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底水油藏水平井水淹规律影响因素

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摘要: 底水油藏往往表现为水体能量大，流体补给充足，开采原油所消耗的地层能量可由底水及时补充，在其开发过程中，水平井一旦见水，将严重影响产量。以油藏数值模拟为手段，研究了水平段长度、无因次水平段避水高度、生产压差与见水时间、无水期累积采油量及含水率的关系，并优化出合理的水平段长度、无因次水平段避水高度和生产压差，其值分别为375 m，0.9和1.0 MPa。应用正交设计试验极差分析法，研究了水平段长度、无因次水平段避水高度和生产压差对水淹规律的综合影响，结果表明，水平井参数对见水时间的影响程度由大到小依次为: 生产压差、无因次水平段避水高度、水平段长度; 对无水期累积采油量的影响程度由大到小依次为: 无因次水平段避水高度、水平段长度、生产压差; 较大的无因次水平段避水高度、较小的生产压差和较长的水平段长度可以延长水平井的见水时间，提高无水期累积采油量，更有利于底水油藏水平井开发。

关键词: 底水油藏 水平井 水淹规律 数值模拟 水平井参数

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中国底水油藏储量大，在开发过程中均存在见水时间早、见水后油井产量急剧下降等缺点[1-10]，高效开发此类油藏具有重要意义。喻高明等[1]利用数值模拟方法研究了采油速度、油水流度比、夹层等因素对砂岩底水油藏开采效果的影响。中国石油勘探开发研究院采用现代电子摄像监视手段和流动试验测试手段，建立了水平井开发底水油藏的二维模型系统[2]，研究水平段长度对无水期累积采油量、无水期采收率及见水时间的影响，以及生产压差对见水时间、无水期采出程度及最终采出程度影响的规律。笔者在前人研究的基础上，运用正交设计试验极差分析法[3]，研究了水平段长度、无因次水平段避水高度、生产压差及其组合对水平井开发底水油藏的影响，以期为延长底水油藏见水时间、提高无水期累积采油量提供参考。

1 地质模型

以胜利油区临盘采油厂某区块储层及流体物性参数为基础，建立三维地质模型。油藏顶面埋深为856 m，有效厚度为25 m，底水厚度为6 m，油水界面埋深为886 m，泄油半径为250 m，孔隙度为0.2，水平渗透率为600 $\times 10^{-3}$ μm^2，垂向与水平渗透率之比为0.15，含油饱和度为0.65，原始地层压力为8.83 MPa，地层温度为50 ℃，原油体积系数为1.1，地层原油密度为0.9 g/cm^3，地层水密度为1.013 g/cm^3，地层原油和水的粘度分别为2和0.5 mPa·s。

模型采用54×35×12的笛卡尔网格系统[4]，I方向网格步长为15 m，J方向网格步长为10 m，K方向网格步长为3 m。在模型中间布置水平井，采用Fetchovich分析水体模拟底水。

2 水平井参数对水淹规律的影响

2.1 水平段长度

为对比不同水平段长度对底水油藏水淹规律的影响，将水平段长度与泄油直径之比定义为无因次水平段长度。水平井定生产压差(1.0 MPa)生产，无因次水平段避水高度(水平段避水高度与油层厚度的比值)为0.7，模拟研究了水平段长度分别为150，225，300，375和450 m，对应的无因次水平段长度分别为0.3，0.45，0.6，0.75和0.9时的水淹规律。数值模拟结果(图1)表明，随着无因次水平段长度的增加，见水时间和无水期累积采油量随之增加，含水率上升速度减慢，合理的无因次水平段长度为0.75，即水平段长度为375 m。

