825	5.78
0.172	2.093	1.931	7.74
0.215	2.201	1.981	9.99

Figure 4.4 and Table 4.4 shows that increasing the number of circulations to five improved the efficiency of the magnetic treatment. For example, for 0.086g/50ml the efficiency was increased from 3.67% to 4.61% for one and five circulations respectively. And for 0.215g/50ml the efficiency was increased from 8.58% to 9.99% for one and five circulations respectively.

For both magnetically treated and untreated solutions, results shows increase in $[\text{Ca}]^{2+}$ as $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ increase in the nominal prepared solutions. This is due to the increase in SO_4^{2-} and Ca^{2+} ions in water which will results in increasing $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ clusters in the solution rather than pipe surface according to equation (2).



Results also shows that magnetically treated solutions have less $[\text{Ca}]^{2+}$ and hence less electrical conductivity.

In other words, as the amount of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ dissolved increase, both of the concentration and electrical conductivity decreased after being circulated through the magnetic field. It was also obtained that the efficiency of the magnetic treatment increased as the number of circulation increased from one to five.

4.2.3 Efficiency of the Magnetic Treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ pH after One and Five Circulations.

Not a lot can be concluded about the ability of the magnetic treatment to increase or decrease the pH value in state of variance amount of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Table 4.5 and table 4.6 shows that although the pH values decreased for most of the magnetized solutions, the change was very small, and there was no relation between the pH and the amount of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ dissolved in water .

Table 4.5: The effect of the magnetic treatment on the pH in of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation.

Mass(g)/50ml	pH	pH*
0.086	6.73	6.64
0.129	6.90	6.55
0.172	6.61	6.84
0.215	6.61	6.55

pH and pH*: pH of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation with and without the MT respectively.

Table 4.6: The effect of the magnetic treatment on the pH of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulation.

Mass(g)/50ml	pH	pH ^{**}
0.086	6.68	6.63
0.129	6.56	6.38
0.172	6.57	6.62
0.215	6.63	6.58

pH and pH^{**} : pH of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations with and without the MT respectively.

The following section, will discuss the effect of basic and acidic mediums on the precipitation and solubility of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

4.3 Effect of the Magnetic Treatment on Calcium Sulfate Dihydrate Electrical conductivity Versus Time.

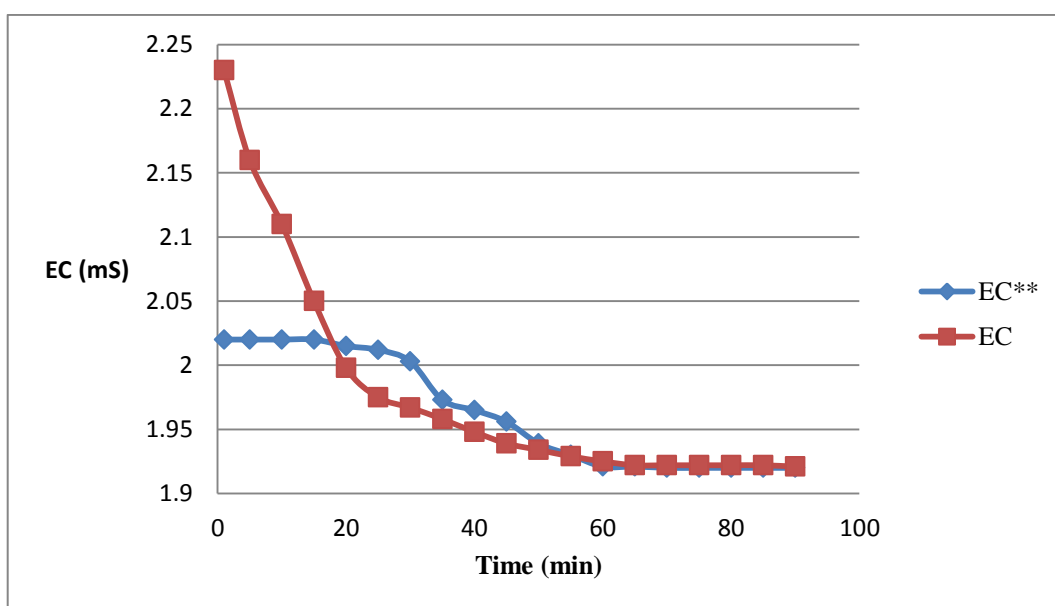


Figure 4.5: Effect of the magnetic treatment on $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ electrical conductivity versus time.

Figure 4.5 illustrates the effect of the magnetic treatment on the electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution for 90 minutes after its circulation in the magnetic device.

