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A preliminary research on polyvinyl alcohol hydrogel: A slowly-released anti-corrosion and scale inhibitor

Ting Gu, Xiaoyan Liu*, Wenbo Chai, Beibei Li, Haoyuan Sun

College of Environmental and Chemical Engineering, Shanghai University, 99 Shangda Road, Shanghai 200444, China

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ABSTRACT

Scale and corrosion problems have become more and more serious during the process of oil production. Adding chemical inhibitors can be a best choice for treatment, especially for green inhibitors such as polyepoxysuccinic acid and imidazoline. However, liquid inhibitors are usually not satisfactory due to the high cost of fluid dosing system and the bad performance during the mixing process. These problems can be perfectly solved by solid corrosion and scale inhibitor which will be slowly released under control. As a release controller, polyvinyl alcohol (PVA) has been widely used in medical fields. In addition, PVA hydrogel based inhibitor can be easily prepared. In the experimental results, our prescription has demonstrated excellent performance in terms of controlled-release and corrosion-scale inhibition.

1. Introduction

Most of the oil fields have entered their mid and late periods in which the mining becomes more and more difficult (Qiao et al., 2012). As a promising low-cost method for enhanced oil recovery (Jing et al., 2013), water flooding is now a well-established and mature operation applied in many reservoirs around the world (Sorbie and Mackay, 2000; Zhang et al., 2007; BinMerdhah et al., 2010). Seawater, due to its abundance, is the most common option for water injection operation (Bader, 2007). However, sea water is rich in diverse ions so the extensive use of sea water injection operation for oil displacement in oil fields often causes a chronic disaster of corrosion and scale on pipeline engineering made of metallic materials (Bedrikovetsky et al., 2009b; Zabihi et al., 2011; Yucheng et al., 2013). This phenomenon is attributed to precipitation and the consequent permeability reduction, which will result in the loss of well productivity, the increase of maintenance cost for pipelines and equipments (Bedrikovetsky et al., 2009a; BinMerdhah et al., 2010; Stack and Abdulrahman, 2010).

The incompatibility of anion and cation in water is the major culprit for corrosion and scale problems. Therefore controlling the salinity of oilfield waters prior to water injection plays a crucial role in the exploration and production of petroleum (El-Said et al., 2009). To lower the salinity of injected water, "planned-water", a mixture of different kinds of water, has been used (El-Said et al., 2009; Shalabi et al., 2014). Moreover, as the main concerns of scale and corrosion problems are iron compounds and calcium carbonate (Moghadasi et al., 2004; Martos et al., 2010; Jing et al., 2013), chemical control, such as adding poly-aspartic acid (Liu et al., 2009) and acetic acid (Zhu et al., 2011), is generally regarded as the most effective method, both in performance and cost (Lavania et al., 2011; Pillay and Lin, 2014). However, from an operational point of view, chemical dosing by means of a remote control system is the ideal scenario (Khramov et al., 2005; Okafor et al., 2009; Abdullayev and Lvov, 2010; Brown et al., 2011). In recent years, hydrogel has been recognized as an interesting vehicle for delivery (Zhao et al., 2014). Poly (vinyl alcohol) (PVA) is biocompatible, non-toxic, chemical stable and cheap (Hui et al., 2014). As a result, polyvinyl alcohol (PVA) hydrogel has attracted increasing attention on its excellent biocompatibility and mechanical strength (Zhu et al., 2014) and has been widely used in pharmaceutical industry.

In this paper, it is recommended to use polyvinyl alcohol (PVA) hydrogel loaded with modified PESA and imidazoline for the first time. The optimal ratio of modified PESA and imidazoline has been identified in our previous work (Gu et al., 2013). The performances of both static and dynamic releasing of PVA hydrogel have been studied. Meanwhile, the anti-corrosion and anti-scale performances of our products have also been evaluated on the simulated pipeline system.

2. Materials and methods

2.1. Material and apparatus

Imidazoline used in our experiment was purchased from the local company called Shayang Corosi chemical co., ltd. In previous

* Corresponding author. Tel.: +86 21 66137767.
E-mail address: lxy999@shu.edu.cn (X. Liu).

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work, the modified PESA was synthesized and verified, the simulated corrosion solution was prepared, and the carbon steel specimens were pretreated for further use. The mass ratio of modified PESA and imidazoline used in the experiment was 50:8 (Gu et al., 2013) and the composite inhibitor was prepared. PVA (1788, SINOPEC) was purchased online.

2.2. Preparation of PVA hydrogel

PVA hydrogel was prepared in physical interactions (Ahmed, 2013). PVA was immersed in distilled water overnight to swell well. Then it was dissolved in the water at 85 °C. The preheated composite inhibitor was added. After fully blended, the mixture was injected into a columnar mold and was placed in oven. The preparation of dried hydrogel was completed after demoulding.

2.3. Study of release performance

A simulated pipeline system of 70 cm in length, 15 cm in height was designed, which consists of sample release section (DN 40 PPR pipe), flowmeter (LCD-M, Shenzhen Okada co., ltd), inlet and outlet sections (both DN 20 PPR pipe).

