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Research on the Influence of Alternating Electromagnetic Field on Conductivity of Hard Water

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The influence to the conductivity of the hard water caused by alternating electromagnetic field was investigated. Through experimental research it was found that the hydrolysis reaction in the hard aqueous solution was promoted during alternating electromagnetic field treatment. The promoted hydrolysis reaction was considered as the main cause for the change of the conductivity, and further more was considered as the anti-fouling mechanism of alternating electromagnetic field treatment because promoted hydrolysis reaction decreased hard water's pH value. Through the experiment research the optimized frequency and output power of excitation signal were also investigated to make more promotion to the hydrolysis reaction in solution.

Keywords: Alternating electromagnetic field; Conductivity; Anti-fouling; Calcium carbonate; Hydrolysis reaction

1. INTRODUCTION

Scale problem is a key problem to the heat exchanger, such as cooling tower and boiler. The scale problem roots on using hard water. The alternating electromagnetic field anti-fouling (AEFA) technology is a very useful physical water treatment method to the scale problem. But to the best knowledge, the anti-fouling mechanism of AEFA technology is still not all clear as yet.

AEFA technology is one kind of magnetic water treatment technology. Therefore the magnetic water treatment technology was studied as the key point. Many researchers have done a lot of qualitative researches on the anti-fouling mechanism of magnetic water treatment technology[1-5]. They have found that many physicochemical property of hard water are changed under extra magnetic field, such as the conductivity of solution. Conductivity is a very important property of electrolyte solution. The change of conductivity can reflect the change of solution concentration, even reflect the change of solution composition[6-9]. The conductivity of electrolyte solution can be changed by magnetic field. Al-Qahtani treated the seawater with permanent magnet whose magnetic intensity was 7,000 gauss[10]. Al-Qahtani found that both of the conductivity and pH value of the treated seawater were higher than those of untreated seawater. Wang et al used permanent magnet to treat tap water, deionized water and distilled water respectively[11]. They found that the conductivity of tap water decreased markedly after magnetic treatment. The conductivity of deionized water and distilled water also decreased but not obviously. Zhu et al treated calcium carbonate suspension with permanent magnet[12]. They found that both of the conductivity and the calcium carbonate's solubility of suspension were increased. They came to the conclusion that the magnetic field increases the calcium carbonate's solubility. According to the research results above, it can be known that magnetic field makes different affect to the conductivity of electrolyte solution with different solute, and the research results are irregular because of the different experiment conditions. Therefore the anti-fouling mechanism of magnetic water treatment technology is hard to be understood, which leads directly to the uncertainty of the anti-fouling mechanism of AEFA technology.

During the alternating electromagnetic treatment processing, the conductivity of hard water also changes[13]. Therefore the anti-fouling mechanism of AEFA technology can be researched through studying the mechanism of the change of electrolyte solution conductivity caused by alternating electromagnetic field. In the present study, the influence to Ca^{2+}, CO_3^{2-} and HCO_3^- ions in hard water caused by alternating electromagnetic field was researched. We use 4 mmol/L calcium chloride solution instead of Ca^{2+}, and use 4 mmol/L sodium carbonate instead of CO_3^{2-} and HCO_3^- respectively in the moderate hard water. An explanation of mechanism of alternating electromagnetic field changing electrolyte solution conductivity is presented by investigating the changes of $CaCl_2$ solution conductivity and Na_2CO_3 solution conductivity under AEFA treatment using the method of theory analysis and experiment validation. The optimized excitation signal produced by alternating electromagnetic field generator was also investigated. Finally, the anti-fouling mechanism of AEFA technology was analyzed based on the study results above.

2. EXPERIMENTAL SET-UP AND PROCEDURE

2.1 Experimental Set-Up

We prepared the alternating electromagnetic field generator for using as the source of alternating electromagnetic field in the experiment. The generator took a certain power, and the alternating electromagnetic field generated by excitation coil treated the hard aqueous solution which flowed through the nonmagnetic tube. The tube diameter was 42mm. The excitation coil was winded on the tube with 70 turns. The wire diameter of coil was 3mm. The structure sketch of the alternating electromagnetic field generator is shown in Fig. 1. The Waveform of excitation signal was square wave. The range of output current was 0~5 A and the range of output voltage was 0~12 V. The maximum of electromagnetic intensity generated by excitation coil was 2 mT.

The frequency range of excitation signal is a important performance parameter of the alternating electromagnetic field generator. Some previous studies[14-15] supposed that relative low frequency was fit for the electromagnetic water treatment because when the frequency of excitation voltage was too high the effective current would become lower and this would cause a weaker electromagnetic field. Therefore the frequency range of excitation signal used in the present study was 10~1000 Hz.

