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Dynamic synergistic scale inhibition performance of IA/SAS/SHP copolymer with magnetic field and electrostatic field

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HIGHLIGHTS

- A new scale inhibitor, IA/SAS/SHP copolymer was synthesized.
- There existed synergistic scale inhibition effect of IA/SAS/SHP copolymer with magnetic and electrostatic field on $CaCO_3$.
- The synergistic scale inhibition efficiency is 100%.
- SEM and XRD analyses morphology and crystal phase of $CaCO_3$ scale.

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ABSTRACT

An IA/SAS/SHP copolymer was synthesized by itaconic acid (IA), sodium allysulfonate (SAS) and sodium hypophosphite (SHP). This IA/SAS/SHP copolymer was characterized by Fourier transform infrared spectrometry (FT-IR) and nuclear magnetic resonance spectroscopy (NMR). The dynamic synergistic scale inhibition performance of the IA/SAS/SHP copolymer against $CaCO_3$ in the presence of magnetic field and electrostatic field was studied using dynamic scale inhibition experiments. The results showed that there existed synergistic scale inhibition effect of IA/SAS/SHP copolymer against $CaCO_3$ with magnetic field and electrostatic field. Comparing with single IA/SAS/SHP copolymer, the synergistic scale inhibition efficiency of IA/SAS/SHP copolymer against $CaCO_3$ increased by 9.76% in the presence of magnetic field and 16.65% in the presence of electrostatic field. The scale inhibition efficiency of IA/SAS/SHP copolymer against $CaCO_3$ in the presence of the magnetic field and electrostatic field as high as 100% was reached when IA/SAS/SHP copolymer concentration was 0.5 mg/L, pH was 7.3, and temperature was 40 °C. Morphology and crystal phase of calcium carbonate were characterized by SEM and XRD.

1. Introduction

Two methods are mainly used in industrial circulating cooling water treatment to inhibit scale formation and precipitation in recent years, chemical method and physical method. The magnetic water treatment and electrostatic water treatment are new types of physical methods in recent decades and have fine prospect [1] because of their less investment, simple operation, non-toxicity, no pollution, scale inhibition, and sterilization [2–4]. Moreover, they can prevent the precipitation of calcium carbonate and remove the formed scale. HaiHua Li et al. [5] combined high-voltage electrostatic field with polyepoxysuccinic acid to investigate the scale inhibition efficiency against $CaCO_3$, found there existed synergistic scale inhibition effect in the static experiment with electrostatic field. Zhan Liu et al. [6,7] studied the synergistic scale inhibition efficiency of ESA/AMPS copolymer against $CaCO_3$ with magnetic field or with electrostatic field in the static experiment. Therefore, physical water treatment methods have positive impact on improving scale inhibition efficiency, have become an important focus in physical water treatment technology [8,9].

In chemical method, the use of scale inhibitor is the most common and effective method to prevent formation of scale [10]. Shuhai Guo et al. [11] investigated an organic phosphate compound inhibitor (ratio of PBTCA, HEDP and ATMP, 2:2:1) during the reuse of oilfield produced-water and achieved a higher scale inhibition efficiency than any of the inhibitors individually. Under the pressure of worsening global ecological and environmental crises [12,13], developing environmentally friendly scale and corrosion inhibitor has become a focus in water treatment agent, which will gradually replace the phosphorous water treatment agents [14–17]. In recent years, copolymer scale inhibitors [18] have attracted intensive interest because of their multi-functional groups [19–21] and show the excellent inhibition properties for different types of scale. Because the function groups in copolymers have strong complexation and superior dispersion performance [22], they

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have been used satisfactorily as the specific scale inhibitors in the circulating cooling water system.

To develop a satisfactory method both in economical and environmental terms [23], we synthesized a novel environmentally friendly multifunctional scale inhibitor IA/SAS/SHP copolymer. This IA/SAS/SHP copolymer was prepared from the monomers of itaconic acid (IA), sodium allysulfonate (SAS), and sodium hypophosphite (SHP) by the oxidation-reduction initiator system, and contained carboxylic acid, sulfonic acid and phosphonic acid groups. The structure of the copolymer was characterized by FT-IR and NMR.

For controlling the dosage of scale inhibitor to reduce the cost of industrial circulating water treatment and in response to environmental guidelines of avoiding the water pollution [24], we attempt to combine this IA/SAS/SHP copolymer with electrostatic field and magnetic field. It is the first time that the dynamic synergistic scale inhibition of scale inhibitor with electrostatic field and magnetic field is reported and applied on industrial circulating water treatment. This method provides a basis for developing a new environmentally friendly water treatment technique for industrial circulating cooling water system, which will economize water treatment cost and has a great application prospect in water treatment field.

2. Experimental

2.1. Materials and instruments

The chemical reagents used are analytical grade sodium hypophosphite (SHP), isopropanol, ammonium ferrous sulfate, sodium hydroxide, hydrogen peroxide, calcium chloride hexahydrate, EDTA, anhydrous ethanol, technical grade itaconic acid (IA) and sodium allysulfonate (SAS).

