永平油田稠油自发乳化降粘剂的筛选及驱油效果评价

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摘要: 针对永平油田稠油粘度大、油层厚度薄、原始含油饱和度低及热采投产后产油量低的现状,筛选出一种能使稠油在地层中发生自发乳化的降粘剂,使稠油以较低粘度的乳状液被采出,从而提高稠油的采收率。针对不同乳化降粘剂对永平油田稠油的乳化效果评价结果表明,自发乳化降粘剂 NS 在质量分数为 2%、温度为 45 ℃的条件下,可将油水界面张力降至 10^{-3} mN/m 数量级以下,并可完全自发乳化等体积的永平油田稠油,降粘率达 99.74%。NS 自发乳化驱油实验结果表明,经过后续水驱后,自发乳化驱的采收率在水驱基础上提高了 38.18%。

关键词: 稠油 自发乳化 界面张力 驱油 提高采收率 永平油田
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目前开采稠油常用加热、掺稀油、稠油改质和加化学药剂等方法降粘[1]。许多油藏因区块分散、含油面积小、油层薄等不能用常规方法进行开采,而乳化降粘技术具有降粘幅度大、工艺简单、投资少及见效快等优点,因此乳化降粘技术近年来受到广泛关注[2-3],开发成本低、用量少的乳化降粘剂成为热点之一[4]。自发乳化是指在乳化过程中不需外界做功,只靠乳化剂本身作用,使原本不相混溶的油水两相自动乳化形成乳状液的过程。笔者曾提出自发乳化驱油方法并研究了自发乳化微观驱油机理,自发乳化驱油方法的主要思路就是通过将原油乳化成粒径小于岩石孔道直径(通常为 1 ~ 50 μm) 的水包油型乳状液,使原油可以在无毛管压力的情况下被开采出,从而提高原油采收率[5-6];并探讨了自发乳化驱提高采收率的微观机理[7]。在上述研究的基础上,针对吉林永平油田稠油,筛选出一种可使稠油发生自发乳化的降粘剂,并通过室内驱替实验考察了其自发乳化驱油效果。

1 实验器材及方法

1.1 实验器材

实验仪器包括: PB1502-S 型电子天平、XMTD-204型数显恒温水浴锅、Brookfield Programmable DV-Ⅱ粘度计、TX-500C 型界面张力仪、Alphaphot-2YS2-H 显微镜、Anton paar 的 MCR 301 流变仪、DHZ-50-180 型化学驱动态模拟评价装置; 长度为 50 cm、直径为2.5 cm的填砂管,其孔隙度为33.75%,含油饱和度为 78.51%,渗透率为 455.27×10^{-3} μm^2。

实验材料包括: NS, NS-1, AES, OP-10, OP-15 和 OP-30 表面活性剂,均为工业品,椰油酰丙基磺基甜菜碱(ASB)、十二烷基磺基甜菜碱(DSB)、十二烷基硫酸钠(AS) 和十二烷基磺酸钠(SDBS),均为化学纯,这些均是实验所用乳化降粘剂; 实验用油为永平油田稠油,在 45 ℃时粘度为 7 198 mPa·s。

1.2 实验方法

自发乳化降粘剂的筛选 选择不同乳化降粘剂配制质量分数为 1% 的乳化降粘剂溶液,以油水体积比为 1∶1 配制油水混合物,在 45 ℃恒温静置 12 h,观察其自发乳化情况; 在剪切速率为 7.34 s^{-1} 的条件下,测定各乳化降粘剂形成的乳状液的粘度,计算其降粘率。根据自发乳化情况和降粘率筛选出合适的自发乳化降粘剂。

在温度为 45 ℃的条件下,观察不同质量分数的溶液在油水体积比为1∶1时的自发乳化效果,测定

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不同质量分数自发乳化降粘剂溶液与永平油田稠油之间的界面张力及其界面剪切粘度，并拍摄乳状液的微观结构图片，观察乳状液液滴粒径的均匀程度。

