SCALE REMOVAL IN WATER PIPELINE WITH A MAGNETIC FIELD

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DEDICATION

This is dedicated specially for,

HAJI OTHMAN BIN MD. JUSOH

HAJAH SHOBARIAH BINTI HANAFI

MY OTHER HALF

MOHD ARIFF

ADAM

SITI YUSRINA

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ABSTRACT

Magnetic water treatment (MWT) is a green concept of water treatment where the magnetic device is installed to the system. This concept is intended to cater to scale problem as it is the most common problem experienced in water pipeline which causes the reduction of system performance. This leads to the pipeline becoming clogged and causing potential damage. Scale is a soluble salt known as calcium carbonate, $CaCO_3$, which usually develop due to the mineral content of the water itself and external factors from surroundings. Calcium carbonate, can be found in almost every type of scale in various water system, is the ingredient of scale. Conventional treatment was used in controlling the scale, but it is harmful to the system and environmentally unfriendly. Thus, water treatment with the application of magnetic field is an alternative for future practice. This study was conducted experimentally in the laboratory where all the samples and variables were installed and conducted in 4 phases. The first phase of this study was aimed to determine the variables of this study. In order to obtain the optimum results, the variables selected were orientation of magnetic devices, the flow rate of water and the intensity of magnetic field under 18 days of operation time. Magnetic devices for treating scale in used water pipes are subjected to different magnetic orientations under inverted and non-inverted, with one control device without magnet. The water flow rate used were 1.0 mL/s, 2.0 mL/s and 3.0 mL/s and the magnet intensity were 0.1 Tesla, 0.3 Tesla and 0.5 Tesla respectively. All these flow rates and magnet intensities were applied and conducted simultaneously under those orientations. These variables were applied in order to achieve the objectives of the next phase of the study, which were water sample characteristics and morphology structure of scale. The final phase for this study was formulating the empirical relationship of scale removal efficiency using Response Surface Methodology (RSM). The results showed that inverted orientation was 28% greater rate of scale removal compared to that of non-inverted which was 20%. For variables of water flow rate, greater flow rate of 3.0 mL/s (78%) gave better results than lower flow rate. Regarding magnetic intensity, the higher the intensity of permanent magnet used, the greater the rate of scale removal. Hence, under inverted orientation with 3.0 mL/s water flow rate and magnetic intensity of 0.5 Tesla, the experiment results of scale removal under MWT was 57% compared to 0.3 Tesla (43%) and 0.1 Tesla (23%). The morphology structure of scale was analysed under Field Emission Scanning Electron Microscope (FESEM) and X-Ray Diffraction (XRD) resulting in the crystal form of scale ranged from harder crystal (calcite) to softer crystal (vaterite and aragonite). From the analysis of Three Dimension Response Surface Plot, it was found that scale removal efficiency had the effects and interaction towards magnet intensity of 0.5 Tesla, water flow rate of 2.98 mL/s and 18 days of operation time under inverted orientation. Experimental validation demonstrated a scale removal prediction of 37.527 mg/L and the observed results from experiments was 36.9 mg/L representing an error of only 1.7%. The outcome of the study bridges the knowledge of magnetic water treatment and will aid the concept to the future practices in water treatment as our world is now ingeared towards sustainable and environmentally friendly treatment.

