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Experimental study and application of tannin foam for profile modification in cyclic steam stimulated well

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ABSTRACT

Background: Tannin foam is a good blocking agent with permeability selection and high temperature tolerance. Tannin foam can improve strength and stability of aqueous foam.
Methods: The aim of the study was to investigate whether tannin foam has good performance for profile modification in cyclic steam stimulated well. Through sandpack displacement experiments with single and parallel sandpacks under high-temperature, the effects of foam quality, permeability, injection mode, temperature, permeability ratio, and oil saturation on blocking and profile modification capabilities of tannin foam were studied. The performances of tannin foam and conventional high-temperature foam were compared.
Results: Experimental results indicate that blocking capability for tannin foam first increases and then reduces with the foam quality, and the best foam quality is 50% in the experiments. The resistance factor increases with permeability, and decreases with temperature. Co-injection of tannin solution and gas is better than SAG injection. Gelled tannin may enhance the bubble film strength, and increase the foam stability and blocking capability compared to the conventional high-temperature foam. When the permeability ratio of two sandpacks is less than 4.18, the profile modification is good. As the permeability ratio increases, tannin foam is easy to flow out of the high permeability sandpack, and profile modification decreases. Although irreducible oil in the sandpack reduces foam strength, tannin foam still has obvious profile modification capability in sandpacks with water-flood irreducible oil. Tannin foam was applied for profile modification in two cyclic steam stimulated wells. The wellhead pressure for steam injection with tannin foam increased at least 2 MPa, indicating that tannin foam blocked steam channels in formation. Oil production improvement and water cut decrease are obvious.
Conclusion: Tannin foam is effective for modifying steam profile, increasing oil production, and decreasing water cut in cyclic steam stimulated wells with high water cut.

1. Introduction

1.1. Aqueous foam

In the process of oilfield development fluid channeling from injection wells to production wells, bottom water coning, and viscous fingering often appear. Fractures or high permeability layers act as highly conductive channels through which injected fluids preferentially flow. Poor sweep efficiency can reduce oil production rates, increase water production. Inefficient use of injected fluids also occurs during workover procedures such as acidizing, profile control, steam injection, and so on. These procedures are complicated by heterogeneous reservoirs because the injected fluid will tend to flow into high permeability layers (Burman and Hall, 1987). Treatments to improve the distribution of injected fluids into a heterogeneous reservoir, called profile modification or profile control have become a common approach to remedy poor vertical sweep efficiency during secondary oil recovery as well as to provide fluid diversion during well stimulation treatments. The ideal profile modification treatment would plug the high-permeability formations and water-rich zones of the reservoir without causing any permeability loss to adjacent low-permeability formations and oil-rich zones.

Aqueous foam, on the other hand, demonstrates selective reduction of water relative permeability in high permeability zones, widely used in acidizing heterogeneous formation. Many researchers agreed that foam does not increase water viscosity (Friedmann and Jensen, 1986; Huh and Handy, 1989; de Vries and Wit, 1990). Foam directly reduces gas mobility in porous media by trapping a large percentage of gas in place (Hirasaki and Lawson, 1985; Falls et al., 1988; Morphy et al., 1998). On the other hand, the presence of foam can increase apparent viscosity of flowing gas,

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then reducing gas mobility (Gdanski, 1993; Hill and Rossen, 1994; Rossen and Bruining, 2004). Both effects are related: the apparent yield stress of foam increases at high capillary pressure, and many bubbles in foam are trapped in place. The presence of foam in a high-permeability or undamaged layer can reduce liquid saturation and liquid relative permeability. Foams are less stable in low-permeability or damaged layers. Water can then be diverted into these layers without zonal isolation. Although foam has many advantages, it has been criticized because of its relative instability during post-flooding condition and instability to plug fractures effectively, or coalescence with high oil saturation (Hudgins and Chung, 1990; Sydansk, 1993). Film rupture in an unstable foam leads to the reduction of gas saturation and loss of blocking capability.

1.2. Foamed gel

One solution to improve the stability of foam is increasing the viscosity of the external phase with water-soluble polymers. Foamed polymer solution, called polymer enhanced foams, has a low liquid drainage rate and Ostwald ripening, and relatively high stability in the presence of residual oil. The total energy of the two-phase system can be decreased via an increase in the size scale of the second phase and thus a decrease in total interfacial area. Such a process is termed Ostwald ripening or coarsening (Voorhees, 1984). Furthermore, these polymer enhanced foams effectively plug fractured systems. Even greater foam stability can be achieved by gelling the external phase of foam. Chemical bulk gels including polyacrylamide, xanthan gum, and silica gel have been widely used for profile control treatments in oil and gas field (Parmeswar and Willhite, 1988; Seright, 1991; Hoefner et al., 1992). Foamed gels are currently used for a wide variety of applications including injection profile control, water shutoff, fracturing, and sand control. In each of these applications, a permeability decrease occurs due to invasion of the foamed gel into the porous media (Miller and Fogler, 1994, 1995; Frienmann et al., 1997; Romero et al., 2002; Romero and Kantzas, 2004).