自发乳化降粘剂驱油效果评价　利用DHZ-50-180 型化学驱动态模拟评价装置评价自发乳化降粘剂的驱油效果，在驱替速度为 0.5 mL/min 的条件下，水驱至含水率为 100%，再注乳化降粘剂溶液段塞，后续水驱至含水率为 98%。

2　结果与讨论

2.1　自发乳化降粘剂的筛选

由不同种类乳化降粘剂对永平油田稠油的乳化降粘效果(表 1) 可以看到，在温度为 45 ℃的条件下，各乳化降粘剂的乳化降粘率均大于 99%，降粘效果较好，但只有非离子型乳化降粘剂 NS 可在静置 12 h 后自发性完全乳化稠油，若稍加搅拌，其即可迅速乳化稠油，形成棕色的水包油型乳状液，均匀乳状液的粘度为 18.5 mPa · s，降粘效果明显。因此，选定 NS 乳化降粘剂作为自发乳化降粘剂。

表 1　不同乳化降粘剂对永平油田稠油的乳化效果

乳化降粘剂名称	乳状液类型	是否发生自发乳化	乳状液颜色	乳状液粘度/(mPa · s)	降粘率,%
AS	水包油	否	黑色	10.6	99.85
SDBS	水包油	否	棕色	2.6	99.96
AES	水包油	否	黑色	35.6	99.51
OP-10	水包油	否	黑色	13.7	99.81
OP-15	水包油	否	黑色	7.6	99.89
OP-30	水包油	否	黑色	31.7	99.56
NS	水包油	是	棕色	18.5	99.74
NS-1	水包油	否	棕色	8.6	99.88
DSB	水包油	否	黑色	8.8	99.88
ASB	水包油	否	黑色	11.5	99.84

分析不同质量分数的 NS 溶液对稠油自发乳化程度结果发现: 在 45 ℃条件下，油水混合物静置 12 h 后，质量分数为 1% 和 1.5% 的 NS 溶液中均有少量的未乳化稠油附着在试管壁上，而质量分数为 2% 的 NS 溶液可以完全乳化同体积稠油，说明随着 NS 质量分数的增加，其乳化能力增强。因此，选定 NS 的质量分数为 2%。

2.2　NS 自发乳化降粘剂的稳定机理

界面性质是影响乳状液稳定性的重要因素，由于 NS 既具有亲油性，又具有亲水性，其分子可在油水界面上形成吸附层，导致界面性质发生改变，从而起到乳化和稳定乳化体系的作用。其中界面张力和界面剪切粘度是评价界面性质的重要参数。

2.2.1　对油水界面张力的影响

不同质量分数的 NS 溶液与永平油田稠油界面张力随时间的变化曲线(图 1) 显示: 当 NS 的质量分数小于 1% 时，NS 与稠油形成的界面张力只能降至 10^{-2} mN/m 数量级; 当质量分数大于 1% 后，界面张力可达到 10^{-3} mN/m 数量级，甚至可达到 10^{-4} mN/m 数量级。超低界面张力可以显著增大毛管数，对提高采收率起着决定性作用[8-9]，超低界面张力还可以引发自发乳化，从而减小原油从岩石表面脱离的粘附力。质量分数为 2% ~2.5% 的 NS 溶液更能满足自发乳化发生的条件，将稠油乳化形成粘度较低的乳状液。

