河南油区稠油油藏水平井开发技术

杨晓培
(中国石化股份河南油田分公司 勘探开发研究院,河南 南阳 473132)

摘要:河南油区稠油油藏通过直井蒸汽吞吐取得了较好的开发效果,但部分储量丰度较差的浅薄层稠油油藏及叠瓦状分布的条带状边水稠油油藏,采用常规直井开发,单井可采储量低,很难取得经济效益。为合理开发河南油区稠油油藏未动用储量,利用数值模拟技术,结合其地质特点,开展水平井开发技术研究,优化了水平井及注采工艺参数。结果表明:水平井目的层段垂深应大于 150 m;最佳水平段长度为 80 ~ 150 m;水平井与油水边界的距离大于 60 m 后,基本未见边水入侵;水平井与断层距离大于 20 m 时,断层不会开启;井底注蒸汽干度大于 50%,开发效果明显改善;第 1 周期注汽量为 2 000 t,油汽比和周期产油量均较高,分别为 0.54 t/t 和 1 000 t,吞吐效果较好;当注汽速度为 300 t/d 时,优选注汽压力为 14 MPa、排液速度为 20 t/d 左右比较合理。

关键词:稠油油藏 浅薄层 边水 水平井 注采参数 河南油区
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河南油区稠油油藏具有埋藏浅、厚度薄、分布散的特点,其中部分稠油储量由于含油层位单一,含油宽度较小等原因,采用常规直井开发,单井可采储量低,经济效益差。随着水平井技术的发展,该类油藏可得到较好动用,一方面水平井可以通过扩大泄油面积提高单井产油量,另一方面水平井可以减缓边水的推进速度。为进一步合理高效开发河南油区稠油油藏,开展了水平井开发技术研究,优化了水平井的部署条件及注采参数。

1 油区概况

河南油区稠油油藏地质情况复杂、原油性质特殊,已开发的新庄、井楼、古城和杨楼 4 个油田,位于南襄盆地泌阳凹陷,是典型的中新生代山间小型含油气断陷湖盆,受南侧基底大断裂控制,均为南深北浅的箕状凹陷,基底落差为 5 800 ~ 8 000 m。储层为古近系核桃园组的扇三角洲、三角洲和湖相沉积,具有砂体多、面积小、厚层发育、岩性复杂和非均质性强的特点。油藏类型主要为构造 - 岩性油藏、断鼻油藏、断块油藏和背斜油藏。油田原始驱动类型为弹性水压驱动,压力系数小,弹性能量低。局部层系和开发单元有较充足的边水能量,为边水驱油藏。油层胶结松散,平均孔隙度为 33%,渗透率为 1 ~ 4 μm^2,含油饱和度为 75%,油藏温度下地面脱气原油粘度为 979.45 ~ 137 079 mPa·s。

2 水平井参数优化

衡量稠油油藏水平井是否具有经济效益最直观的指标是累积产油量和油汽比[1-2]。累积产油量决定能否收回钻井投资,而油汽比决定是否具有开采效益。结合累积产油量和油汽比 2 项指标,利用数值模拟技术及实际生产情况,对河南油区稠油油藏水平井相关参数进行优化论证。

2.1 水平井目的层段垂深

浅层水平井能否实施与不整合面深度、地层胶结程度、岩性等多种因素有关。表层套管深度制约着水平井目的层段的垂深[3],因为造斜点在表层套管以下 50 ~ 60 m 才能开始定向,造斜点太浅,地层胶结过于松软,井径扩大率易过大;另外,钻具质量轻,钻压小,严重影响造斜率。从目前钻井工艺水平分析河南油区稠油油藏水平段垂深的下限约为 150 m。根据河南油区自身特点,2007 年部署 4 口浅层稠油油藏水平井,目的层段垂深为 160 ~ 194 m,位垂比为 1.94 ~ 2.42。因此,水平井目的层段的垂深应大于 150 m。

2.2 水平段长度

注蒸汽热采水平井存在着直、斜段井筒热损失,水平段物性变化造成水平井吸汽不均,部分水平段

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作者简介:杨晓培,男,高级工程师,从事油气田开发研究。联系电话:(0377)63836219,E - mail:yxp19591007@163.com。
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加热效果变差[4-5]。因此，热采水平段长度并非越长越好，河南油区已投产井的实际开发效果及数值模拟结果(图 1)显示，对于厚度为 3 m 的油层，水平段长度超过 80 m 后，水平井累积产油量达到经济产油量，产油量及油汽比增幅变缓；当水平段长度为 150 m 时，水平井累积产油量及油汽比基本没有增幅，据此确定最佳水平段长度为 80 ~ 150 m。