Instruments include 724 spectrophotometer (Shanghai Optical Instrument, China), SP100 Fourier transform infrared spectrometer (FT-IR, Perkin-Elmer, Germany), Ultima IV X-ray diffraction instrument (XRD, Rigaku, Japan), Inspect S50 scanning electron microscope (SEM, FEI, USA), Nuclear and magnetic Resonance Spectroscopy (NMR, BRUKERAC-P500, USA), Dynamic dirt detector (DGC-II, Xinyou Instrument Factory), and Gauss Meter (CH-1600, Shanghai Jianyi Instrument, China).

2.2. Water sample

Underground water was used in the dynamic scale inhibition experiments, composition and content as follows: total hardness is 773 mg/L (with $CaCO_3$ as the benchmark); content of Ca^{2+} is 557 mg/L (with $CaCO_3$ as the benchmark); total alkalinity is 320 mg/L (with $CaCO_3$ as the benchmark); content of Cl^- is 205 mg/L.

2.3. Experimental device

The electrostatic treatment unit and the magnetic treatment unit used on dynamic simulative water treatment device were made by ourselves. The schematic diagrams of these units are shown in Figs. 1 and 2, respectively.

2.3.1. Electrostatic water treatment unit

As seen in Fig. 1, the electrostatic water treatment unit is composed of a water treatment device and a high-voltage DC power supply (the range of electrostatic voltage was 2000 V–8000 V).

The anode of water treatment device was a metal rod with good conductivity and was placed in a tetrafluoroethylene cylinder, the cathode was a seamless steel pipe. The anode and cathode maintained a certain distance and formed a cavity. The high voltage DC power supply was another part of the electrostatic water treatment equipment and could provide high voltage to the water treatment device. The output voltage of DC power supply was connected to the metal rod of the water treatment device, ground wire was connected to housing of the water treatment device. Strong electrostatic field could be obtained by adjusting the voltage of power supply, acted on the flowing water of the cavity.

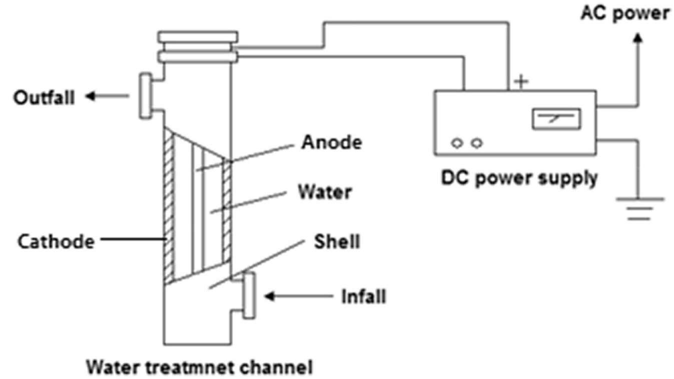

Fig. 1. Schematic diagram of electrostatic water treatment unit.

2.3.2. Magnetic water treatment unit

The cross-sectional view of the magnetic water treatment unit is shown in Fig. 2. The Nd–Fe–B rare-earth permanent magnetic materials were installed in the bracket of PVC, the magnetic field direction was orthogonal to the water flow direction. The magnetic field strength was 0.6 T.

2.3.3. Dynamic simulative water treatment device

The dynamic synergistic scale inhibition performance of IA/SAS/SHP copolymer with magnetic field and electrostatic field was studied by the dynamic simulative water treatment device, as shown in Fig. 3. In the experiment, the physical water processor was installed in the circulation pipeline. The dynamic synergistic scale inhibition performance could be studied by the changes of the fouling thermal.

The heat exchanger was a main component, and composed of glass tube and stainless steel heat exchanger tube. Both ends of the heat transfer tube connected with the alternating current, the heat transfer intensity could be changed by adjusting the heating voltage. Water sample flowed through the heat exchanger and scale would be deposited on its surface. Circulating way of the dynamic water treatment device was closed cycle. Test conditions are as follows: electrostatic voltage was 5000 V, flow rate was 0.01 $m \cdot s^{-1}$, the experimental temperature was 40 °C, pH was 7.3 and experimental time was 10 h.

2.4. Preparation of IA/SAS/SHP copolymer

52 g of itaconic acid (IA), 13 g of sodium allysulfonate (SAS), 2 mL isopropanol and 2 g of ammonium ferrous sulfate were added into deionized water and were stirred till completely transparent. The mixed solution was heated to 90 °C, and 7.15 g of NaH_2PO_2 and 30 mL hydrogen peroxide were added to the above solution slowly in 1.5 h. Then the solution was heated to 102 °C and maintained for 2 h, the IA/SAS/SHP copolymer was obtained. Synthesis route of the IA/SAS/SHP copolymer is shown in Scheme 1.

2.5. Evaluation of scale-inhibition performance

The thermal resistance of the scale samples was calculated as:

$$R_d = \frac{A}{Q}(\Delta T_{md} - \Delta T_{mc})$$

where R_d ($m^2 \cdot K \cdot W^{-1}$) is thermal resistance, A (m^2) is heat transfer area, Q (W) is heat transfer rate, ΔT_{md} (K) and ΔT_{mc} (K) are the average