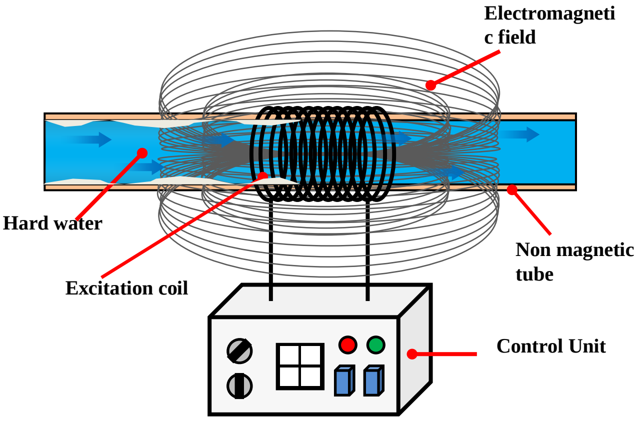

Figure 1. Structure sketch of alternating electromagnetic field generator

The water used in this study was high-level purified water, which was produced by a Milli-Q Millipore System and had a resistivity of about 18.2 MΩ, 298 K. The total organic carbon and dissolved oxygen of the water were below 0.05 mg/L and 5.0 mg/L, respectively. The analytically pure anhydrous calcium chloride was used for preparing the 4 mmol/L $CaCl_2$ solution(this molarity was used in the present study according to the molarity range of natural hard water), and the analytically pure anhydrous sodium carbonate was used for preparing the 4 mmol/L Na_2CO_3 solution.

The alternating electromagnetic field water treatment system using in the experiment is depicted in Fig. 2.

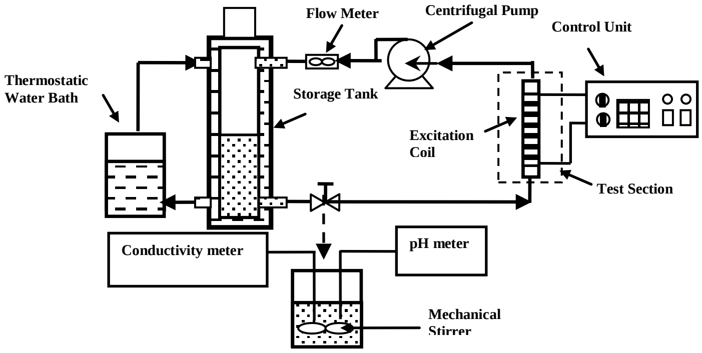

Figure 2. Schematic diagram of experimental setup

It consisted of a two layer storage tank, a centrifugal pump, an alternating electromagnetic field generator, a glass tube test section, a flow meter and a thermostatic water bath. The volume of the inside layer of the storage tank was 2 L. The outside layer of the storage tank was filled with 298 K constant temperature circulatory water from the thermostatic water bath which was used to keep the temperature of test aqueous solution constant. The test section was a glass tube winded by the excitation coil. The excitation coil was connected with the alternating electromagnetic field generator. The fluid was pumped from the storage tank through the glass tube test section with a constant flow rate 1 L/min. The time of test aqueous solution treated by alternating electromagnetic field was 2 h.

2.2 Experimental procedure

Part 1. A certain quantity of 4 mmol/L $CaCl_2$ (or Na_2CO_3) solution was added into the storage tank for starting the test. The pump was turned on, and the flow rate was regulated to the preset value. At the same time the water circulatory system of 298 K constant temperature circulatory water from the thermostatic water bath was turned on(The research object of the present study was the influence of alternating electromagnetic field on conductivity of hard water. However a high experiment temperature may cause the precipitate of $CaCO_3$ and the change of ion concentration would interfere with making the study conclusions. Therefore the experiment temperature was set as indoor temperature 298 K). Then the alternating electromagnetic field generator was turned on. In the present study we used the alternating electromagnetic field with the frequency of 200 Hz，300 Hz，400 Hz，500 Hz，600 Hz，700 Hz，800 Hz，900 Hz and 1000 Hz to treat the test aqueous solution respectively when the output power of the generator was 6 W. And we also used the alternating electromagnetic field with the frequency of 400 Hz when the output power of the generator was 6W, 9W and 12 W respectively. When finishing the test aqueous solution treatment, the alternating electromagnetic field water treatment system was turned off and 100 mL treated $CaCl_2$ (or Na_2CO_3) solution was sampled and put into a reaction beaker with magnetic stirrer. The reaction beaker was put into a thermostatic water bath and the temperature in the reaction beaker was controlled at 298 K. The conductivity meter (precision: ±0.5% of measurement results) was used to measure the conductivity of the treated solution and the pH meter (precision: ±0.03) was used to measure the pH value of the treated solution. Then we repeated the water-cycle experimental steps above without alternating electromagnetic field, and the testing time was also 2 h, and in this way we produced 9 “untreated” water samples for comparison.

