边水断块油藏层系重组的技术政策界限

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摘要：边水断块油藏具有纵向上含油层系多、层间非均质性强及各小层的含油条带宽度和水体倍数差异大等特点，当含油条带宽度和水体倍数相差较大的小层组合为一套层系进行开发时，对井网的部署及开发效果影响较大。因此，在层系重组时，除考虑渗透率级差和粘度级差等政策界限外，还应考虑含油条带宽度级差和水体倍数级差界限。通过分析含油条带宽度和水体倍数不同的小层组合对开发效果的影响，建立了层系重组的含油条带宽度级差和水体倍数级差政策界限，并将研究结果应用到东辛油田辛 11－21 断块油藏沙二段 11—W 砂层组的层系重组方案中，增加可采储量为 19.32×10^4 t，最终采收率由 46.5% 提高到 50.4%，能够达到较好的开发效果。

关键词：边水油藏 层系重组 含油条带宽度 水体倍数 政策界限
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断块油藏类型较多，其中具有不同边水能量的边水断块油藏占了较大比例[1－2]。边水断块油藏具有构造复杂、断层发育、纵向上含油层系多、层间非均质性强的特点，且各小层含油条带宽度和水体倍数差异大。有的小层边水能量强，完全依靠边水能量就能保证地层压力的要求；但有的小层边水能量弱，或者无边底水，需要注水开发。如果含油条带宽度和水体倍数不同的小层组合为一套开发层系，井网的部署就会受到较大影响，影响最终的开发效果。

目前，层系重组政策界限研究主要针对常规的储层物性，如渗透率和地层原油粘度等[3－10]，对于边水断块油藏中含油条带宽度和水体倍数对层系重组的影响研究较少。为此，笔者在分析含油条带宽度和水体倍数对开发规律影响的基础上，建立了层系重组中含油条带宽度级差和水体倍数级差的政策界限，以期改善边水断块油藏层系重组的开发效果，最大限度地提高断块油藏采收率。

1 含油条带宽度小层重组政策界限

1.1 模型建立

建立 2 层地层倾角为 5°的剖面模型，其含油条带宽度不同，各层水体倍数为 5 倍。2 层采用 1 套井网合注合采，油井位于高部位，距离断层 50 m，水井位于宽含油条带小层的水区。各层储层物性及流体参数相同，地层原油粘度为 10 mPa·s，渗透率为 500×10^{-3} μm²。

1.2 含油条带宽度对开发效果的影响

由不同含油条带宽度小层单采和合注合采开发的含水率与采出程度关系曲线(图 1)可以看出，合注合采时的无水采收率小于含油条带宽度为 200 和 400 m 小层单采时的无水采收率；合注合采的含水率在早期相同的采出程度下高于 2 层单采的含水率，后期与含油条带宽度为 200 m 小层单采的含水率接近；含水率为 98% 时合注合采的采出程度介于 2 层单采的采出程度之间。

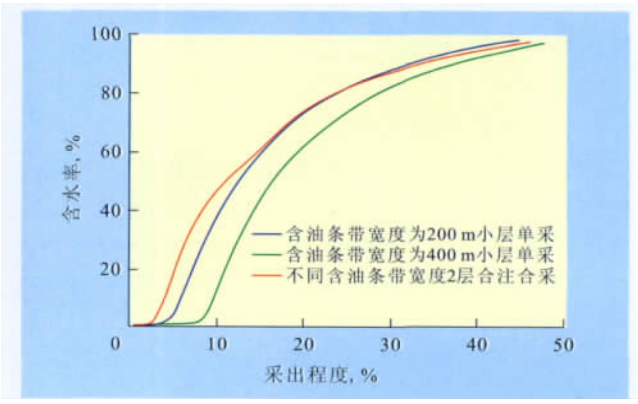

图 1　不同含油条带宽度小层单采和合注合采含水率与采出程度的关系

将宽含油条带小层的渗流阻力与窄含油条带小层的渗流阻力之比定义为渗流阻力比。由含油条带

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宽度级差分别为 1.5 和 2.0 时的渗流阻力比的关系曲线(图 2)可以看出:含油条带宽度级差越大,渗流阻力比越大;随着开发的进行,层间渗流阻力比逐渐增大。由于宽含油条带小层的渗流阻力大于窄含油条带小层的渗流阻力,在合注合采的情况下,窄含油条带小层分配的水量越来越多,其渗流阻力下降快;宽含油条带小层分配的水量越来越少,其渗流阻力下降慢。

