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Review Article

A Review: Methodologies Review of Magnetic Water Treatment As Green Approach of Water Pipeline System

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ABSTRACT

This review is aimed to present an in-depth review of several methodologies on magnetic water treatment (MWT) that are employed as scale treatment in water pipeline and to critically discuss each method in order to determine the best outcome of MWT. The magnetically assisted water in pipeline in various applications are presented, argued and best variables are listed according to the performance of each MWT. The advantages and limitations of MWT are discussed and the main outcome from the review summarize the best method in MWT, especially in effectiveness of treating scale in terms of sustained environment benefits. Magnetic field application in water treatment has the potential to improve the water pipeline performance and lifetime. The application is also significant in controlling the growth of scale in upcoming system. Both of these benefits lead to healthier water treatment, increasing and maintaining the lifetime and performance of water system.

Keywords: Magnetic water treatment, permanent magnet, pipe, scale, water

INTRODUCTION

MWT is an interesting research field because the treatment is consuming zero energy (Esmaeilnezhad et al., 2017) and has high potential as physical water treatment, which is more environmentally friendly compared to chemical water treatment, which is not desirable (Simonic & Urbancl, 2017). Even now, in 2018, there is still ongoing

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researches that relate to magnetic water treatment, proving that this topic is still eagerly explored by researchers worldwide. It is demanded because recent incentives to 'go green' treatment (Harfst, 2010) require less budget (Mysliwiec et al., 2016) and produce less harmful effects (Alimi et al., 2007). For a long term of MWT implementation, especially in pipeline system, it will improve its life-span as the pipeline with magnetic devices were less affected by scale formation. This free-scale of pipeline is definitely having less possibility to get damaged, corrosion and leakage and it fulfils the concept of environmentally friendly. Hence, pipeline with magnetic devices are facing less problems, and its life-time period will be increased (Gholizadeh et al., 2005; Mosin & Ignatov, 2015).

The magnetization principles or hypotheses of MWT can vary depending on the objective chosen such as Lorentz Force (Chang & Thai, 2010), magnetic memory (Esmaeilnezhad et al., 2017), nucleation (Simonic & Urbancl, 2017), colloidal (Mosin & Ignatov, 2014) and Pauli exclusion principle (Madsen, 2004). The methodologies are strictly selected from previous researches which focus only on magnetic field, scale and water. These chosen methodologies will be elaborated in detail, where any advantages and disadvantages will be discussed. Thus, in particular, this paper reiterates conclusions of prior studies regarding the best methodology in MWT to maximize treating scale in water pipeline.

Scale is generally an assemblage of calcium carbonate, magnesium hydroxide and calcium sulfate (Sohaili et al., 2016) which is normally hard, insulator layer off-white in color. The water flowing continuously inside the water pipeline continues to be heated and cooled with additive substances that might accelerate the scale formation growth. Scale creates a cake perforation, which in turn clogs the media, decreasing internal diameter of pipe and disturbing the fluid flow in the media. The main catalyst of scale formation is water hardness which contains large quantities of dissolved compounds of calcium and magnesium.

The formation is boosted with increasing temperature, and existence of metallic elements normally coming from the pipe. The major sources of drinking water are ground water, rivers, lakes, rain water, seawater, among others. All these sources are natural water which usually contains high level of hardness. Scale in water pipeline causes many problems either in daily life or industrial activities. In daily life, scale leads to clog water instruments such as faucet, shower head and tends to affect health (Larson & Skold, 1957).

For industrial activities, the problems result in increased maintenance and operating cost (Banejad & Abdosalehi, 2009), reducing equipment performance (Quinn et al., 1997) because the scale is reducing the diameter of pipe, thus lowering the flow rate of fluid and increasing the energy consumption of the pumps (Spiegler & Laird, 1980). Previously, most scale problems were treated by chemical water treatment such as water softening (Harfst, 2010) or directly by using hydrochloric acid. This chemical water treatment cannot overcome the problem of scale where the procedure must be conducted consistently, which becomes a very costly and harmful procedure. Physical water treatment is strongly recommended where it is implemented by applying methods or technologies without using any substances as prevention of scale problem.

