EFFECT OF MAGNETIC FIELD ON SCALE REMOVAL IN DRINKING WATER PIPELINE

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To my lovely God

And my beloved parents, brother, friends and lecturers

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ABSTRACT

The presence of scale in drinking water pipeline causes economical and environmental problems. It caused the corrosion of water pipeline, affected the water pressure and distribution system. Magnetic field was proposed as a physical treatment method on scale prevention. However, there is minimal study regarding the removal of scale drinking water pipeline. This study also developed the magnetic devices with different magnetic flux orientation to determine the effect on scale removal, by determining the concentrations of Ca^{2+} and Mg^{2+} in the water. Several parameters were investigated for preliminary tests, which were pH, turbidity and total suspended solids. In preliminary test, three different of magnetic flux density were conducted in the experiment, which were 0.120 Tesla, 0.050 Tesla and 0.025 Tesla. The treatment system without magnetic field acted as control sample. After the preliminary test, two self-designed magnetic devices with the magnetic flux density of 0.4 Tesla, 0.3 Tesla and 0.1 Tesla were developed. Three different flow rates of 1.0 mL/s, 1.3 mL/s and 1.5 mL/s were studied throughout the experiments. The systems conducted in a circulation flow system. Magnetic field reduced turbidity and TSS of water sample around 50% and 20% respectively. In the outlet of water sample of the system with magnetic field, the concentration of Ca^{2+} and Mg^{2+} were 90% and 20% higher than the system without magnetic field. Besides, with flow rates of 1.5 mL/s, the self-designed inverted magnetic devices showed the concentration of Ca^{2+} and Mg^{2+} of 13.45 mg/L and 4.91 mg/L respectively in the outlet of water sample. Its concentration was 40% higher than non-inverted magnet devices. The non-inverted magnetic devices were detected the concentration of Ca^{2+} and Mg^{2+} of 9.51 mg/L and 2.57 mg/L respectively. Compared between different magnetic flux density, 0.4 Tesla inverted magnetic devices removed Ca^{2+} and Mg^{2+}, which were 40% higher than 0.1 Tesla and 0.3 Tesla inverted magnetic devices with the flow rates of 1.5 mL/s. Investigation of the effect of flow rates, 1.5 mL/s showed higher concentration of Ca^{2+} and Mg^{2+} in effluent of water sample compared with 1.0 mL/s and 1.3 mL/s. It can be concluded that the presence of magnetic field reduced the turbidity and TSS of water sample. It also enhances the removal of scale in drinking water pipelines. With higher magnetic flux density and higher flow rates, the removal of scale from the drinking water pipeline is higher.

ABSTRAK

Kehadiran kerak dalam saluran air menyebabkan masalah ekonomi dan alam sekitar. Ia menyebabkan hakisan saluran paip air, menjejaskan sistem tekanan dan pengagihan air. Medan magnet telah dicadangkan sebagai satu kaedah rawatan fizikal untuk menyelesaikan masalah kerak dalam paip air. Walau bagaimanapun, terdapat kajian yang minimum mengenai penyingkiran kerak dari saluran paip air minuman. Kajian ini juga membina peranti magnet dengan pelbagai orientasi medan magnet bagi menentukan kesan terhadap penyingkiran kerak, dengan menentukan kepekatan Ca^{2+} dan Mg^{2+} dalam air. Beberapa parameter telah disiasat untuk ujian awal, iaitu pH, kekeruhan dan jumlah pepejal terampai. Dalam ujian awal, tiga ketumpatan fluks magnet yang berbeza telah digunakan dalam kajian ini, iaitu 0.120 Tesla, 0.050 Tesla dan 0.025 Tesla. Sistem rawatan tanpa medan magnet bertindak sebagai sampel kawalan. Selepas ujian awal, dua peranti magnet telah dibina dengan ketumpatan fluks magnet 0.4 Tesla, 0.3 Tesla dan 0.1 Tesla. Tiga kadar aliran yang berbeza iaitu 1.0 mL/s, 1.3 mL/s dan 1.5 mL/s telah dikaji sepanjang eksperimen. Sistem yang dijalankan dalam sistem aliran edaran. Medan magnet mengurangkan kekeruhan dan jumlah pepejal terampai sampel air sebanyak 50% dan 20% maing-masing. Dalam outlet sampel air, sistem yang bermedan magnet, mangandungi kepekatan Ca^{2+} dan Mg^{2+} yang tinggi sebanyak 90% dan 20% daripada sistem tanpa medan magnet. Selain itu, dengan kadar aliran sebanyak 1.5 mL/s, peranti magnet yang songsang magnet menunjukkan kepekatan Ca^{2+} dan Mg^{2+} sebanyak 13.45 mg/L dan 4.91 mg/L masing-masing di outlet sampel air. Kepekatannya adalah 40% lebih tinggi daripada peranti magnet bukan songsang. Peranti magnet yang bukan songsang menunjukkan kepekatan Ca^{2+} dan Mg^{2+} sebanyak 9.51 mg/L dan 2.57 mg/L masing-masing. Berbanding kesan ketumpatan fluks magnet, 0.4 Tesla peranti magnet songsang menyingkirkan Ca^{2+} dan Mg^{2+} yang sebanyak 40% lebih tinggi daripada 0.1 Tesla dan 0.3 Tesla peranti magnet songsang dengan kadar aliran sebanyak 1.5 mL/s. Kajian atas kesan kadar aliran, 1.5 mL/s menunjukkan kepekatan yang lebih tinggi daripada Ca^{2+} dan Mg^{2+} dalam efluen sampel air berbanding dengan 1.0 mL/s dan 1.3 mL/s. Ini dapat membuat kesimpulan bahawa dengan kehadiran medan magnet dapat mengurangkan kekeruhan dan jumlah pepejal terampai sampel air. Ini juga meningkatkan penyingkiran Ca^{2+} dan Mg^{2+} dari saluran paip air. Dengan kepadatan fluks magnet yang lebih tinggi dan kadar aliran yang lebih tinggi, penyingkiran Ca^{2+} dan Mg^{2+} dari saluran paip air minuman adalah lebih tinggi.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
ANOVA	Analysis of Variances
AWWA	American Water Works Association
Ca^{2+}	Calcium ions
$CaCO_3$	Calcium Carbonate
CO_3^{2-}	Carbonate ions
FESEM	Field Emission Scanning Electron Microscope
H^+	Hydrogen ions
HCO_3^-	Hydrated carbonate ions
Mg^{2+}	Magnesium ions
$MgCO_3$	Magnesium Carbonate
MHD	Magneto-hydrodynamic
mg/L	milli gram per Litre
mL	milli Litre
mL/s	milli Litre per second
mm	milli Meter
mT	milli Tesla
MTD	Magnetic Treatment Devices
MWT	Magnetic Water Treatment
NdFeB	Neodynmium-Feerrite-Cobalt
Q	Flow rates
T	Tesla
TSS	Total Suspended Solids
WHO	World Health Organization