The effect of the magnetic treatment was found to be the highest in the first 15 minutes after the treatment. However, the effect of the magnetic treatment on the electrical conductivity of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ start to decrease until 50 minute after the treatment where the magnetic effect was hardly seen.

4.4 Effect of the pH on the Magnetic Field Ability to Reduce $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Deposition.

Since the magnetic treatment showed the highest efficiency when 0.215 g was dissolved in water. In this section, the efficiency of the magnetic treatment was studied for 0.215g/50ml after five circulations at the same intensity shown in Figure 3.3. For acidic, basic and neutral mediums.

Results shown in the following tables illustrates the effect of the magnetic treatment when $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ solution was circulated five times in the magnetic device at different pH ranges. The parameters X and X^{**} are for TSS, EC, and $[\text{Ca}]^{2+}$ with and without the MT respectively.

Table 4.7: Efficiency of the magnetic treatment at pH range 6-7.

Parameter	X	X ^{**}	%R
TSS	1003.3	1306.7	30.24
EC (mS)	2.185	1.957	10.43
[Ca] ²⁺	0.0167	0.0150	11.33

X and X^{**}:TSS, EC, and [Ca] with and without the MT respectively.

Table 4.8: Efficiency of the magnetic treatment at pH range 10-12.

Parameter	X	X ^{**}	%R
TSS	1410.0	1606.7	13.95
EC(mS)	2.320	2.110	9.01
[Ca] ²⁺	0.0128	0.0110	14.06

X and X^{**}:TSS, EC, and [Ca] with and without the MT respectively.

Table 4.9 : Efficiency of the magnetic treatment at pH range 2-4.

Parameter	X	X ^{**}	%R
TSS	1156.7	1210.0	4.61
EC	4.120	4.000	2.91
[Ca] ²⁺	0.0168	0.0166	1.19

X and X^{**}:TSS, EC, and [Ca] with and without the MT respectively.

Tables show that the scale/ deposition reduction percentage (TSS) was 30.24% in the pH range 6-7. Whereas the pH range 10-12 had a scale reduction percent of 13.95%. The lowest scale reduction percentage was obtained in the pH range 2-4 which was 4.61%.

In the pH range 2-4, the solubility of calcium sulfate dihydrate was the highest when compared with other mediums. Due to the high solubility of calcium sulfate dihydrate in HCl the percentage reduction in concentration was 1.19% .The reduction in the electrical conductivity was 2.91 % which corresponds to the reduction in the concentration. Scale reduction percent was 4.61% which means that most of the solid calcium sulfate dihydrate remained and deposited on the pipe walls.

In the pH range 10-12 the solubility of calcium sulfate dihydrate was the lowest when compared with the other mediums. Although the magnetic field was able to cause a reduction in the concentration of calcium sulfate dihydrate with 14.06%, the scale reduction percentage was not the highest.

The magnetic treatment ability to decrease the deposition of calcium sulfate dihydrate in the pH range 10-12 was declined due to the increase in the solid amount in the solution which promoted the crystal growth and scale layer thickening.

In the pH range 6-7, the percentage reduction in the concentration and the electrical conductivity were 11.33% and 10.43% respectively. The efficiency of the magnetic field in preventing the deposition of calcium sulfate dihydrate was the highest in this medium.

Results obtained and showed in the previous tables indicate that the pH range 6-7 had the highest ability to decrease the deposition of calcium sulfate dihydrate on pipe walls . Whereas the pH range 10-12 showed the highest percent reduction in concentration.

The pH range 2-4 results showed a decline in the effect of the magnetic treatment on the concentration, electrical conductivity and scale reduction percentage.

4.5 Efficiency of the Magnetic Treatment in State of Variance Magnetic Field Intensities.

The results shown in table 4.10 illustrates the effect of different magnetic intensities on the concentration, electrical conductivity and total suspended solids of 0.215g/50ml calcium sulfate dihydrate solutions when compared with non-magnetized solution. Whereas table 4.11 shows the reduction percentage (R%) in the electrical conductivity, concentration and total suspended solid for the same solutions.

Table 4.10: The effect of different magnetic intensities on the EC, [Ca], and TSS of 0.215g/50ml CaSO₄.2H₂O

Parameter	Non-magnetized	MF _{0.48-0.34}	MF _{0.45}	MF _{0.43-0.34}	MF _{0.35}
EC	2.185	1.944	1.957	1.978	1.981
[Ca]	0.0167	0.0147	0.0149	0.0150	0.0152
TSS	1003.3	1320.0	1306.7	1281.7	1256.7

Table 4.11: The percent reduction (R %) in the EC, [Ca], and TSS for different magnetic intensities.