MWT has been employed for almost a century (Harfst, 2010). The first research regarding this topic was in 1890 (Raisen, 1984) and first commercial device was patented in 1945 in Belgium (Vermeiran, 1958). For Malaysia, by considering all types of water distribution either in domestic or industrial purposes, the state of Johor had consumed at least 155.3 million Ringgit Malaysia for the replacement of a total of 222,741 meters of water pipes between 2003 and 2005 (Ranhill Utilities Berhad, 2006). Britain spends around £600 million each year to clean or repair pipes and boilers damaged by scale (Donaldson & Grimes, 1988). There are disagreements and debate exists on MWT due the efficacy of this treatment. However, this review paper offers unbiased information and a discussion of the claims made by various researches on MWT based on their methodology and findings. The goal of this literature review is to summarize the results of previous researches that are relevant to the MWT on treating the scale and to recommend the best MWT methodology.

The Principles of MWT

The principle of MWT is referring to various aspects. According to Busch et al. (1996), MWT principle is associated with Faraday's Law, which considers the changes in voltage and current of conducting solutions that pass through magnetic field (Salman et al., 2015). Faraday's Law formula is $E = v \times B$, where E is electric field vector, v is fluid linear velocity and B is magnetic induction vector. The magnetic application is also related to the physics of interaction between a magnetic field and a moving electric charge ion, which can be known as the theory of Lorentz's force, where Lorentz force is $F_L = q\ |B \text{ x } v|$, where q is quantity of charged ion, B is magnetic induction and v is flow velocity. In support of this principle, Chang & Tai (2010), Gabrielli et al. (2001), Lipus et al. (2011), Madsen (1995) and Parsons et al. (1997) demonstrated that the maximum effect of magnetic field would occur when B and v were perpendicular to each other.In regard to the contact frequency between ions and magnetic field, Gholizadeh et al. (2005) found that the magnetic field caused the ion particles to collide with each other, and the redirection of the particles tended to increase the frequency of ions with opposite charge to collide and combined to form a mineral precipitate or insoluble compound. This process has generated the formation of suspended solids contains of mineral of scale and the amount is enhanced by implementation of magnetic field (Alimi et al., 2009). Another principle of MWT is magnetic memory, which is defined as the ability of particles to sustain their magnetization properties for a period of time after being exposed to magnetic field or a transformation towards metastable state (Esmaeilnezhad et al., 2017). Zaidi et al. (2014) had supported this and found that the high strength of permanent magnets would contribute to the higher potential of the water sample to gain higher magnetic memory.

Besides having reaction with water particles, magnetic field also shows effect on metallic, non-metallic ions and suspended solids but varies in their rate of effectiveness. Although magnet is known as a device that attract to metals, it also can attract non-metals (Alimi et al., 2009), as long as the material has a large number of electrons with parallel spins occurring within a crystal. In terms of magnetism, the materials can be classified into three, which is ferromagnetic, paramagnetic and diamagnetic. Ferromagnetic is the materials that have strongest attraction to magnetic field (cobalt, nickel, iron) even in very low intensity of magnet. These materials were able to point all of the electron spins into same direction over macroscopic length scales even without an applied magnetic field. Paramagnetic is the materials that require magnetic field to order and rearrange the spins randomly. Lastly, diamagnetic is the materials that obviously are not attracted to magnetic field even in very high intensity of magnet.

Methods of Magnetic Device Set-up for Scale Treatment

The optimum effectiveness of MWT can be achieved by proper and correct methodology. The experiment has sometimes given insufficient results due to improper set-up. The chosen methods from previous researches have been selected based on the similar concepts which are mainly related to scale that forms in pipeline due to the existence of water and treatment by permanent magnets. The existing scale in pipeline is either removed or decreased and growth of scale has been delayed.

