

大庆油区杏六区中部油藏三次加密合理布井方式

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摘要:大庆油区杏六区油藏经过43 a注水开发, 现已进入高含水开发后期, 剩余油分布零散, 低渗透薄差储层动用程度较低。在储层精细地质描述的基础上, 应用剩余油综合描述技术, 分析了杏六区中部油藏二次加密后剩余油分布特点、油层水洗状况和可调砂岩厚度。针对有效厚度小于0.5 m的表内薄层和表外储层, 开展了三次加密调整合理布井方式研究。主要采用三次加密调整与原井网、注采系统调整及后期三次采油相结合的优化布井方式, 通过实施调整井网类型、注采井距、注采系统等措施, 达到完善注采系统、充分挖潜剩余油的目的。在杏六区中部油藏实施三次加密调整措施后, 采收率同比提高2.72%, 表外储层水驱控制程度提高9.69%, 表内薄层、一类表外储层和二类表外储层动用砂岩厚度比例分别提高了4.32%, 6.13%和14.78%, 并形成了配套的三次加密调整技术。

关键词:薄差储层 三次加密调整 布井方式 表外储层 杏六区中部油藏

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大庆油区杏六区油藏为河流—三角洲沉积体系, 埋深为800~1 200 m, 平均砂岩厚度为75.6 m, 平均有效厚度为26.4 m, 表内储层(表内薄层和表内厚层)和表外储层相对较发育^[1-5]。截至2009年12月底, 研究区地层压力为8.89 MPa, 综合含水率为92.6%, 采出程度为42.75%, 水驱井网密度为37.7口/km², 已进入高含水、高采出程度、高井网密度开发期。在目前井网控制程度下, 剩余油难以动用, 为此, 笔者对三次加密调整合理布井方式进行了研究, 以期对开发后期油藏三次加密调整提供依据。

1 三次加密潜力分析

1.1 剩余油分布特点

杏六区中部油藏剩余油分布类型以吸水差型和注采不完善型为主。平均单井薄差储层(表内薄层和表外储层)剩余油层数为16.9个, 剩余油层叠加厚度为10.1 m, 有效厚度为0.8 m, 薄差储层中剩余油层叠加厚度占非主力油层的23.4%。吸水状况较差或不吸水的油层占剩余油总层数的63.9%, 注采不完善所形成的油层占32.1%。

剩余油主要分布在三角洲外前缘相的Ⅲ类和Ⅱ类储层中。剩余油层在三角洲外前缘相Ⅲ类储层中所占层数和厚度比例分别为60.4%和56.6%, 在

外前缘相Ⅱ类储层中所占层数和厚度比例分别为14.7%和17.2%。

一类和二类表外储层是剩余油的主要富集区。密闭取心井水洗资料表明, 非主力油层有效厚度大于0.5 m的表内厚层已全部水淹, 表内薄层水淹厚度比例达97.1%; 一类和二类表外储层水淹厚度比例分别为69.5%和43.7%, 一类和二类表外储层分别占薄差储层剩余油总层数的51.0%和32.8%, 占总厚度的55.0%和26.4%。

剩余油分布高度分散。纵向上, 每百米约有12.2个剩余油层, 且大部分与见水层交互分布; 从单层剩余油分布看, 平面上剩余油分布零散, 水驱控制程度较低, 挖潜难度大。

1.2 油层水驱动用状况

随着注水开发的进行, 一类油层水淹层数和厚度比例不断提高, 采出程度和油层动用程度也不断提高, 三次加密前采出程度达到了47.8%, 水淹层数比例为100%, 水淹厚度比例达到93.2%(表1)。

表1 一类油层不同开发阶段取心井水洗状况

取心时间	井数/口	水淹层数比例, %	水淹厚度比例, %	驱油效率, %	采出程度, %
一次加密前	2	80.0	61.6	55.70	34.3
二次加密前	2	100	75.9	51.30	38.9
三次加密前	2	100	93.2	51.30	47.8

