孤岛油田中一区馆3区块聚合物驱后微生物驱油先导试验

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摘要:为了探索微生物驱油技术在聚合物驱后油藏的适应性和驱油效果,在孤岛油田中一区馆3区块开展了先导试验。在室内筛选了激活剂配方,有效激活了试验区块的内源微生物群落;同时筛选了4株在油藏环境下能大量生长繁殖的外源高效驱油菌种,对试验区原油具有良好的乳化作用。室内物理模拟驱油实验结果表明,聚合物驱后微生物驱可提高驱油效率7.8%~8.3%。在室内实验基础上开展了现场试验,油井产出液跟踪检测结果表明,油藏微生物得到了有效激活,且具有良好的代谢活性,代谢产物乙酸根质量浓度最高可达105 mg/L;生产动态分析表明,试验后油藏的生产动态得到了显著改善,提高采收率为1.27%,试验期间试验区采出程度提高了4.7%,达57.8%。

关键词:微生物驱油 聚合物驱后 先导试验 提高采收率 孤岛油田
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微生物驱油是经济环保的提高采收率技术,具有成本低、不伤害地层、环境友好、产出液不需特殊处理等优点,有望在油田开发后期发挥巨大作用[1-6]。油藏在经历聚合物驱开发后,仍有大量剩余油留在地下,具有进一步提高采收率的潜力[7-10]。聚合物驱转后续水驱后,综合含水率迅速回升,产量递减快,开发形势严峻。如何改善聚合物驱后油藏的开发效果,进一步提高原油采收率已成为亟待解决的难题[11-12]。为探索微生物驱油技术在聚合物驱后油藏的适应性和驱油效果,在孤岛油田中一区馆3区块开展了聚合物驱后微生物驱油先导试验。

1 区块概况

孤岛油田中一区馆3区块的含油层系为馆上段第3砂层组,属于河流相沉积的疏松砂岩油藏。油藏南高北低,埋深为1 173~1 230 m,油藏温度为69 ℃,地下原油粘度为46.3 mPa·s,原始地层水总矿化度为3 850 mg/L,空气渗透率为1.5~2.5 μm^2。

微生物驱油试验区含油面积为0.86 km^2,石油地质储量为164.9×10^4 t。1971年投入开发,经历3 a天然能量开发,20 a水驱开发,3 a聚合物驱开发,11 a后续水驱开发。试验区有注水井6口,对应采油井17口,试验前采出程度为53.1%,综合含水率为97.3%;其中5口中心井,中心井组采出程度为56.9%,综合含水率为97.8%。试验区综合含水率和采出程度高,产量递减快,含水率上升快,大孔道发育,剩余油分布零散,水油流度比高,开发形势严峻。

2 室内实验

2.1 内源微生物激活实验

现场取样分析发现,试验区存在较为丰富的内源微生物群落,具备利用内源微生物驱油的物质基础。内源微生物在地下的激活过程可分为2个阶段:第1阶段是在含氧较为丰富的注水井及其近井地带,主要有烃类氧化菌(HOB)、腐生菌(TGB)等好氧类微生物;第2阶段是在地层深部,主要有厌氧发酵菌(AFB)及产甲烷菌(MPB)等厌氧类微生物。

为了模拟这一过程,设计好氧和厌氧2个阶段激活实验来筛选激活配方。好氧阶段激活实验,以注入水和产出液作为激活的最初底物,通过加入激活剂激活近井地带的好氧类内源微生物。厌氧阶段激活实验,以好氧阶段激活实验的代谢产物作为代谢底物,进一步激活油藏深处的厌氧菌群。激活实验结果表明,筛选的激活剂可有效激活试验区块

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的内源微生物群落，好氧类的烃类氧化菌、腐生菌浓度上升到10^6个/mL以上，厌氧类的厌氧发酵菌、产甲烷菌浓度也明显上升（表1）。整个激活实验过程中，硫酸盐还原菌（SRB）得到了有效抑制。

表1　厌氧阶段内源微生物激活实验结果　个/mL

井号	厌氧发酵菌浓度		产甲烷菌浓度		硫酸盐还原菌浓度	
	激活前	激活后	激活前	激活后	激活前	激活后
6-13	未检出	4.5×10^7	45	4.5×10^4	0.9	未检出
7N11	未检出	2.5×10^7	15	9.5×10^4	14	未检出
8X815	未检出	6.5×10^7	9.5	1.2×10^5	45	未检出