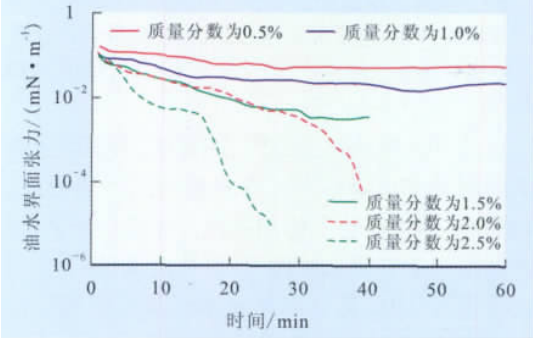

图 1　不同质量分数的 NS 溶液与永平油田稠油界面张力随时间的变化曲线

分析质量分数为 2% 的 NS 溶液形成的含水率为 50% 的水包油型乳状液的微观图像(图 2) 可知，粒径小于 3 μm 的液滴约占 70%，粒径为 3 ~5 μm 的液滴约占 20%，粒径大于 5 μm 的液滴约占 10%，由此可见，液滴的平均粒径较小，液滴比较均匀，在宏观上表现为乳状液的稳定性较好，表观粘度较小。

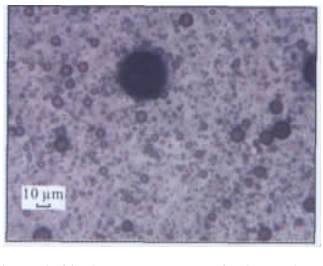

图 2　质量分数为 2% 的 NS 溶液形成的含水率为 50% 的水包油型乳状液微观图像

2.2.2　对油水界面剪切粘度的影响

当剪切速率为 0.631 s^{-1} 时，不同质量分数 NS 自发乳化降粘剂的油水界面剪切粘度曲线(图 3) 表明，随着 NS 质量分数的增大，界面剪切粘度呈增加的趋势，而当质量分数大于 0.3% 后基本保持不变。这主要是由于界面剪切粘度反映的是 NS 在油水界

面层所发生的变化，在油水界面上不存在表面活性剂分子时，界面上只形成刚性液膜；而加入 NS 后，表面活性剂的疏水基团通过疏水相互作用，向油相一端伸展，而亲水基团伸入到水相一端，在油水界面上形成吸附层，界面膜强度增加；随 NS 质量分数的增大，界面上吸附的 NS 分子越来越多，分子之间排列得越来越紧密，且在质量分数达到一定值后，甚至可以形成多层吸附，导致界面膜强度越来越大，界面剪切粘度也随之增加，乳化体系的稳定性增强，若继续增加 NS 的质量分数，油水界面上的 NS 分子数基本不再发生变化，界面剪切粘度也基本保持不变。

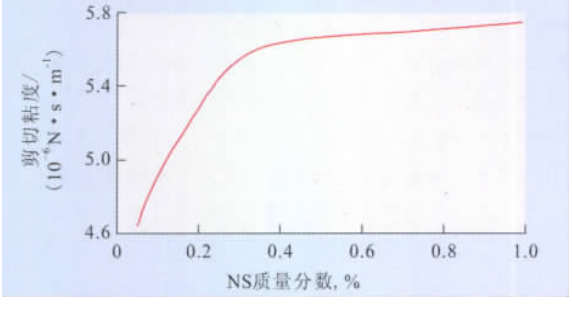

图 3　不同质量分数 NS 自发乳化降粘剂在剪切速率为 0.631 s^{-1}时的界面剪切粘度

2.3　驱油效果评价

由 NS 自发乳化降粘剂的驱油结果(表 2) 可知，乳化降粘段塞和后续水驱阶段稠油均以乳状液形式被采出，破乳产生的原油总体积为 24.82 mL，通过自发乳化驱替采收率可提高 38.18%。

表 2　NS 自发乳化降粘剂驱油实验结果

注入段塞	采出乳状液总体积/mL	破乳形成的原油体积/mL	提高采收率,%
乳化降粘段塞	38.61	9.90	15.23
后续水段塞	251.4	14.92	22.95
合计	290	24.82	38.18