Part 2. For verifying the conclusion obtained from Part 1 experiment, an scaling experiment was performed and the experimental procedure was as follow:

(1) We treated 1 L 4 mmol/L $CaCl_2$ solution with 400 Hz excitation signal and 6w output power for 2 h in the testing system which was shown in Figure 2. Then as comparison we put another 1L 4 mmol/L $CaCl_2$ solution without AEFA treatment in the same testing system for 2 h. In the whole process the solution temperature was kept at 298 K.

(2) We sampled 100mL from the two 1L 4 mmol/L $CaCl_2$ solution, and added 100mL 4 mmol/L Na_2CO_3 solution to the two samples respectively. Then after 10 minutes of reaction time we measured the two sample solution’s pH value with a pH meter(precision: ±0.03) and measured the particle number of calcium carbonate with different sizes with a particle size analyzer (measurement range:2μm~25μm).

In the present paper every experiment was done ten times, and the measure result was read ten times too. The final measure result was the average value of ten experiment result. This method can decrease the experimental measurement error. The experimental results with and without AEFA treatment were studied contrastively.

3. RESULTS AND DISCUSSION

3.1. The experiment result for the change of $CaCl_2$ solution's conductivity after AEFA treatment

In order to investigate the influence to the conductivity of $CaCl_2$ solution caused by AEFA treatment, the conductivity values of treated $CaCl_2$ solution were measured by a conductivity meter. We used the alternating electromagnetic field with different frequency and signal output power. So this test can also find out which excitation signal frequency (within the output frequency range of the alternating electromagnetic field generator used in the present paper) and whether the excitation signal with lower output signal power or the higher output signal power can give more observably influence to the conductivity of $CaCl_2$ solution. The experimental result(from **Part 1** experiment) is shown in Fig. 3 and Fig. 4.

The experimental result shown in Fig. 3 and Fig. 4 reveal that the conductivity of 4 mmol/L $CaCl_2$ solution is decreased after the 2 h AEFA treatment. According to the result in Fig. 3, it can be known that the alternating electromagnetic field with different frequency can make the different influence to the conductivity. The alternating electromagnetic field with 400 Hz frequency made the lowest conductivity 934 μS/cm. According to the result in Fig. 4, it can be known that the alternating electromagnetic field with a higher signal power can give more observably influence to the conductivity.

