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Dynamic Laboratory Research on Synergistic Scale Inhibition Effect of Composite Scale Inhibitor and Efficient Electromagnetic Anti-Scaling Instrument

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Abstract: This study studied the synergistic anti-scaling performance of composite scale inhibitor and efficient electromagnetic anti-scaling instrument. And experiments were conducted to investigate the anti-scaling performance of composite scale inhibitor and anti-scaling performance and mechanism of efficient electromagnetic anti-scaling instrument, respectively. The crystallization of CaCO_3 was characterized by Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD). The experimental results showed that the highest anti-scaling rate of composite scale inhibitor (1#) was 80.68% and highest anti-scaling rate of composite scale inhibitor (2#) was 76.53%, average anti-scaling rate of efficient electromagnetic anti-scaling instrument was 51.46%. Efficient electromagnetic anti-scaling instrument promoted CaCO_3 crystallization process and promoted calcite into aragonite. When efficient electromagnetic anti-scaling instrument worked with composite scale inhibitor, synergistic anti-scaling rate of composite scale inhibitor (1#) had a 15% higher than composite scale inhibitor (1#) and synergistic anti-scaling rate of composite scale inhibitor (2#) had a 20% higher than composite scale inhibitor (2#).

Keywords: Calcium carbonate, composite scale inhibitor, efficient electromagnetic anti-scaling instrument, synergy

INTRODUCTION

Oil field water injection system scaling is a widespread problem. Scaling problems lead to decreased operating efficiency, shortened equipment life, higher maintenance cost and increased energy consumption (Xiaokai, 2008; Melo *et al.*, 1988; Kazi *et al.*, 2010). It is observed that scales include calcium carbonate, barium sulphate, calcium sulphate, ions scales, silica and others. The most common form of is calcium carbonate (Hasson *et al.*, 1968; Watkinson *et al.*, 1974). Calcium carbonate scaling is one of the most common scales found in is oil field water (Xiaokai, 2008).

The use of antiscalants or chemical inhibitors by means of chelation (Chen and Chan, 2000) dispersion (Wang *et al.*, 2002) and inhibition (Lisitsin *et al.*, 2005; Ketrane *et al.*, 2009; Al-Mutairi *et al.*, 2009; Kukulka and Devgun, 2007) is an effective method to control scaling problems. This chemical method however, is expensive and can change the water chemistry (Macadam and Parsons, 2004; Baker and Judd, 1996; Coetzee *et al.*, 1998). A good and green alternative is with the use of non-chemical methods. There are many physical and mechanical techniques used for water treatment and mitigation of scaling. Among such are continuous recirculation of cleaning devices through tube lines, turbulence promoters ultrasound method,

use of multiple alloys as catalytic materials and magnetic and electric field method (Macadam and Parsons, 2004; Chibowski *et al.*, 2003; Fathi *et al.*, 2006; Tang *et al.*, 2010; Shahryari and Pakshir, 2008; Alimi *et al.*, 2007; Tijing *et al.*, 2009; Kim *et al.*, 2007).

Although Physical antifouling technology is a simple and feasible water treatment technology and it also has certain limitation. The treatment effect is affected by many kinds of factors. On many occasions, physical technology cannot be used, especially in oil field production. Therefore, the application of physical antifouling technology is limited. So anti-scaling performance of physical anti-scaling instrument should be studied before the application. There is no a set of perfect system or standard to evaluate physical anti-scaling instrument.

The objectives of this study were to investigate the synergistic anti-scaling performance of composite scale inhibitor and efficient electromagnetic anti-scaling instrument. Two kinds of composite scale inhibitors were investigated and the influence of different concentration to anti-scaling performance of calcium carbonate was discussed. And a set of dynamic laboratory evaluation device of physical anti-scaling instrument was designed to study anti-scaling performance and mechanism of efficient electromagnetic anti-scaling instrument.