The most basic factor having a significant influence on MWT effectiveness is the necessity of the water to perpendicularly pass through magnetic field where permanent magnets were attached to the side of water pipeline and all water flowing passes through this magnetic field (Meyer et al., 2000) as illustrated in Figure 1. The position of the permanent magnets must be oriented 90^{o} relative to the flow of water (Gholizadeh et al., 2005). Generally, the arrangement of permanent magnets plays a more important role in efficiency of MWT than other factors such as magnetic strength, water flow rates and temperature. The set-up may differ based on the purpose i.e. either for scale removal or scale formation. In terms of removing scale in water pipeline, MWT functions by either mounting permanent magnets inside pipe sections and reaction chambers or clamped to the outside of pipe in order to cause the water to flow through magnetic field (Harfst, 2010; Faunce & Cabell, 1890; Orb, 2007).

The effect of magnetic field on water hardness reduction is focusing on the results of particle type and particle size of calcium carbonates from water sample (Banejad & Abdosalehi, 2009). The MWT has been done by using seven U-shape magnets equivalent to 25 cm in length of North Pole and South Pole. The magnet is formed from central nucleus

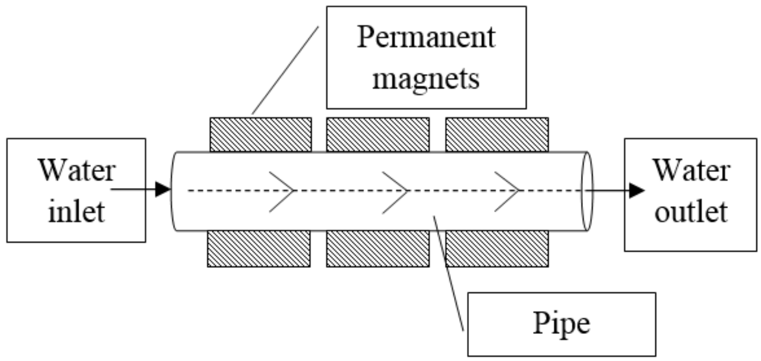

Figure 1. Schematic of the permanent magnets orientation with water pipe

that consists of 300 grams of twisted copper wire for each magnet. This experiment was accomplished by four levels of magnetic field intensity (0 T, 0.05 T, 0.075 T and 1.0 T) and two levels of water flow rate (4 l/h and 30 l/h). U-shape magnet was used as this type of magnet has strong magnetic field due to both North and South poles were facing the same direction, thereby creating a high peak of magnetic peak. The strongest magnetic flux was from magnet pole as it creates the atomic currents per unit volume that give the magnetization (Tanel & Erol, 2008). Since U-shape magnet had both poles in same direction, it was able to double the strength of magnets, especially in legs of U as the homogeneous magnetic field occurred approximately there as illustrated in Figure 2. However, there is limitation in using U-shape magnet in MWT as it only fits into certain diameter of pipes.

Note that the details of procedure, sample test and MWT set-up are not discussed in this paper. This MWT used U-shape permanent magnets in 7 units with 4 different strengths,

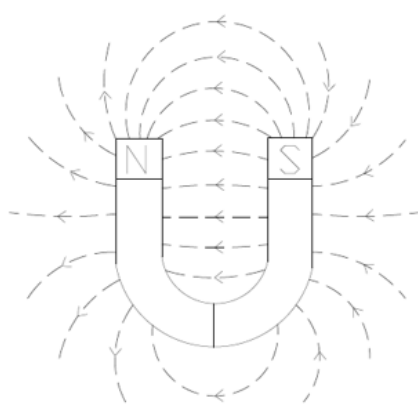

Figure 2. Magnetic flux of U-shape magnet

supported with copper wire and undergoing 2 flow rates. The higher the quantity and strength of permanent magnets used, the higher the removal rates of scale treated. Only two flow rates were used, and they were significantly different.

The study of MWT performed in the industrial boilers have investigated the effect of magnetic field on scale formation in pipeline system and to the boilers (Gholizadeh et al., 2005). A static magnetic field, with about 6000 G was installed in pipeline system right after water pump to ensure magnetized water went into boiler. Magnetic device was used to focus on the effectiveness of magnetic field without any contributions from external factors such as types of water internal flow. Thus, the results obtained were caused only by the magnetic field itself.

