Eco. Env. & Cons. 26 (November Suppl. Issue) : 2020; pp. (S98-S103)

ISSN 0971–765X

The effectiveness of solenoid magnetic fields to reduce precipitation levels of $CaCO_3$ in hard water

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(Received 24 February, 2020; Accepted 20 June, 2020)

ABSTRACT

The formation of scale in the pipe walls and operating units due to high water hardness is a serious problem that is often found in industry. In general, scale deposits are composed of compounds which have low solubility, such as calcium carbonate ($CaCO_3$). This study aims to determine the effect of the magnetic field and the duration of magnetic field exposure on CaCO3 precipitation in hard water and to determine the relationship between the magnetic field and the duration of exposure to $CaCO_3$ precipitation. Sampling was carried out by mixing a solution of Na_2CO_3 and $CaCl_2$ to form water hardness levels of 190-210 ppm. The sample is placed in a box that is capable of causing water to circulate. Samples were divided into Group T0, ie the control group without treatment, Group B1 was treatment with a magnetic field of 160 mT, group B2 was treatment with a magnetic field of 180 mT, and group B3 was treatment with a magnetic field of 200 mT with time exposure of the magnetic field is done for t1 is 30 minutes, t2 is 60 minutes, and t3 is 90 minutes. $CaCO_3$ precipitation levels were measured using EDTA complexometric titration techniques. The data obtained were analyzed by factorial ANOVA statistics to determine the effect of treatment factors and the value of optimal treatment factors. The EDTA complexometry titration results showed a decrease in $CaCO_3$ precipitation levels by 73.57 - 173.41 ppm or about 25.99% - 64.72% along with the induction of magnetic fields and the duration of exposure. The results of the factorial anova analysis showed that the most influential magnetic field at 200 mT and the most optimal exposure time at 90 minutes was able to reduce $CaCO_3$ precipitation levels by 64.72%. Thus, the magnetic field and the duration of exposure affect the $CaCO_3$ precipitation and there is a correlation between the magnetic field and the exposure time.

Key words : *Magnetic field, Solenoid, $CaCO_3$ Precipitation, Hard water*

Introduction

Hard water is water that contains dissolved ions such as Ca_2^+, Mg_2^+, Be_2^+, Br_2^+ ions, and two positively charged ions (Saksono, 2006). Hard water is expressed in units of ppm $CaCO_3$ or mg ($CaCO_3$) / liter. Calcium carbonate ($CaCO_3$) is the result of precipitation from hard water. The existence of this precipitation indicates the level of water hardness (Alimi *et al.*, 2006). The level of water hardness is influenced by $CaCO_3$ levels. The level of water hardness is divided into five, namely very low (levels 0-70 ppm), low (70-140 ppm), moderate (140-210 ppm), high (210-320 ppm) and very high (320-350 ppm) (Hasan *et al.*, 2011).

In general, $CaCO_3$ precipitation can cause the formation of a little foam so that the use of detergent soap increases. In the industrial world, $CaCO_3$ precipitation is a problem in the piping system which can inhibit the flow rate in the pipe so that the pump work becomes heavier (Gholizadeh *et al.*, 2005).

These problems can be overcome in several ways, such as distillation, addition of dissolved ions and chemicals, and the provision of magnetic fields (Gabrielli *et al.*, 2001). Magnetic fields have been shown to stimulate the reactions of photochemical type 2 in the photosensitization process to produce ROS which have antimicrobial effects (Astuti *et al.*, 2017). In addition, the combination with magnetic fields with light gives the effect of biomodulation and cell activation (Astuti *et al.*, 2015) and provides the effect of organ repair in diabetic cases (Suhariningsih *et al.*, 2019) and kidneys (Astuti *et al.*, 2017). Besides the magnetic field is also effective for reducing lead in wastewater (Astuti, 2020).