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MATERIALS AND METHODS

Materials: Composite scale inhibitor (1#, industrial product, made in Daqing). Composite scale inhibitor (2#, industrial product, made in Chengdu). Efficient electromagnetic anti-scaling instrument (made in Daqing) produced electromagnetic signal in the pressure pipe, forming high frequency electromagnetic field of a certain intensity in the instrument and electronic circuit produced high-frequency electromagnetic oscillation. Hard water went through the electromagnetic field before heating. In order to avoid scaling, the ion and molecular movement in hard water was interfered.

Facility: To study the anti-scaling performance of efficient electromagnetic anti-scaling instrument, a set of dynamic laboratory evaluation device of physical anti-scaling instrument was designed. Figure 1 showed a schematic diagram of dynamic laboratory evaluation device. Figure 1a was dynamic circulation pipeline with physical anti-scaling instrument and Fig. 1b was blank dynamic circulation pipeline.

Methods:

Evaluation method of chemical scale inhibitor: Anti-scaling rate of composite scale inhibitors were measured by calcium carbonate precipitation method of Chinese Standard 16632-1996. The Anti-scaling rate was defined as Eq. (1):

$$\eta = \frac{X_2 - X_1}{0.240 - X_1} \quad (1)$$

where,

X_1 : Calcium ion concentration of blank test liquid without scale inhibitor

X_2 : Calcium ion concentration of test liquid with scale inhibitor and 0.240 is calcium ion concentration of test liquid before test

Evaluation method of physical anti-scaling instrument:

Since calcium carbonate crystals did not dissolve easily in water, the simulated hard water was used as test solution. The solution was prepared by dissolving a certain quantity of calcium chloride (CaCl_2) and sodium bicarbonate (NaHCO_3) in water and the molar ratio of the former to the latter was 0.5. Test solution was added to the constant temperature bath and the sheet metal was hang in the device for starting the test. The temperature controller was adjusted and the temperature was regulated to the preset value. The pump was turned on and the flow velocity was regulated to the preset value. Solution sample was taken by every thirty minutes and then titrated the salt concentrations by Ethylene Diamine Tetra acetic Acid (EDTA). As the test solution was circulating, the hardness was decreasing because CaCO_3 crystals formed through the test solution and deposited on the heated surface or settled down to the bottom of the constant temperature bath. Therefore, the test solution was replaced by new solution from another bath after 4 h circulation. Meanwhile, the sheet metal was removed and weighed. During the experiment, the solution temperature and the flow velocity were all kept constant on both sides by adjusting the corresponding instruments. The anti-scaling rate was defined as Eq. (2):