由 NS 自发乳化降粘剂的驱油动态曲线(图 4) 可以看到，在原油以乳状液采出后，注入压力上升幅度较大。其原因有2个：①不能流动的稠油被乳化变成可流动的乳状液，增加了渗流阻力，使压差增大；②原油被乳化成微小的液滴后，滞留在喉道处，产生叠加的贾敏效应，导致流动阻力变大[10]，压差的增大扩大了乳化降粘剂溶液的波及体积，更多的稠油被乳化，乳状液的含油量增加，自发乳化降粘作用使更多原油被驱替采出，含水率也大幅度下降，提高了原油采收率。

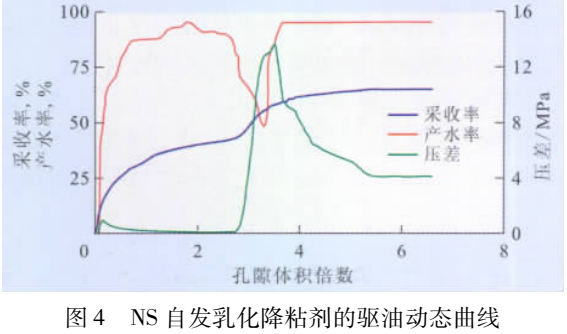

图 4　NS 自发乳化降粘剂的驱油动态曲线

3　结束语

NS 乳化降粘剂可形成较好的自发乳化降粘体系，在其质量分数为 2%、温度为 45 ℃的条件下，油水界面张力可降至 10^{-3} mN/m 数量级以下，可完全自发乳化等体积的永平油田稠油，降粘率达 99.74%；同时，NS 自发乳化降粘剂可在油水界面上形成具有一定强度的界面膜，起到稳定原油乳状液的作用；NS 自发乳化降粘剂驱油实验结果表明，经过后续水驱后，自发乳化驱的采收率在水驱基础上提高了 38.18%，提高采收率效果明显。但自发乳化驱油机理复杂，须进一步研究自发乳化驱油提高采收率机理、动力学规律及乳状液渗流规律，为稠油自发乳化现场应用提供理论依据。

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common types of low resistivity reservoirs, and summarize its inherent rule. The identification principles are using the conventional logging data as the basis, and supplemented by the geochemistry and gas-logging information, and supported by the regional oil and gas accumulation and distribution.

Key words: low resistivity oil layers; exploration practice; microscopic mechanism; geological genesis; evaluation method; Shengli oilfield

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Sun Hai, Yao Jun, Sun Zhixue et al. Recent development and prospect on numerical simulation of shale gas reservoirs. *PGRE*, 2012, 19(1): 46-49

Abstract: Shale gas reservoirs are important unconventional reservoirs. Numerical simulation has played important role on the development of shale gas. In this paper, the recent development of numerical simulation of shale gas is reviewed and the future trends are given. The gas storage and transport mechanisms in shale gas reservoirs and the methods describing the gas flow in shale pores are discussed. The current numerical simulation models such as dual continuum model, multi-continuum model and effective continuum model are summarized. In addition, the shortcomings of the existing numerical simulation methods are pointed out and the prospect of numerical simulation methods of shale gas is explored. The future shale gas numerical simulation should be developed in the following three aspects: firstly, the shale gas numerical simulation models should take into account of gas-water two phase transport mechanisms; secondly, the distribution of organic matter in shale and the gas-water transport mechanisms in organic matter should be studied and considered in the numerical models; thirdly, the adsorbed gas transport mechanism in shale should be studied and numerical models should consider the transport mechanism.

Key words: shale gas; numerical simulation; storage; migration; trend

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Wang Yanguang. Study and application of time-lapse seismic in Shengli oilfield. *PGRE*, 2012, 19(1): 50-54