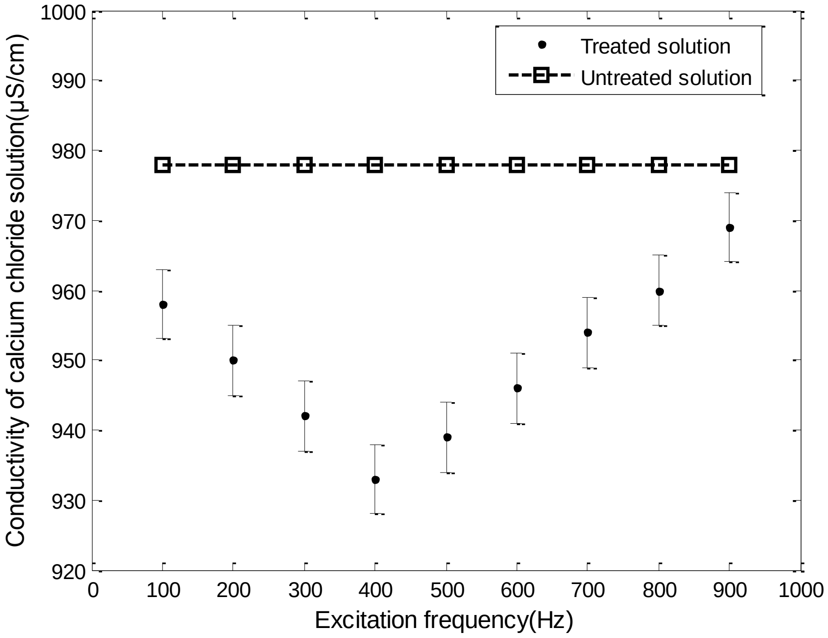

Figure 3. Conductivity of $CaCl_2$ solution under different signal frequency

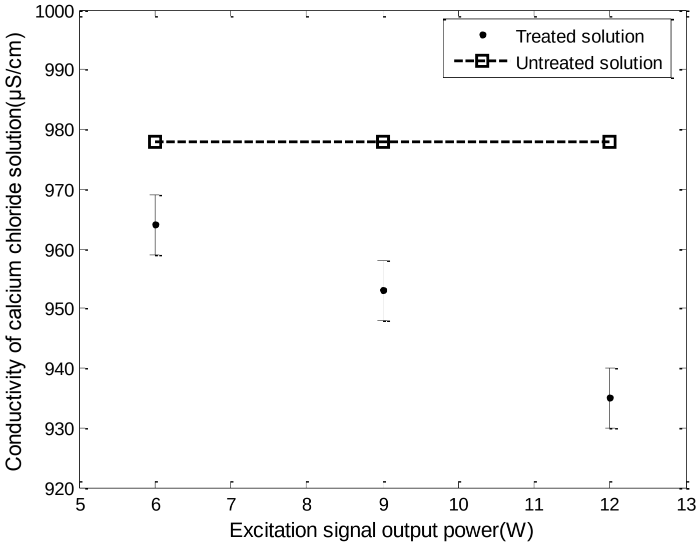

Figure 4. Conductivity of $CaCl_2$ solution under different signal power

3.2. Mechanism analysis for change of $CaCl_2$ solution's conductivity

Many factors can influence the conductivity of solution, such as quality of solute, electro mobility of charged ions and number of charged ions.

During the **Part 1** experiment the experimental temperature and pressure were constant and the quality of solute didn't change. The mobility of charged ions increased. Cho et al [16] explained this phenomenon with the reduction of the surface tension of the aqueous solution after AEFA treatment. Because the reduction of the surface tension can lead to the reduction of the resistance of ion electrophoresis and increase of electro mobility of charged ion. Cheng et al[17] also suggested that the increase of aqueous solution conductivity was because that the ion hydration was weaken by magnetic field and the resistance of central ion movement was reduced. But the experimental data in Fig. 3 and Fig. 4 shows an opposite result that the conductivity of $CaCl_2$ solution was decreased after AEFA treatment. Therefore the most possible factor which leaded to the conductivity of solution decreasing is that the number of charged ion in the solution was changed. In the $CaCl_2$ solution there are two kinds of charged ion: Ca^{2+} and Cl^-. Therefore it means that the number of Ca^{2+} or Cl^- was changed.

It is generally known that calcium chloride is the salt of strong acidic-weak base and its aqueous solutions is weak acidic. This is because hydrolysis reaction happens during the process of $CaCl_2$ dissolving in the water. The chemical reaction equations of this hydrolysis reaction is:

$$\begin{cases} H_2O \rightleftharpoons OH^- + H^+ \\ CaCl_2 \rightleftharpoons Ca^{2+} + 2Cl^- \\ 2CaCl_2 + 2H_2O \rightleftharpoons CaCl_2 + Ca(OH)_2 + 2H^+ + 2Cl^- \end{cases} \tag{1}$$

$Ca(OH)_2$ is present in solution as molecule. Therefore, according to equation (1) it can be found that there are 3 charged ions on the left side, and after the hydrolysis reaction there are only 2 charged ions on the right side(Because the way of H^+ electro migration is special, the change of the number of

H^+ doesn't influence the conductivity of solution.). The number of charged ion in solution is decreased. Then according to the experimental data in Fig. 3 and Fig. 4, and equation (1), we can assume that the AEFA treatment promotes the hydrolysis reaction in $CaCl_2$ solution.

For proving this assumption we did further experiment researches. It can be found from equation (1) that there are 2 hydrogen ions produced on the right side. If the hydrolysis reaction in the $CaCl_2$ solution is promoted after AEFA treatment, the pH value of treated $CaCl_2$ solution will be lower than that of untreated $CaCl_2$ solution.

We treated the $CaCl_2$ solution using alternating electromagnetic field with different frequency and signal output power, and measured the pH value of treated solution with a pH meter. The experimental result(from **Part 1** experiment) is shown in Fig. 5 and Fig. 6.

