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重质石油磺酸盐化学驱方案设计方法研究及应用

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摘要:基于室内化学驱油实验和区块的开发动态评价,合理选择化学驱注入参数,用正交实验方法设计了不同注入参数水平下的各种化学驱注入方案,并利用油藏数值模拟方法对各种化学驱方案的开发指标进行了预测。采用综合模糊评判技术对最佳注入参数进行了优化,利用优化后的参数即可对矿场实施方案进行优化设计。用这种方法对孤岛油田南区 N28-1 井区重质石油磺酸盐(WPS)驱实施方案进行了矿场设计。实施新方案后,目前已增油 3.48 $\times 10^4$ t,取得了较好的经济效益。

关键词:WPS 驱油;参数优选;方案设计;提高采收率

中图分类号:TE 357.46 **文献标识码**:A

引 言

化学驱油是提高采收率的方法之一[1~3],但成本较高。因此,科学、合理地制定化学驱实验方案,对矿场试验具有重要意义。化学驱方案优化设计过程主要包括:(1)水驱开发效果评价;(2)注入参数选择及优化设计;(3)矿场实施方案设计;(4)增油效果预测。笔者以孤岛油田南区 N28-1 井区重质石油磺酸盐(WPS)驱为例,对化学驱优化设计方法进行分析。

1 水驱开发效果评价

正确评价区块的开发动态是制定合理开发方案的基础。运用油藏工程方法和数值模拟方法评价水驱开发效果,确定剩余油分布和压力分布,可为后续的化学驱数值模拟研究提供基础资料。评价水驱效果常用的油藏工程方法有:水驱曲线法、经验公式法、流管法和数值模拟法。这些方法的主要目的,一是正确评价开发动态,准确预测水驱开发指标如采收率等,为化学驱开发效果与水驱开发效果的对比提供依据;二是水驱数值模拟得到的压力场、饱和度场及其他物性参数将作为化学驱数值模拟的初始值。

孤岛油田南区 N28-1 井区属于高渗透、高饱和压力、高粘度的疏松砂岩油藏,含油面积 0.528 km^2,地质储量 123.14 $\times 10^4$ t。主要含油层系为 Ng3 砂层组的 3^3,3^4,3^5 三个含油小层。1973 年 7 月投入开发,到 1976 年 11 月为弹性开发阶段,采收率为 3.8 %。1976 年 12 月投入注水开发,到 1997 年 5 月,井区已进入特高含水期,目前采出程度为 26.03 %,综合含水率达 94.2 %,平均地层总压降为 1.0 MPa。采用 7 种水驱曲线方法、8 个相关经验公式、流管概算法和数值模拟方法等预测的采收率为 33.06 %,可采储量为 40.80 $\times 10^4$ t。采用水驱数模软件 WORKBENCH 中的黑油模型,得到了各层的剩余油饱和度分布和压力分布,将其作为 WPS 化学驱数值模拟的初始值。

2 化学驱注入参数选择及优化设计

不同的化学驱方案涉及不同的注入参数。对于聚合物驱要选择聚合物溶液浓度、注入速度、注入段塞的尺寸和方式作为优化参数。由于 WPS 驱的注入速度对驱替效果影响不大,因此,选择 WPS 的浓度和注入段塞尺寸作为优化参数。对于选择的优化参数给出不同的水平值,应用正交实验设计方法设计出可能的化学驱方案,然后利用化学驱数值模拟 CMG 软件中的 Stars 模块预测开发指标,最后采用模糊综合评判模型优化注入参数。

化学驱注入参数的优化设计过程实质上可以看作是一个多因子多水平的数值试验过程。选择

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WPS溶液浓度和段塞尺寸为优化参数,并建立WPS驱注入参数水平取值选择表(见表 1,V_p 为孔隙体积),表中各注采参数均在其合理的取值范围内等间距取 3 个水平值,正交设计结果见表 2。