$$p = \frac{X_3 - X_4}{X_3} \times 100\% \quad (2)$$

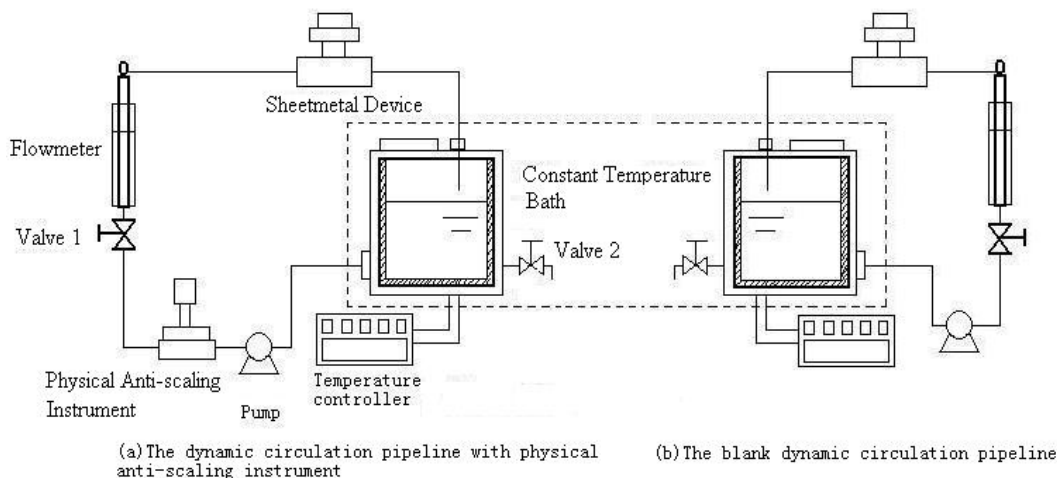


Fig. 1: Schematic diagram of dynamic laboratory evaluation device

where,

X_3 : Scaling quality of sheetmetal in the blank pipeline

X_4 : Scaling quality of sheetmetal in the pipeline with anti-scaling instrument

Evaluation method of synergy chemical scale inhibitor and physical anti-scaling instrument:

Composite inhibitors were added to the constant temperature bath and the operation steps were the same as evaluation method of physical anti-scaling instrument.

RESULTS AND DISCUSSION

The anti-scaling rate of chemical inhibitors:

Composite scale inhibitor (1#) and composite scale inhibitor (2#) were investigated from 10 to 60 mg/L as shown in Fig. 2. It can be observed from Fig. 2 that concentration of composite scale inhibitor had influence on the anti-scaling rate to a certain extent. As concentration of composite scale inhibitor (1#) increasing from 10 to 50 mg/L, the anti-scaling rate was gradually increasing from 72.77 to 80.68%. However, when the concentration was increased to 60 mg/L, the anti-scaling rate decreased to 75.27%. An increasing concentration of composite scale inhibitor (2#) from 10 to 40 mg/L resulted in the gradually increase in the anti-scaling rate and the anti-scaling rate increased from 66.87 to 76.53%. However, the anti-scaling rate decreased gradually with the concentration increasing.

The anti-scaling performance of efficient electromagnetic anti-scaling instrument:

Analysis of the calcium concentration change tendency:

Anti-scaling performance of efficient electromagnetic anti-scaling instrument was carried out at temperature of 40°C and a calcium ion concentration of 200 mg/L. A series of experiments were conducted to determine the effect of efficient electromagnetic anti-scaling instrument on calcium concentration. The experimental results were presented in Fig. 3. It can be seen in Fig. 3, with the continuous depositing of $CaCO_3$ scales, calcium concentration decreased with time increasing. However, calcium concentration after treatment was higher than that without treatment all the time. The results show that efficient electromagnetic anti-scaling instrument improves the solubility of calcium ions and prevents calcium carbonate scale formation.

The anti-scaling rate of efficient electromagnetic anti-scaling instrument:

The anti-scaling rate of efficient electromagnetic anti-scaling instrument were conducted for five times and the duration of the scaling test was about 240 h. Anti-scaling rate average values

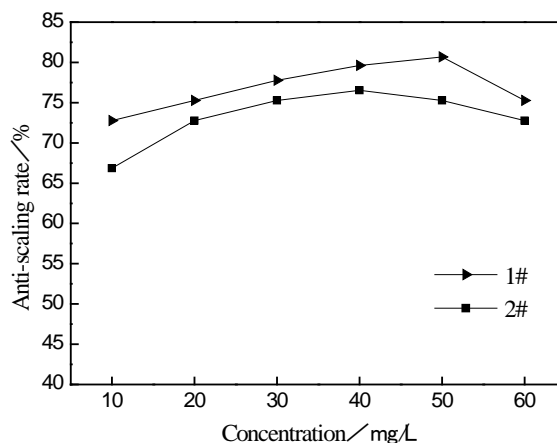


Fig. 2: Anti-scaling rate of composite scale inhibitor (1#) and composite scale inhibitor (2#)