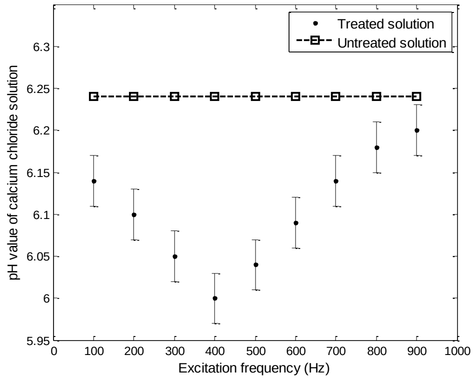

Figure 5. pH value of $CaCl_2$ (4 mmol/L) solution under different signal frequency

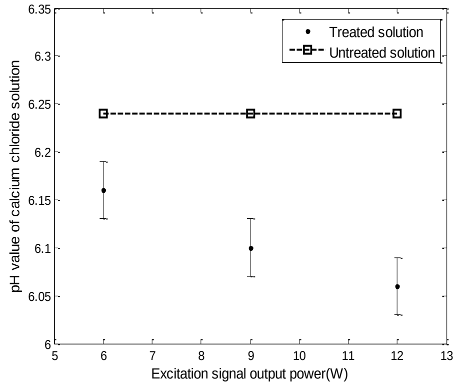

Figure 6. pH value of $CaCl_2$ (4 mmol/L) solution under different signal power

According to the result in Fig. 5, it can be known that the alternating electromagnetic field with 400 Hz frequency made the lowest pH value 6.01. According to the result in Fig. 6, it can be known that the alternating electromagnetic field with a higher signal power can give more observably influence to pH value. The experimental result shown in Fig. 5 and Fig. 6 reveal that the pH value of 4 mmol/L $CaCl_2$ solution is decreased after AEFA treatment, which consistent with equation (1). Therefore the assumption that AEFA treatment promoting the hydrolysis reaction in the $CaCl_2$ solution is proved.

3.3. Influence to the conductivity of Na_2CO_3 solution caused by AEFA treatment

Since there are not only metal ions but also HCO_3^- ions and CO_3^{2-} ions in the hard water, the influence to the conductivity of HCO_3^- and CO_3^{2-} solution caused by AEFA treatment should be studied. There are small amounts of CO_3^{2-} and HCO_3^- in the hard water, and the quantity of each kind of ions depends on the temperature, pressure and some other conditions in the hard water. Therefore we used Na_2CO_3 solution as the experimental subject. According to the research conclusion obtained in section 3.1 and section 3.2 above, we also assumed that the AEFA treatment promotes the hydrolysis reaction in the Na_2CO_3 solution. The chemical reaction equation of the hydrolysis reaction in the Na_2CO_3 solution is:

$$2Na^+ + CO_3^{2-} + H_2O \rightleftharpoons 2Na^+ + OH^- + HCO_3^- \qquad (2)$$

According to equation (2) it can be found that there are 3 charged ions on the left side, and after the hydrolysis reaction there are 4 charged ions on the right side. After the hydrolysis reaction the number of charged ion is increased. It also can be found that there are OH^- ions generated. Therefore if the assumption that the AEFA treatment promoting the hydrolysis reaction in the Na_2CO_3 solution is valid, after the AEFA treatment the conductivity and pH value of Na_2CO_3 solution should be increased. We also used the alternating electromagnetic field with different frequency and signal output power to treat the 4 mmol/L Na_2CO_3 solution. A conductivity meter and a pH meter were used to measure conductivity and pH value of Na_2CO_3 solution respectively. The experimental result(from **Part 1** experiment) is shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

According to the results in Fig. 7, it can be known that the alternating electromagnetic field with 400 Hz frequency made the highest conductivity 939 μS/cm of 4 mmol/L Na_2CO_3 solution. According to the results in Fig. 9, it can be known that the alternating electromagnetic field with 400 Hz frequency made the highest pH value 10.66. According to the results in Fig. 8 and Fig. 10, it can be known that the alternating electromagnetic field with a higher signal power can give more observably influence to the conductivity and pH value.