LIST OF SYMBOLS

ψ	Potential
ψ_m	Potential after magnetic exposure
$\mathbf{B}$	Magnetic Field
C	Concentration of the mineral in the water sample
C_o	Original of concentration of the mineral in the water sample
$\mathbf{F}_L$	Lorentz Force
R	Concentration of Removal
T	Duration
$\mathbf{v}$	Velocity
V_i	Initial volume of water sample
V	Volume of water sample

CHAPTER 1

INTRODUCTION

1.1 Study Background

Scale is a composed of calcite which formed from calcium carbonate present in the water. The soluble salt calcium carbonate sparingly presents in water. After a long time it flows through the water pipeline, the soluble calcium carbonate will form an encrustation on susceptible surface in the water pipeline (Baker and Judd, 1996; Alimi *et al.*, 2009). Glater *et al.* (1980) stated scale usually forms in high temperature, different flow rate, high pressure and some very adherent conditions. Since the scale form in these critical conditions, it has strongly bond with the material of water pipe especially metal water pipe. Hence, it is very difficult to remove scale from water pipe.. Scale deposit in natural waters is a common problem that always leads to economical issues. In the review paper from Baker and Judd (1996) and Wu and Li (2011), there are many results that show the buildup of scale deposits poses costly problem. The buildup of scale on the internal wall of metal pipes will reduce the internal bore and ultimately restricting flow and reduce water pressure at the faucet. This will cause the wastage of water and influence the water quality.

The traditional scale control known as water softening method involves a lot of chemical reagents such as lime and soda ash. These chemical reagents are used to convert the soluble calcium carbonate compounds into insoluble calcium carbonate (Darshan, 2006). Another traditional method of scale removal is deposing water pipeline which is full of scale. Some mechanical methods such as drilling or hammering have been used to remove strong bonded scale from metal surface (Glater *et al.*, 1980). However, if the amount of chemical does not control or monitor properly, it will affect the drinking water quality. It is harmful to human and it will cause pollution. Deposing water pipeline or drilling methods are eventually very costly and not environmental friendly methods.

However, magnetic field in water treatment is a simple physical treatment. It is conducted by flowing water through magnetic fields. Baker and Judd (1996) suggested some possible mechanism in their review paper. They suggested that the magnetic fields able to change the electron configuration and coordination of the water ions. Besides, they also summarized that magnetic fields can also affect in zeta potential and dissolution. Many researchers such as Gehr *et al.* (1995) and Baker and Judd (1996) claimed that due to the characteristic of magnetic fields, it can change the physicochemical properties of the particles that exposed to it. According to Beruto and Giordani (1995), the magnetic fields able to redistribute the surface charge of the particles or molecules when it passing through the magnetic fields. Therefore, this phenomenon will enhance the coagulation and precipitation of the particles.