The prepared PVA hydrogel had been placed in the simulated pipeline system. Both its dynamic and static releasing performances were studied. Continuous sampling was conducted every 24 h during the releasing stage. All the performances of PVA releasing, anti-scaling and corrosion inhibition were tested.

The concentration of the released PVA was tested based on the method presented by Gu Runnan (Gu and Lin, 2005). After adding the aqueous boric acid and iodine, the amount of PVA in the sample was measured with a visible spectrophotometer (LENG GUANG, 722) at a maximum absorption wavelength of 640 nm with reference to a previously prepared calibration curve. This maximum absorption wavelength was determined by the product from the reaction of PVA with iodine in the presence of boric acid (Lin and Hsu, 2013). The calibration curve obtained by using aqueous PVA at a concentration of 0–16 mg/L describes a linear relationship observed between the concentration of PVA and the absorbance at 640 nm. Therefore, during the experiment, the concentration of the released PVA could be monitored with the spectrophotometrical method at this wavelength.

2.4. Weight loss measurements

The experiments were carried out with the rotary coupon corrosion test instrument (RCC-II, Jiangsu Jiangdu Jianhua instrument and meter factory). Carbon steel specimens with surface treatment were prepared in triplicate, weighed and then immersed in CO_2-saturated corrosion solution beneath which PVA hydrogel was loaded with imidazoline. The solution was kept in polyethylene (PE) bottles of 1000 mL for 48 h at 50 °C. Then the specimens were rinsed with distilled water. After that they were immersed in petroleum ether (bp. 60–90 °C) and absolute alcohol. Each dried sample was weighed again. Finally, the inhibition efficiency (*IE*%) is calculated by the equation (Bentiss et al., 2000)

$$IE\% = [(\Delta W_0 - \Delta W)/\Delta W] \times 100\% \quad (1)$$

where ΔW_0 and ΔW stand for the weight loss of carbon steel after immersion in solutions without and with inhibitor, respectively.

2.5. Static anti-scaling method

Based on standard Q/SY126-2005, static anti-scaling experiments were carried out. The inhibition solution added in the PE bottles was sampled from the releasing system every 24 h. Then the PE bottles were heated in an oven. After the incubation period, an aliquot of inhibition solution was filtered through a 0.45 μm membrane. Then the calcium ion in the filtrate was determined by aqueous titration. And the calcium carbonate scale inhibition ratio was calculated based on the following equation (Choi et al., 2002):

$$\eta = (C_1/C_2) \times 100\% \quad (2)$$

where η represents anti-scaling efficiency, C_1 represents Ca^{2+} concentration in the test and C_2 stands for original Ca^{2+} concentration.

3. Results and discussion

3.1. Form selection experiment of PVA

The purchased PVA had three forms (Fig. 1), floccule, powder and particle. Fig. 2 showed the state of the three forms of PVA after being placed into distilled water for 3 h. It is obvious that the only particle form of PVA is compatible with water. After the three samples were heated, neither of the first two performed well. It may result from different surface structures of the PVA. Therefore, the third one, particle form, was chosen for latter experiments due to its compatibility with distilled water.

3.2. Infiltration performance of the particle PVA

In order to find out a suitable ratio of PVA to distilled water, 5 g PVA was immersed into different amounts of distilled water ranging from 10 to 25 mL (Fig. 3). With observation of the limited swelling behavior of PVA (Gao et al., 2011), it can be concluded that 10 mL of distilled water was not enough for 5 g PVA to uptake, 25 mL was too much and 15, 20 mL were appropriate for 5 g PVA.

3.3. Corrosion inhibition performance of PVA hydrogel loaded with imidazoline

The optimum ratio of PVA to distilled water was further verified. Four kinds of PVA hydrogels were prepared, which consists of 1 g PVA, distilled water ranging from 2 mL to 5 mL and 1 g imidazoline. Different corrosion inhibition performances of PVA hydrogel were tested. As the results (Fig. 4) showed, the inhibition efficiency of both

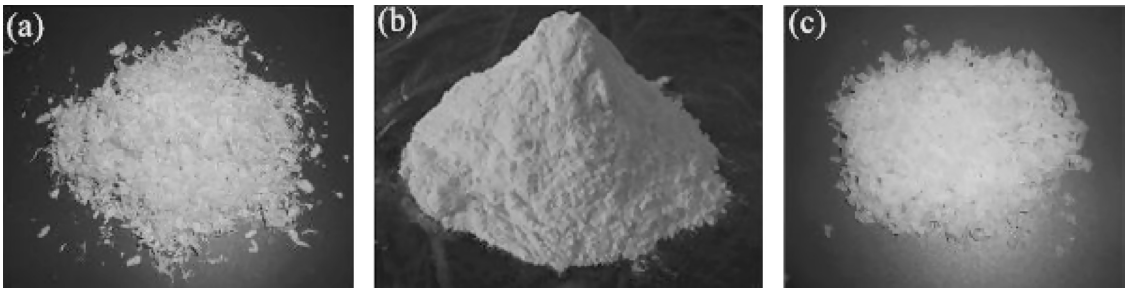

Fig. 1. Three forms of PVA (a, floccule; b, powder; and c, particle).