ABSTRAK

Olahan air magnetik (MWT) adalah olahan air berkonsep hijau di mana peranti magnet dipasang pada sistem. Konsep ini bertujuan untuk mengatasi masalah kerak kerana kebanyakan saluran paip mengalami masalah kerak yang menyebabkan prestasi sistem terganggu. Ini menyebabkan saluran paip tersumbat dan boleh menyebabkan kerosakan. Kerak ialah garam terlarut yang dikenali sebagai kalsium karbonat, $CaCO_3$ yang terbentuk disebabkan kandungan mineral yang hadir di dalam air itu sendiri dan juga dari faktor keadaan sekeliling. Kalsium karbonat, boleh dijumpai hampir di kesemua jenis kerak dalam pelbagai sistem air. Olahan air konvensional telah dipraktiskan untuk mengawal kerak tetapi kaedah ini mendatangkan bahaya kepada sistem dan tidak mesra alam sekitar. Oleh itu, olahan air dengan menggunakan peranti magnet merupakan satu alternatif yang berpotensi pada masa hadapan. Kajian ini dijalankan secara eksperimen di makmal iaitu semua sampel dan pembolehubah dilaksanakan sepenuhnya di makmal. Kajian ini dimulakan dengan fasa mengenal pasti pembolehubah untuk penyelidikan ini. Untuk mendapatkan hasil eksperimen yang optimum, antara pembolehubah yang dipilih ialah orientasi peranti magnet, kadar aliran air dan keamatan medan magnet dalam tempoh 18 hari masa beroperasi. Peranti magnet yang digunakan adalah tertakluk kepada orientasi magnet yang berbeza, iaitu terbalik dan tidak terbalik, dengan satu peranti kawalan tanpa magnet. Kadar aliran air yang digunakan adalah 1.0 mL/s, 2.0 mL/s dan 3.0 mL/s manakala keamatan magnet yang digunakan adalah 0.1 Tesla, 0.3 Tesla dan 0.5 Tesla. Kesemua kadar aliran air dan keamatan magnet ini digunakan dan dilaksanakan secara serentak di bawah orientasi magnet yang berikut. Pembolehubah ini digunakan supaya objektif untuk fasa seterusnya dalam kajian ini iaitu ciri-ciri sampel air dan struktur morfologi kerak dapat dicapai. Fasa terakhir untuk kajian ini adalah merumuskan hubungan empirikal kecekapan penyingkiran kerak dengan menggunakan kaedah Metodologi Permukaan Tindak Balas (RSM). Hasil eksperimen menunjukkan bahawa orientasi terbalik memberi kadar penyingkiran kerak yang lebih besar iaitu 28% berbanding dengan tidak terbalik dengan 20%. Manakala untuk pembolehubah kadar aliran air, kadar aliran lebih tinggi 3.0 mL/s (78%) memberikan hasil yang lebih baik daripada kadar aliran yang lebih rendah. Diikuti pula dengan pembolehubah keamatan magnet, semakin tinggi keamatan magnet kekal yang digunakan, semakin besar kadar penyingkiran kerak. Oleh itu, di bawah orientasi terbalik dengan kadar aliran air 3.0 mL/s dan keamatan magnet sebanyak 0.5 Tesla, keputusan penyingkiran kerak di bawah MWT adalah 57% berbanding 0.3 Tesla (43%) dan 0.1 Tesla (23%). Struktur morfologi kerak telah dianalis di bawah Mikroskop Elektron Pengimbas Medan (FESEM) dan Difraksi Sinar-X (XRD) yang menunjukkan perubahan kristal kerak daripada kristal yang lebih kuat (kalsit) menjadi kristal yang lebih lemah (vaterit dan aragonit). Hasil analisis Plot Permukaan Tindakbalas Tiga Dimensi, didapati kecekapan penyingkiran kerak mempunyai kesan dan interaksi terhadap keamatan magnet sebanyak 0.5 Tesla, kadar aliran air 2.98 mL/s dan 18 hari waktu operasi di bawah orientasi terbalik. Pengesahan eksperimen menunjukkan penyingkiran kerak yang diramalkan adalah 37.527 mg/L dan hasil yang diperhatikan dari eksperimen adalah 36.9 mg/L di mana ianya berbeza hanya 1.7%. Hasil kajian ini akan menjadi rujukan terhadap pengetahuan tentang olahan air magnetik dan akan membantu konsep ini untuk praktis masa depan dalam sistem olahan air kerana dunia kita kini lebih ke arah lestari dan mesra alam.

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LIST OF ABBREVIATIONS

APHA	-	American Public Health Association
HDPE	-	High Density Polyethylene
PVC	-	Polyvinyl
SEM	-	Scanning Electron Microscopy
MWT	-	Magnetic Water Treatment
RO	-	Reverse Osmosis
^{o}C	-	Degree Celcius
mg/L	-	milligram per Liter
T	-	Tesla
NTU	-	Nephelometric Turbidity Units
mmol/L	-	milimoles per Liter
gpg	-	grain per gallon
ppm	-	parts per million
WHO	-	World Health Organization
M	-	Magnetization
χ_v	-	measured magnetic susceptibility
H	-	magnetic exposure
FL	-	Faradays Law
E	-	electric field vector
v	-	fluid linear/flow velocity
B	-	magnetic induction
LF	-	Lorentz Force
q	-	quantity of charged ion
PEX	-	high-density cross-linked polyethylene
ANOVA	-	Analysis of Variances
UTM	-	Universiti Teknologi Malaysia
FESEM	-	Field Emission Scanning Electron Microscopy
XRD	-	X-Ray Diffraction
mm	-	millimetre
NdFeB	-	Neodymium-Ferrite-Boron