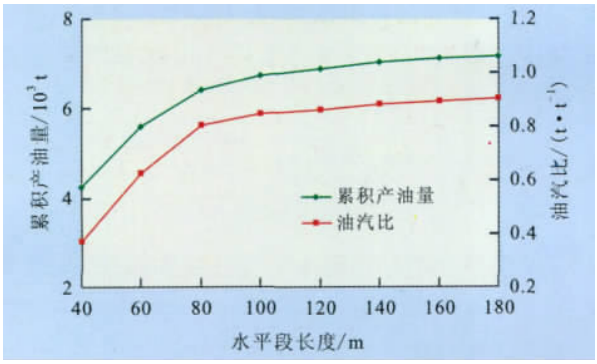

图 1　水平段长度与累积产油量和油汽比的关系

2.3　水平井与油水边界的距离

边水稠油油藏采用直井开发往往导致压差过大，引起边水锥进、指进，而水平井是通过扩大油层泄油面积来提高油井产量的[6-9]，因此开采过程中抑制边水的能力，相对于直井更具优势。数值模拟结果(图 2)表明，水平井与油水边界的距离超过 60 m 后，基本未见边水入侵，而直井与油水边界的距离超过 90 m 才能获得较好效果。新浅 24 – 平 3 井距离油水边界最近，为 56 m，该井累积生产 552 d，累积产油量为 4 120 t，目前仍处于正常吞吐阶段。为确保水平井开发效果，分析认为水平井与油水边界的距离大于 60 m 较为合理。

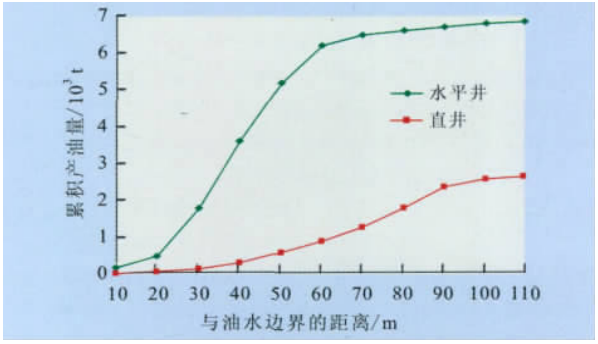

图 2　累积产油量与油水边界的关系

2.4　水平井与断层的距离

稠油注蒸汽吞吐时，为防止蒸汽吞吐致使断层开启[10]，需考虑水平井与断层的距离。断层的临界开启压力与油藏埋深、断层倾角有关。物理模拟实验表明，当断层处地层压力上升为 3.65 MPa 时，断层将开启。采用数值模型模拟了注汽时断层附近压力变化，历史拟合第 1 周期注汽压力为 14 MPa，注汽量为 3 000 t，注汽结束 12 d 后，注汽压力的传递距离约为 50 m。由注汽期间井底压力与原始地层压力之差的径向分布(图 3)可知，生产井与断层距离为20 m时，井底压力较原始地层压力升高了3.65 MPa。河南油区稠油油藏所部署水平井中，新浅25 – 平 7 井距离断层最近，约为 18 m，该井第 1 周期注汽压力为 14 MPa，注汽量为 1 515 t，周期产油量为 722 t，周期产水量为 109 m^3，截至 2011 年 12 月 27 日，累积产油量为 4 627 t，未发生断层开启现象。数值模拟及生产实践证明，当水平井与断层的距离大于 20 m 时，断层不会开启。

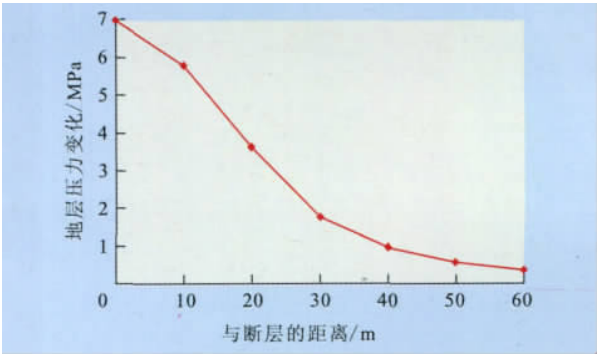

图 3　注汽期间井底压力与原始地层压力之差的径向分布

3　注采工艺参数优化

3.1　注蒸汽干度

在相同的蒸汽注入量下，蒸汽干度越高，注入单位体积蒸汽的热焓值越大，加热效果越好[11]，数值模拟结果(表 2)表明：在注汽量相同的前提下，井底注蒸汽干度从 10% 增加到 50%，周期产油量从 778 t 增加到 1 072 t，油汽比由 0.39 t/t 增加到 0.54 t/t，开发效果明显改善，河南油区稠油油藏井底注蒸汽干度约为50%，均取得了较好的效果。因此，综合

表 2　井底注蒸汽干度对水平井吞吐效果的影响

注蒸汽干度，%	生产时间/d	周期注汽量/t	周期产油量/t	油汽比/(t·t⁻¹)
10	60	2 000	778	0.39
30	65	2 000	928	0.46
50	67	2 000	1 072	0.54
60	69	2 000	1 126	0.56
70	70	2 000	1 130	0.57

优选的井底注蒸汽干度应大于 50% 。

3.2 注汽量

在油层厚度为 3 m、水平段长度为 100 m、井底注蒸汽干度为 50% 的条件下，模拟了第 1 周期注汽量为 500，1 000，1 500，2 000，2 500，3 000，3 500 和 4 000 t 时的蒸汽吞吐开发效果。在优化时，既要确保获得较高的累积产油量，又要确保获得较高的累积油汽比。模拟结果(图 4) 表明，第 1 周期注汽量为 2 000 t 时，油汽比和周期产油量均较高，分别为 0.54 t/t 和 1 000 t，吞吐效果较好。为了不断扩大蒸汽吞吐的加热半径，提高开发效果，根据稠油开发经验，后续吞吐周期注汽量依次递增 15% 。