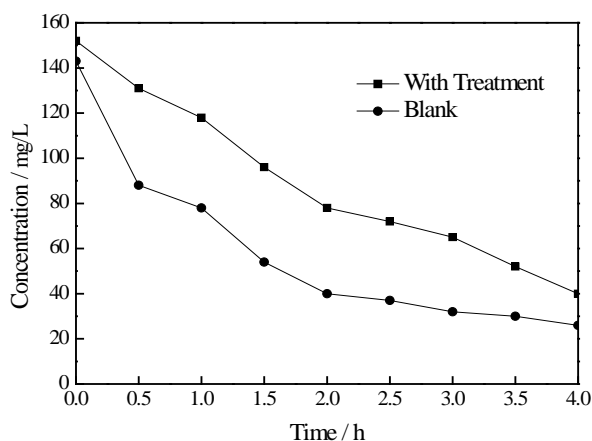


Fig. 3: Calcium concentration change tendency

Table 1: The anti-scaling rate of efficient electromagnetic anti-scaling instrument

Test time (h)	Anti-scaling rate (%)
48	48.52
48	51.81
48	52.29
48	52.21
48	52.47

were calculated. Table 1 showed anti-scaling rate at different times. The result illustrated that the anti-scaling rate was 48.52% at the first time. However, anti-scaling rate was about 52% at the other four times. It is because the sheetmetal is new and the surface is smooth that is difficult to scaling on the sheetmetal surface at the first time.

Effect of efficient electromagnetic anti-scaling instrument on the X-ray diffraction:

In order to validate the effect and identify the efficient

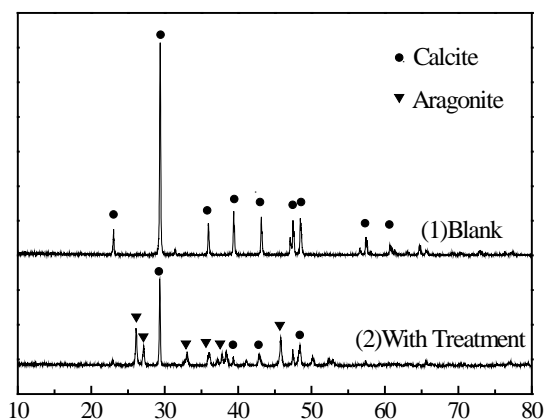


Fig. 4: XRD spectra of calcium carbonate crystal type

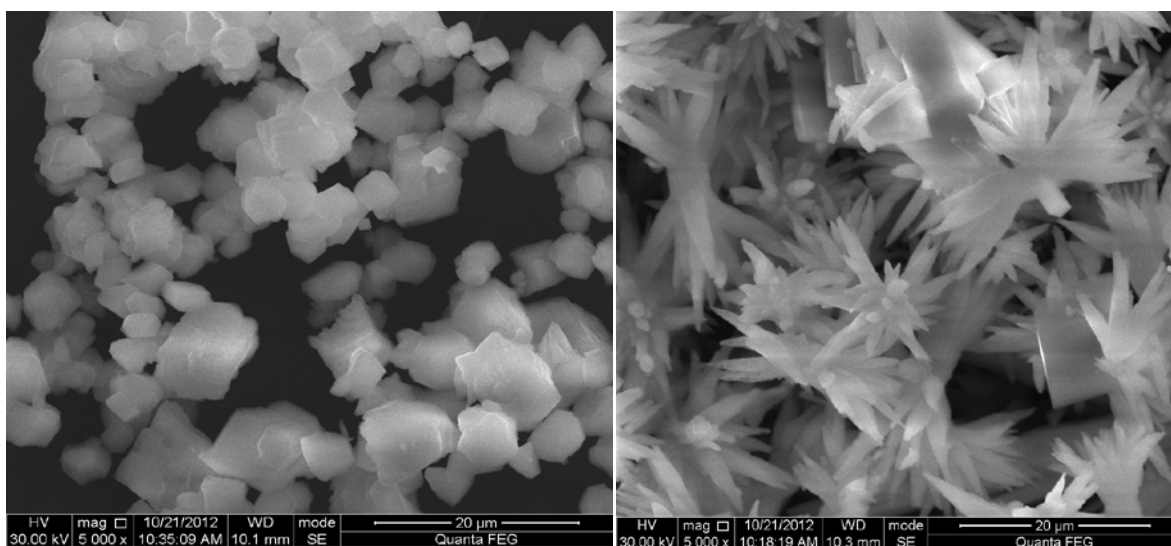
electromagnetic anti-scaling instrument mechanism, a series of experiments were carried out, either with or without efficient electromagnetic anti-scaling instrument. The crystal types of the deposited CaCO_3 scales were determined by X-Ray Diffraction (XRD). The experimental results were presented in Fig. 4. Through XRD analysis, the deposits formed in no treatment case are found to be all calcite scales, while those in the efficient electromagnetic anti-scaling instrument treatment case are calcite scales and aragonite scales. This is probably because additional particles are produced in bulk water due to the effect of efficient electromagnetic anti-scaling instrument by providing more chances for ions to collide, thus forming into more aragonite.