2.2　外源微生物筛选及评价

为了发挥最佳驱油效果，在开展内源微生物激活实验同时，针对油藏条件进行了外源高效驱油微生物的筛选及评价。从胜利油区油井产出液、云南腾冲热泉及各地土壤中采集样品，在油藏条件下进行菌种的富集培养，筛选出能在油藏环境下良好生长的菌种25株。经优化，筛选出4株高效驱油菌种。实验结果（表2）表明，筛选出的菌种在油藏环境下代谢旺盛，细菌浓度和标志性代谢产物乙酸根质量浓度大幅提高，菌液表面张力与地层水空白样相比明显下降，对试验区原油有良好的乳化作用。

表2　菌种在油藏环境下生长代谢实验结果

菌种名称	细菌浓度/（个·mL^{-1}）	乙酸根质量浓度/（mg·L^{-1}）	表面张力/（mN·m^{-1}）
地层水空白样	未检出	8	49.3
ZJ-3	3.0×10^7	820	31.9
A1	2.0×10^7	600	35.0
B2	3.0×10^7	650	33.7
DM-2	1.5×10^7	360	35.3

2.3　物理模拟驱油实验

为了研究筛选的激活剂和外源微生物的驱油性能，模拟油藏条件，采取内源与外源相结合的方式，开展了物理模拟驱油实验。实验模拟岩心为人工装填石英砂岩心，长度为600 mm，直径为38 mm，模拟温度为69 ℃。实验结果（表3）表明，微生物的驱油效率显著提高，单独激活内源微生物可提高驱油效率4.4%，单独注入外源微生物可提高驱油效率5.7%。而采用内源及外源复合驱油方式，微生物提高驱油效率达7.8%～8.3%。

表3　单管岩心微生物驱油实验结果

岩心序号	孔隙度，%	渗透率/μm^2	总驱油效率，%	微生物驱注入配方	培养时间/d	提高驱油效率，%
A	37	1.8	57.4	空白样	15	0.6
B	37	1.6	56.7	0.3倍孔隙体积激活剂	21	4.4
C	36	1.8	62.4	0.3倍孔隙体积外源微生物	15	5.7
D	36	1.7	58.0	0.2倍孔隙体积外源微生物+0.3倍孔隙体积激活剂	21	7.8
E	37	1.9	57.3	0.1倍孔隙体积厌氧菌+0.1倍孔隙体积好氧菌+0.3倍孔隙体积激活剂	21	8.3

3　现场试验

现场试验自2008年11月开始，通过站内流程连续注入的方式实施，设计注入量为0.5倍孔隙体积，2012年7月完成全部设计注入量，共注入外源菌液1 590 t，激活剂6 900 t。项目实施过程中，跟踪监测了对应17口油井的生产动态，并选取7N11，6-413，6-13，8X815共4口与注入井对应关系较好的油井作为生化参数跟踪监测对象。

3.1　油藏微生物检测结果

为了分析微生物在油藏中的生长情况，对油井产出液中细菌浓度进行了检测。结果表明，实施微生物驱油试验后，对应采油井产出液中好氧菌的浓度无明显变化，原因是油藏中仅注水井附近为好氧环境，随着微生物的运移，好氧菌无法适应油藏深部的厌氧环境。而试验后期厌氧菌中的产甲烷菌的浓度明显上升（图1），达到10^5个/mL以上，这表明油藏中微生物被大量激活。对硫酸盐还原菌的检测表明，激活剂较好地抑制了该菌的生长。

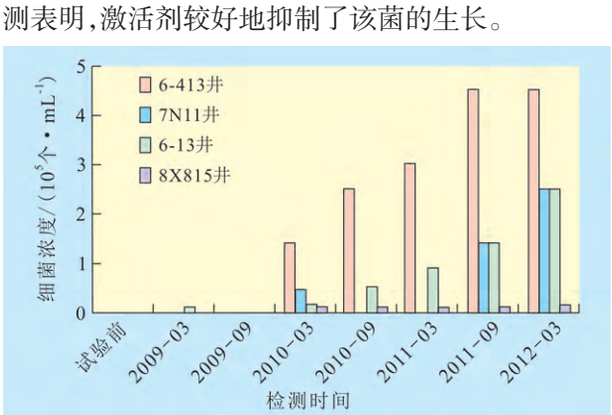

图1　产甲烷菌检测结果

3.2　乙酸根检测结果

对试验前后乙酸根质量浓度的变化进行检测，

结果(图2)表明,开展微生物驱油试验后,产出液中乙酸根质量浓度整体呈上升趋势,这表明试验后微生物在油藏中具有良好的代谢活性。2009年11月6-413井产出液中乙酸根质量浓度达到105 mg/L的峰值,随后由于油藏深部厌氧菌的生长消耗部分乙酸根,其质量浓度下降并稳定在40 mg/L左右。