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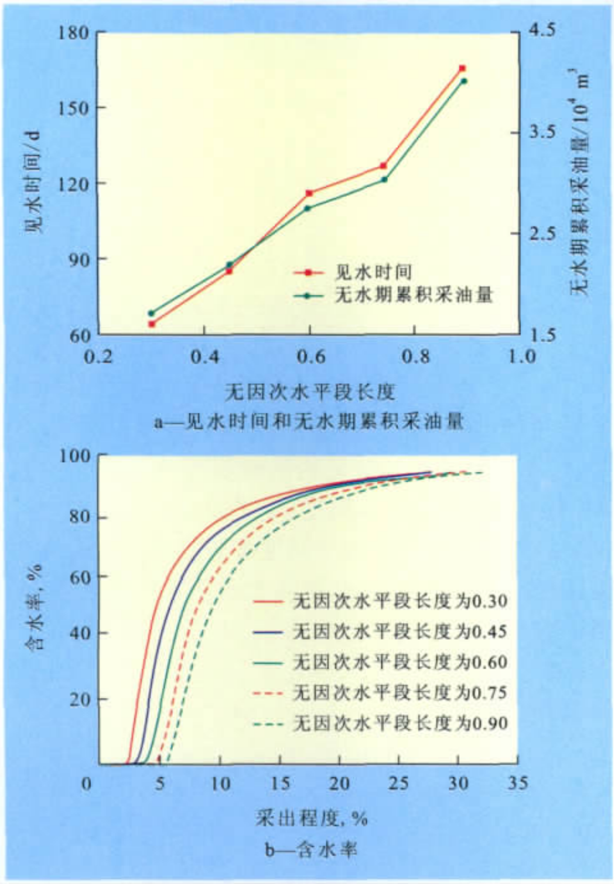

图 1　无因次水平段长度与见水时间和无水期累积采油量及含水率的关系

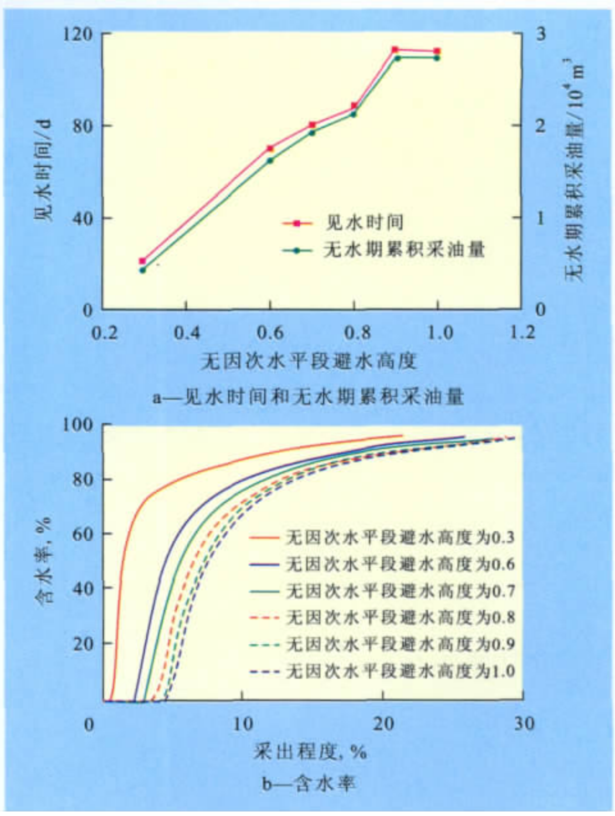

图 2　无因次水平段避水高度与见水时间和无水期累积采油量及含水率的关系

2.2　无因次水平段避水高度

为对比不同水平段避水高度对底水油藏水淹规律的影响，水平井定生产压差(1.0 MPa)生产，水平段长度为 375 m，模拟研究了无因次水平段避水高度分别为 0.3，0.6，0.7，0.8，0.9 和 1.0 时的水淹规律。数值模拟结果(图 2)表明，随着无因次水平段避水高度的增加，水平段见水时间随之延长，无水期累积采油量也随之增加，含水率上升速度减慢。合理的无因次水平段避水高度为 0.9。

2.3　生产压差

为了对比不同生产压差对底水油藏水淹规律的影响，模拟研究了水平段长度为 375 m，无因次水平段避水高度为 0.9，生产压差分别为 0.5，1.0，1.5，2.0 和 2.5 MPa 时的水淹规律。数值模拟结果(图 3)表明，随着水平段生产压差的增加，水平段见水时间呈递减趋势，无水期累积采油量也随之减小；随着水平段生产压差的减小，含水率上升速度减慢，但变化不大。因此，较小的生产压差有利于水平井开发底水油藏。合理的水平段生产压差应为 1.0 MPa。