Research on the use of magnetic fields has been carried out by several researchers (Busch *et al.*, 1997; Gabrielli *et al.*, 2001; Kobe *et al.*, 2003; Saksono, 2006). The magnetic field used is a permanent magnetic field with a certain magnetic field (Mahmoud *et al.*, 2016), a certain magnetization time, as well as with static water conditions (static) and flowing water (dynamic) (Mysliwiec *et al.*, 2016). The purpose of this magnetic field is to accelerate the $CaCO_3$ precipitation process so as to reduce water hardness. The results of the study by Gabrielli *et al* (2000) who used ten pairs of permanent magnets concluded that the greater the value of the magnetic field, the Ca^{2+} ions in the solution decreased. In addition, Saksono *et al.* (2007) who used 7 pairs of permanent magnets with a magnitude of 2000-5200 Gauss magnetic field concluded that the greater the magnetic field exerted, the $CaCO_3$ precipitation increased. This is influenced by four things, including flow velocity, magnetization time, concentration of solution and magnitude of the magnetic field.

According to Alimi *et al.* (2006), the treatment of acidity (pH) of the solution and flow velocity in the magnetization area was 1600 Gauss and had a very important effect in the formation of nucleation and precipitation types of $CaCO_3$. Saksono (2006) proved that there was a decrease in Ca_2^+ levels in the solution which was marked by a decrease in $CaCO_3$ precipitation at the 30th minute in the solution. While there was an increase in Ca_2^+ levels in the precipitancy results. This is caused by the transformation of solution particles into a precipitate. $CaCO_3$ precipitation with a magnetic field is the effect of the Lorentz force of the Ca_2^+ and CO_3^- molecules that move through the magnetic field. The Lorentz force effect can cause polarization of the solution so that the ion shift occurs so that it encourages local displacement in the solution which can contribute to the increasing fusion of ions. In addition, $CaCO_3$ precipitation is caused by the presence of Van der Walls forces or the attractive forces between particles in solution (Alimi *et al.*, 2007).

This study aims to determine the effectiveness of the $CaCO_3$ precipitation process in hard water using a solenoid electromagnetic field with a magnetic field variation of 160 mT, 180 mT, 200 mT and variations in the exposure time of 30 minutes, 60 minutes, 90 minutes.

Materials and Methods

Sample Soluton

The hard water solution model used to see the process of forming $CaCO_3$ particles is a mixture of $Na2CO_3$ and $CaCl_2$ solution. The reaction equation can be written as follows (Saksono *et al.*, 2006) :

$$Na_2CO_3.10H_2O + CaCl_2.H_2O \rightarrow CaCO_3+2NaCl+11H_2O$$

Mole ratio = 1: 1: 1: 2: 11

Because the water hardness level is equivalent to 1 ppm CaCO3, then determine the CaCO3 mole first.

$$\text{mol } CaCO_3 = \frac{g}{Mr\ [CaCO]_3}$$

$$\text{mol } CaCO_3 = 0{,}0125 \times 10^{-3} = 0.0125 \text{ mmol}$$

$$\text{mol } CaCO_3 = 0{,}0125 \text{ mmol}$$

Determine the mass of $Na_2CO_3.10H_2O$

Mr [$Na_2CO_3.10H_2O$] = 262

Mass $Na_2CO_3.10H_2O$ = mole × Mr = 3.275 mg

So, for 1 ppm requires mass of $Na_2CO_3.10H_2O$ 3,275 mg/L.

Whereas for 200 ppm, the mass of $Na_2CO_3.10H_2O$ = 3.275 × 200 = 655.00 mg/L.

Because the sample is 7.5 L, so the mass of $Na_2CO_3.10H_2O$ needed is:

655.00 mg x 7.5 = 4912.50 mg = 4.9125 g

So as to determine mass of $CaCl_2.H_2O$

Mr [$CaCl_2.H_2O$] = 10^3

Mass of $CaCl_2.H_2O$ = mole × Mr = 1,289 mg

The total precipitation of $CaCO_3$ in hard water is a combination of $CaCO_3$ precipitation in solution and on the surface (deposit) (Strazisar *et al.*, 2016). The amount of $CaCO_3$ deposit and total $CaCO_3$ precipitation is a parameter that is measured directly in this experiment, while the number of $CaCO_3$ particles formed in the solution can be calculated using a mass balance. Calculation of $CaCO_3$ levels using the equations 1-3:

$$\text{Mol } CaCO_3 = \text{mol}_{EDTA} \times \frac{V_{EDTA}}{1000} \quad ..\ (1)$$

$$\text{Mass of } CaCO_3 = \text{mol } CaCO_3 \times \frac{100.09 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3} \quad ..\ (2)$$

$$CaCO_3 \text{ Levels} = \frac{\text{mass of } CaCO_3}{\text{Vhard water (Lt)}} \quad ..\ (3)$$