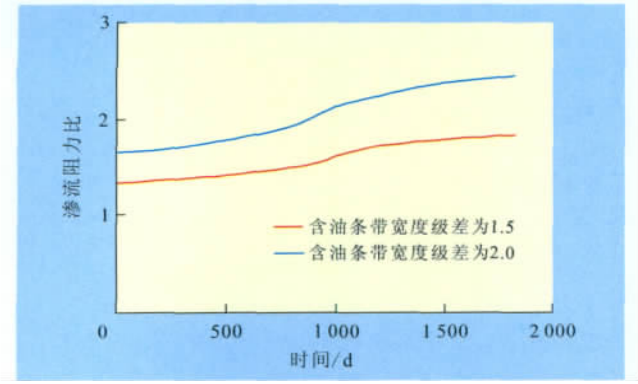

图 2　不同含油条带宽度级差小层合注合采时的渗流阻力比

1.3　政策界限

在不同的水体能量情况下,分析了不同含油条带宽度小层合注合采的开发效果。共设计了 3 种方案:方案Ⅰ,边水能量较弱,2 层水体倍数均为 5 倍,2 层均注水开发;方案Ⅱ,边水能量较强,2 层水体倍数均为 50 倍,2 层均不注水,完全依靠天然能量开发;方案Ⅲ,2 层天然能量存在差异,第 1 层边水能量较强,水体倍数为 50 倍,第 2 层边水能量较弱,水体倍数为 5 倍,前者依靠天然能量开发,后者注水开发。

分析不同含油条带宽度组合下含水率为 98% 时的采出程度(图 3)发现,随着含油条带宽度级差的增加,方案Ⅰ和方案Ⅱ的采出程度逐渐降低;方案Ⅲ的采出程度在含油条带宽度级差为1.5时最高。

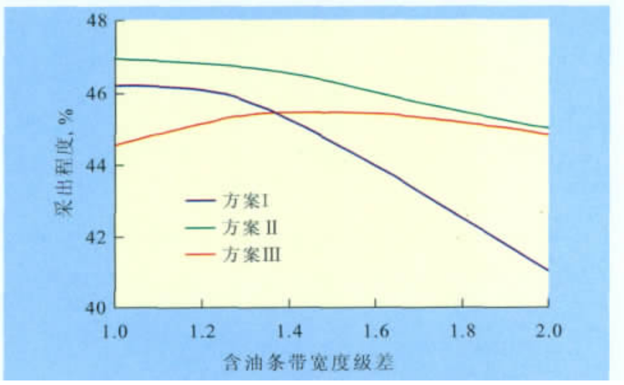

图 3　不同含油条带宽度小层合注合采时开发效果对比

因此,在层系重组时,无论是采用注水开发还是利用边水开发,需要考虑将含油条带宽度相近的小层组合为一套层系,以减少层间干扰,提高采收率。综合考虑 3 种情况,在层系重组时含油条带宽度级差的界限定为 1.5。

2　水体倍数小层重组政策界限

依然采用 2 层剖面模型,两者含油条带宽度相同,但各层水体倍数不同。设计了 2 种方案:方案Ⅰ,2 层边水能量均较弱,采用注水开发,合注合采,其中第 1 层水体倍数为 1 倍,通过改变第 2 层边水水体倍数,计算不同水体倍数小层组合后的开发效果;方案Ⅱ,2 层边水能量均较强,不需注水,利用天然能量开发,合注合采,其中第 1 层水体倍数为 20 倍,通过改变第 2 层边水水体倍数,计算不同水体倍数小层组合后的开发效果。

由不同水体倍数组合下含水率为 98% 时的采出程度(图 4)可以看出:在水体能量较弱的情况下注水开发,水体倍数的差异对开发效果影响不大,利用天然能量开发,2 层合采,随着水体倍数级差的增加,采出程度逐渐降低;从相邻 2 个水体倍数级差的采出程度减小量可以看出,当水体能量级差为 4 时,采出程度减小量为极小值。因此,水体倍数级差界限定为 4。

