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RESEARCH PAPER

Current development and application of chemical combination flooding technique

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Abstract: Great progress and success have been achieved in the fundamental study and field test of chemical combination flooding in recent years. In China, a low concentration ASP formula is employed to achieve ultra-low interfacial tension by the synergistic effect of alkali and surfactant. The viscosity of polymer solution prepared from produced water can meet the technological requirement when salt tolerance polymer is applied. ASP or SP flooding can increase both oil displacement efficiency and sweep volume. ASP pilot tests and industrial field tests in Daqing Oilfield have resulted in an oil recovery increase of 18.5%–26.5%. The chemical combination flooding has entered into the industrial promotion and application stage, with a series of supporting techniques formed in the field tests. The main challenges in this technique include short pump-checking period and difficulty in produced liquid handling and high cost. Micelle-polymer flooding as the major chemical combination flooding technique was applied abroad in the early stage of chemical flooding tests. However, the micelle-polymer flooding has not been applied widely due to its high cost. With the rise of oil price in recent years, low concentration chemical combination flooding has drawn more attention. Because of high temperature and high salinity in most reservoirs abroad where chemical combination flooding is used, high performance temperature and salt tolerance oil displacement agents are the bottleneck for future chemical flooding.

Key words: chemical combination flooding; oil displacement mechanism; field test; enhanced oil recovery

Introduction

Oilfields in China are mainly continental sedimentary reservoirs. which are characterized by severe heterogeneity, high wax content, high aromatic hydrocarbon content and high crude oil viscosity, so oil recovery of water flooding is low, averaging around 33%. Most oilfields have entered into a high water cut and high recovery percent stage. Studies on enhanced oil recovery (EOR) technologies indicate that chemical combination flooding is a promising technique which can increase oil recovery significantly. Unlike one chemical component flooding such as polymer flooding, alkali flooding or surfactant flooding, a chemical combination flooding system such as surfactant-polymer (SP) flooding and alkali-surfactant-polymer (ASP) flooding employs more than two chemical components in the oil displacing formula. Due to the synergetic effect and multiple functions of chemicals, the oil recovery of chemical combination flooding is higher than that of one component chemical flooding. ASP flooding pilot tests was successful in Daqing, Shengli and Xiangjiang Oilfield. The incremental oil recovery is higher than 20%[1−2]. In addition, Daqing has carried out industrial field tests of ASP flooding and the incremental oil recovery was also significant[1−2]. ASP thus has become a cost effective EOR technology. Due to the development of ASP flooding, it will replace polymer flooding in the future and become the main EOR method in China.

With the increase of oil price, the research and application of chemical combination flooding have also been conducted in many foreign countries. Most of reservoirs abroad are marine carbonates reservoirs with high temperature and high salt content, posing major challenges to ASP flooding

This paper introduces the current progress in oil displacement mechanism, chemical formula and reservoir adaptability of chemical combination flooding, and the tests and application of chemical combination at home and abroad.

1 Progress in the mechanism studies of chemical combination flooding.

Oil recovery is the product of oil displacing efficiency and sweep efficiency. Chemical combination flooding can increase both oil displacing efficiency and sweep efficiency. The incremental oil recovery can be high with the synergistic effect among alkali, surfactant and polymer in chemical com-

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bination flooding.

The viscosity of displacing fluid can be increased by one or even two orders of magnitude by adding polymer into water, which in turn will result in the drop of mobility ratio of water and oil, mitigation of displacing fluid fingering, and ultimately increase in swept volume. The relationship between water/oil mobility ratio and sweep efficiency is shown in Table 1 under a fixed injection rate for a homogenous reservoir (five spot well pattern) [3].

At present, the produced water is commonly applied to prepare chemical solutions for re-injection. The relationship of viscosity with concentration of five polymer samples prepared with Daqing produced water (salinity 4 500 mg/L) at reservoir temperature 45°C is shown in Fig. 1, which indicates that the new type of salt tolerance polymer KYPAM, STARPAM and A-DH outperforms MO4000 and HPAM in property of visosifying ability.

In chemical combination flooding, surfactant and alkali can decrease the interfacial tension (IFT) between oil and water. According to the capillary number theory proposed by Foster and Lake [4], the capillary number is the ratio of displacement force to the capillary resistance force. For different porous media and oil drops in various sizes, whether the oil can be removed or displaced is directly governed by capillary number [3–4].

$$N_c = \frac{\mu_w v}{\phi \sigma_{ow}} \tag{1}$$

where, N_c—capillary number; v—velocity of displacement fluid, cm/s; ϕ—porosity, %; μ_w—viscosity of displacement fluid, mPa·s; σ_{ow}—interfacial tension between oil and water, mN/m.