Effect of efficient electromagnetic anti-scaling instrument on the SEM micrographs:

Scanning Electron Microscope (SEM) micrographs of the calcium carbonate crystal type were obtained. Figure 5a and b showed the SEM images of CaCO_3 crystal formed without and with efficient electromagnetic anti-scaling instrument treatment, respectively. The SEM photographs of the scales formed without treatment reveal that CaCO_3 scales are mainly calcite scale, which are symmetry and cube shape or rectangular block shape, while the scales produced with efficient electromagnetic anti-scaling instrument present a quite different structure. There are lots of aragonite phase being dispersive needle shape in the crystal scales formed with efficient electromagnetic anti-scaling instrument treatment, as shown in Fig. 5b. They are thin and set into the bunch crystal. In this case, the aragonite particles go to the surface in the form of particulate scale by gravitational settling or particle transport. Particulate scale is known to produce softer form of deposits and is easily removed with enough shear force from flowing water (Cho *et al.*, 2004; Lee *et al.*, 2006; Tijjng *et al.*, 2007) which leads to thinner scale deposit layers.

Synergistic effect of composite scale inhibitor and efficient electromagnetic anti-scaling instrument:

Synergistic effect of efficient electromagnetic anti-scaling instrument and composite scale inhibitors were investigated as shown in Fig. 6 and 7, respectively. It can be observed from Fig. 6 and 7 that the anti-scaling rate of synergistic effect was obviously higher than that of the single using composite scale inhibitor or efficient



(a) Blank

(b) With treatment

Fig. 5: SEM micrographs of calcium carbonate crystal type

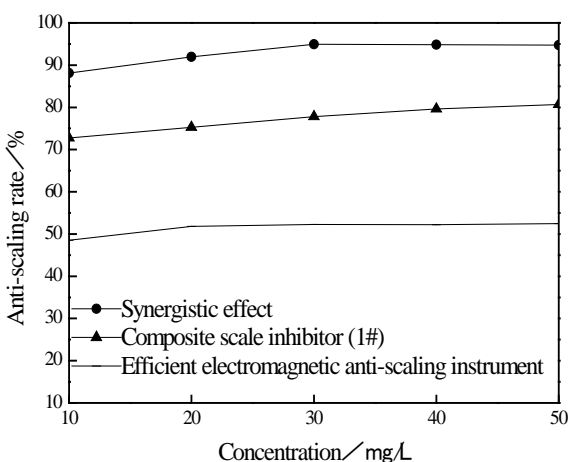


Fig. 6: Synergistic effect of efficient electromagnetic anti-scaling instrument and composite scale

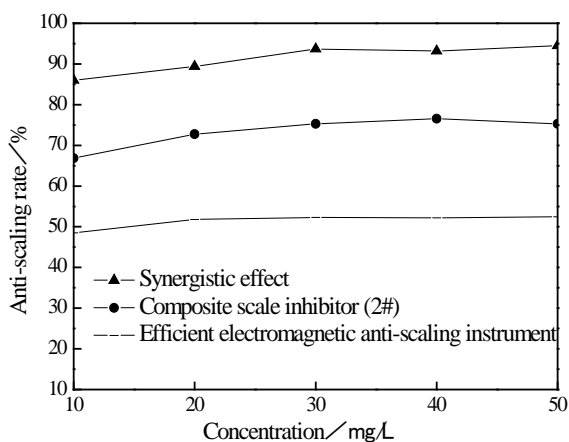


Fig. 7: Synergistic effect of efficient electromagnetic anti-scaling instrument and composite scale inhibitor (2#)