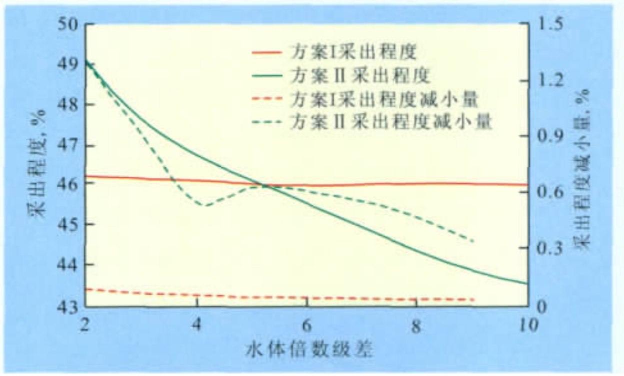

图 4　不同水体倍数小层组合后的采出程度对比

3　应用实例

东辛油田辛 11 -21 断块油藏构造上位于东营凹陷中央隆起带中段,是半开启的反向屋脊油藏。分为沙二段 8—10 砂层组、11—12 砂层组和 13—W 砂层组 3 套开发层系。其中 13—W 砂层组内储层非均质性强,各小层渗透率差异较大,最大值为

1 162 × 10^{-3} μm²，最小值仅为 41.5 × 10^{-3} μm²，渗透率级差为 28。各小层的含油条带宽度相差较大，最宽为沙二段 11 – 3 小层，含油条带宽度达到 1 000 m，最窄为 14 – 6 小层，其含油条带宽度仅为 140 m，多数为 200 ~ 500 m，含油条带宽度级差达到 7.14。

辛 11 – 21 断块油藏于 1969 年投入开发，1973 年开始注水，截至 2011 年 6 月采出程度为 43.5%，综合含水率为 95.2%；各小层采出状况差异较大，沙二段 8—10，11—12 和 13—W 砂层组中各小层采出程度分别相差 39.7%，15.7% 和 50.8%。

根据目前各小层的开发状况和层系重组的政策界限，进行了层系重组。根据上述研究成果及开发区块的储层物性情况，制定了层系重组的原则：①同一套开发层系内油层的分布形态和分布面积应接近，含油条带宽度级差小于 1.5；②由于采用注水开发，不考虑各小层水体倍数差异的影响；③同一开发层系渗透率级差应小于 3，地层原油粘度级差小于 2。根据以上要求编制了层系重组方案，沙二段 8—10 砂层组保持一套开发层系不变，将沙二段 11—W 砂层组分为 4 套开发层系（表 1），其中，W 砂层组二类小层组成的开发层系中由于小层个数多，渗透率级差大于 3，其余各层系的含油条带宽度级差、渗透率级差均满足政策界限要求，对层系重组方案采用油藏数值模拟进行预测，增加可采储量为 19.32 × 10^4 t，最终采收率由 46.5% 提高到 50.4%，能够达到较好的开发效果。

表 1　东辛油田辛 11 – 21 断块油藏沙二段 11—W 砂层组层系重组方案预测结果

开发层系	小层个数	石油地质储量/10^4 t	渗透率/10^{-3} μm²	渗透率级差	含油条带宽度级差	采出程度，%	采收率，%			15 a 累积增油量/10^4 t
							重组前	重组后	提高值	
11—12^3 砂层组一类小层	8	164.5	709 ~ 911	1.28	1.43	53.7	55.4	58.0	2.6	2.91
11—12^3 砂层组二类小层	3	110.5	506 ~ 801	1.58	1.25	45.0	46.8	55.2	8.4	9.11
12^4—W1^5 砂层组一类小层	8	48.2	730 ~ 1 162	1.59	1.50	53.5	54.8	58.6	3.8	2.13
W 砂层组二类小层	17	92.9	62 ~ 371	5.98	1.36	18.0	26.2	27.2	1.0	0.63

4　结论

由于不同含油条带宽度小层合注合采时含油条带宽度小的层渗流阻力小，分配的水量多，使得该层过早水淹，导致不同含油条带宽度小层合采时的无水采收率小于各小层单层开发的无水采收率。

不同含油条带宽度小层合注合采时，无论是进行注水开发还是利用边水的天然能量开发，当含油条带宽度级差大于 1.5 时，随着含油条带宽度级差的增加，油藏采收率迅速下降。因此，在层系重组时含油条带宽度的级差界限定为 1.5。

不同水体倍数的小层合注合采，小层间水体倍数的差异对开发效果影响不大。在各小层水体倍数都较大的情况下，各小层组合后采用天然能量进行合采，随着层间水体倍数级差的增加，采出程度逐渐减小，层系重组时层间水体倍数级差界限定为 4。

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Liu Shun, He Heng, He Yanxiang et al. Data processing correlation on stress sensitivity experiment for low-permeability reservoirs. *PGRE*, 2012,19(4):71-73.