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三类油层表内储层的采出程度随着开发的进行而增大,但采出程度较低,到三次加密前表内薄层水淹层数比例为80.3%,水淹厚度比例为65.7%,采出程度仅为27.0%(表2)。表外储层的采出程度

相比表内储层更低,二次加密前基本为0,到三次加密前也只达到6.4%。水淹层数比例为25.6%,水淹厚度比例为14.5%。随着表外储层单层厚度变薄,水淹状况减弱。

表2 三类油层不同开发阶段取心井水洗状况

取心时间	井数/口	表 内 薄 层				表 外 储 层			
		水淹层数比例,%	水淹厚度比例,%	驱油效率,%	采出程度,%	水淹层数比例,%	水淹厚度比例,%	驱油效率,%	采出程度,%
一次加密前	2	18.0	14.9	41.3	6.1				
二次加密前	2	37.1	36.9	39.4	14.5				
三次加密前	2	80.3	65.7	41.1	27.0	25.6	14.5	43.9	6.4

对比表1和表2可知,三类油层中表内薄层及表外储层水洗程度仍较低,三次加密的主要挖潜对象是表外储层和有效厚度小于0.5 m的表内薄层。

1.3 可调砂岩厚度预测

利用神经网络法^[6],对杏六区中部油藏897口油水井、102个单砂层进行了逐层剩余油研究。在隔层厚度为1 m的条件下,平均可调砂岩厚度为8.77 m,有效厚度为1.43 m,折合有效厚度为3.26 m。

为准确预测三次加密调整的可调砂岩厚度,选择20口新井,进行模拟射孔。结果表明,在隔层厚度为1 m的条件下,预测可调砂岩厚度为13.08 m,有效厚度为0.85 m,折算有效厚度为3.91 m。

综合上述2种方法,确定可调砂岩厚度为9.7 m,有效厚度为1.1 m,折合有效厚度为3.25 m。由此可知,杏六区中部油藏三次加密调整虽具有一定的物质基础,但挖潜难度很大^[7]。

2 三次加密调整方法

2.1 合理井网的选择

统计结果表明:二次加密后,表内薄层和表外储层水驱控制程度分别为79.9%和72.5%;单向连通比例较高,分别为28.8%和34.7%,多向连通比例较低,仅为21.4%和13.4%,不利于储层动用。主要原因是油水井数比偏高(约为1.6:1),注采井网不完善,在三次加密调整中,应适当增加注水井井数。对比线性、五点法和反九点法3种布井方式的开发效果可知,五点法面积井网平均水驱控制程度比其他井网高8%~10%^[7-9],含水率相同时采出程度比其他注水方式高。同时,五点法井网易于调整,故三次加密调整时应选用五点法注采井网。

2.2 合理井距的确定

三次加密调整井开采的储层以薄差储层为主,

由于储层物性差,渗流阻力大,为建立有效的注采驱动压差^[9],注采井距不宜过大。由于低渗透储层存在启动压力梯度,随着渗透率的降低,启动压力梯度急剧增大。通过岩心驱替实验,得到该区表外储层启动压力梯度与渗透率的关系式为

$$\frac{\Delta p}{L} = 0.389 3K^{-0.7916} \quad (1)$$

式中: Δp 为注采压差,MPa; L 为注采井距,m; K 为渗透率, $10^{-3} \mu\text{m}^2$ 。

计算结果表明,在渗透率为 $5 \times 10^{-3} \mu\text{m}^2$ 、注采井距为200 m的条件下,只有注采压差和注水压力分别大于21.78和14.09 MPa时,才能使这部分表外储层得到有效动用。但在目前开采条件下,注采压差很难达到该值。因此,若要有效动用这部分表外储层,合理的注采井距应控制在170 m以内。

杏六区中部油藏采油井环空测试资料结果表明,随着注采井距的减小,表外储层动用比例增大,注采井距小于150 m可以使表外储层动用比例达到60%以上,因此注采井距确定为100~150 m。