分别对正交设计表产生的 9 套方案进行 WPS 驱数值模拟计算。如果仅用某一指标进行优化,不同决策指标的选取将导致不统一甚至完全相反的结论。因而,应用模糊综合评判模型[4,5]进行综合评判,计算结果亦列于表 2。

为了考察各因子(注入参数)对开采动态的敏感程度,对其进行了显著性检验(即方差分析),以找出其中的敏感因素,结果见表 3。

表 1　试验区注入参数水平取值表

水平数	因　素	
	A:WPS 浓度/ %	B:段塞尺寸/ V_p
1	0.10	0.15
2	0.20	0.20
3	0.30	0.25

表 2　注入参数优化正交设计及计算结果

方案号	A 1	B 2	3	4	采收率提高率/ %	注剂利用率/ (t·t^{-1})	综合评判值
1	1	1	1	1	1.91	61.68	0.4999
2	1	2	2	2	2.50	60.55	0.5777
3	1	3	3	3	2.79	54.06	0.5157
4	2	1	2	3	3.10	50.05	0.4990
5	2	2	3	1	3.96	47.95	0.6046
6	2	3	1	2	4.25	41.17	0.5377
7	3	1	3	2	3.69	39.72	0.4214
8	3	2	1	3	4.64	37.46	0.539c0
9	3	3	2	1	4.96	32.03	0.5000
$\overline{\mathrm{I}}_j$	0.531	0.473	0.526	0.535			
$\overline{\mathrm{II}}_j$	0.547	0.573	0.526	0.512			
$\overline{\mathrm{III}}_j$	0.487	0.518	0.514	0.518			
S_j	1.95×10^{-3}	5.05×10^{-3}	9.07×10^{-5}	2.76×10^{-4}			

注:$\overline{\mathrm{I}}_j$、$\overline{\mathrm{II}}_j$、$\overline{\mathrm{III}}_j$分别表示正交表中第 j 列的 1～3 水平所对应的平均综合评判值;S_j 表示正交表中第 j 列数据的偏差平方和;注剂利用率定义为每吨活性剂增油量。

表 3　方差分析表

方差来源	偏差平方和	自由度	平均偏差平方和	F 比	显著性
A(WPS 浓度)	$S_A = S_1 = 0.00195$	2	0.000980	10.63	* (显著)
B(段塞尺寸)	$S_B = S_2 = 0.00505$	2	0.002530	27.53	* *(高度显著)
误差	$S_e = S_3 + S_4 = 0.00037$	4	0.000092		

注:$F_{0.01}(2,4) = 18.0$, $F_{0.05}(2,4) = 6.94$, $F_{0.1}(2,4) = 5.32$。

从表 3 中看出,WPS 浓度和段塞尺寸对开发效果的影响都较为敏感。参照注入参数不同水平取值下的综合评判值对比直方图(图 1)可知,随着 WPS 浓度和段塞尺寸的加大,采收率提高率增加,但注剂利用率却降低,使得增产油量带来的效益一部分被抵消,因此,它们存在一个最优值。该试验区的优化结果:WPS 浓度为 0.2 %,段塞尺寸为 0.2 V_p。依照优化的注入参数组合形成的方案预测的综合评判值最高,开采效果相对最优。

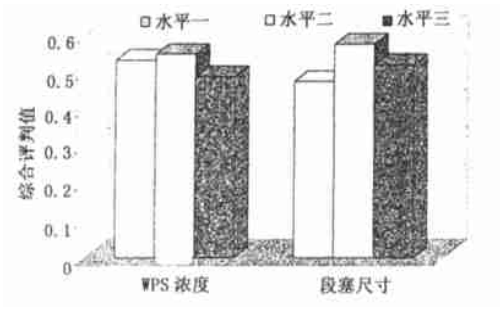

图 1　综合评判值对比直方图

3　矿场实施方案设计

根据试验区的实际地质情况、配产配注方案以及上述方法优化出的注入参数,进行矿场注入方式设计,并计算方案实施所需要的段塞溶液量、注入时间以及化学剂用量等。

3.1　配产配注方案

参照目前生产井动态,同时考虑平面流体场分布的合理性及注入液推进的均衡,确定试验区 7 口油井产液速度为 400 t/ d,单井配产见表 4。注采比按 1.0,试验区 3 口注入井配注 400 m^3/ d,单井配注见表 5。

