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Property evaluation of a new selective water shutoff agent for horizontal well

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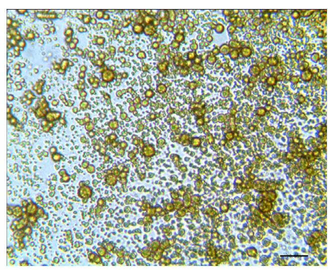
HIGHLIGHTS

- Emulsified asphalt was developed for water shutoff in horizontal well.
- IFT is relevant to the emulsifying ability of surfactant for asphalt.
- Zeta potential and emulsion stability at normal temperature is well related.
- Interfacial viscosity mainly affects emulsion stability due to varying temperature.
- The mechanism of surfactant improving the injection efficiency is found out.

GRAPHICAL ABSTRACT

Micro-morphology of emulsified asphalt prepared with 114 emulsifier system.



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ABSTRACT

In this paper, emulsified asphalt, a new type of selective water shutoff agent for horizontal well was developed. The emulsifying effect of surfactants on asphalt, the influence of inorganic salt, temperature and surfactant stabilizer on the stability of emulsified asphalt, and the impact of core permeability and surfactant pre-flush fluid on the injection efficiency of emulsified asphalt were studied. Moreover, the effect of external conditions on the stability and injection efficiency of emulsified asphalt was analyzed from the point of the interfacial electrical property and interfacial viscosity. The results indicate that the oil–water interfacial tension (IFT) is relevant to the emulsifying ability of surfactant for asphalt, and the emulsifying ability is improved as the IFT decreases. However, there is no relationship between the IFT and the stability of emulsified asphalt.The Zeta potential of emulsified oil droplet and emulsion stability at normal temperature is well related under the influence of inorganic salt, and the emulsion stability becomes better as the absolute value of Zeta potential increases. Under the influence of temperature, Zeta potential turns to have nothing to do with the stability of emulsified asphalt, while the oil–water interfacial viscosity gets to be the main affecting factor on it, that is, high interfacial viscosity is beneficial to the emulsion stability. Surfactant additives can enhance the emulsion stability through regulating the Zeta potential, and the surfactant pre-flush fluid can improve the injection efficiency of emulsified asphalt by increasing its stability. The above results can be used as guidance in the formulation design and mechanisms studies of emulsified asphalt for selective water shutoff for horizontal well.

1. Introduction

Water production in oil wells brings many hazards, such as consuming stratum energy, reducing the pump efficiency, accelerating the corrosion and scale formation of pipes and devices, increasing the load of dehydrating stations, and so on. The environment will be polluted if the produced water is excreted without

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being handled. Thus, decreasing the water production has been an important work in oilfield, and water shutoff technology gets more and more significant in oilfield exploitation, especially the selective water shutoff technology which supports general injection and can reduce the construction cost [1]. In recent years, horizontal wells have developed rapidly due to its unique advantage. However, its shortcomings are also obvious, and the most prominent one is that excess water is easy to be produced since the overlong well bore of horizontal well is parallel to the reservoir, leading to the sharp cutoff of oil output, the rapid increase of water content in output liquids, and even an overflow in the whole oil layer. Therefore, horizontal well is easier to produce water compared with the traditional one, and how to block water effectively has becomes the key problem needed to be solved in horizontal wells' production. But the operation process of a horizontal well is complex, the logging (water exploration) information is few, and the completion method is slotted liner (screen liner), leading to that the water shutoff in horizontal wells is far more difficult than that in traditional ones and the effect of traditional water shutoff agents becomes inefficient [2–5]. However, few studies have been done on selective water shutoff agents for horizontal wells, and the one that can be widely used has not been found yet. Thus it is necessary to carry out more researches on efficient selective water shutoff agents for horizontal wells.