The duration of the treatment was started 24 hours after the installation, where the flow rate, pipeline condition and chemical of water properties were recorded. The pipeline conditions were observed every three months and the final observation will be recorded one year after installation. The observations were made in order to study the internal conditions of pipeline, boilers and water chemical properties. The ready-made magnet was used with strength of 6000 Gauss, equivalent to 0.6 Tesla. This study focused only on effectiveness of magnet without involving any other factors that might accelerate the removal rate.

Next is the study of the application of MWT on ordinary and heavy water (Madsen, 2004). The study has created artificial $CaCO_3$ solution where the ordinary water has been demineralized first by activated carbon and ion exchange method. Electromagnet treatment was also performed by setting a thermostat chamber with temperature of 25^oC, small size of permanent block magnets of 40×25 mm with 0.25 T of strength, while mix solution had been prepared by equal volume of 2.5 cm^3 for each 0.1M $CaCl_2$ with 0.1M $NaHCO_3$ and 0.006M $CaCl_2$ with 0.006M Na_2HCO_3. The samples were taken after 1 hour mixing for microscopy and crystal size distribution was determined visually with Zeiss Jenapol polarizing microscope. For electromagnetic, the duration of treatment was about 30 minutes before the samples were taken. This study used medium magnetic strength, supported by thermostat and two types of sample in order to find the variation of MWT.

MWT implementation in investigating few type of scale which is calcium carbonate ($CaCO_3$), calcium sulphate ($CaSO_4$) and barium sulphate ($BaSO_4$) in two configurations, closed and open loop, with different techniques at ambient temperature of 22^oC (Salman et al., 2015). The experiment consisted of tank attached by three pairs of rectangular permanent magnets with north and south poles facing each other with strength of 0.16 T. The saturated solutions of $CaCO_3$, $CaSO_4$ and $BaSO_4$ were prepared and magnetized for 24 hours before testing. The samples were drawn from the sample tank for every one minute at stagnant condition in order to analyse the selected parameters (turbidity and scale concentration). For the closed loop configuration, the magnetized solution in the sample tank flowed continuously throughout the system. In this configuration, moving solution helps the scale treatment by measuring turbidity and scale concentration of these saturated solution. The samples were drawn from the sample at one minute interval at stagnant condition in order to analyse the selected parameters (turbidity and scale concentration).

This research has found that the moving solution gives better results of MWT compared with stagnant solution. Thus, this experimental set-up can be further improved. This research is much improved where it varies the type of scale, the loop and conditions of the treatment process while maintaining the basic factors such as quantity and strength of magnet used. The type of various scale, for example magnesium carbonate (Esmaeilnezhad et al., 2017), magnesium hydroxide and calcium sulphate (Sohaili et al., 2016) that exists inside the water pipeline is different due to different situation and place.

The study of MWT by different conditions of new pilot scale and old existing water system had created a pilot scale water distribution system built in laboratory with eight parallel lines of two materials of looping pipes, where four of them were copper pipes (upper part) and rest were high density cross-linked polyethylene (PEX) pipes (Latva et al., 2016). Water was supplied by 60 litre stainless steel storage tank to this system with the help of water pump and exposure of 26mT maximum of magnetic field. The sample were taken once in a month and sampled from nine different of sampling point through a tap which started before the system and followed by another eight taps at each lines of pipes. The pipe lines were detached from the pilot system after nine months of use and the sample of calcium content that attached onto inner surface was measured by draining 0.1M hydrochloric acid for an hour, while turning it upside-down every 15 minutes. Then, the lines were continuously rinsed with 10 mL acid to ensure complete solubility of calcium. This study considered MWT in experiment and real water system with 2 different materials of pipeline. However, the magnet strength used was very low and not supported by other variables.