表 4 试验区单井配产结果表

序号	井号	配产/ (t·d⁻¹)
1	N29X0	40
2	N27XN1	20
3	N27-201	90
4	N28-01	50
5	N28-201	70
6	N28-X202	30
7	N30-1	100

表 5 试验区配注结果表

井号	层位	配注/ (m^3·d^{-1})	厚度/ m
N26N1	3^3	40	9.4
	3^4	30	5.5
	3^5	40	8.6
N26X01	3^3	50	9.6
	3^4	30	3.9
	3^5	50	9.9
N29N1	3^3	70	8.9
	3^4	—	—
	3^5	90	9.0

3.2 矿场注入方式设计

根据室内实验和数值模拟研究结果,并充分考虑现场实施过程中 WPS 在地层的吸附损耗,设计两段塞注入方式,即在主段塞前注入一个高浓度的活性剂段塞。

第一段塞:浓度为 0.35 %,段塞尺寸为 0.015 V_p;

第二段塞:浓度为 0.20 %,段塞尺寸为 0.185 V_p。

根据配产配注和段塞设计,方案实施所需要的段塞溶液量、注入时间以及 WPS 药剂量见表 6。

表 6 试验区注入方案设计

段塞	段塞尺寸 / V_p	注入液量 / 10^4 m^3	活性剂浓度/ %	WPS 用量 /t	连续注入时间/ d
1	0.015	3.84	0.35	134.4	96
2	0.185	47.36	0.20	947.2	1184

4 矿场实施增油效果预测

利用化学驱数值模拟方法对设计的矿场实施注入方案进行指标预测,主要包括采收率提高率、见效期以及含水率变化等,为实施方案的可行性评价提供决策依据。

利用化学驱数值模拟预测的 N28-1 井区开发指标为:矿场采收率提高率 4.05 %,增产原油 5.02 ×10^4 t,折合 1 t 活性剂增产原油 48.2 t,注入当年开始见效,有效期 8 a,第 2～5 年为见效高峰期(图 2)。

图 3 为含水率曲线拟合图。它反映出数模预测曲线与矿场实际曲线吻合较好,预测趋势表明试验区 WPS 驱比水驱具有更好的降水增油效果。

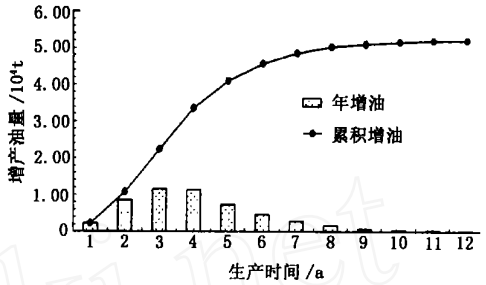

图 2 矿场注入方案增油效果预测曲线

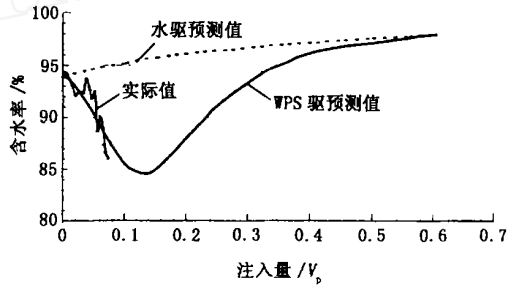

图 3 WPS 驱与水驱含水率曲线对比

5 结束语

从驱油剂物化性质及油田开发动态评价入手,提出了一套利用室内驱油实验、数值模拟技术、正交实验设计方法和模糊评判方法进行化学驱注入参数优化以及油藏工程方案设计的科学、实用方法。用该方法对孤岛油田 N28-1 井区化学驱方案进行了设计,该井区实施化学驱后,目前已增油 3.48 ×10^4 t,取得了较高的经济效益。该方法对油田各种开发方案的设计具有普遍的指导意义。