Apparatus Chamber

The instrument used is an electrical design of a solenoid winding connected to an iron plate and mounted on the container where the solution is. Inside the container there is a pump as a solution of circulation. The source of the magnetic field chosen in this study is the solenoid (Linares *et al.*, 2016). Solenoids are made of 1 mm diameter copper wire and a wire type resistance of 1.72x10-8 Ωm. The solenoid has a length of 3.85 ± 0.05 cm, 2.10 ± 0.05 cm in diameter and 325 turns. The resistance of the solenoid is 1.00 ± 0.05 Ω measured using a digital multimeter DB-860. The set-up of experimental devices is shown in Figure 1.

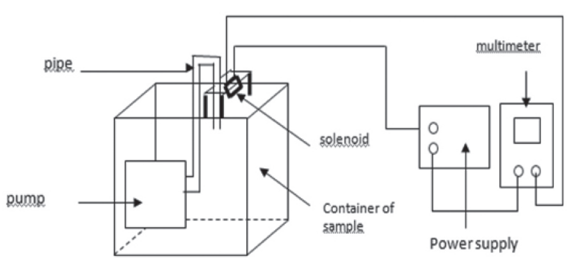

Fig. 1. Set-up of apparatus chamber

Sample Treatment

Samples were divided into Group T0, ie the control group without treatment, Group B1 was treatment with a magnetic field of 160 mT, group B2 was treatment with a magnetic field of 180 mT, and group B3 was treatment with a magnetic field of 200 mT. Treatment in the form of exposure to a magnetic field is done for t1 is 30 minutes, t2 is 60 minutes, and t3 is 90 minutes.

Each solution is placed in a container that is able to circulate the solution and then given a magnetic field exposure from a solenoid winding with a current of 0-3A. The magnetic field is measured using a TM-03 digital meter and the current is measured using a TM-03 digital meter. To find out the level of $CaCO_3$ precipitation EDTA titration test was performed on all samples so that changes can occur.

Stataistical Analysis

Data obtained were analyzed by Anova test to determine the effect of magnetic field exposure and the length of time of exposure to $CaCO_3$ precipitation. To find out the optimal exposure that results in the largest percent reduction in $CaCO_3$ levels using the Post Hoc Tukey test. Calculation of percentage reduction in $CaCO_3$ levels uses the following equation 4:

% $CaCO_3$ levels =

$$\left|\frac{\Sigma\, CaCO_3 \text{ levels treatment} - \Sigma\, CaCO_3 \text{ levels control}}{\Sigma\, CaCO_3 \text{ levels control}}\right| \quad ..\ (4)$$

Results and Discussion

After setting the solenoid, the next step is to calibrate the solenoid. Calibration is carried out by measuring current and magnetic fields (Wahyudi and Ahmad, 2013; Yudhistira and Wibowo, 2019). Provision of current using a DC current source with 0-3 A current specifications. Current flowing is measured using a digital multimeter DT-860B and magnetic field measurements using a TM-03 digital teslameter. Calibration of a solenoid using a conductor produces a magnetic field three times greater than a solenoid without a conductor. The magnetic field calibration data is shown in Figure 2. The calibration results show the magnitude of the linear magnetic field relative to the amount of current flowing. The greater the current applied, the greater the magnetic field produced.

The characterization result of hard water is shown in Table 2.