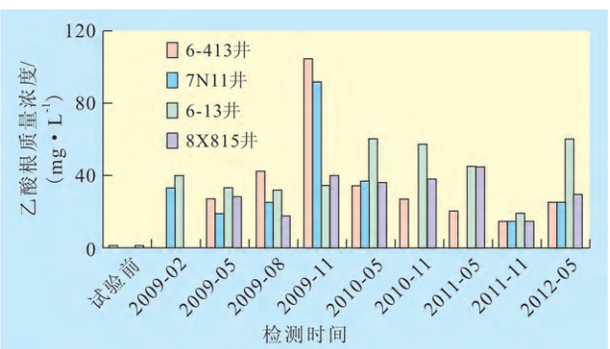

图2　乙酸根检测结果

3.3　微生物乳化原油结果

对原油的乳化作用是微生物驱油的重要作用机理之一。在此次试验中,激活内源微生物可乳化原油,同时,加入的外源微生物也具有良好的乳化作用。试验后产出液中微生物数量明显增加,并存在大量的乳化油滴。这表明微生物在油藏中大量生长,代谢产生具有乳化功能的活性产物,对原油产生乳化作用,启动了残余油。

3.4　生产动态结果

实施微生物驱油后,试验区开发效果明显好转,区块产量递减、含水率上升的趋势得到了控制,试验区产油量由试验前的45 t/d上升至55 t/d,含水率由试验前的97.1%下降至96.3%。但试验后期由于试验区大孔道发育更加严重,微生物的驱油作用得不到有效发挥,影响了试验效果。截至2012年7月,试验区采出程度为57.8%,中心井区采出程度达59.9%,分别比试验前提高了4.7%和3.0%。用水驱递减预测产油量并与实际生产曲线对比,试验区块累积增油量为21 000 t,提高采收率为1.27%(图3)。

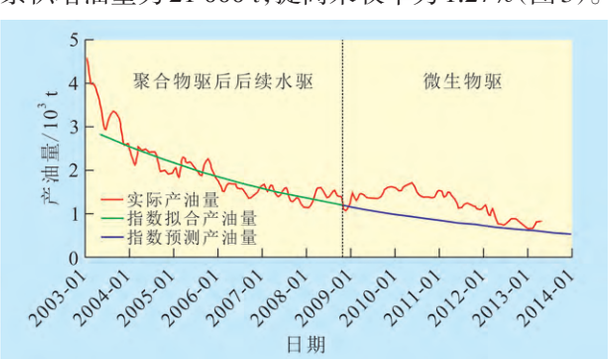

图3　试验区水驱递减预测产油量与实际生产曲线的对比

4　结束语

微生物驱油技术对聚合物驱后油藏具有良好的适应性,可进一步提高油藏采收率。实验结果表明,微生物在油藏中得到激活,通过代谢产生具有乳化功能的产物,将原油乳化,启动了残余油,改善了聚合物驱后油藏的生产动态,提高了油藏的采收率。但是针对孤岛油田中一区馆3区块的油藏地质特点和开发形势,微生物驱油技术不具备提高波及效率的能力,其主要机理在于提高洗油效率。而现场试验仅在试验前采取了调剖措施,导致试验前半段效果较好,而试验后期由于大孔道发育更加严重,微生物的驱油作用得不到有效发挥,影响了试验效果。在今后的应用中,应根据需要全程配套调剖措施,让微生物充分接触剩余油,将更有利于微生物驱油效果的发挥。

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lem of horizontal well into two parts, one is the problem in several ellipsoidal supply boundary near the wellbore, the other is the linear flow far from the well bore, based on the displacement between two similar flow mode and the law of equivalence percolation resistance, then eventually proposing a new productivity formula of horizontal well. Through case study, the results calculated by new formula has been compared with that calculated by the formulas of Borisov et al, it shows that the new result is more than the results calculated by conventional formulas, meanwhile, the new result has a small relative error compared to the practical oil production by only 10.09%. Analysis shows that this is because the resistance in ellipse drainage area is less than that in pseudo-circular drainage area, and the assumption of pseudo-circular will bring a great relative error. So, we can conclude that the new formula will not only predict the productivity accurately, but also accord with the practical flow mode of horizontal well.