L	-	Length
W	-	Width
T	-	Thickness
USA	-	United States of America
mL	-	mili Liter
^{o}	-	Degree
N	-	North Pole
S	-	South Pole
cm	-	Centimetre
B	-	Blank orientation
NI	-	Non-Inverted orientation
N. I	-	Non-Inverted orientation
INV	-	Inverted Orientation
Q1	-	1.0 mL/s
Q2	-	2.0 mL/s
Q3	-	3.0 mL/s

LIST OF SYMBOLS

H_2CO_3	-	Carbonic Acid
H_2O	-	Water
$CaCO_3$	-	Calcium Carbonate
CO_2	-	Carbon Dioxide
Cu	-	Copper
Zn	-	Zinc
$Ca(OH)_2$)	-	Calcium Hydroxide
Na_2CO_3	-	Sodium Carbonate
$Mg(OH)_2$	-	Magnesium Hydroxide
Na^{2+}	-	Sodium ions
Ca^{2+}	-	Calcium ions
Mg^{2+}	-	Magnesium ions
H^+	-	Hydrogen ions
OH^-	-	Hydroxide ions
%	-	Percentage
$CaCl_2$	-	Calcium Chloride
$CaSO_4$	-	Calcium Sulphate
$BaSO_4$	-	Barium Sulphate
Fe	-	Iron

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is one of the most crucial resources and is required by every lifeform or living creature in the world. We as human can survive without food for up to 73 days but without water, we only can survive for five days (Popkin *et al.,* 2010). In addition to staying hydrated in order to prevent harm to our body, water is also very important for humans on a daily basis. These situations definitely show the importance of water in our life. The causes of water disruption might due to the water supply problems such as broken water pipeline, interruption in water treatment plant and water pollution. Currently, there is water supply problem in Shah Alam, Malaysia due to the old pipeline system (Mohd, 2019), where 400 km out of total 27 000 km of pipeline were replaced over a 3 year period. The issue of broken pipeline is believed to be due to formation of scale and corrosion which causes brittle and leakage to the pipeline. All of these issues have caused the interruption of water supply especially to the consumer on a daily basis. Thus, the technology and technique concerning water treatment and water supply is continues to be developed and has become a compulsory process to produce a continuous supply of clean water, especially for daily necessities of human life.

Water treatment is an application that consists of few processes in producing clean and safe water, compliance with specific end-uses such as drinking water, water for recreation and irrigation (Khoshravesh *et al.*, 2018). Water treatment is practiced worldwide according to the environment, such as the type of water sources and water pipeline. The problem of water disruption is basically from the lack of management in water supply strategy, poor technology of water treatment and protection of natural water resources. Water pollution basically comes from various factors such as natural sources, human being and industry activities. The other common water issue is

leakage. Although leakage seems to be small matter, it tends to create big problems, especially to humans if the leakage is not handled early. Scale formation is one of the main factors that leads to leakage where its formation is due to the high concentration of minerals from water sources. Formation of scale in water pipeline is a very common problem due to the existence of hardness from natural sources where water is used frequently as a main medium (Alabi *et al.,* 2015). It is not formed because the water is polluted, as this problem also occurred to the treated water. The growth of scale may be generated by many external factors, such as water temperature, which is one of the main factors that enhances the scale growth (Donaldson and Grimes, 1988).

Scale is an assemblage deposit of calcium carbonate, magnesium hydroxide and calcium sulphate (Sohaili *et al.*, 2016) which is normally hard and insulator layer off-white in color. Scale deposits attach in the pipeline wall and tend to reduce the pipeline internal diameter, clogging the pipe and obstructing the flow of fluid especially when the scale is heavily grown. The sources of scale formation come from various factors but the growth is faster with the existence of high temperature and higher water hardness. Hardness is described as minerals dissolved in water specifically calcium and magnesium (Latva *et al.*, 2016).