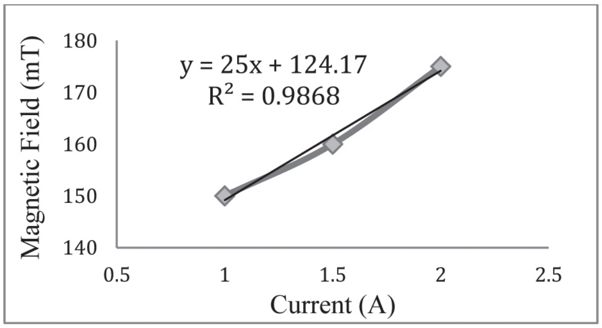

Fig. 2. The magnetic field calibration

Table 2. Data of hard water characterization

Control	V_{EDTA} (mL)	$CaCO_3$ Levels (ppm)
1	1.85±0.05	194.42±0.05
2	1.98±0.05	208.09±0.05
3	1.98±0.05	208.09±0.05

The results of hard water characterization showed no significant difference in various VEDTA. Figures 3 and 4 show the effect of the magnetic field and the duration of exposure on $CaCO_3$ precipitation levels.

The graph above shows that the $CaCO_3$ level decreases with the administration of the magnetic field

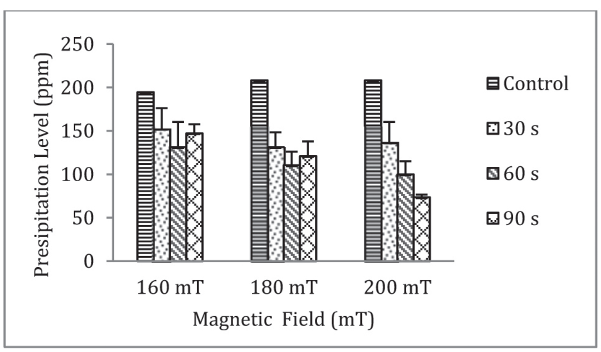

Fig. 3. Graph of the relationship between precipitation levels of $CaCO_3$ versus magnetic fields

and the exposure time of the magnetic field. This proves that the magnetic field and exposure time influence the $CaCO_3$ precipitation.

Factorial statistical test results showed the influence of magnetic fields (p = 0.02), duration of exposure (p = 0.013) and interaction of magnetic fields and duration of exposure (p = 0.049) significantly influence the percentage reduction in $CaCO_3$ levels ($p < 0.05$). Tukey Post hoc test results showed that an effective treatment to reduce $CaCO_3$ precipitation was at 200 mT treatment and 90 minutes exposure

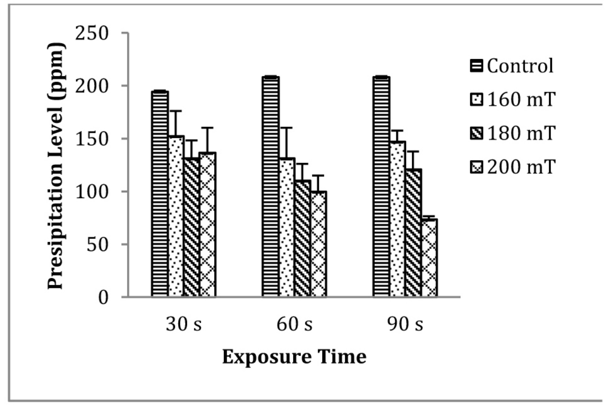

Fig. 4. Graph of the relationship between $CaCO_3$ precipitation levels versus time exposure

time with a percentage decrease in $CaCO_3$ levels of 64.72%. Data from the statistical test results are shown in Table 3 below.

Interaction of the Magnetic Field with Precipitation of $CaCO_3$

The results of data analysis in this study indicate that $CaCO_3$ levels before and after treatment have decreased. This shows that water hardness decreases. The levels of $CaCO_3$ precipitation before treatment were around 190-210 ppm, after treatment the levels decreased with the administration of magnetic fields and duration of exposure. At 160 mT magnetic field $CaCO_3$ precipitation levels around 142.46 ppm, 180 mT magnetic field $CaCO_3$ precipitation levels around 125.53, and 200 mT magnetic field $CaCO_3$ precipitation levels around 105.09 ppm. Whereas for 30 minutes of $CaCO_3$ precipitation levels around 141.29 ppm, 60 minutes for $CaCO_3$ precipitation levels around 116.19 ppm, and 90 minutes for $CaCO_3$ precipitation levels around 115.60 ppm. The results of this calculation indicate that the magnetic field 200 and the exposure time of 90 minutes have the greatest influence in decreasing the level of water hardness.

