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边水稠油油藏水驱后蒸汽吞吐方案设计

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摘要:注水开发多年的具边水的普通稠油油藏的原油粘度高、流度比大,加之油藏非均质及边水入侵的影响,其注水开发效果较差。到含水高于 90 %时,仍有大部分原油未开采出来,因此,有必要转换开发方式,进一步提高采出程度。针对以上问题,应用黑油模型和热采模型,在对水驱阶段历史拟合和现代油藏工程评价的基础上,从筛选标准、吞吐试采产能及吞吐模拟等方面评价了注蒸汽热采的可行性,并用正交设计分析方法优选了吞吐注汽参数。结果表明,该类油藏由注水开发转为注蒸汽开采,可以有效地提高采出程度。这种设计方案为相似类型稠油油藏的开发提供了一套较为完善的借鉴方法。

关键词:断块;稠油油藏;水驱;蒸汽吞吐;油田开发设计

中图分类号:TE 357.44 **文献标识码**:A

1 油藏概况

胜利油区某断块注水开发已有 20 多年的历史,由于地下原油粘度高,导致注水开发效果较差。至 1994 年,采出程度为 12.3 %,综合含水 92 %,注水开发已到后期,必须转换开采方式。

该断块油层埋深为 1226～1300 m,主要开采目的层为 Ng_3^3、Ng_3^4、Ng_3^5 和 Ng_4^2。地层有效厚度为 14.1 m,平均有效渗透率为 1.115 μm^2,油层平均孔隙度为 0.34,原始平均含油饱和度为 0.65,初始地层温度为 72 ℃,油藏原始地层压力为 12.69 MPa,油藏条件下原油粘度为95mPa·s,脱气油粘度为 1.7～3.0 Pa·s。西部为边水,南北为断层。

从 1974 年试采开始,该断块大致经历了天然能量开发、注水提高油层产能、综合调整稳油上产和注蒸汽热力采油挖潜增效 4 个阶段。在开发过程中形成了以下生产特征:

(1) 油水粘度比大,水驱开发效果差。由于原油粘度高,水超越原油流向生产井底形成的平面突进现象严重,波及系数小,采出程度低,地下剩余储量高。

(2) 油层具非均质性,各层采出程度不一致。除主力油层 Ng_3^3 外,各层内均有不同程度的尖灭,加上各层渗透率、孔隙度的差异,造成各层的采出程度不同。其中 Ng_3^3 层的情况较好,1993 年初采出程度为 14.26 %,而 Ng_3^{4+5} 层效果较差,采出程度仅为 8.5 %。

(3) 长期注水,使得地层温度略有下降。

2 水驱开采评价

2.1 数值模拟研究

以 SimBest II 为模拟器,对水驱阶段进行数值模拟研究,以预测水驱采出程度。经计算,该断块水驱阶段各层开发状况如表 1 所示。由表 1 可知,Ng_3^3 为该断块的主力开发层,剩余储量为 397.36 $\times 10^4$ t,可以对其采取新的开采工艺,以提高采收率。

表 1 水驱阶段各层开发数据

层位	原始油量 N/万 t	采出油量 N_p/万 t	剩余油量 N_{or}/万 t	采出程度 R/ %
Ng_3^3	463.46	66.10	397.36	14.26
Ng_3^{4+5}	214.70	18.26	196.44	8.50
Ng_4^2	140.00	16.39	123.61	11.71
合计	818.16	100.75	717.41	12.31

由数模结果可知,垂向上各层剩余油饱和度均不相同,但各层南部剩余油饱和度均在 0.53 以上,仍具开发潜力。该断块为正韵律沉积,渗透率自上而下逐渐升高,因此,水侵状况不尽相同。上部主力层水侵较弱,而非主力层水侵较强。考虑蒸汽超覆,注蒸汽采油将有利于主力层的开采。

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在动态历史拟合的基础上,对水驱过程的各种方案进行动态预测,各方案的最终采收率仅在 15 %～16 %。其主要原因是油的粘度高,水油流度比大,易形成水窜,降低波及系数。虽然地层渗透性好,但油相渗透率偏低,故含水率高,采出程度低。

2.2　现代油藏工程评价

由于水的比热较大,边水能量的大小将会严重影响注蒸汽开采的效果,并可能决定热采方案的可行性,因此,应用物质平衡原理和非稳态水侵渗流规律对水区大小进行估算,计算得出水区与油区半径比 r_D 为 3,边水并不活跃。由产量特征曲线图 1 可以看出,该断块原油产量从上升到稳产阶段一直保持在较低水平(采油速度仅为 0.7 %左右),符合一般稠油油田水驱开采特点。选用校正水驱曲线和产量双曲递减分析方法,以采油速度 0.3 %为极限,预测最终采收率为 16.1 %。