Abstract: In this paper, the author takes the old dataset and the newly-acquired 3D dataset in the development stage from Shengli oilfield as an example, on one hand, the feasibility of time-lapse seismic has been discussed, on the other hand, the application of the multiple acquisition dataset in the oilfield development has been explored as well. Concerning the inconsistencies to the multiple seismic data acquisition and processing as well as inconsistencies in the analysis later on, the prestack consistency and poststack cross-equalization processing are applied in order to eliminate the effects to the energy, frequency and phase of the seismic data caused by inconsistencies between acquisition and processing, and make the difference caused by the reservoir more evident. Integrating with the dynamic production data, we try to analyze reservoir continuity and residual oil distribution as well as the adjustment of the injection-production scheme, so as to achieve the EOR. Based on the application in Shengli oilfield, it indicates that the time-lapse seismic can be applied in certain favorable and feasible conditions. Furthermore, it is a strategic issue on how to apply the re-acquired high-precision 3D data integrated with reservoir engineering to solve more development problems. The two aspects of time-lapse (multiple acquisition) seismic application in the oilfield development should be considered in a comprehensive way.

Key words: time-lapse seismic; multiple acquisition seismic; consistency processing; differential seismic data; Shengli oilfield

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Li Zhaomin, Liu Wei, Li Songyan et al. Research on in-depth profile modification of foam and microgel complex system. *PGRE*, 2012, 19(1): 55-58

Abstract: Multi-phase foam system (MFS), a new in-depth profile control agent, integrates the merits of microgel system and foam system. This paper studies the compatibility of microgel with foam, injection behaviors of foam and microgel, EOR situations of foam system, microgel system and MFS. According to the experiments: the MFS obtains the best stability in air when the concentration of microgel is 5 000 mg/L; The injection pressure of MFS exhibits a "step" ascending trend, besides absorbing on the rock pore surface, the microgels can block the formations through forming bridges in pore throats. Large pressure fluctuation which is favorable for enhancing the oil recovery occurs in the injection process of MFS. The oil recovery of MFS is higher than that of foam system and microgel system, and after MFS flooding, the ultimate oil recovery of low permeability core is higher than that of high permeability core.

Key words: microgel; foam; multi-phase foam system; heterogeneity; in-depth profile control; pressure fluctuation

Li Zhaomin, School of Petroleum Engineering, China University of Petroleum (East China), Qingdao City, Shandong Province, 266555, China

Kang Wanli, Liu Yanli, Meng Lingwei et al. Screening of emulsified viscosity reducer on heavy crude oil and effect evaluation of oil displacement, Yongping oilfield in Jilin. *PGRE*, 2012, 19(1): 59-61

Abstract: An emulsion with low viscosity comes into being from two immiscible phases of oil and water by the spontaneous emulsi-

fication of surfactant, which can be used to reduce the viscosity of heavy oil. In view of the situation of low production of thermal heavy oil recovery in Yongping oilfield of Jilin Province due to the characteristics of high viscosity for heavy oil, thin reservoir and low initial oil saturation. A formula of emulsified viscosity reducer which can make heavy oil self-emulsified in stratum is developed in order to reduce the oil viscosity and improve the heavy oil recovery in Yongping oilfield. The behaviors of spontaneous emulsification of the heavy oil in Yongping oilfield are studied by Brookfield DV-Ⅱ viscometer, TX-500C interfacial tensiometer and microscope. The results show that the viscosity of equal volume heavy oil in Yongping oilfield can be decreased by 99.74% and the interfacial tension between oil and water is dropped to 10^{-3} mN/m under the performance of emulsified viscosity reducer (NS) with concentration of 2wt% and temperature of 45 ℃. Flooding experiment test indicates that the final oil displacement efficiency may be increased by 38.18% and remarkable performance on heavy oil recovery may be achieved.