$CaCO_3$ precipitation is influenced by two forces, namely Van der Walls force (attraction force) (Saksono, 2006) and Lorentz style (Busch *et al.*, 1997; Kobe *et al.*, 2003). Based on the interaction of Van der Walls style, the interaction that occurs in hard water is dipole-dipole interaction. This is because the molecules formed in hard water are polar molecules. Interactions that occur include (1) interactions between Ca_2^+ ions and CO_3^- ions to form $CaCO_3$ particles, (2) interactions between $CaCO_3$

Table 3. Data from statistical test results

Factor	Group	N	Percentage decrease of $CaCO_3$ content (%)		ANOVA	
			Avg	SD	Sig.	Conclusion
Magnetic Field	Magnetic Field 160 mT[(a)]	3	30.004	3.054	p=0.002	Significanly different
	Magnetic Field 180 mT[(ab)]	3	38.323	3.054		
	Magnetic Field 2000 mT[(b)]	3	48.367	3.054		
	Total	9	38.910	3.054		
Time	Time 30 min[(a)]	3	30.579	3.054	p=0.013	Significanly different
	Time 60 min[(b)]	3	42.914	3.054		
	Time 90 min[(b)]	3	43.201	3.054		
	Total	9	38.910	3.054		
Interaction	B 160 t 30 min[(a)]	3	25.990	5.291	p=0.049	Significanly different
	B 160 t 60 min[(a)]	3	36.313	5.291		
	B 160 t 90 min[(a)]	3	27.710	5.291		
	B 180 t 30 min[(a)]	3	32.013	5.291		
	B 180 t 60 min[(a)]	3	45.783	5.291		
	B 180 t 90 min[(a)]	3	33.733	5.291		
	B 200 t 30 min[(ab)]	3	37.173	5.291		
	B 200 t 60 min[(ab)]	3	46.647	5.291		
	B 200 t 90 min[(b)]	3	64.720	5.291		
	Total	27	38.898	5.291		

particles to form crystals (Alimi *et al.*, 2006), (3) interactions of ions with water molecules to form ions hydrates (Saksono *et al.*, 2008), and (4) interactions between water molecules to form hydrogen interactions.

The first interaction, the magnetic field affects the shift of ions Ca_2^+ and CO_2^- to shift in the direction of the magnetic field so that the formation of $CaCO_3$. In the second interaction, the magnetic field affects the shift between $CaCO_3$ particles that have formed. The displacement of ions and particles is caused by the effect of the Lorentz force, where ions and particles that move in the magnetic field will experience the Lorentz force (Batista, 2018; Griffith, 1999). This is in accordance with the results of the Kobe *et al* (2003) simulation which shifts from 0.2 to 10 nm for ions and 0.2 nm - 20 μm for particles. In the third interaction, Ca_2^+ and CO_2^- ions will be hydrated by water molecules to form hydrate ions. Hydrate ion formation can be reviewed based on the electronegativity of the ion (Budikania *et al.*, 2010). $CaCO_3$ compounds have electronegativity differences, so the bonds formed are polar bonds. Compounds in polar bonds tend to be easily hydrated by water molecules, so they can form hydrate ions (Saksono, 2007). Hydrate ion formation is also influenced by the conductivity of the solution. The more the conductivity increases, the more hydrate ions that form as a magnetic field increase. In addition, the formation of hydrate ions is also influenced by ion hydration energy due to the presence of a magnetic field. The higher the hydration energy, the stronger the molecules are bound around these ions.

The results of this study indicate that water hardness can be reduced by applying a magnetic field. At 200 mT magnetic field exposure and 90 minutes exposure time is the optimum exposure to accelerate $CaCO_3$ precipitation in hard water so as to reduce water hardness.

Conclusion

The EDTA complexometry titration results showed a decrease in $CaCO_3$ precipitation levels by 73.57 - 173.41 ppm or about 25.99% - 64.72% along with the induction of magnetic fields and the duration of exposure. The results of the factorial anova analysis showed that the most influential magnetic field at 200 mT and the most optimal exposure time at 90 minutes was able to reduce $CaCO_3$ precipitation levels by 64.72%. Thus, the magnetic field and the duration of exposure affect the $CaCO_3$ precipitation and there is a correlation between the magnetic field and the exposure time.

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