The relationship between capillary number and oil displacement efficiency or residual oil saturation can be obtained through experiment (Fig. 2)[5]. Capillary number after water

Table 1 Effect of water/oil mobility ratio on swept volume

Water/oil mobility ratio	Sweep efficiency/%	
	Water breakthrough	Water cut higher than 90%
10.0	51	83.0
2.0	60	88.0
1.0	70	98.0
0.5	82	99.0
0.3	87	99.5

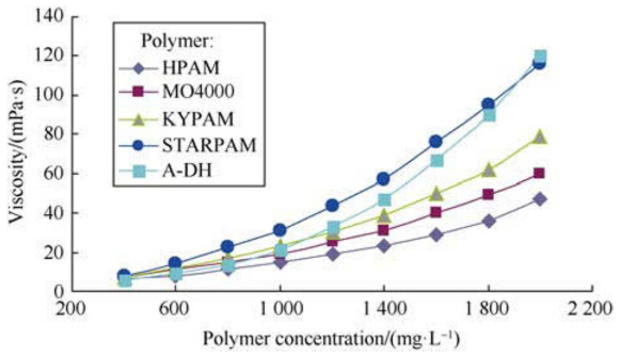

Fig. 1 Relationship of viscosity of polymer solution with polymer concentration for five polymers

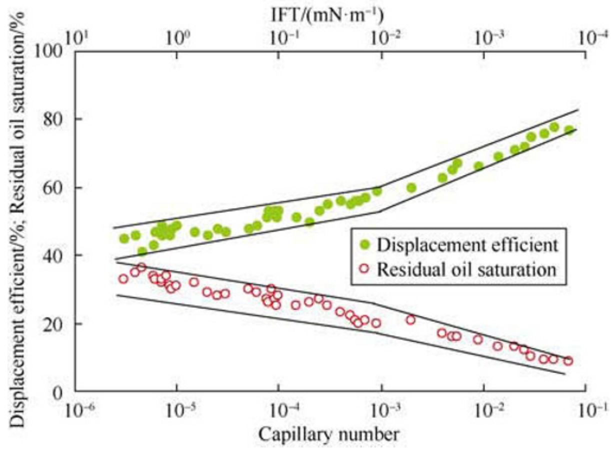

Fig. 2 Relationship of oil recovery and residual oil saturation with capillary number

flooding is commonly 1×10^{-6}. In order to decrease the residual oil saturation and enhance oil recovery markedly, the capillary number should be larger than 1×10^{-3}. According to the capillary number theory, there are three ways to improve the capillary number. Firstly, increase the velocity of displacement fluid (two or three times of origin in general). Secondly, increase the viscosity of displacement fluid. Thirdly, decrease the interfacial tension between crude oil and water (3-4 orders of magnitude). Alkali and surfactant combined system shows favorable synergetic effect and can decrease the oil and water interfacial tension to 1×10^{-4}–5×10^{-3}mN/m. Thus the capillary number can be increased by three to four orders of magnitude, which will make the residual crude oil in porous media mobile and enhance oil recovery. This is one of the theoretical basis of chemical combination flooding.

Alkali-Surfactant-Polymer flooding or Surfactant-Polymer flooding can increase oil recovery by increasing the viscosity of displacement fluid and decreasing interfacial tension between oil and water, thus increasing sweep efficiency and displacement efficiency simultaneously.

Latest lab experiments and pilot tests indicate that the emulsification ability of chemical combination system is beneficial to improve the oil recovery [6–8]. Core flooding experiment of different emulsification degrees indicates that oil can be easily dispersed into tiny drops and form continuous oil bank as emulsifying ability increases [6–7]. Then these oil drops will be easily displaced. When the interfacial tension of chemical combination system is 1×10^{-1} mN/m, oil recovery can be increased by 5%–10% by increasing the emulsification ability. Due to the significant emulsification ability of alkali in ASP system, the incremental oil recovery degree of ASP flooding system is higher than that of SP flooding system.

Alkali or surfactant can alter the wettability of rock surface from oil-wet to water-wet[8], and decrease the viscosity of oil and water interfacial film. This process can help the residual oil get away from the rock surface and thus increase oil recovery.

The viscoelasticity [9] of chemical combination system can