Key words: heavy crude oil; spontaneous emulsification; interfacial tension; oil displacement; EOR; Yongping oilfield

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Zhang Tongkai, Li Yonghuan, Zhao Fenglan. Laboratory research of oil displacement compound system for layer IV5-11, Shuanghe oilfield. *PGRE*, 2012, 19(1): 62-65

Abstract: Based on the reservoir properties of layer IV5-11 in Shuanghe oilfield, the polymer mass concentration, surfactant types and mass fraction are selected through orthogonal test method. The binary system and ASP system are obtained. And, the binary system is composed of ZL-Ⅱ whose mass concentration is 1 500 mg/L and QY-3 whose mass fraction is 0.3%. The ASP system is composed of ZL-Ⅱ whose mass concentration is 1 500 mg/L, QY-3 and Na_2CO_3 whose mass fraction is respectively 0.3% and 0.1%. These two systems all can form ultra-low interfacial tensions for the Shuanghe oil, and all can achieve moderate viscosity. Using homogeneous and nonhomogeneous artificial core and microscopic heterogeneity simulation model, the displacement experiments of selected compound flooding systems are conducted. And, when the reservoir permeability difference is 3 which is representative conditions, the ASP system injection mode may be optimized. The results show that the EOR effect of ASP system is obviously better than that of binary system in homogeneous conditions. And, in heterogeneity conditions, as the heterogeneity increased, the EOR effects difference between ASP system and binary system decreased. But, the EOR effect of ASP system is still better than that of binary system. For the same oil displacement system, as the heterogeneity increased, the oil recovery will increase firstly and then decrease, and the EOR performance reaches peak when the permeability difference is 3. Through comprehensive analyses, the ASP system is better than binary system. And, when injected 0.05 PV cross-link polymer slug both before and after ASP, the oil recovery after ASP flooding will be increase by 4% compared to corresponding un-plug.

Key words: surfactant screening; compound flooding system; heterogeneity; EOR; injection mode

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Liu Chuntian, Li Xing. Effect of main properties of flooding system on oil displacement efficiency. *PGRE*, 2012, 19(1): 66-68

Abstract: Experiments are implemented to analyze the effects of viscosity and interfacial tension and viscoelasticity of displacement system. The interfacial tensions of ASP solutions have different quantitative features under the same concentrations of surfactant and alkali. The displacement system can diminish the error caused by the change of chemical concentration. The result shows that the viscoelasticity of polymer is higher than that of ASP solution with same viscosity; it proves that the ASP solution enhances the displacement efficiency by reducing the interfacial tension. Single polymer or "surfactant and alkali" can enhance the efficiency within limited range. The concurrent function on increasing the viscosity and reducing the interfacial tension is better than simple mixture of these two single factors. The change of recovery ratio improves when the interfacial tension is below 10^{-1} mN/m especially. Interfacial tension affects the displacement efficiency more apparently than the viscosity.

Key words: displacement efficiency; viscosity; interfacial tension; viscoelasticity; polymer; tri-component composite system

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Quan Hongpin, Huang Zhiyu, Zhang Tailiang et al. Synthesis and evaluation of oil soluble viscosity reducer for heavy oils. *PGRE*, 2012, 19(1): 69-71

Abstract: For the problems of current heavy oil soluble viscosity reducer, such as typically low adaptability and low viscosity reduction performance, herein, we design a new kind of branch-type heavy oil soluble viscosity reducer. It contained polar group and alkyl group, the polar group can reduce the hydrogen bond between colloid and asphaltene in heavy oil, and alkyl group can increase reducer's solubility and effectiveness. This new kind of branch-type heavy oil soluble viscosity reducer is designed and synthesized through two steps. The optimal synthetic conditions are obtained by studying the factor of synthesis: the molar ratio of glycol, epichlorohydrin and stearyl chloride are 4∶4∶1.5; and the first step of principal chain reaction temperature is 110 ℃, the reaction time is 8 h and the accelerator N is 1.4% (mass fraction); the second step of graft reaction temperature is 110 ℃ and the reaction time is 14 h. The branch-type heavy oil soluble viscosity reducer possesses certain viscosity reducing ability for heavy oil and the viscosity breaking rate of 49%, and the structures are characterized through FTIR, structure is in accordance with which we designed.

Key words: heavy oil viscosity reducer; oil soluble; branch-type; heavy oil; viscosity breaking rate