They are many researches regarding the effect of magnetic fields on scale in the water distribution system. Their researches mostly focus on scale prevention. Barrett and Parsons (1998), Parsons *et al.* (1997), Kozic and Lipus (2003) and Fathi *et al.* (2006) claimed that magnetic fields can change the physicochemical properties of water molecules when the water sample passed through a magnetic field. Therefore, it will help to prevent the crystallization of calcium carbonate in water sample and this leads to prevent the formation of in water pipeline.

1.2 Problems Statement

Hardness in water is caused by calcium and magnesium ions resulting from water coming in contact with geologic formation (Warren Viessman and Mark, 2005). This condition can cause increased soap consumption and scale deposition in the water distribution system (WHO, 2011). When calcium carbonates formed in the water pipelines, it reduces the efficiency of the water pipelines. This will lead to corrosion tendencies of water pipelines. Corrosion can be associated with health risks.

From year 2003 to year 2005, Johor state consumed at least RM 155.3 million in pipe replacement (Ranhill Utilities, 2006). A total of 222,741 m of water pipes were replaced. Ranhill Utilities (2006) estimated another 620km of pipelines need to replace until year 2008. Most of the pipe had been deposed due to the condition of installation, environment of the pipe being exposed and the water pressure during distribution. Formation of scale affects the pressure in water distribution system. It leads to the damage of the water pipe. To overcome the formation of scale issues, some chemicals such as strong acids or polyphosphates have been used in the water treatment. However, over usage of chemical is harmful for human and deleterious for the environment (Fathi *et al.*, 2006).

Many researchers are conducting the researches mostly concentrate on the effects of magnetic fields on scale precipitation. In another words, most of the researches are focus on scale prevention. Saksono *et al.* (2009) applied magnetic fields in high super-saturated calcium carbonate solution, to determine the effects of magnetic fields on reduced precipitation of calcium carbonate. Alimi *et al.* (2007; 2009) also conducted experiments on increasing precipitation by using magnetic fields with different pipe materials. Furthermore, magnetic fields can reduce 99% of water hardness by using weak magnets (Banejad and Abdosalehi, 2009). Another precipitation research by using magnetic field is conducted by Dong *et al.* (2011). They found that magnetic field can promote the precipitation of aragonite polymorph of calcium carbonate precipitation (Dong *et al.*, 2011). From their observation, the crystal shaped of $CaCO_3$ completely changed from hexagonal crystal calcite to needle-like aragonite.

However, all of the studies mostly point to scale prevention in water distribution system. In Malaysia, there is lack of studies regarding the application of magnetic fields in water treatment. In addition, there is no study regarding the magnetic fields on scale removal in existing drinking water pipeline. Therefore, this study is important to determine the effects of magnetic fields on scale removal.

1.3 Objectives of Study

(i) To determine the effects of magnetic field on characteristic of water (pH, turbidity and Total Suspended Solids) in water pipeline.

(ii) To determine the effect of magnetic field on scale removal (concentration of Ca^{2+} and Mg^{2+}) in the water pipeline.

(iii) To determine the effect of two different magnetic devices unit (Inverted permanent magnets and non-inverted permanent magnets) o from drinking water pipeline.

(iv) To determine effects of flow rates, Q and magnetic flux density, B on concentration of Ca^{2+} and Mg^{2+} removal from drinking water pipelines.

1.4 Scope of Study

This study was conducted by using the permanent magnets to determine the effects of magnetic field on water characteristic and scale removal. Self-designed magnet devices, which categorized into inverted and non-inverted magnet devices, were used to determine its on scale removal. Furthermore, this study continued with the determination of effects of magnetic flux density and flow rates on scale removal. All the samples were passing through circulation system with attachment of magnetic field. The circulation system without magnetic field was used as control sample. 0.1 Tesla, 0.3 Tesla and 0.4 Tesla magnets were used in the experiments. Flow rates from 1.0 mL/s to 1.5 mL/s were estimated. Besides, the parameters of this study are calcium ions, Ca^{2+} and magnesium ions, Mg^{2+}. The analysis was conducted at Environmental Engineering Laboratory, Civil Engineering Faculty, Universiti Teknologi Malaysia.

1.5 Significant Study

When the drinking water pipelines, which contained scale, exposed with magnetized water, it will reduce the turbidity and total suspended solids of the water. By passing through magnetic field, the concentration of Ca^{2+} and Mg^{2+} in the outlet of water sample will increase due to the removal of Ca^{2+} and Mg^{2+} from the drinking water pipeline. Furthermore, the inverted magnetic devices will increase the efficiency of Ca^{2+} and Mg^{2+} removal due to its variation of the magnetic induction in the gap for inverted pairs. Besides, as magnetic flux density increases, the concentration of Ca^{2+} and Mg^{2+} removal also will increase in the outlet of water sample. From this study, the flow rate also has been investigated. It expects with a higher flow rates in the circulation system, the concentration of Ca^{2+} and Mg^{2+} in effluent of water sample is higher. This study can be a potential finding for real application in solving scale problem in drinking water pipeline.

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