Key words: horizontal well; productivity formula; similar flow; ellipse; pseudo-circular

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Ming Yukun. Electrolytic simulation experiment of multi-stage fracturing horizontal well for water flooding development. *PGRE*, 2013, 20(6): 91-93

Abstract: In order to study the production stimulation mechanism of water flooding by multi-stage fracturing horizontal well, the electrolytic simulation experiment of fractured horizontal well is designed according to the water and electricity resembling principle, and the pressure distribution and the productivity influence factors are studied. The experiment results show that the pressure contour is distributed in parallel in the middle of horizontal which has the fracture, and the fluid flow is unidirectional, it shows that the multi-stage fracturing horizontal well can improve the fluid flow characters and decrease the percolating resistance. The horizontal productivity can be enhanced by increasing the horizontal penetration ratio, the fracture numbers and penetration ratio, the angle between horizontal and fracture. The best parameters are as follows: the horizontal penetration ratio is 0.8, the fracture numbers are 6 (the space between fractures is 91 m), the fracture ratio is 0.25, the angle between the fracture and the horizontal section is 90 degree. The well pattern is staggered line-drive well network, and the ranges of those parameters which have effect on the productivity are 0.032, 0.024, 0.018, 0.018 and 0.004. The field application showed that the productivity of multi-stage fracturing horizontal well is 2 times than that of vertical well, and it is the effective development style for low permeability reservoir.

Key words: multi-stage fracturing; horizontal well; water flooding; electrolytic simulation experiment; productivity

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Cao Gongze, Liu Tao, Ba Yan et al. Microbial flooding after polymer flooding pilot test in N*g*3 of Zhong1 area, Gudao oilfield. *PGRE*, 2013, 20(6): 94-96

Abstract: In order to study the adaptation and effect of microbial flooding after polymer flooding pilot, the test was conducted as pilot project in N*g*3 of Zhong1 area. The indigenous microorganisms are first activated and then filtrated; at the same time, 4 strains of functional bacteria are obtained, the bacteria are mass propagated at the reservoir environment, and the crude oil can be emulsified by the microbe. Meanwhile, the physical simulation experiment is studied under the pressure and temperature of the reservoir, and, the result indicates that the oil recovery is enhanced by 7.8%-8.3% by the bacteria. The field test indicates that the microbe is activated and the concentration of metabolism of acetate may reach 105 mg/L. The production dynamic is improved, and the oil recovery is enhanced by 1.27%, and the recovery factor in the pilot is increased by 4.7% to 57.8%.

Key words: MEOR; post-polymer flooding; pilot test; enhanced oil recovery; Gudao oilfield

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Gao Baoguo, Hua Hui, Ding Wenge et al. Technical treatment in extra-high water cut stage for low permeable reservoir-case study of Yi11 area, Bonan oilfield. *PGRE*, 2013, 20(6): 97-99

Abstract: Due to the serious heterogeneity in plane, interlayer and layer, it is full of imbalances in injection-production pattern, and the production decline reaches 14.8% in Yi11 area of Bonan oilfield, so the technical treatment is needed to ameliorate the decline of the development. The non-stable injection and optimized liquid yielding are adopted to control the water and stabilize oil production in response to the high water cut and serious flooding in the major oil-production layers. Moreover, the water drive producing reserves are produced by improving and completion of well pattern in response to incomplete injection-production pattern. The interlayer problems are resolved by means of layer-oriented injection and plugging of high water cut layer. For the sand body edge and secondary oil-bearing layers, the reservoir reformation, intensive injection, individual layer production are adopted to enhance the reserve utilization. The development effect is remarkably improved. The production decline rate decrease to 4.1% and the recovery factor is further increased from 30.7% to 32%.

Key words: extra-high water cut stage; flow unit; technical treatment; EOR; injection-production completion; Bonan oilfield