Parameter	MF _{0.48-0.34}	MF _{0.45}	MF _{0.43-0.34}	MF _{0.35}
EC	11.02	10.42	10.37	9.35
[Ca]	11.98	10.78	10.18	8.98
TSS	31.57	30.24	27.74	25.25

The highest scale reduction percent was 31.87 % for MF_{0.48-0.34} followed by MF_{0.45}, MF_{0.43-0.34}, and the finally MF_{0.35} which had the lowest percent of 25.25 %.

The same order was seen in concentration and electrical conductivity results, the highest reduction percentage for the concentration and electrical conductivity were 11.02 % and 11.98 % respectively for MF_{0.48-0.34}. And the lowest values were for MF_{0.35} with 8.98 % and 9.35 % percent reduction in the concentration and electrical conductivity respectively.

Such results indicates that the decline in the magnetic intensity causes a decreases in the reduction percentage of the concentration $\%R_{[Ca]}$, electrical conductivity $\%R_{EC}$, and calcium deposition. This means that as magnetic intensity decrease the efficiency of the magnetic treatment will decrease.

It was also noticed that when the treatment had an irregular magnetic intensity the scale reduction percent was 31.57 %. Whereas the scale reduction percent was 30.24 % when the magnetic device had regular magnetic intensity of 0.45T.

The same thing was seen when another set of steady 0.35 T magnetic intensity and irregular magnetic intensities that started with 0.43 T followed by 0.37 T were used. In which the irregular magnetic field showed better result with scale reduction percent of 27.74% for $MF_{0.48-0.34}$, and the steady magnetic field had 25.25 % scale reduction percent.

In other word, using irregular magnetic can give higher efficiency when compared with a steady magnetic field throughout the treatment.

4.6 The Effect of the Pipe Material on the Treatment Efficiency.

The influence of the nature of the pipe material that calcium sulfate dihydrate solutions were circulated in was investigated. Three different materials were studied; stainless steel which known to be a conducting material. The other two materials investigated were glass and polyethylene

and they are known as insulators. Results shown in the following tables illustrates the change in the concentration and the electrical conductivity of calcium sulfate dihydrate solutions after being treated in the magnetic device.

After five circulations in the magnetic device with the stainless steel pipe the percentage reduction in the concentration and the electrical conductivity were 10.18% and 9.47 % respectively. However, when the pipe was made of glass the percentage reduction in the concentration and the electrical conductivity were very low when compared with the stainless steel pipe. And when the pipe was made of polyethylene the magnetic treatment was inefficient. The results obtained in this study are consistent with Gabrielli et al.¹ Who find out the effect of the magnetic treatment is more pronounced for conducting materials than for insulators.

Table 4.12: The effect of the magnetic treatment when stainless steel pipe was used.

Parameter	X	X**	%R
[Ca] ²⁺	0.0167	0.0150	10.18
EC (mS)	2.185	1.978	9.47

Table 4.13: The effect of the magnetic treatment when glass pipe was used.

Parameter	X	X**	%R
$[\text{Ca}]^{2+}$	0.0150	0.0147	2
EC (mS)	1.915	1.963	2.51

Table 4.14: The effect of the magnetic treatment when polyethylene pipe was used.

Parameter	X	X**	%R
$[\text{Ca}]^{2+}$	0.0150	0.0150	0
EC (mS)	1.947	1.951	0.2

Conclusions

1. The efficiency of the magnetic treatment increased with increasing the amount of calcium sulfate dihydrate dissolved in water.
2. The highest %R_[Ca] was obtained for 0.215g/50ml .
3. Increasing the number of circulation in the magnetic field from one to five causes the increase in %R_[Ca] for 0.215g/50ml from 8.48% to 9.67%.
4. Increasing the number of circulation in the magnetic field from one to five causes the increase in %R_{EC} for 0.215g/50ml from 8.58% to 9.99%.
5. At different pH ranges, the highest scale reduction percentage was 30.24% for the pH ranges 6-7.and the lowest percentage was 4.61% for the acidic medium with the pH range 2-4.
6. The highest scale reduction percentage was 31.57% for **MF**_{0.48-0.34}.
7. As the magnetic field intensity decrease the efficiency of the magnetic treatment decrease.
8. Using irregular magnetic field that starts with high intensity followed by lower values can give higher efficiency when compared with a steady magnetic field throughout the treatment.

9. The magnetic treatment was more effective when the pipe was made of conducting material such as stainless steel when compared with insulators like glass and polyethylene pipes.
10. The effect of the magnetic treatment was found to be the highest in the first 15 minutes after the treatment, after that the efficiency start to decrease.