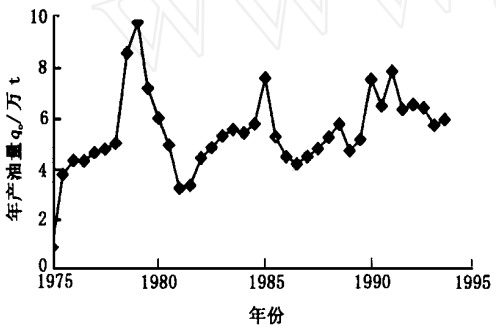

图 1　区块产量特征曲线

3　蒸汽吞吐可行性评价

将油藏参数与国内外筛选标准进行对比发现,该断块原油相对密度和油层埋深等指标都处于筛选标准低限值,但孔隙度和渗透率等储层物性参数则高于筛选标准。因此,该断块参数处于筛选界限附近,在采取配套工艺技术和方案设计的基础上进行热采,仍可能取得较好效果。

1992 年底至 1993 年初分别对该断块的 B21 - 7 - 12,B21 - 11 - 15,B21 - 11 - 19 和 B21 - 9 - 13 井进行了蒸汽吞吐试验,1993 年 1 月至 1995 年 4 月的试采结果如表 2 所示。

经过蒸汽吞吐开采,这 4 口井均获得较高产量,并能持续生产很长一段时间,平均日产油量为 5.4～12.16 t。至 1995 年 4 月,周期产油量 3 663～5 155 t,平均 4 210 t;油汽比为 1.194～3.437,平均 1.893。

又选择 B21 - 9 - 13 井和 B21 - 11 - 19 井进行单井吞吐历史拟合,以认识地层及地下流体的热物性特征。在动态历史拟合后,对 B21 - 11 - 19 井进行了 5 个周期的吞吐效果预测。该井射开层段为 1 274.5～1 281.3 m,第一周期注汽量 1 500 t,以后每周期按 20 %递增,累积注汽 11.162 $\times 10^3$ t。预测结果为:累积产水 46.418 $\times 10^3$ t,累积产油 6.207 $\times 10^3$ t,平均日产油 25 t,油汽比为 0.556。

表 2　蒸汽吞吐试采结果

井　号	层位	有效厚度 h_e/ m	生产时间 t/ d	累积产油 N_p/ t	累积产气 N_g/ 万 m^3	产油峰值 q_{omax}/ (t·d^{-1})	累积产水 W_p/ t	平均产油 $\bar{q}_o$/ (t·d^{-1})	含水率 f_w/ %
B21 - 7 - 12	Ng_3^3	14.0	323	3 928	6.29	12.8	10 993	12.16	73.67
B21 - 11 - 15	Ng_3^3	10.1	796	4 094	16.92	18.0	22 649	5.14	84.69
B21 - 11 - 19	Ng_3^3	6.8	717	5 155	14.74	13.4	30 316	7.19	85.47
B21 - 9 - 13	Ng_3^3	11.0	678	3 663	17.07	8.5	73 863	5.4	95.28

4　蒸汽吞吐注汽参数优选

以 B21 - 11 - 19 井的拟合参数和操作条件为基础,考虑周期注汽量、注汽速度、井底干度和焖井时间等 4 个因子,每个因子考虑 3 个水平,对这 12 个参数组合进行筛选对比,结果如表 3 所示,计算结果见表 4。

由表 4 可知,周期注汽量是影响产油量的最敏感的参数,是设计最佳蒸汽吞吐措施的主要参量,它的大小与产油量和油汽比有关(如图 2)。

如果注汽量低,则油汽比值高,产油量低;如果注汽量高,则油汽比低,产油量高。综合考虑产油量、油汽比两个因素,周期注汽量在 170～200 t/ m 较为合适。

注汽速度也是影响蒸汽吞吐开发效果的重要因素(见图 3)。高速注入可减少热损失,并缩短因注蒸汽而停产的时间,加大受热半径,利于增油。但必须考虑到蒸汽发生器的能力、油层注入能力的限制和地面管线及井筒热损失。经计算,该断块的注汽速度为 7～10 t/ h 较为合适。

井底蒸汽干度对蒸汽吞吐开发效果也有影响。

井底干度高,则蒸汽热利用率高,进入地层内部的热量多,产油量和油汽比高。由于油层埋藏较深,井筒热损失较大,故尽量保证井底干度在 65 %～70 %以上,吞吐初期井底干度不能低于 30 %。