electromagnetic anti-scaling instrument. As can be seen in Fig. 6, when using scale inhibitor (1#) alone at 50 mg/L, anti-scaling rate reached the highest which was 80.68%. However, scale inhibitor (1#) at 40 mg/L, anti-scaling rate reached the highest which was 94.95% in the synergy. As can be seen in Fig. 7, when using scale inhibitor (2#) alone at 50 mg/L, anti-scaling rate reached the highest which was 76.53%. However, scale inhibitor (2#) at 30 mg/L, anti-scaling rate reached the highest which was 94.5% in the synergy.

This is because synergistic effect of composite scale inhibitor and efficient electromagnetic anti-scaling instrument can improve the chelating ability of Ca^{2+} . When the water flows through efficient electromagnetic anti-scaling instrument. The water is magnetized and magnetic field affects the formation

conditions of Ca^{2+} and CO_3^{2-} combined with CaCO_3 . CaCO_3 dipole distance and solubility are increased, so the free energy of the molecular crystallization process is increased. Macromolecular chain of composite scale inhibitor adsorbs on the unstable dispersion CaCO_3 crystals and electromagnetic field improves the chelate disperse performance of composite scale inhibitor. The results show that synergistic effect of efficient electromagnetic anti-scaling instrument and composite scale inhibitors not only improves the anti-scaling rate but also reduces the dosage of composite scale inhibitor.

CONCLUSION

The following are the conclusions drawn from this study:

- The highest anti-scaling rate of composite scale inhibitor (1#) was 80.68% at 50 mg/L and highest anti-scaling rate of composite scale inhibitor (2#) was 76.53% at 40 mg/L.
- Average anti-scaling rate of efficient electromagnetic anti-scaling instrument was 51.46%. Efficient electromagnetic anti-scaling instrument treatment produced mostly aragonite crystal structures, which were less dense, less adherent and easily removed type of CaCO_3 scale.
- Efficient electromagnetic anti-scaling instrument worked with composite scale inhibitor (1#), synergistic scale inhibition was 20% higher than composite scale inhibitor (1#) and was 40% higher than efficient electromagnetic anti-scaling instrument worked alone, respectively. Efficient electromagnetic anti-scaling instrument worked with composite scale inhibitor (2#), synergistic scale inhibition was 10% higher than composite scale inhibitor (2#) and was 50% higher than efficient electromagnetic anti-scaling instrument worked alone, respectively.

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REFERENCES

- Alimi, F., M. Tlili, M. Ben Amor, C. Gabrielli and G. Maurin, 2007. Influence of magnetic field on calcium carbonate precipitation. *Desalination*, 206: 163-168.