FINDINGS OF THE MWT

Experimental results of Banejad and Abdosalehi (2009) indicated that magnetic field controlled with magnetic strength and water flow rate had reduced water hardness by 99%. The efficiency of MWT increased with the increment of magnetic field strength and water flow rate as the magnetic strength increase from 0 Tesla till 0.1 Tesla, the rate of efficiency was also increased. As the water flow rate was changed from 4lit/h into higher speed, 30lit/h, the rate of efficiency were getting even more higher which the increment is about 6.6 to 8.8%. As the experiment was performed under U-Shape magnet, it can be clearly seen from the figure that the higher the intensity of magnetic field, the higher the rate of magnetic treatment efficiency were recorded. Compared to the water influent, the results were only slightly higher with higher flow rate. In the perspective of another shape of permanent magnet, Gabrielli et al. (2001) was using block-shape permanent in performing

MWT resulting up to 30% reduction of calcium concentration. By comparing both cases, it was clearly shown that U-Shape gave higher rate of MWT effectiveness but most of the recent researches prefered block-shape magnet in their research work because block-shape magnet was able to be customized into many concepts, ideas and configurations. It helps the researchers to inspire more ideas in future.

The result on particles of $CaCO_3$ under U-Shape magnet on MWT had changed calcite to aragonite by at least 70% due to chemical analysis by X-ray and supports the findings of higher intensity of magnetic field gives higher efficiency rate of MWT. Calcite is much stronger layer than aragonite, non-soluble and adheres to the wall surfaces. When the amount of aragonite is much greater than calcite, the process of water treatment will be much easier (Orb, 2007; Simonic & Urbancl, 2017; Sohaili, et al., 2016).

Regarding the result of experiment tested using industrial boilers (Gholizadeh et al., 2005), the new pipeline was well protected from scale formation and internal corrosion, while the boilers and pipelines system were automatically cleared, the solid material became loose and fell off. As for chemical properties, there was a difference in the amount of two crystallographic forms of $CaCO_3$ as demonstrated by X-ray analysis. The changes of crystal forms of $CaCO_3$ without magnetic field and with magnetic field were (Calcite = 65%, Aragonite = 35%), (Calcite = 27%, Aragonite = 73%), respectively. Normally, calcite is a very strong layer formed in the pipe's wall and is hard to dissolve. Aragonite is a more soluble layer and normally strongly adheres to pipe walls. It is a good indicator if the content of aragonite is higher than calcite. It has been concluded that MWT required continuous and fast water flow. As for permanent magnet criteria needed, it has to be sufficient in strength and must be oriented 90^o in respect of water flow direction.

The study conducted comparing ordinary and heavy water had proven that there is an effect on the crystallization of calcium carbonate in ordinary water due to the existence of magnetic field (Madsen, 2004). It found out that the median of crystal size changed against magnetic field strength. They had an inverse relationship as the median crystal size was decreasing by the increment of magnetic field strength. The smaller the size of crystal indicates the existence of aragonite which is easily removed in this treatment. It demonstrates an acceleration of nucleation of $CaCO_3$. But it differs based on the field strengths applied. The relation of crystal size and the strength of magnetic field is inversely proportional as crystal size is decreasing with increasing of magnetic field strength.

According to study by Salman et al. (2015), saturated solution of scaling compounds ($CaCO_3$, $CaSO_4$ and $BaSO_4$) was created, each having different method. 0.5 M of calcium chloride and 0.5 M of sodium carbonate are required in order to prepare $CaCO_3$ solution, 0.5 M $NaSO_4$ and 0.5 M $CaCl_2$ in preparing $CaSO_4$ solution and $BaSO_4$ was prepared by mixing barium chloride and $NaSO_4$. It had been proven that moving solution helps the scale in artificial solution to accumulated together, hence the solution turbidity and concentration was decreasing and cause the precipitation of scale. By comparison with stagnant solution, the parameters tested were only marginally different. The moving solution had enhanced the scale to precipitate and caused reduction in turbidity and concentration of the solution. According to Alimi et al. (2009), MWT helps to increase total precipitation of $CaCO_3$ by influencing the crystallization process. This is how magnetic field enhances the formation of suspended scale instead of incrustation on the pipe's wall. MWT has effective result in controlling scale but the performance is greater on treating $CaCO_3$ than $CaSO_4$ and $BaSO_4$.

A comparison study between new and old drinking water system (Latva et al., 2016) has decided on one copper line as well as one PEX line in order to compare efficiency of magnetic water treatment in pipes made from two different materials. Other lines acted as reference lines. The parameters measured were listed in Table 1 below. The calcium content that had been taken from inner pipe surfaces was analysed with ICP-OES according to standard SYP600/SFS-EN ISO11885 and the morphologies were evaluated using field emission scanning electron microscope. For identifying electrical conductivity, a thin carbon layer was coated before the sample was analysed.