3 三次加密调整井网部署原则

3.1 与原井网相结合

三次加密调整是在二次加密调整的基础上,以完善薄差储层注采关系,挖潜剩余油。受二次加密井网限制,三次加密部署应与老井相结合,综合考虑布井方式^[10-14]。不同阶段开发对象不同,射开油层的层数比例也不同。从基础井网到三次加密,射开的表内厚层层数比例逐步降低,表内薄层和表外储层层数比例逐步增加。与调整井相同井别的井距要大于50 m,不同井别的井距要大于80 m。根据具体情况采取灵活的布井方式,完善注采关系。同时,为防止套损,原则上断层附近不布水井。

3.2 与注采系统调整相结合

综合考虑二次加密井和三次加密井的注采关系,与注采系统调整相结合,考虑布井方式^[11]。针对杏六区中部三类油层井网、构造和套损及砂体注采不完善这3种影响因素,依据研究区存在的问题,进行了注采系统调整,结果如表3所示。

影响因素	存在问题	调整方向	
井网	油水井数比偏高,水驱控制程度低,供液能力差	转注反九点法的角井或不规则五点法的部分油井,形成适合不同类型单砂体面积井网	
构造和套损	砂体控制程度较低	钻补充井、大修、更新、侧斜等	
砂体注采不完善	油井射孔、注水井未射孔	注水井补孔或增加注水井点	
	油井未射孔、注水井射孔	油井补孔	
	油水井均未射孔	油水井对应补孔	
	油井或注水井砂体变差	受效差	措施改造
	油水井间有其他油井射孔	二线受效	增加注水井点

3.3 与后期三次采油相结合

三次加密调整应与后期三次采油相结合,以提高井网综合利用率,提高经济效益。杏六区中部油藏尚未开展三次采油,若采用高质量浓度聚合物驱三次采油井网加密可提高采收率为3%,聚合物驱可提高采收率达15%以上。在三类油层水驱注采系统调整的基础上,对三类油层复合驱、聚合物驱开展研究,预计提高采收率达10%以上。

4 三次加密调整效果

实施三次加密调整措施后,水驱井网平均产油量为2.58 t/d,含水率为81.61%;基础井网产油量高,为3.5 t/d,加密井平均产油量约为2 t/d;三次采油井产油量为3.3 t/d,含水率为92.76%。采收率同比提高了2.72%,表外储层水驱控制程度提高了9.69%。表内和表外储层单向连通层数分别降低了13.45%和12.42%,表内薄层和表外储层多向连通层数分别提高了18.43%和17.10%,多向连通率增大,提高了薄差储层的动用程度,减缓了老井产量的递减,延长了油田稳产时间。三次加密调整后,开发效果得到了明显改善:表内薄层、一类表外储层和二类表外储层动用砂岩厚度比例分别为65.58%,50.35%

和42.94%;与加密前相比,分别提高了4.32%,6.13%和14.78%。

5 结束语

大庆油区杏六区中部油藏主要以河流—三角洲前缘外缘沉积为主,表内薄层和表外储层相对较发育。二次加密调整后,仍有部分表内薄层和表外储层尚未动用或动用较差,具有加密调整的潜力。研究表明,预测可调砂岩厚度为9.7 m,有效厚度为1.1 m,三次加密调整选取五点法注采井网,注采井距为100~150 m。同时,三次加密井应遵循与原井网、注采系统调整和后期三次采油相结合的原则,合理优化布井,既要考虑三次加密井与聚合物驱井的关系,也要有利于井网后期的综合利用。

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Wang Weidong. Change rule and control method of sulfate-reducing bacteria in oilfield produced water. *PGRE*, 2013, 20(6): 61-64

Abstract: The correlation between the sulfate-reducing bacteria (SRB) in oilfield produced water and some factors such as oil content or suspended solids is revealed through systematic analysis of the presence of SRB of produced water in the oil production process. The presence of SRB is an inherent feature of the produced water. And, the concentration of SRB always keeps stable in the produced water of a certain reservoir, however, it will vary with each production process. The on-way deterioration of water and viscosity loss of polymer caused by SRB have become the major problems in the development of oilfield. Inhabitation of SRB through adding bactericide can only relieve the deterioration temporarily. For the future oilfield production, some technical ideas and control strategies to the SRB prevention are proposed, the first is to open the treatment systems of re-injected oilfield wastewater, and apply air flotation rather than bactericides as much as possible.