Recommendations

- The possibility of using the magnetic treatment to increase the efficiency of RO filtration.
- Studying the effect of presence of foreign ions in the aqueous solution of calcium sulfate dihydrate on the efficiency of the magnetic treatment.
- Studying the effect of temperatures and different flow speeds on the efficiency of treatment.

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Appendix

Data Tables of Experiments

Data for 4.1: Effect of the Magnetic Treatment on calcium sulfate dihydrate after one circulation

Efficiency of the magnetic treatment on $[\text{Ca}]^{2+}$ of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation.

Mass(g)/50ml	[Ca]	[Ca] [*]	S	S [*]
0.086	0.0091	0.0088	7E-05	0.0003
0.129	0.0126	0.0121	1E-04	3E-05
0.172	0.0148	0.0139	0.0002	5E-05
0.215	0.0165	0.0151	0.0002	0.0004

Efficiency of the magnetic treatment on EC of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation.

Mass(g)/50ml	EC (mS)	EC [*] (mS)	S	S [*]
0.086	1.418	1.366	0.0156	0.0429
0.1292	1.842	1.759	0.0186	0.0040
0.172	2.015	1.888	0.0214	0.0100
0.2151	2.225	2.034	0.0250	0.0765

Efficiency of the magnetic treatment on the pH value of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after one circulation.

Mass(g)/50	pH	pH [*]	S	S [*]
0.086	6.73	6.64	0.0173	0.3876
0.1292	6.90	6.55	0.09	0.0289
0.172	6.61	6.83	0.1501	0.0653
0.2151	6.61	6.55	0.0462	0.1332

Data for 4.2: Effect of the Magnetic Treatment on calcium sulfate dihydrate after five circulations

Efficiency of the magnetic treatment on $[\text{Ca}]^{2+}$ of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations.

Mass(g)/50ml	[Ca]	[Ca] ^{**}	S	S ^{**}
0.086	0.0100	0.0096	6E-05	0.8426
0.1292	0.0140	0.0132	6E-05	1E-04
0.172	0.0154	0.0143	8E-05	0.0002
0.2151	0.0166	0.0150	0.0006	0.0002

Efficiency of the magnetic treatment on EC of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations.

Mass(g)/50ml	EC (mS)	EC^{**} (mS)	S	S^{**}
0.086	1.537	1.466	0.0012	0.0023
0.1292	1.937	1.825	0.0465	0.0107
0.172	2.093	1.931	0.0153	0.0333
0.215	2.201	1.981	0.0819	0.0535

Efficiency of the magnetic treatment on the pH value of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ after five circulations.

Mass(g)/50ml	pH	pH^{**}	S	S^{**}
0.086	6.68	6.63	0.1172	0.0866
0.1292	6.56	6.38	0.4155	0.3831
0.172	6.57	6.62	0.4157	0.4933
0.2151	6.63	6.58	0.1744	0.2316

Data for 4.4: Effect of the pH on the Magnetic Field Ability to Reduce Calcium Sulfate Dihydrate Deposition.

Efficiency of the magnetic treatment at pH range (6-7)

Parameter	X	X [*]	S	S [*]
TSS	1003.3	1306.7	5.7735	11.547
EC (mS)	2.185	1.9573	0	0.0117
[Ca] ²⁺	0.0167	0.0150	0	0.0002

Efficiency of the magnetic treatment at pH range (10-12).

Parameter	X	X [*]	S	S [*]
TSS	1410.0	1606.7	17.321	11.547
EC (mS)	2.320	2.110	0.0200	0.2075
[Ca] ²⁺	0.0128	0.0110	2E-05	0.0016

Efficiency of the magnetic treatment at pH range (2-4).

Parameter	X	X [*]	S	S [*]
TSS	1156.7	1210.0	11.55	10.00
EC (mS)	4.120	4.000	0.0721	0.0100
[Ca] ²⁺	0.0168	0.0166	1E-04	5E-05

Data for 4.4: Efficiency of the Magnetic Treatment in state of variance magnetic field intensities.