Abstract: Stress sensitivity presents in low-permeability reservoirs. Choose 17 blocks low-permeability cores to stress sensitivity experiment according to SY/T 5358-2010 standard. The Darcy law equation and power-law non-linear percolation equation are adopted to analyze the experimental data. The parameter of power-law non-linear percolation equation is regressed from the relations between rate and stress gradient derived from other 8 blocks experimental cores. The results show that the peripheral pressure numbers are greater and the permeability number reduces less. Also, the conclusion can be achieved that the reduced ratio of permeability number from the two correlated calculated methods is nearly same. But, the permeability number based on power-law percolation method is quadruple to Darcy law method. So, the power-law non-linear percolation equation suggests to be used to data analysis in low-permeability reservoir.

Key words: low-permeability reservoirs; stress sensitivity; Darcy law; power-law non-linear percolation; pressure gradient

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Liu Yongge, Liu Huiqing, Pang Zhanxi et al. Study on nitrogen foam anti-water-cresting by double horizontal wells for bottom water heavy oil reservoir. *PGRE*, 2012,19(4):74-77.

Abstract: By means of numerical simulation, below the producing horizontal well, another horizontal well is placed to put off water cresting. When water cresting reached up to the height of producing horizontal well, we shut in the producing horizontal well and inject nitrogen foam into the horizontal well below. After two days'soaking, the upper horizontal well is opened to produce again. This process can be repeated for many times. The results of numerical simulation show that the development efficiency by double horizontal wells is much better, and the effect of water cresting can be alleviated greatly comparing to injecting nitrogen foam and producing oil only by a single well. The development style, distance away from the bottom water, length, liquid producing rate and the moment of injecting nitrogen foam are optimized by simulation. After optimization, the quantity and amplitude of incremental oil can reach up to 19,000 cubic meters and 48.7% respectively.

Key words: horizontal well; foam; bottom water heavy oil reservoir; water cresting; numerical simulation

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Li Nan, Cheng Linsong, Chen Hongquan et al. Study on water injection in ultra low permeability reservoir. *PGRE*, 2012,19(4):78-80.

Abstract: This article starts from the mechanism of advanced water injection, combining with the numerical simulation and actual production data, it contrasts the pressure profiles between the water injection well and oil well under the different water injection timing, then, optimizes the water injection timing in ultra low permeability reservoirs, and under the optimal water injection timing, it analyzes the effect on transmission of pressure by different ways of advanced water injection. Based on low permeability reservoirs property of start-up pressure gradient, stress the sensitive, thin pore throats, we analyze the effect on the lifting amplitude of oil wells, water wells and reservoir pressure by the different ways of advanced water injection. At the condition of the maximum of spread coefficient and under the rock breakdown pressure, screening and combining different ways of advanced water injection, we found that, it could be able to get the best development performance in ultra low permeable reservoir by anti-step mild water injection. Taking Changqing BMZ oilfield as example, the development effect has been analyzed under different water injection, and we evaluated the development effect of the method of anti-step mild water injection, which has certain directive significance to make the technology policy.

Key words: ultra low permeability reservoir; advanced water injection; stepped injection; mild injection; anti-step mild water injection; pressure profile

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Wang Jian. Study on technical policy limits of layer recombination in edge water fault block reservoir. *PGRE*, 2012,19(4):81-83.

Abstract: Fault block reservoir possesses the characteristics of many oil-bearing strata, serious heterogeneity. In addition, for the layers in the edge water fault block reservoirs, their oily strip width and edge water body multiples are different. The combination of the layers with different oily strip width and edge water body multiples have great impact on the development effect of the development unit. Therefore, in addition to considering the policy limits of permeability differences and oil viscosity differences, such the policy limits as oily strip width differences and edge water body multiples differences should be considered during the layers recombination. In this paper, the effect of the combination of different layers with oily strip width differences and edge water body multiples differences on the reservoir performance is analyzed. And, the policy limits of oily strip width differences and edge water body multiples differences are set up. The research result was applied to the actual fault block reservoir development, and achieved good results.

Key words: edge water reservoir; layer recombination; oil stripe width; water body multiples; policy limits

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Wang Hua. Application of improved water drive curve in recoverable reserves. *PGRE*, 2012, 19(4): 84–86.