There are several technical advantages of the foamed gel system. During the injection of immature foamed gel, polymer solution enhances the liquid viscosity and elasticity, thereby increasing the stability of foam. After gelation, the gel in the film is staggered overlapping network structure, which can improve the residual resistance factor of foam, and reinforce residual blocking ability and validity. Foamed gel also has the selection of permeability and oil and water layers as aqueous foam. The enclosed gas in foam bubbles reduces the required polymer mount. So foamed gel has both advantages of bulk gel and aqueous foam. It is an effective method for the profile control and water shutoff (Kantzas et al., 1999; Roero-Zeron and Kantas, 2006; Romero-Zeron and Kantzas, 2002, 2006, 2007).

1.3. High-temperature foam

Steam cyclic injection is a popular method used for heavy oil recovery. However, factors such as steam channeling, gravity segregation, steam override, and reservoir heterogeneities often result in poor contact of oil formation with the injected steam, leading to low oil recoveries of heavy oil. One method of profile control which has received considerable attention is the using of high-temperature foams, which can reduce steam mobility, particularly in formations of low oil saturation. Some laboratory research and field application using steam foam have been reported (Hirasaki, 1989; Castanier, 1989; Mohammadi and McCollum, 1989). However, high-temperature foams do suffer from some disadvantages. Surfactant should be continually injected to maintain the foam, and foam stability is sensitive to the high temperature, residual oil, and divalent ions in the formation (Tad, 1996). Limit gravity override in flat and moderately thick reservoirs.

There are several advantages for high-temperature foam injected with steam. Foam can improve steam injection profile. Steam injection profile was improved by foam and that this improvement disappeared rapidly when surfactant injection was stopped in steam–foam injector 68BW (Friedmann et al., 1994). A longer-lasting profile improvement was reported for another injector in MWSS (Waninger and Hoang, 1993). Foam can also improve steam sweep. In all pilots that had observation wells, dramatic improvements of vertical sweep were detected (Patzek and Koinis, 1990; Paulsson et al., 1992). In Mobil's Tulare, steam zones grew thicker: up to 4.6 m over two-thirds of the pattern area in Zone B and up to 1.5 m over half the pattern area in Zone C. Foam can increase steam injection pressure. In most of the field application, a sustained 340–1700 kPa increase of downhole injection pressure was reported (Djabbarah et al., 1990).

1.4. Tannin foam for steam injection

Cyclic steam stimulation is a kind of effective recovery method for heavy oil and super heavy oil. Along with steam stimulation cycles processing, steam channeling will occur which can greatly reduce the oil recovery efficiency. To solve the above mentioned problems, one of the most effective methods is profile control technology under high temperature. High temperature blocking agent produced by tannin and formaldehyde was reported in 1987 (Mitchell et al., 1987). Since then, many experts have done an in-depth study on its performance. Tannin as a kind of high temperature blocking agent has the following characteristics: high strength, high blocking capability, good temperature resistance (up to 300 °C), and good salt resistance. Solid tannin is extracted from certain plant roots, stems, leaves, and fruits. Larch tannin extract is a kind of condensation type tannin, whose chemical composition is polymeric procyanidins (Li and Qi, 2007).

1.5. Purpose of this paper

In this paper, a new type of high temperature blocking agent of tannin foam was investigated which can enhance conventional high-temperature foam. There are few results of tannin foam blocking and profile modification properties under high-temperature conditions in the literatures (Asghari and Taabbodi, 2005; Li and Qi, 2007). This paper proceeds with experimental apparatus, materials and procedures. Next, the results of sandpacks flooding experiments are presented in detail and discussed. Through sandpack displacement test, the effects of foam quality, permeability, injection mode, temperature on tannin foam blocking capability, and the effects of permeability ratio, oil saturation on profile improvement were carefully examined under high temperature. Then, the tannin foam was applied in two cyclic steam stimulated wells to verify the effectiveness in oilfield, and the main conclusions are drawn.

2. Experimental methods

2.1. Apparatus

A coreflood apparatus shown schematically in Fig. 1 was utilized in the experiments for the single and parallel sandpacks. Constant gas and liquid flow rates were imposed and pressure differences for sandpacks were measured with pressure transducers (Model 3210PD, full-scale deflection of 50 MPa and accuracy of 0.1% full scale, Haian Group, China). Sandpacks with different permeabilities and porosities were used in the single and parallel sandpack experiments. For all the experiments the sandpacks