Table 1

The methods used according to the suitable parameters

Parameter	Method
Temperature, pH, dissolved oxygen, redox, electrical conductivity.	YSI professional plus meter
Free chlorine, total chlorine, sulphate, chloride, microbial nutrients ammonium, phosphate, nitrite, nitrate.	Hach Lange DR 2800 Spectrophotometer
Alkalinity.	SFS 3005
Total hardness.	SFS 3003
Copper, iron contents.	SFS-EN ISO 11885:2009

The results were plotted using the average value and standard deviations for all samples of pipes. After MWT, the value of all parameters shows that they were only slightly different (approximately to 0% of rate difference) except for alkalinity (1.60%), hardness (1.91%) and pH (2.73%). Based on the impact of MWT on pipe materials, copper pipes were more pronounced compared to PEX pipes but the percentage of calcium precipitated onto the pipe walls with MWT in both pipe materials was almost 15%. These results are in agreement with Alimi et al. (2009) that the total precipitation of scale was due to the amount of contaminants present in water, and not the pipe material. This is answering the question of two different materials of pipe that have almost the same percentage of scale precipitate. This signifies that MWT reduced the amount of $CaCO_3$ either present in the bulk solution or attached onto pipe surfaces (Alimi et al., 2009; Gholizadeh et al., 2005; Salman et al., 2015).

This study also found that the calcium content from copper pipes was higher than PEX pipes which was about 63% increment. Eventhough few parameters react with positive results to the MWT such as water hardness, pH, alkalinity, crystal size and amount of $CaCO_3$ in the water, but there is also other parameters such as water quality parameters (temperature, ammonium, nitrite, nitrate, chloride) which do not contribute much and can be neglected due to the slight difference in value before and after MWT implementation. MWT has very little effect on water quality parameters.

Magnetic water treatment has different effectiveness on metallic and non-metallic pipes. Alimi et al. (2009) showed that non-metallic material of pipe had the most efficient results in magnetic water treatment. However, it was due to the presence of the contaminants in water while passing the magnetic field. The material of non-metallic pipe made of Tygon have tendency to create contaminant when in contact with water. Since this pipe creates substance in the water, the flux of magnetic field exerted the force to the substances ions and tends to deposit them. Referring to Chawla et al. (2012), the magnetic treatment has been performed on cast iron pipe and their scale composition was indicating the highest element was iron (Fe= 60.52%), followed by oxygen (O=34.11%) and the lowest is aluminium (Al=0.15%). Iron and aluminium are metal ions, but the results show an opposite percentage. This findings were explained and support that the effectiveness of MWT did not rely on metallic or non-metallic properties, but most important was that the magnetism was influencing the constituents in the water that passed through magnetic field. Magnetic field created effect and exerted forces on the particles present in water and was not attracted to the metal materials of the pipe.

A summary regarding the best operational set-up for MWT based on the chosen previous researches can be easily recognised as shown in Table 2 below. As for the permanent magnet itself, the higher strength is recommended and it must attach to the pipeline 90^o relative to the water flow. The water sample is perpendicular to the magnetic field in order to enhance the magnet memory and boost the scale removal ability. Many types of pipeline material such as steel, copper and PEX can be affected by MWT, but the most efficient MWT is towards the material with metal properties. The water sample can be any type of water depending on the objectives of the study, but the purer the water, the less the effectiveness of magnetic field (Barret & Parsons, 1998).