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Key words: horizontal well; fracturing; productivity; coupling model; pressure distribution

ANALYSIS ON SEEPAGE FLOW AND PRODUCTIVITY OF A HORIZONTAL WELL IN AN ANISOTROPIC RESERVOIR / *LIU Yue-tian. College of Petroleum Engineering in the University of Petroleum, China, Beijing* 102249 / *Shiyou Daxue Xuebao*, 2002, 26(4): 40～44

The effects of principal values and directions of permeability and boundaries of an anisotropic reservoir on seepage flow of a horizontal well were investigated by the pseudo-three-dimension method. The analytic solutions of pressure, velocity of seepage flow and capacity of a horizontal well were given, and the relative figures and tables were provided as well. The controlled reserves and productivity of a horizontal well were determined by the wellbore direction, the principal values of main direction and permeability of the anisotropic reservoir. Both the distance and the direction from the well to the boundary must be considered in the caluclation of flow capacity. While the angle between the wellbore and the maximum principal direction of the permeability is raised, and the anisotropy of the permeability is strongened, the controlled reserves and the flow capacity of a horizontal well will increase. The flow rate distribution on a horizontal wellbore and the pressure distribuion on the straight line of the wellbore are not affected by the horizontal well direction or the anisotropy of permeability. The effect of the permeability in the horizontal direction on the flow capacity of a horizontal well is much more than that of the vertical direction, when the horizontal scales of the reservoir are much bigger than the thickness of the reservoir. When the horizontal wellbore goes far from the vertical center of the well, or the length of the horizontal section of the well is shortened (relative to the formation thichness), the flow capacity of the horizontal well will go down. The equipressure lines are not orthogonal to the streamlines in a reservoir with an anisotropic permeability.

Key words: anisotropic reservoir; horizontal well; pressure field; velocity field; control reserves; flow capacity

APPLICATION OF VARIABLE WEIGHTS METHOD IN SELECTION OF CANDIDATE WELLS FOR BLOCK PROFILE CONTROL / *FENG Qi-hong, WANG Shu-yi, WU Yan and SONG Xu-sheng. College of Petroleum Engineering in the University of Petroleum, China, Dongying* 257061/ *Shiyou Daxue Xuebao*, 2002, 26(4): 45～47

There are some shortcomings in the fuzzy integrative evaluation model with constant weights applied to select the optimum candidate wells for block profile control. A new fuzzy model with variable weights that can avoid the shortcomings is proposed. The method and two theorems for applying the variable weights are presented. The weights can be automatically adjusted in accordance with the evaluated wells. This method can avoid some errors resulted from the constant weights. The result of practical application shows that the candidate wells selected by using variable weights method are more reasonable and reliable than that by the constant weight method.

Key words: fuzzy evaluation; constant weight; variable weight; profile control; candidate well selection

DESIGN AND APPLICATION OF CHEMICAL DISPLACEMENT PILOT WITH WEIGHTED PETROLEUM SULFONATE / *ZHANG Shao-dong, FU Ji-tong, YAO Jun, et al. Gudao Oil Production Factory of Shengli Oilfield Stock Company, Dongying* 257231/ *Shiyou Daxue Xuebao*, 2002, 26 (4): 48～50

The chemical displacement experiment in laboratory and the performance evaluation of block development were carried out. Some injection programs with different levels of injection parameters were designed by using orthogonal experiment method. The development indexes of different chemical displacement programs were predicted by the use of reservoir numerical simulation technique, and the injection parameters were optimized using the complex fuzzy evaluation technique. The chemical displacement pilot can be designed by the use of optimized parameters. On the basis of these theory and method, the weighted petroleum sulfonate displacement pilot of N 28-1 was designed. Application of the pilot obtained a considerable economic benefit. The production of crude oil increased by 3.48×10^4 t.