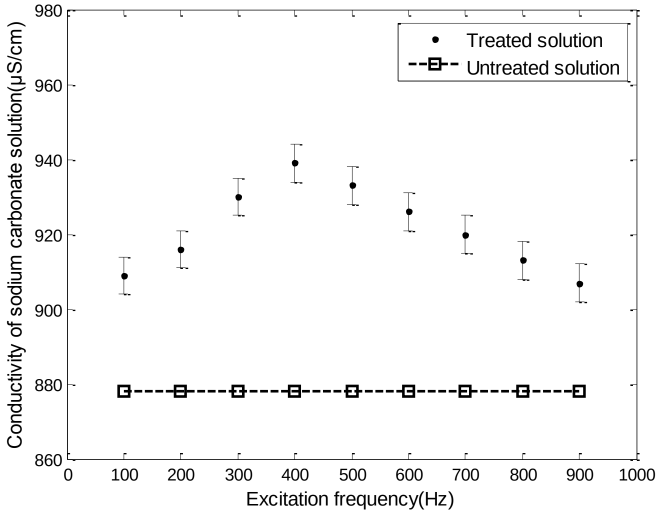

Figure 7. Conductivity of Na_2CO_3 solution under different signal frequency

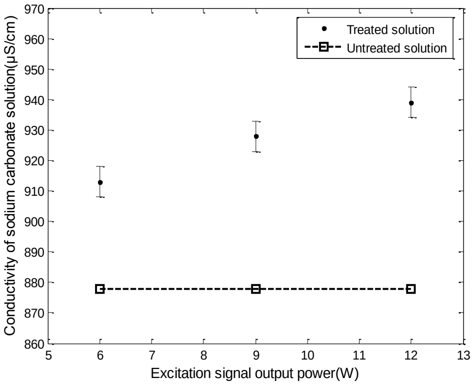

Figure 8. Conductivity of Na_2CO_3 solution under different signal power

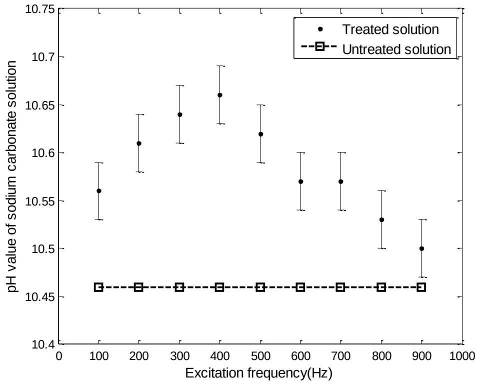

Figure 9. pH value of Na_2CO_3 solution under different signal frequency

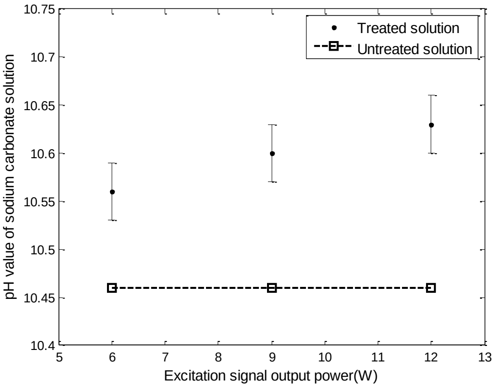

Figure 10. pH value of Na_2CO_3 solution under different signal power

The experimental result shown in Figure 7, Figure 8, Figure 9 and Figure 10 reveal that the changes of conductivity and pH value of 4 mmol/L Na_2CO_3 solution are both increased after AEFA treatment, which consistent with equation (2). Therefore the assumption that AEFA treatment promoting the hydrolysis reaction in the Na_2CO_3 solution is proved.

The experiment results obtained from the changes of the conductivity of Na_2CO_3 and $CaCl_2$ solution caused by AEFA treatment partly meet with Szczés 's study[18]. Szczés et al. founded in their experiment that after magnetic field treatment the conductivity of KBr and Na_2SO_4 solution was increased respectively, but the change of conductivity of KCl and KI solution was on the contrary. They suggested that this magnetic effect was related to the character of the ions present in the solutions and the thickness of the hydration shell around the ions. The magnetic field greatly affects the ions with less ordered water hydrating shell. Then the thickness of the hydration shell changes smaller, which is good for increasing the diffusivity of hydrated ions. Pang and Deng[19] also obtained the similar conclusion in their study. But Szczés and Pang didn't discussed the correlation between the changes in conductivity and the kind of investigated salts, and they also didn't pay attention to the change of pH in the solution. In the present study we founded that the pH in the solution was changed after AEFA treatment, which means that there must be hydrolysis reaction happening in the solution.

Hydrolysis in the solution is because of ion's polarization ability[20]. Ionization reaction happens when inorganic salts dissolve in water, then ions forms. The ions can interact with H^+ or OH^- which are from water molecules ionization. The ions with good polarization ability can bind with H^+ or OH^- which can form weak electrolyte. Then the number of charged ion changes. This process, which is called hydrolysis reaction, promotes water hydrogen bond's breakage and breaks aqueous ionization balance. The intensity of hydrolysis reaction increases proportionally to ion's polarization ability, and the number of charged ion changes more or less. Li et al. [21] also obtained the similar result in their experiment. They suggested that the increase in the electrical conductivity of sodium aluminate solution can be attributed not only to some changes in the water structure but also to the change of the number of aluminate anion. This conclusion can explain why different kind of salts in solution can cause the different conductivity change.