Key words: re-injected oilfield wastewater; sulfate-reducing bacteria; on-way deterioration; viscosity loss; opening treatment system; flotation; control bacteria

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Qu Yaguang. Development influence on heterogeneity by in-situ combustion in heavy oil field. *PGRE*, 2013, 20(6): 65-68

Abstract: In-situ combustion is one of the effective methods used for heavy crude oil. The reservoir heterogeneity is bound to affect the development performance. Three kinds of heterogeneous model including permeability, thickness and geometry form are proposed based on the distribution characteristics of the sedimentary micro-facies of certain reservoir. Then, 18 reservoir simulation models are built by applying the method of reservoir numerical simulation. The development effectiveness of injection-production pattern caused by heterogeneity is studied. The research result shows that the initial and cumulative production is different due to different injection-production pattern at the same condition. In order to improve the development effectiveness of in-situ combustion, the injection-production pattern should be optimized. And, the impact of geometry form is the biggest, thickness secondly, then the permeability.

Key words: heavy oil field; heterogeneity; in-situ combustion; injection-production pattern; numerical simulation; development performance

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Lei Gang, Dong Pingchuan, You Wenhao et al. Water flooding response and its affecting factors in low permeability deformed medium sandstone reservoirs. *PGRE*, 2013, 20(6): 69-72

Abstract: For the threshold pressure gradient and the medium deformation characteristic in low permeability deformed medium sandstone reservoirs, an unsteady-state seepage model, which could predict the flood response time under different affecting factors more accurately, is established on the basis of the flow formula considering threshold pressure gradient and media deformation factor. The average formation pressure in the excited area has been solved by using repeated iteration method. And, the water flooding response calculation model in low permeability deformed medium sandstone reservoirs has also been established according to material balance method. The water flooding response is mainly affected by the well spacing, the average formation pressure in the excited region, the threshold pressure gradient and the media deformation factor. The flood response time sharply increases with the increase of well spacing or excited radius and the increase of water flooding response is getting faster with well spacing's increment. The threshold pressure gradient or the media deformation factor greatly affects the water flooding response, and the greater the threshold pressure gradient or the media deformation factor, the longer the flood response time.

Key words: low permeability sandstone reservoir; deformed media; threshold pressure gradient; excited radius; flood response time

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Hu Wei, Yan Chao, Chen Zhengtao et al. Study of reasonable well planning for third infilling in Xing6 Central, Daqing oilfield. *PGRE*, 2013, 20(6): 73-75

Abstract: After forty-three years water flooding development, the reservoir in Xing6 area is in high water cut stage of development, the scatter distribution of remaining oil and the poor development on thin and poor oil layers are present problems. On the basis of elaborate reservoir geological description, and using the skills of comprehensive description of the remaining oil, we analyze the features of remaining oil, as well as all types of layers' washing condition and adjustable sandstone thickness after second infilling in Xing6 area. In response to the sand layers with effective thickness under 0.5 m, the third infilling stage is implemented. Under the "three combinations" policy of optimizing well distribution, and through the adjustment of the well pattern, injection producer distance, well density, water flooding system, etc., the perfect injection and production systems are achieved to fully produce the remaining oil. The good results have been achieved in Xing6 area, and formed the matching infilling techniques.