- Al-Mutairi, N.N., F.A. Aleem and M.I. Al-Ahmad, 2009. Effect of antiscalants for inhibition of calcium sulfate deposition in thermal desalination systems. *Desalin. Water Treat.*, 10: 39-46.
- Baker, J.S. and S.J. Judd, 1996. Magnetic amelioration of scale formation. *Water Res.*, 30: 247-260.
- Chen, T.Y. and S.H. Chan, 2000. Novel biological inhibitors of fouling and scale formation on heat transfer surfaces through genetic engineering. *Microsc. Thermophys. Eng.*, 4: 103-108.
- Chibowski, E., L. Holysz and A. Szczes, 2003. Adhesion of in situ precipitated calcium carbonate in the presence and absence of magnetic field in quiescent conditions on different solid surfaces. *Water Res.*, 37: 4685-4692.
- Cho, Y.I., A.F. Fridman, S.H. Lee and W.T. Kim, 2004. Physical water treatment for fouling prevention in heat exchangers. *Adv. Heat Transfer.*, 38: 1-71.
- Coetzee, P.P., M. Yacoby, S. Howell and S. Mubenga, 1998. Scale reduction and scale modification effects induced by Zn and other metal species in physical water treatment. *Water SA.*, 24: 77-84.
- Fathi, A., T. Mohamed, G. Claude, G. Maurin and B.M. Mohamed, 2006. Effect of magnetic water treatment on homogeneous and heterogeneous precipitation of calcium carbonate. *Water Res.*, 40: 1941-1950.
- Hasson, D., M. Avriel and W. Resnick, 1968. Mechanism of calcium carbonate scale deposition on heat transfer surfaces. *Ind. Eng. Chem. Fund.*, 7: 59-65.
- Kazi, S.N., G.G. Duffy and X.D. Chen, 2010. Mineral scale formation and mitigation on metals and a polymeric heat exchanger surface. *Appl. Therm. Eng.*, 30: 2236-2242.
- Ketrane, R., B. Saidani, O. Gil, L. Leleyter and F. Baraud, 2009. Efficiency of five scale inhibitors on calcium carbonate precipitation from hard water: Effect of temperature and concentration. *Desalination*, 249: 1397-1404.
- Kim, J.O., J.T. Jung, I.T. Yeom and G.H. Aoh, 2007. Electric fields treatment for the reduction of membrane fouling: The inactivation of bacteria and the enhancement of particle coagulation. *Desalination*, 202: 31-37.
- Kukulka, D.J. and M. Devgun, 2007. Fluid temperature and velocity effect on fouling. *Appl. Therm. Eng.*, 27: 2732-2744.
- Lee, G.J., L.D. Tijing, B.C. Pak, B.J. Baek and Y.I. Cho, 2006. Use of catalytic materials for the mitigation of mineral fouling. *Int. Commun. Heat Mass.*, 33: 14-23.
- Lisitsin, D., Q. Yang, D. Hasson and R. Semiat, 2005. Inhibition of CaCO₃ scaling on RO membranes by trace amounts of zinc ions. *Desalination*, 183: 289-300.
- Macadam, J. and S.A. Parsons, 2004. Calcium carbonate scale control: Effect of material and inhibitors. *Water Sci. Technol.*, 49: 153-159.
- Melo, L.F., T.R. Bott and C.A. Bernardo, 1988. *Fouling Science and Technology E: Applied Science*, NATO ASI Series 145. Kluwer Academic Publishers, Netherlands.
- Shahryari, A. and M. Pakshir, 2008. Influence of amodulated electromagnetic field on fouling in a double-pipe heat exchanger. *J. Mater. Process. Technol.*, 203: 389-395.
- Tang, Q.G., J.P. Meng, J.S. Liang, L. Nie and Y.X. Li, 2010. Effects of copper based alloys on the nucleation and growth of calcium carbonate scale. *J. Alloys Compd.*, 491: 242-247.
- Tijing, L.D., B.C. Pak, B.J. Baek, D.H. Lee and Y.I. Cho, 2007. An experimental study on the bulk precipitation mechanism of physical water treatment for the mitigation of mineral fouling. *Int. Commun. Heat Mass.*, 34: 673-681.
- Tijing, L.D., H.Y. Kim, D.H. Lee, C.S. Kim and Y.I. Cho, 2009. Use of an oscillating electric field to mitigate mineral fouling in a heat exchanger. *Exp. Heat Transfer.*, 22: 257-270.
- Wang, X., B.I. Lee and L. Mann, 2002. Dispersion of barium titanate with polyaspartic acid in aqueous media. *Colloid Surf. A.*, 202: 71-80.
- Watkinson, A.P., L. Louis and R. Brent, 1974. Scaling of enhanced heat exchanger tube. *Can. J. Chem. Eng.*, 52: 558-562.
- Xiaokai, X., 2008. Research on the electromagnetic anti-fouling technology for heat transfer enhancement. *Appl. Therm. Eng.*, 28: 889-894.