The effect of different magnetic intensities on the EC, [Ca], and TSS of 0.215g/50ml CaSO₄.2H₂O

Parameter	Non-magnetized solution	MF _{0.48-0.34}	MF _{0.45}	S	S*
EC (mS)	2.185	1.944	1.957	0.031	0.012
[Ca]	0.0167	0.0147	0.0149	3E-04	2E-04
TSS	1003.3	1320.0	1306.7	11.55	11.55

The effect of different magnetic intensities on the EC, [Ca], and TSS of 0.215g/50ml CaSO₄.2H₂O

Parameter	Non-magnetized solution	MF _{0.43-0.34}	MF _{0.35}	S	S*
EC (mS)	2.185	1.9713	1.981	0.003	0.014
[Ca]	0.0167	0.0150	0.0152	2E-04	4E-04
TSS	1003.3	1281.7	1256.7	21.09	5.25

جامعة النجاح الوطنية

كلية الدراسات العليا

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ناهد ثابت يوسف صوافطه

إشراف

أ.د شحدة جودة

قدمت هذه الأطروحة استكمالاً لمتطلبات درجة الماجستير في الكيمياء بكلية الدراسات العليا في
جامعة النجاح الوطنية في نابلس، فلسطين.

2017

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الملخص

يعد التكلس احد أهم المشاكل الناجمة عن تراكم الشوائب المترسبة من الماء على جدران الأنابيب، أو نتيجة استقرار المواد المعلقة في المياه على أسطح المعادن بحيث يصبح من الصعب التخلص منها أو إزالتها. وتعتبر كبريتات الكالسيوم ثنائية الهيدرات والمعروفة باسم الجبس واحدة من أكثر مسببات التكلس شيوعاً.

في هذه الدراسة، تم استخدام تقنية مغنطة المياه كوسيلة للحد من ترسب كبريتات الكالسيوم ثنائية الهيدرات على جدران الأنابيب، عن طريق جهاز مغناطيسي مركب يدويا ويعمل في نظام متحرك.

تم تقييم كفاءة المعالجة المغناطيسية من خلال قياس التركيز، التوصيل الكهربائي، درجة الحموضة، ومجموع المواد الصلبة العالقة (TSS) للمحاليل الممغنطة ومقارنة النتائج مع المحاليل الغير ممغنطة.

وقد تم قياس كفاءة وفعالية المعالجة المغناطيسية عن طريق تخفيض نسبة تركيز كبريتات الكالسيوم ثنائية الهيدرات في المياه. بالإضافة إلى تخفيض نسبة التوصيل الكهربائي للمياه، والتقليل من نسبة كبريتات الكالسيوم ثنائي الهيدرات المترسبة على جدران الأنابيب. وتزداد فعالية المعالجة المغناطيسية بازدياد نسبة الانخفاض في التركيز، الموصلية الكهربائية، و مجموع المواد الصلبة العالقة.

تم دراسة التغيرات في كفاءة المعالجة المغناطيسية لعدة محاليل مختلفة التركيز من كبريتات الكالسيوم ثنائية الهيدرات وهي: 0.086 غم/50 مل، 0.129 غم/50 مل، 0.172 غم/50 مل، و 0.215 غم/50 مل. كما تم دراسة كفاءة المعالجة عند تغيير عدد الدورات من واحدة إلى خمس

دورات في الجهاز المغناطيسي. وتم استخدام أوساط مختلفة في درجة الحموضة بحيث تراوحت درجة الحموضة من 10-12 في الوسط القاعدي. وبين 4 - 2 في الوسط الحمضي. وكانت 7 - 6 في الوسط المتعادل وذلك للعثور على الوسط الذي يقدم أعلى كفاءة للمعالجة باستخدام المجال المغناطيسي. بالإضافة الى استخدام عدة تشكيلات للمجال المغناطيسي (منتظمة وغير منتظمة) لمعرفة الشكل الأكثر كفاءة وفعالية، وأخيرا تم دراسة تأثير تغيير نوع الأنابيب المستخدمة على كفاءة المعالجة المغناطيسية.

وأظهرت النتائج أن كفاءة المعالجة المغناطيسية تحسنت عندما زادت كمية ثنائي هيدرات كبريتات الكالسيوم المذاب. وتم الحصول على نتائج مختلفة عند تغيير عدد الدورات من واحدة إلى خمسة دورات في الجهاز المغناطيسي، بحيث أن الخمس دورات أعطت نتائج أفضل وكفاءة أعلى للمعالجة. ولم يوجد للمعالجة المغناطيسية أي تأثير على درجة الحموضة في المحاليل الممغنطة. على الرغم من أن كفاءة وفعالية المعالجة قد تغيرت بتغير درجة الحموضة المستخدمة. وقد لوحظ تحسن بسيط في فعالية المعالجة المغناطيسية عند استخدام تشكيل مغناطيسي غير منتظم مقارنة بالتشكيل المنتظم الذي أعطى فعالية اقل. كما تبين أن المعالجة المغناطيسية كانت أكثر كفاءة عند استخدام الأنابيب المصنوعة من مواد موصلية كالفولاذ مقارنة مع مواد عازلة كالزجاج ومتعدد الإثيلين.