Key words: poor and thin oil layers; third infilling; well pattern; contingency reserve; middle reservoir of Xing6 area

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Xiong Jian, Liu Haishang, Zhao Changhong et al. Study on productivity of asymmetrical vertical fracture well in low-permeability gas reservoirs. *PGRE*, 2013, 20(6): 76–79

Abstract: In view of the asymmetrical vertical fracture in the low permeability reservoir after fracturing development, and based on the steady seepage theory, and by means of the conformal transformation method, a prediction model for the finite-conductivity asymmetrical vertical fracture wells is established in the low-permeability gas reservoirs, and the various factors on the gas well productivity are analyzed. The result shows that, under the same bottom-hole pressure, the fracture asymmetry factor has little effect on the productivity of the gas well with asymmetrical vertical fracture. When the fracture conductivity capacity is small, there is great difference in the productivity of the fracture gas well with respect to fracture length or fracture asymmetry factor. And, when the fracture conductivity capacity is high, there is little difference in productivity with respect to variable fracture length or fracture asymmetry factor in gas well. The longer the fracture length, the less the fracture asymmetrical factor, and the greater influence on the fractured gas well productivity.

Key words: low-permeability gas reservoirs; asymmetrical vertical fracture; fracture conductivity capacity; fracture asymmetry factor; productivity forecast

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Li Aifen, Li Huihui, Lv Jiao et al. Experimental study of foam on gas-liquid relative permeability at different temperature. *PGRE*, 2013, 20(6): 80–82

Abstract: There are many researches about the influence of the foam on gas-liquid relative permeability, but the influence of the temperature on foam relative permeability curve needs to be further studied. The curve reflecting the relationship between foam block pressure and gas-liquid flow rate ratio is measured at different temperature in this paper. So, the impact of the gas-liquid flow ratio and temperature on the block pressure is analyzed. The gas-liquid relative permeability curves both with the and without effects of foam are measured by using steady-state method in this paper. On this base, the flow rules of foam at different temperature are also characterized. The results indicate that the higher the experimental temperature, the better the sealing performance. And, both the foam block pressure and the blocking performance of foam can attain the highest degree in the range of gas-liquid flow ratio between 2 and 4. The foam has no effect on the relationship between the liquid relative permeability and the water saturation. The gas relative permeability, however, has a sharp decline under the action of foam. With the experimental temperature, the critical water saturation became higher with the increase of temperature and the moderate values of the gas relative permeability became lower with the increase of temperature.

Key words: temperature; foam; block pressure of foam; steady-state method; gas-liquid relative permeability; critical water saturation

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Yang Hongbin, Pu Chunsheng, Li Miao et al. Laboratory evaluation and field application on profile control of self-adaptive weak gel. *PGRE*, 2013, 20(6): 83–86

Abstract: In response to the problems of fully developed micro-fractures in low permeability oil fields, severely heterogeneous reservoir and the fact that traditional profile control are less effective, the self-adaptive weak gel is developed. The static performance, sealing characteristics and displacement efficiency are evaluated through lab tests. The results show that the self-adaptive weak gel has good temperature-resistant and salt-resistant properties. When the salinity of formation water is 41 811.5 mg/L, the weak gel system can gelatinize rapidly in 38 hours, and the gel strength is 28 549 mPa·s under the condition of 70 °C. Its plugging ratio is 84.08% and the recovery ratio reaches 12.1%. The field experiments of the well S in Ganguyi oilfield indicate that the preferred path of water breakthrough of water injection well is controlled after profile control and flooding, and the injection pressure rises, at the same time, the water content of well group fell to 69.16% from 78.51%, and daily fluid production rate increases by 135.14%, while the daily oil production rate increases by 237.5%. The deep profile control technology of self-adaptive weak gel has good adaptability in fractured low permeability oil fields. It can enlarge the sweep volume of injected water and enhance oil recovery factor greatly, so it can provide reference for other similar reservoirs to obtain good performance on water control and oil increment.

Key words: self-adaptive weak gel; profile control; gelation intensity; plugging; micro fractures; Ganguyi oilfield

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Yuan Lin, Li Xiaoping, Sun Fei et al. Deduction of productivity formula for horizontal well with displacement method between two similar flow. *PGRE*, 2013, 20(6): 87–90

Abstract: As the technology of horizontal well had been widely used in the gas and oil fields, the productivity forecast of horizontal wells will be of great importance. Based on the ellipse constant pressure surfaces near the wellbore, the author divides the seepage prob-