Abstract: Water drive curve is one important method for estimate recoverable reserves of water drive reservoir, this method is widely used in high water–cut stage of development, but the water drive curve starts to rise upward at extra high water cut stage, it is an obvious non–adaptability that uses water drive reservoir to calculate recoverable reserves in this period. For the development characteristic of extra–high water cut development stage, it has improved the formula of water drive curve, and established a new formula for water drive curve at high water–cut stage to calculate recoverable reserves, which has widened the scope of water drive curve. The recoverable reserve is estimated to be 555 million tons in Gudong oilfield 54–61unit by the improved formula, and the recovery rate is 39.1%, and the result accords well with the field practice. To validate the applicability of improved method, it has screened 6 units of Shengli oilfield which is in extra high water cut stage and its water drive curve is upward to calculate recoverable reserves. The results prove that the improved method is more applicable to the oilfield production.

Key words: extra high water cut period; water drive curve; technical recoverable reserve; least square method curves

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Huang Wenfen, Qin Xuejie, Du Xiaoyong. Study on development effectiveness of water injection and gas injection for reservoirs with low volatile black oil. *PGRE*, 2012, 19(4): 87–89.

Abstract: The crude oil in O72&O73 reservoirs of Plutonio oil field has good properties and low volatility. The saturation pressure of reservoirs is very near to the initial formation pressure. Injecting fluid to maintain the formation pressure is an effective way to enhance the recovery of this kind of reservoir. Analyzing the balance between injecting and producing and flooding effects of different injecting fluids will be helpful for adjusting injection volume timely and enhancing the development performance. Studies on the ratio of injection–production show that there is fluid communication between two reservoirs. Research on relative permeability curves and the simulation model show that the water–flooding has higher oil displacement efficiency and the gas–flooding sweeps larger area. Both water and gas are injected to maintain the reservoir pressure since the very beginning of the development in field. It turns out that, after 3 years production, the recovery degree of two reservoirs is up to 18.5% and 10.9% respectively, with the average production rate of 3.3% and 5.5%.

Key words: low volatility black oil; GOR; injection–production ratio; oil displacement efficiency; recovery rate

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Yin Junlu, Zhao Dingnan, Dong Jiashan et al. Numerical simulation on factors affecting flooding mechanism of bottom–water reservoir in horizontal wells. *PGRE*, 2012, 19(4): 90–92.

Abstract: Bottom water reservoir, often with a big water body and enough fluid supply, can supply its formation energy used in exploiting crude oil immediately by bottom water. The production rate will be seriously affected once water breakthrough in horizontal wells during the development process. Based on the numerical simulation, the relationship of horizontal section length, height of water avoidance, producing pressure drop and water breakthrough time, cumulative recovery of water–free period and water cut has been studied in this paper, and the reasonable dimensionless horizontal section length, dimensionless height of water avoidance and producing pressure drop are respectively 0.75, 0.9 and 1.0 MPa. The results show that the influence degree on water breakthrough from high to low is respectively producing pressure drop, dimensionless height of water avoidance and dimensionless horizontal section length; and the influence degree on cumulative recovery of water–free period from high to low is respectively height of water avoidance, horizontal section length and producing pressure drop. A big height of water avoidance and a small producing pressure drop and a long horizontal section length could prolong the water breakthrough time and increase the cumulative recovery of water–free period and is more beneficial to develop the bottom water reservoir.

Key words: bottom water reservoir; horizontal well; water–flooding pattern; numerical simulation; horizontal well parameters.

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He Yifan, Liao Xinwei, Xu Mengya et al. Deduction and application of deliverability prediction model for low permeability fractured horizontal gas well. *PGRE*, 2012, 19(4): 93–96.

Abstract: Because of the existence of fractures in fractured horizontal well, gas converges in the wellbore with high velocity and large capacity, this would cause extra turbulent pressure drop. So, the deliverability equation of fractured horizontal gas well should consider the influence of non–Darcy flow rule. This paper adopts complex potential theory and superposition principle to deduce the seepage equation of fractured horizontal well and finally obtain the binomial deliverability equation of fractured horizontal gas well after considering the additional pressure drop caused by turbulent flow in the fractures. This equation is verified by field data and the elements which can influence the turbulent flow of fractured horizontal gas well are analyzed. The result is that this equation deduced in the paper fits the demand of field production and can guide the development and production of oilfield.

Key words: low permeability reservoir; fractured horizontal well; binomial deliverability equation; influence factor; non–Darcy flow; flow conductivity

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