Water is an excellent solvent, capable to move and make contact in any medium such as soil and rock, which generally make the water hard. Even if the amount of mineral content in the solution is small, the minerals will accumulate and increase the hardness concentration over time. The level of hardness becomes higher with the greater content of calcium and magnesium where it is referred as concentration of multivalent cations dissolved in water. When ionic substances dissolve in water, they tend to split into their own element ions. However, these ions of calcium and magnesium were not remained the same if they were exposed to certain circumstances such as evaporation, where the water becomes saturated and tends to precipitate salt crystal.

Scale in water pipeline can be controlled by implementing magnetic water treatment (MWT). MWT is one of the physical water treatment approaches which known as green technology, environmentally friendly, low cost maintenance and

simple treatment compared to others. Application of magnetic field in water pipeline was applied to remove the existing scale in pipeline. Magnetic field was created by permanent magnets incorporated into many water devices and even water conditioning devices. The principle of magnetic technology involves the physics of interaction between a magnetic field and a moving electric charge (ion) as a force is exerted on each ion and causes redirection of the particles. It tends to increase the frequency with which ions of opposite charge collide and combine to form a mineral precipitate or insoluble compound (Gholizadeh *et al.*, 2005). Another theory (Madsen, 2004), which is Pauli exclusion principle, is focused on proton transfer where magnetic field influences proton spin relaxation.

Although wide-ranging studies by many researches had been carried out in order to identify the effectiveness of magnetic field in treating scale, the findings were still lacking and confusing where the exact factors in optimizing the efficiency of MWT were not clear yet. The findings of previous researches have their own limitation which need to be explored further. These issues will be elaborated in Chapter 2. Thus, with the modification of magnetic devices to the water pipeline, this research is expected to cater the scale problem through determination of water parameters changes and identify new potential mechanism of scale removal process under references of previous findings. Lastly, the determination of relationship by empirical formula, which prove the significant factors of MWT effectiveness, as one of the main contributions of this study results.

1.2 Problem Statement

The existence of scale in water pipeline often creates problem in both domestic purposes and industrial activities. The major problem of pipeline in water supply either for general purposes or industrial activities is scale formation especially when it involves the usage of hot water such as water heater, boiler and cooling tower. Scale causes problems of pipe deterioration (Abdelhady *et al.*, 2011), blockage, corrosion and biofilm formation (Latva *et al.*, 2016). These problems caused many difficulties and disruption to the performance system of the pipe and the worst part is the damage

caused to the pipe itself when the scale was heavily grown. It takes a long time and very costly for the maintenance and replacement of the new pipeline. In addition, damaged pipe tends to pollute the environment and the water itself. Pipeline with scale had caused the hardness of water to be higher due to the existence of Ca^{2+} and Mg^{2+} ions from scale. The impact on environment is where the hardness affects fish and other aquatic life due to existence of the metal ions in harder water. Some of the metal ions in the hard water form insoluble precipitates and drop out of solution and are not available to be taken in by the organism. Large amounts of hardness are undesirable mostly for economic or aesthetic reasons. If drinking water source comes from nature, hardness can present problems in the water treatment process. Hardness must also be removed before certain industries can use the water. For this reason, the hardness test is one of the most frequent analysis done by facilities that use water.

Scale often leads to interrupt the water flow inside the pipes for domestic equipment and limit the heat transfer in heat exchanger for industrial plants, leading to technical and economic problems. Mostly, scale growth is enhanced by water temperature and becomes big problem to the industrial and technology activities which implicate heat-transfer, heat exchanger or any that related to water temperature such as water distribution systems boilers and cooling towers. The problem increases as water gets hotter (Donaldson and Grimes, 1988). In many industrial processes that use natural water supplies, scale formation is a common and costly problem (Banejad and Abdosalehi, 2009) due to existing of various minerals that influence scale growth. When any heat-transfer surface becomes scaled, this insulating layer inside the pipeline reduces the efficiency of the equipment, increases fuel requirements and maintenance due to the internal diameter of the pipelines have been decreased (Quinn *et al.,* 1997). This may lead to increasing electric bill of users (Orb, 2007).

A few treatments were implemented in controlling the scale formation and most of them have applied chemical reagents to achieve target. But these treatments are not environmentally friendly, harmful and not economical and generate harmful waste. All the drawbacks of these treatment will be explained more in detail in Chapter 2. Since the drawbacks of these treatments were more critical than it function,

extensive research on environmentally friendly approaches in controlling scale formation is required.