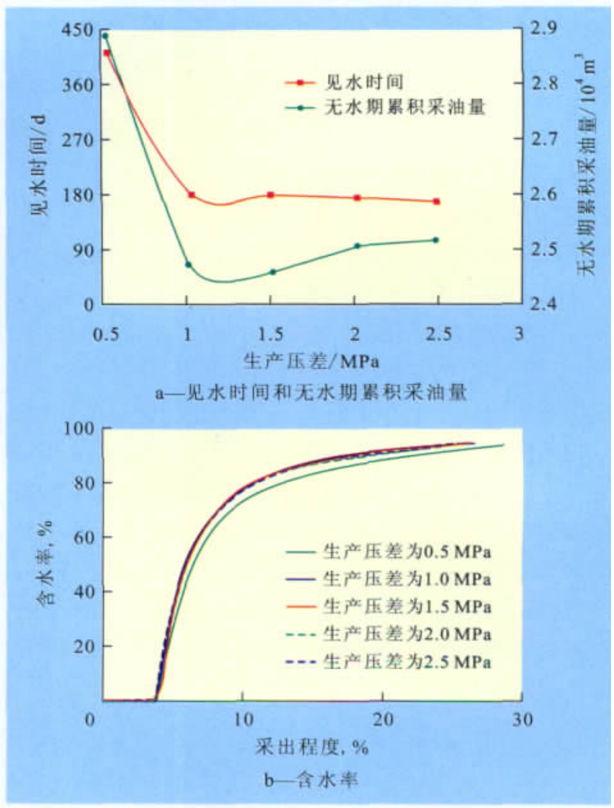

图 3　生产压差与见水时间和无水期累积采油量及含水率的关系

3 水平井复合参数对水淹规律的影响

水平井复合参数对水淹规律的影响指水平段长度、无因次水平段避水高度和生产压差的综合对水淹规律的影响。利用正交设计试验方法设计了 9 种实验方案(方案 1—9)。其中,水平段长度 3 个水平,分别为 225,300 和 450 m;无因次水平段避水高度 3 个水平,分别为 0.3,0.5 和 0.7;生产压差 3 个水平,分别为 0.5,1.0 和 2.0 MPa(表 1)。采用极差分析法[3],研究了水平井复合参数对水平井见水时间和无水期累积采油量的影响(表 1)。

表 1 水平井复合参数对见水时间和无水期累积采油量的影响

实验方案	水平段长度/m	无因次水平段避水高度	生产压差/MPa	见水时间/d	累积采油量/m^3
1	225	0.3	0.5	206	4 734.6
2	225	0.5	1.0	196	11 380.5
3	225	0.7	2.0	172	19 478.3
4	300	0.3	1.0	68	6 967.8
5	300	0.5	2.0	88	16 636.7
6	300	0.7	0.5	1 095	35 040.0
7	450	0.3	2.0	39	11 878.8
8	450	0.5	0.5	730	25 550.0
9	450	0.7	1.0	360	40 150.0

利用极差分析法计算可知,不同水平的水平段长度、无因次水平段避水高度和生产压差对应的见水时间极差分别为 225.667,438.000 和 577.333 d;对应的无水期累积采油量极差分别为 13 995.133,23 695.700,5 776.934 m^3。由此可见,水平井复合参数对见水时间的影响程度由大到小依次为:生产压差、无因次水平段避水高度、水平段长度;若从见水时间考虑,底水油藏水平井开发过程中,应优先确定合理的生产压差,然后确定合理的无因次水平段避水高度,最后确定合理的水平段长度。水平井复合参数对无水期累积采油量的影响程度由大到小依次为:无因次水平段避水高度、水平段长度、生产压差;若从无水期累积采油量的角度考虑,在水平井开发底水油藏过程中,应优先确定合理的无因次水平段避水高度,然后确定合理的水平段长度,最后确定合理的生产压差。较大的无因次水平段避水高度和较小的生产压差可以延缓水平井见水时间,提高无水期累积采油量。

4 结论

较长的水平段长度、较高的无因次水平段避水高度、较小的生产压差有利于水平井开发底水油藏。水平井复合参数对见水时间的影响程度由大到小依次为:生产压差、无因次水平段避水高度、水平段长度,对无水期累积采油量的影响程度由大到小依次为:无因次水平段避水高度、水平段长度、生产压差。较大的无因次水平段避水高度和较小的生产压差可以延缓水平井见水时间,提高无水期累积采油量,有利于底水油藏开发。

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China

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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