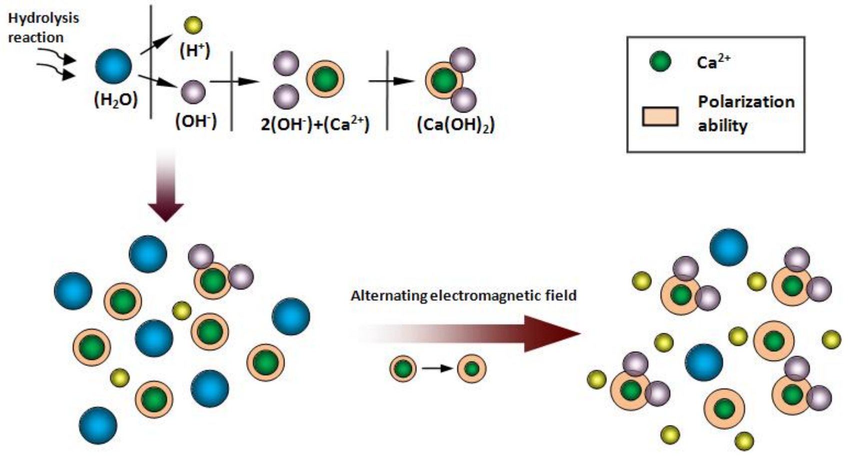

Figure 11. Schematic diagram of the increase of polarization ability of calcium ion under alternating electromagnetic field which causes the promotion of hydrolysis reaction

The ion's polarization ability can be increased when ionic charges increase or ionic radius decreases. In the present study the intensity of hydrolysis reaction was promoted because of the enhanced ion's polarization ability. Taking calcium chloride solution (which was studied in this paper) as an example, polarization ability of calcium ion is poor so that the intensity of hydrolysis reaction in solution is weak. But our previous studies[22] showed that the radius of calcium ion significantly changed smaller under alternating electromagnetic field. It means that calcium ion's polarization ability is increased, and further more the intensity of hydrolysis reaction in calcium chloride solution is increased. The schematic diagram is shown in Figure 11.

3.4. Positive role of hydrolysis reaction in promoting anti-fouling

$CaCO_3$ is the major ingredient of hard water scale, which is formed by the chemical reaction of Ca^{2+} and CO_3^{2-}. At the beginning of the $CaCO_3$ crystal forming, the cluster is amorphous. Amorphous calcium carbonate (ACC) is a hydrated, poorly ordered, nanoparticulate and metastable precursor to crystalline $CaCO_3$ (e.g., calcite, vaterite, aragonite). The crystallization of $CaCO_3$ polymorphs from ACC is affected by the pH of solution[23]. Some experimental studies[24,25] have shown that the solubility and dissolution rate of ACC increases proportionally to the pH, which means the solution with a higher pH would have higher supersaturation with respect to $CaCO_3$. High supersaturation levels are needed for the nucleation of vaterite. Thus the formation of a higher pH ACC precursor favours vaterite formation over calcite, and oppositely more calcite will be obtained in the lower pH solution. According to the study conclusion above, it is considered that the AEFA treatment promotes the hydrolysis reaction in hard water. It can be known from equation (1) that there are excess $Ca(OH)_2$ generated when the hydrolysis reaction is promoted. In the hard water there is little CO_3^{2-} but small amounts of HCO_3^-. The source of HCO_3^- is the CO_2 soluble in water. The excess $Ca(OH)_2$ can be chemically programmed to react with HCO_3^- in the hard water as:

$$HCO_3^- + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + OH^- + H_2O \qquad (3)$$

According to equation (1) and equation (3) it can be known that there are two H^+ generated in equation(1) but there is one OH^- in equation(3). Therefore the pH of solution will decline after the two chemical reactions, which means the promotion of hydrolysis reaction declines the pH value of hard water during the formation of $CaCO_3$ precipitate. Then more calcite will form in hard water under AEFA treatment. This conclusion agrees with Xing's experimental study results[26]. They found that vaterite was the major in the precipitated crystals when hard water was at heating condition. But under the same experiment condition there was more calcite forming in the precipitated crystals when AEFA treatment was used.

We did an scaling experiment(**Part 2** experiment) to verify the viewpoint above. The experiment pH result shows that the pH values of untreated mixed solution and treated mixed solution were 8.53 and 8.44 respectively, and it revealed that the combination of reaction 1 and 3 actually leads to obtain a lower pH value. The particle number of calcium carbonate with different sizes is shown in Table 1 and Table 2.

According to the Table 1 and Table 2, it can be seen that comparing with the untreated mixed solution the particle number of calcium carbonate with different sizes was all increased and especially the number of particle with big size (10 μm, 15 μm, 20 μm, 25 μm) was significantly increased. It means that the AEFA treatment can promote the calcium carbonate's formation and growth. Furthermore, at room temperature the bigger the size of precipitated crystals is, the higher the proportion of calcite is in the water scale. Xing has also observed the same phenomena with scanning electron micrograph (SEM) in their experimental study results[26].