焖井时间对周期产油量影响不大,但它能使压力稳定并促使蒸汽在加热带内消失,扩大蒸汽带。同时,蒸汽凝结成水,从而减少开井生产时液体带出的热量。对该断块焖井时间可取为 3～5 d。

表 3 注汽参数优化因子水平

水平	因子			
	周期注汽量 q_{is}/ (t·m^{-1})	焖井时间 t_1/ d	井底干度 X/ %	注汽速度 v_{ig}/ (t·h^{-1})
Ⅰ	160	3	30	6
Ⅱ	265	6	50	8
Ⅲ	378	9	70	12

表 4 计算结果

试验编号	因子水平				采油量 q_{oh}/ (t·m^{-1})
	A	B	C	D	
	1	2	3	4	
1	1	1	1	1	57.5
2	1	2	2	2	55.88
3	1	3	3	3	53.82
4	2	1	2	3	56.76
5	2	2	3	1	61.91
6	2	3	1	2	57.06
7	3	1	3	2	63.53
8	3	2	1	3	57.79
9	3	3	2	1	62.09
水平 K_1	55.73	59.26	57.45	60.49	
水平 K_2	58.58	58.53	58.23	58.82	
水平 K_3	61.13	57.65	59.75	56.12	
R 极差	5.4	1.61	2.3	4.37	
较优水平	A_3	B_1	C_3	D_1	
因子主次	1	4	3	2	

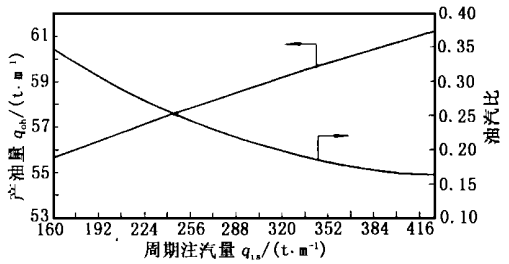

图 2 周期注汽量与油汽比和产油量的关系

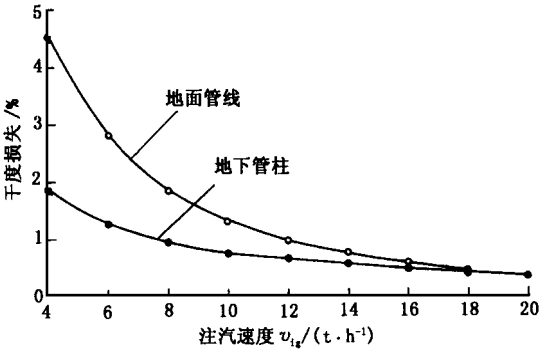

图 3 注汽速度与 100 m 管线热损失的关系

5 现场应用

自 1995 年至 1997 年 2 月,在该断块共进行了注汽吞吐采油试验 29 井次,注汽速度为 8.0～9.5 t/h。由于实际条件的限制,锅炉蒸汽出口干度在 65 %～75 %。经计算可知实际井底干度在 54 %左右,略低于优化结果,注汽温度在 350 ℃左右。据统计,在此期间累计增产原油 2.7 ×10^4 t,因而取得了较好的开发效果。

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cles settled in flowing water are obtained by the experiment in vertical pipes. Under the effect of velocity distribution of liquid in the pipe , the settling velocity is not equal to the vector sum of free untimate settling velocity and average velocity of fluid. There is a statistical linearity relationship between these parameters , which is the critical condition for sand to move downward , upward or suspend in wellbore. The critical condition can be taken as the theoretical basis of effective sand control in wellbore.

Key words : wellbore ; sand particle ; ultimate settling velocity ; corrective coefficient ; critical velocity ; lifting sand experiment

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Wang Xian-jun , Gai De-lin and Zhang Qi/ **OPTIMUM DESIGN OF PLUNGER LIFT FOR GAS WELL/** 2000 **,** (24) 2 **:** 36～39

Plunger lift technology is efficient for rising the energy of a gas-liquid well. The dynamics of plunger during up-travel are analyzed. Considering kinds of factors including the effect of gas-liquid producing on the rising of plunger and liquid , the dynamic models of up-travel and down-travel of plunger are established. Moreover , according to the production status of gas wells , an optimal design model is accomplished. It can be used to calculate the velocity of liquid accumulation , the optimal lift velocity of plunger and the maximum casing pressure that is needed to lift liquid column from bottom hole to land surface. Therefore , the number of operation period and the liquid volume are forecasted. The results of field tests indicate that the model can combine the plunger operation performance with the well production status. It is applicable to the changes of fluid , hole condition and character or parameters of reservoir. The calculation agrees with the practical results generally.