It is proven that high strength of permanent magnet, high flow rate of water, moving

Table 2

Summary of contrasting results from previous researches

Author(s)/Date	Research Title	Findings
Raisen (1984)	The control of scale and corrosion in water systems using magnetic fields.	With magnetic field, scale forms were a soft sludge that can be removed easily by blowdown. Without magnetic, scale forms was hard and only be removed by chemical treatment.
Donaldson and Grimes (1988)	Lifting the scales from our pipes.	Magnetic unit was removing existing calcite scale and that further hard scale was not forming.
Barret and Parsons (1997)	The influence of magnetic fields on calcium carbonate precipitation.	Magnetic effect maintains for at least 60 hours after exposure.
Coey and Cass (2000)	Magnetic water treatment.	Magnetic field promotes nucleation of aragonite and the magnetic memory stable for hundreds of hours.
Meyer et al. (2000)	Scale prevention in a hot-water storage tank with a magnetic physical water treatment device.	Magnetic device reduce the scale formation by 34% and have made the storage tank shinier and cleaner from the scale deposits.
Gabrielli et al. (2001)	Magnetic water treatment for scale prevention.	Magnetic decreasing the ionic calcium content of the solution even for a single-pass.
Madsen (2004)	Crystallization of calcium carbonate in magnetic field ordinary and heavy water.	Magnetic field affects the crystalization of $CaCO_3$ by reducing the crystal size .
Gholizadeh et al. (2005)	The effect of magnetic field on scale prevention in the industrial boilers.	Magnetic device gives protection to the new pipeline from scale and corrosion. Magnetic field reduces the amount of calcite and enhances the amount of aragonite by 38%

Table 2 *(Continue)*

Author(s)/Date	Research Title	Findings
Orb (2007)	Reducing formation of scale with magnetic descaler.	Magnetic descalers; maintenance free, operate interminably, maintaining their magnetic properties, do not consume additional resources.
Banejad and Abdosalehi (2009)	The effect of magnetic field on water hardness reducing.	Magnetic field cause depletion of water hardness by 99%.
Chawla et al. (2012)	Corrosion of water pipes: a comprehensive study of deposits.	There are different type of primary constituents of brown deposits due to different pipe diameters and surrounding environment.
Mosin and Ignatov (2015)	Practical implementation of magnetic water treatment to eliminate scaling salts.	Magnetic affects both an influence on the water, mechanical impurities and scaling-form salts and ions. Magnetic changes the hydration of ions, salts solubility, pH value.
Salman et al. (2015)	The effect of magnetic treatment on retarding scaling deposition.	MWT has stronger effect on treating $CaCO_3$ than $CaSO_4$ and $BaSO_4$.
Latva et al. (2016)	Studies on the magnetic water treatment in new pilot scale drinking water system and in old existing real-life water system.	MWT has minor effect on alkalinity, hardness and pH compared to other parameters such as chlorine, nitrate, nitrite, sulfate and chloride.

and continuous flow of water passing perpendicular passing through the magnetic field will increase the effectiveness of MWT towards scale removal and formation. The capability of MWT, especially in controlling scale growth in water pipeline, can be improved by ensuring these factors are implemented as many as possible in order to get the best result. Nowadays, there is MWT devices has been commercialized in various purposes, where the magnetic devices were designed as non-chemical technology for scale or hardness control. It can be found in online purchase but there is not official research or report to justify deeply in their magnetic device concept. The functions can be found in many scope such as for agriculture, vehicles and pipes.

For an example, MWT devices for water distribution system for residential purpose, are said to be made by strongest permanent magnet with high magnetic intensity and powerful combination of materials. Advantages of this is, it designed to suits the four climate countries by considering hot and cold situations with variety designs and size to suits few conditions in residential purposes, poses powerful magnetic flux to maximise the magnetic device effectiveness and it said to be forever lasting due to its magnet plating to avoid abrasion and corrosion. It comes with a fix size, thus it cannot be modified or reused to different size of pipe. It will be the best if the MWT devices can be design and commercialized in customization concept, where the holder of the permanent magnet can be adjusted in order to fit into varies diameter of pipe by keep maximising the exposure of magnetic flux towards pipe.

CONCLUSION

MWT has several types of operational system due to the different cases such as water sample, material of water pipeline, operational system and ambient surrounding. The effectiveness of the MWT implementation can be improved based on the summarisation made in this paper. Implementation of magnetic devices into water treatment with correct orientation, high strength of permanent magnet, high water flow rate and ensuring the water is not in stagnant condition must be considered as basic factors in applying MWT. The installation and maintenance procedure is relatively easy and very seldom where it prolong the life-span of pipeline, thereby minimizing operational and maintenance cost compared to other water treatment.

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