Table 1. Measuring results of particle number in the mixed solution of both untreated $CaCl_2$ and Na_2CO_3

size (μm)	2	3	5	7	10	15	20	25
number	43563	42715	39493	36871	30005	16988	6564	1243

Table 2. Measuring results of particle number in the mixed solution of treated $CaCl_2$ and untreated Na_2CO_3

size (μm)	2	3	5	7	10	15	20	25
number	45277	44399	41545	39270	33371	20762	8495	1992

More calcite forming in the solution under AEFA treatment is helpful for anti-fouling. The adhesiveness of calcite is less than vaterite's. Thus vaterite is easier to adhere to the tube wall than calcite. Since the promotion of hydrolysis reaction which is caused by AEFA treatment declines solution pH value, more calcite forms during the formation of $CaCO_3$ precipitate. The adhesiveness of $CaCO_3$ precipitate with more calcite changes smaller and less $CaCO_3$ precipitate adheres to the tube wall. More precipitate, which does not adhere to the tube wall, is washed away by flowing water. At last the scale problem is alleviated. Therefore the anti-fouling mechanism of AEFA technology can be explained as that the hydrolysis reaction in the hard water is promoted by alternating electromagnetic field.

3.5. Optimal signal frequency and output power for anti-fouling

Many factors can impact the anti-fouling effect of AEFA treatment such as signal frequency, output power, solution concentration and so on. In the present experimental study we made the output power and sample solution concentration as a constant and studied the change of the conductivity and pH value of solution under different signal frequency from 100Hz to 900Hz. The experiment result(from **Part 1** experiment) showed that the change rules of conductivity and pH value of $CaCl_2$ solution (4 mmol/L) and Na_2CO_3 solution (4 mmol/L) were the same as the signal frequency was growing, and the maximums all occurred when the signal frequency was 400Hz. Therefore in our experimental study the most optimal signal frequency is 400Hz. But some other studies have shown different results. Xing et al.[27] suggested that the most optimal signal frequency for anti-fouling effect was 700Hz when excitation current was 0.634A, the water hardness was 1000mg/L, flow velocity was u=0.25 m/s, and the rate of volume flow was 140L/h. Wang et al.[13] suggested that the most optimal signal frequency for anti-fouling effect was 1000Hz when excitation current was 3A, the water hardness was 1000mg/L, flow velocity was u=0.4 m/s, and the rate of volume flow was 140L/h. The different experimental results above show that most optimal signal frequency value is not constant under different experimental conditions. Therefore in a practical application AEFA system works with scanning frequency signal output in order to meet the needs of different conditions. With Scalewatcher (water treatment system, made by B&D Ingenieursburo BV company), for example, its out signal range is 500Hz-5000Hz.

In the present study we also made the signal frequency and sample solution concentration as a constant and studied the change of the conductivity and pH value of solution under different signal output power. The experiment result showed that conductivity and pH value of $CaCl_2$ solution (4 mmol/L) and Na_2CO_3 solution (4 mmol/L) increased proportionally to signal output power. This conclusion agrees with other studies' results. Xiong et al.[28] found that with a invariable excitation current, the higher output voltage was, the less the scale weight was on the water tube wall when the water hardness was 1000mg/L, 180 mg/L and 500 mg/L respectively. Liu et al.[29] treated hard water (hardness was 300mg/L) with alternating electromagnetic field making by solenoid and filtered the precipitate. Then the hardness of filtrate was measured. They found that the larger the excitation current of solenoid was, the lower the hardness of filtrate was.

4. CONCLUSIONS

The promotion to the hydrolysis reaction in hard water caused by the applied alternating electromagnetic field was confirmed. The conductivity and pH value of $CaCl_2$ solution and Na_2CO_3 solution were measured after the AEFA treatment. The changes of the conductivity and pH value were consistent with the hydrolysis reaction equations in the hard water. It is considered that the promotion to the hydrolysis reaction decreases the pH value of solution, which can increase the proportions of calcite in the scale and reduce the scale's adhesive force to the tube wall. The promotion to the hydrolysis reaction caused by the applied alternating electromagnetic field can give a good explanation to the anti-fouling mechanism of AEFA technology. It has also been confirmed that under the experiment condition of the present paper, the alternating electromagnetic field with a higher signal power can give a better observably influence to the hydrolysis reaction in solution. But the most optimal signal frequency should be determined according to the composition of hard water and other conditions.

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