Key words: weighted petroleum sulfonate displacement; paramer optimization; designed pilot; enhanced oil re-

covery

ESTABLISHMENT OF A PRACTICAL WATERFLOODING MODEL AND ITS APPLICATION TO ANALYSIS OF ENHANCED OIL RECOVERY EFFICIENCY/ *LI He-quan, WU Zhao-liang, LI Ming-yuan, et al. Faculty of Chemical Engineering in the University of Petroleum, China, Beijing* 102249/ *Shiyou Daxue Xuebao*, 2002, 26(4): 51～52

Based on Darcy's law and relation between water-cut and pore volume, a practical equation for describing water flooding regulation was established. The oil production and recovery efficiency was predicted, and the efficiency of enhanced oil recovery (EOR) obtained from the equation was analyzed and compared with the oil production and recovery efficiency by applying the (EOR) technology. The practical application shows that oil production was raised by 969 t after 0.1 V_p colloid dispersed gel (CDG) was injected in the pilot area. One third of raised production was accomplished in the central well.

Key words: water flooding; mathematical model; production prediction; enhanced oil recovery; efficiency analysis

EXPERIMENT STUDY ON DYNAMIC RESPONSE OF SINGLE POINT MOORED TANKER / *XU Xing-ping, College of Mechanical and Electronic Engineering in the University of Petroleum, China, Dongying* 257061/ *Shiyou Daxue Xuebao*, 2002, 26(4): 53～55

The single point moored (SPM) tanker has the advantages of a high flexibility, a good economic efficiency and early operation, which makes it become the main equipment in the early production of offshore oilfields. The causes resulted in the six movements of surge, sway, heave, pitch, roll and yaw (six degrees of freedom) for the SPM tanker were analyzed. The effect of each movement on the operation of the devices on the tanker was discussed. It shows that surge, heave and pitch have a great effect on the normal operation of devices. In order to determine these movements, the simulation tests were made and the movement regulations of SPM tanker under sea wave were acquired. Some measures for inbihiting the movements of the tanker were put forward.

Key words: single point mored; tanker; dynamic response

ANALYSIS ON STRESS STATE OF PIPE SPRAYED WITH A COATING OF PORCELAIN / *WANG Jin-long, YAN Xiang-zhen and HAN Tao. College of Transport & Storage and Civil Engineering in the University of Petroleum, China, Dongying* 257061/ *Shiyou Daxue Xuebao*, 2002, 26(4): 56～57

Because the expanding coefficients of the base metal and pipe coating are different, the stress of the porcelain coating sprayed on the pipe is different from that of the base metal. The coating is of a compressive stress and the base metal is of a tensive stress. The location of the coating is also related to the stress. The inner coating stress of pipeline is less than the outer coating stress. As the radium of pipe increases, the absolute value of the radial stress decreases, and the compressive stress on the coating is reduced as well. The compressive stress of inner wall of pipe is bigger than that of outers.

Key words: sprayed pipeline with porcelain; porcelain coating; stress status; anti-corrosion

NUMERICAL SIMULATION OF UNSTEADY FLOW FIELD IN PULSE CLEANING SYSTEM OF CERAMIC FILTER / *WANG Su-hua, JI Zhong-li and WANG Shu-li. College of Mechanical and Electronic Engineering in the University of Petroleum, China, Beijing* 102249/ *Shiyou Daxue Xuebao*, 2002, 26(4): 58～62

On the basis of experimental results of instantaneous velocity, the flow in the entraining region of unsteady flow field in the pulse cleaning system of a ceramic filter is regarded as two-dimensional, unsteady, compressible and axisymmetrical flow. The computation analysis shows that the interaction process between the pulsed jet and entrained gas can be observed. In the initial stage, there exist the secondary-entrained phenomena because of lower jet pulsing velocity. The mass flowrate of entrained gas increased gradually, while increasing the jet pulsing velocity. The computed and measured transient velocities are in good agreement. The simulation result is useful to performance analysis and optimum design of pulse-backing cleaning system.

Key words: ceramic filter; pulse cleaning system; unsteady flow; numerical simulation