Nowadays, the selective water shutoff agent which has been focused on is the relative permeability modifier (RPM), or disproportionate permeability reducer (DPR). It is a kind of chemical agent that can increase the oil phase permeability and reduce the water phase permeability, whose main components are high molecular polymers. When injected into oil wells, it can increase the output of oil and decrease the water production. Thereby, RPM have been done a wide range of application tests in the production site in recent years. Water control diagnostic plots technique has been proposed by Chan et al. [6], and the compound crosslinking systems prepared by high molecular weight polyacrylamide were used in Prudhoe Bay oilfield for plugging water in horizontal well. Zaitoun et al. [7] from Institut Francais Du Petrole squeezed polymers into slotted liner to block water, and field experimentations were conducted in Pelicanlake oilfield in Western Canada. Besides, they also used low hydrolysis degree HPAM in the water shutoff of the horizontal well VN-21 in Saint-Clair-Sur-Epte reservoir. Before the water shutoff, the water/gas ratio of this well was about three times greater than the average ratio of the facility. After plugging water for 2 years, the water/gas ratio reached the average level of the field, and thus the production efficiency of natural gas was increased greatly [8]. In 2002, a horizontal well in Wafa Ratawl oilfield in Kuwait made use of a new type of polymer jelly in water plugging. A system which was similar to hydroxyethyl cellulose was used as a temporary plugging agent at the toe of the well to protect the oil layer, and a kind of organic crosslinking polymer was injected to the root as a water shutoff agent. Then, the water content dropped from 82% to 70–80% after the plugging [9].

The above examples show that the selective blocking agent similar to the RPM has played an important role in plugging water in horizontal wells. However, the successful use of selective water shutoff agents in the oil field is extremely less, and the on-site implementation scale is relatively small. Therefore, there is no selective water shutoff agent so far that has been widely used in the production field. The main reasons are as follows. Firstly, the selectivity of the agents is not good and the oil output is also declined while the water is plugged, leading to low economic benefit. Secondly, the agents are expensive and so the return of investment is low. Thirdly, the agents can be applied only in mild stratum conditions, and their effect in the reservoir situation of high temperature and high salinity is poor. Therefore, more work should be done to solve these problems, which is mainly to develop a new type of selective water shutoff agent that can be widely applied.

Table 1
Properties of asphalt used.

Softening point (°C)	Penetration at 25 °C (0.1mm)	Ductility at 15 °C (cm)	Density at 25 °C (g/cm^3)
59.7	23.3	66.5	0.987

A novel type of selective water shutoff agent for horizontal wells, oil-in-water emulsified asphalt, was developed in this paper. The relevance between the oil–water IFT and the emulsifying effect was studied. Besides, the influence of inorganic salt, alkali, temperature and surfactant stabilizer on the stability of emulsified asphalt was analyzed from the point of the interfacial electrical property and interfacial viscosity. The mechanism that the surfactant pre-flush fluid can improve the injection efficiency of emulsified asphalt is proposed, providing theoretical directions for the use of the emulsified asphalt as the water shutoff agent.

2. Materials and methods

Unless otherwise specified, the test temperature is 20 °C. It should be noted that the concentration in the paper is on a weight basis, and the asphalt content is 5% in the emulsified asphalt diluent.

2.1. Materials

The asphalt was taken from Karamay refinery, and its basic property is shown in Table 1. Chemicals applied in this study, such as NaOH, Na_2CO_3, NaCl and $CaCl_2$, were all analytical-grade reagents, Hexadecyl trimethyl ammonium chloride (1631, ≥98%), octadecyl trimethyl ammonium chloride (1831, ≥98%), and alpha olefin sulfonates (AOS, 96%) used in this experiment were all chemically pure, and they were all purchased from Sinopharm. The anionic surfactants, ethoxylated lauryl alcohol sulfates (AS-8, AS-0-4), were synthesized in our laboratory.

2.2. Preparation of emulsified asphalt

Asphalt (180 °C) and compound surfactant solution (70 °C) were placed in a colloid mill with a ratio of 1:1, and the emulsified asphalt was obtained after the mixture was smoothly circulated in the colloid mill for 5 min.

2.3. Determination of interfacial tension

Determination of the IFT between surfactant solutions and oil phase was performed by using a spinning drop method with a Texas-500, and the results were gotten through the following equation:

$$\sigma = 1.2336(\rho_w - \rho_o)\omega^2 \left(\frac{D}{n}\right)^3, \frac{L}{D} \geq 4$$

where σ is the interfacial tension (mN/m), ρ_w is the density of the heavy water phase (g/cm^3), ρ_o is the density of the oil phase (g/cm^3), ω is the rotational velocity (rpm), D is the measured drop width (mm), L is the length of the oil drop (mm) and n is the refractive index of the water phase.

2.4. Determination of emulsion stability

Place the emulsified asphalt and its diluent in a test tube with a plug and record the volumes of the precipitated water at different moments, so as to evaluate the stability of the emulsified asphalt.