If the scale is not either prevented or treated from the early stage, it will accelerate the degradation process of pipeline or lead to complete failure in thermal and hydraulic performance which increases initial and operating cost (Meyer *et al.,* 2000) over time. Also, scale created insulator layer which increases operation and maintenance costs by lowering the flow rate of water and the thermal transfer coefficient in heat exchangers and also increasing the energy consumption of the pumps in drinking water systems (Abdelhady *et al.,* 2011). Formation of scale on heat transfer surfaces is equivalent to coating the surface with an effective insulating material (Glater *et al.,* 1980).

As the world is currently focusing on green approach, especially in main activities such as construction, treatment system, transportation and more, any approaches that are sustainable and biodegradable are preferable. MWT is a physical water treatment that has big potential and environmentally friendly where the entire process does not use any chemicals or produce any harmful waste. Magnetic field has potential in controlling the scale and can be replace the existing scale treatment and solve most of the drawbacks produced by conventional treatments. Hence, this research embarks to investigate the effectiveness of magnetic field on scale removal in water pipeline under several variables in order to enhance the effectiveness of MWT where all the variables were set from previous researches on MWT. The empirical relationship of MWT between each variable will be formulated using the results from MWT experiments.

1.3 Objectives

The aim of this study is to investigate the potential of implementing the magnetic field devices into water pipeline due to scale problem. This aim can be achieved by following objectives:

i. To evaluate the effects of magnetic orientation, water flow rate, magnetic intensity and water temperature towards removing the existing scale in water pipeline.

ii. To measure the water characteristics that reflects on the effectiveness under the effects of magnetic exposure.

iii. To measure the changes of scale molecular structure in their crystal form as reflection of magnetic field exposure

iv. To formulate as empirical equation among the rate of scale removal under variables of orientation of permanent magnets, water flow rate and magnetic intensity.

1.4 Scope of Study

The scope of work for this study can be stipulated as follows:

i. Used water pipes made from steel were collected in order to performed the tests. The usage of steel pipe in water pipeline is still in demand due to the specialty of steel pipe in temperature resistance which required in most industrial activities. This study was focused on water pipe made of steel, which can be related to any system using steel pipe to convey water such as pipeline system in domestic and industry purposes.

ii. The permanent magnet used on this study have various strength which is 0.10 ~ 0.5 Tesla. These permanent magnets have been installed in orientation of inverted, non-inverted and non-magnetic as a control.

iii. The operating variables selected for this experimental work were flow rate of water (1.0 mL/s ~ 3 mL/s) and temperature of water ($27\pm2^{o}C$ ~ $50^{o}C$).

iv. The main idea for enhancing the effectiveness of MWT were to expose the water sample into strong magnetic flux and enhance the contact frequency between water molecules, magnetic flux and scale in the pipe's wall. These

can be achieved by implementing circulation flow, where the water will be able to become the stronger magnetized water.

v. The methods used for analytical parameters were referred from Standard Methods for the Examination of Water and Wastewater (American Public Health Association, APHA, 2005) and conducted in Environmental Engineering Laboratory, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia.

1.5 Significance of Study

Regarding on scale control, MWT plays an important role among chemical water conditioning methods (Banejad and Abdosalehi, 2009) because physical water treatment of MWT process was developed to substitute chemical water treatment methods which employ chemical product that is harmful to the environment and human health (Cai *et al.,* 2009). Magnetic treatment has significant effect on water quality of irrigation (Bogatin *et al., 1999*). In addition to its benefits as non-chemical treatment, it identifies whether the best method to remove the scale is by inverted or non-inverted magnetic field. According to Donaldson and Grimes (1988), magnetic device removed existing calcite scale and further hard scale was not forming. Thus, it can help to recognize scale removal in water pipeline with magnetic field. The findings of this result will introduce a new potential mechanism on scale removal process and at the end of this study, the empirical relationship can be formulated according to this optimum results. A significant contribution of this study is the knowledge and understanding of optimum design of magnetic devices in scale removal, which has not been critically researched nor considered in empirical formula yet. This empirical relationship formula was targeted to be implemented as a new guideline for the future researchers in order to obtain further progressive results.

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