Key words : gas well ; artificial lift ; liquid drawing ; plunger ; dynamic model ; optimum design

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Liu Yue-tian and Ge Jia-li/ **ANALYTIC SOLUTION FOR FLUID FLOW THOUGH A CIRCULAR ANISOTROPIC FORMATION/** 2000 **,** (24) 2 **:** 40～43

This paper investigates the problem of the steady flow from a circular anisotropic formation to a central circular wellbore and presents an analytic solution of it. The original problem is transformed to that of the flow from an elliptical isotropic formation to a central elliptical wellbore. The numerical experiments show that the transformed flow can be divided into two flows in inner and outer areas respectively. The inner area is between two confocal elliptical boundaries. The inner flow problem is solved by a conformal transformation. The flow in the outer area is similar to the flow in a point source between two straight line boundaries with a uniform pressure. It is solved by the substitution method with the similar flow. The whole analytic solution of the original problem is obtained by combining the solutions of the inner and outer flow problems. The error of the substitution method is generally negligible. The computed results of the solution with typical parameters of anisotropic reservoirs are compared with that of the isotropic reservoir. The effect of anisotropic permeability on reservoir production is obvious.

Key words : circular boundary formation ; permeability ; anisotrope ; isotrope ; elliptical boundary formation ; steady flow ; analytic solution

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Du Dian-fa , Yao Jun and Liu Li-zhi/ **PROGRAM OF STEAM SOAK FDR HEAVY OIL RESERVOIR AF-**

TER WATER FLOODING/ 2000, 2(24): 44～46

The development effectiveness of water flooding for the heavy oil reservoir with edge water is poor because of the high oil viscosity, high mobility ratio and the invasion of edge water. In later period of water flooding, the recovery percent of reserves is very low while the water cut gets more than 90 %. So it is necessary to change the development scheme for enhancing oil recovery. The history match and modern reservoir engineering analysis on the water drive stage of a fault block in Shengli oilfield are made. This block has edge water, and water injection has been made for more than 20 years. The feasibility of steam soak is investigated by using sieving standard, steam soak pilot production and numerical simulation. The steam-injecting parameters are optimized with quadrature analysis method. The result shows that cyclic steam stimulation can enhance oil recovery economically and effectively. This program of steam soak offers a perfect method for the development design of the same reservoirs.

Key words: fault block; heavy oil reservoir; water flooding; steam soak; oilfield development design

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Wu Xiao-dong, Zhang Ying-chun and Li An-qi/ **NUMERICAL SIMULATION FOR COALBED METHANE PRODUCTION**/ 2000, 24(2): 47 ～ 49

Coalbed methane exists in a coal matrix by adsorption. The cleat system of coals acts an flow channel. The adsorption of coalgas is determined by Langmuir equation in the coal matrix. The diffusion process to the cleat system is described by using Fick's law. The flow in the cleat system can be described by Darcy's law. Two-dimensional non-equilibrium sorption pseudo-steady state model of coalbed methane for vertical well is derived in combination of an American model with the filed situation. The numerical simulation model of coalbed methane for single well is testified by on-site examples.

Key words: coalbed methane; production; coal matrix; cleat system; adsorption; mathematical model; numerical simulation

About the first author: *Wu Xiao-dong, male, professor, graduated from East China Petroleum Institute in* 1982 *and gained MS degree in* 1988. *Now he works on oil and gas development engineering in the University of Petroleum, China (Dongying:* 257062*).*

Hou Lian-hua/ **STUDY ON RESERVOIR SENSITIVITY OF QUDI OILFIELD** / 2000, 24(2): 50～53

The rock ingredient and fluid properties of Qudi oilfield are analyzed. All kinds of potential sensitivities of reservoir are researched on fluid now experiment. The result shows that there exist strong water sensitivity, salt sensitivity, alkali sensitivity and other weak sensitivity in the reservoir. The different layers have differential sensitivities. Some measures for reservoir protection, such as reduction of drilling density, application of completion fluid with the similar salinity to formation water, usage of P-216 inhibitive drilling fluid, are taken in differential reservoirs. The good results have been obtained during oilfield development.

Keyword: Qudi oilfield; reservoir; sensitivity evaluation; reservoir protection

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Zhang Shi-cheng and Liu Yong-xi / **DESIGEN METHOD FOR FRACTURED INJECTION WELL PROFILE MODIFICATION**/ 2000, 24(2): 54 ～57

As for low permeability reservoir, it is mainly by hydraulic fracturing to improve injection-production capability of wells and keep formation pressure. After block integral reconstruction by fracturing, the fracture parameters arc the decisive factors influencing the production-injection rate of the wells. In multilayer heterogeneous reser-