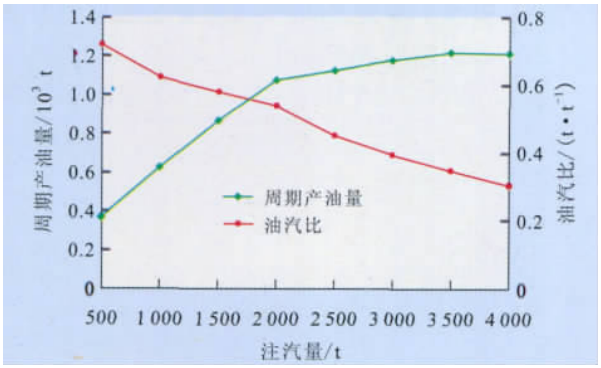

图 4 注汽量与周期产油量和油汽比的关系

3.3 注汽速度及压力

注汽速度高有利于降低热损失，提高热能利用率，提高注汽速度也可缩短油井停产注汽的时间，有利于增产。数值模拟结果表明，随着注汽速度的增加，周期产油量和油汽比也随之增加，当注汽速度大于 300 t/d 时，周期产油量增加幅度很小。河南油区稠油油藏水平井注汽速度约为 300 t/d，第 1 周期生产效果统计表明，产油量约为 11 t/d，取得了较好的开发效果。综合分析认为，河南油区稠油油藏水平井注汽速度应优选为 300 t/d。

注汽压力与注汽速度存在相关性，当注汽速度从 200 t/d 提高到 300 t/d 时，最大注汽压力从 13.5 MPa 提高到 14.5 MPa，在保证注汽速度的条件下，优选注汽压力为 14 MPa 比较合适，不过在现场实际操作时，以小于地层破裂压力为基准，根据现场实际注入情况，在确保安全的前提下可适当提高。

3.4 排液速度

在油层供液能力允许的条件下，尽可能快速采出是提高开发效果的重要措施。从减少回采过程中热损失和提高采油速度的角度出发，排液量大比较好; 但从抑制边水突进、储层条件、地层能量保持和提高最终采收率来看，水平井热采排液量并不是越大越好。开发实践表明，水平井排液速度控制在 20 t/d 左右比较合理。

3.5 其他技术

为确保水平井的开发效果，采用了定向射孔、注氮气、降粘剂辅助蒸汽吞吐[10] 及短周期吞吐等技术，通过一系列的技术革新，较大程度地抑制了边水的推进速度，扩大了水平井蒸汽吞吐波及半径，提高了驱油效率。

4 结束语

河南油区稠油油藏水平井开发实践证实，水平井是开发边水及薄层油藏有效的技术，今后应该加大对常规直井难开发区块的储量评估及效益评估，利用水平井技术动用难采储量。

由于水平井的油层厚度为 3 m 左右，钻进实施存在一定难度和风险，因此应加强沉积微构造及微相研究，确保水平井严格中靶。同时进一步加强配套工艺技术的科技攻关，不断提高浅薄层油藏的开发效果，拓宽该类油藏的动用界限。

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application technology, the horizontal well has little production without fracturing. The flow rates of the fractured horizontal well with open hole completion are only more than that of perforation completion at the initial time. The gas production rises with the increasing number of fractures, and the flow rate in each fracture is approximately equal at the unsteady state. But, for the quasi-steady state, there is a "U" shape gas output distribution of fractures due to the interferences from fractures and wellbore. Taking the production technology and economic factors into consideration, the fractured horizontal wells with perforation completion should be more suitable for the tight gas reservoir. The interferences from fractures have to be paid enough attention in fracturing design, so, there should be longer fractures at both ends of horizontal wellbore.

Key words: tight gas reservoir; fractured horizontal well; unsteady state; quasi-steady state; fractures; completion methods

Xu Mengya, MOE Key Laboratory of Petroleum Engineering, China University of Petroleum (Beijing), Beijing City, 102249, China

Yang Xiaopei. Development techiniques of horiontal wells on heavy oil reservoir, Henan oilfield. *PGRE*, 2012, 19(2): 72-74.

Abstract: The development of steam stimulation in vertical wells has acquired preferable effects in the host area of Henan heavy oil reserves. But the technique of conventional vertical well, in thin layer of the heavy oil reserves with poor reserves abundance and banded edge water heavy oil distribution, has low single well recoverable reserves, and it is difficult to obtain economic benefits. In order to develop the reserves mentioned above, we consider the geologic characters of Henan heavy oil reserves and use numerical stimulation to carry out the research in horizontal well, and then optimize the deployment and production parameters of horizontal well in Henan heavy oil reserves. The results show that: the vertical depth of horizontal intended interval should be greater than 150 m; the best horizontal length is 80-150 m, and the oil production and oil-gas ratio have no increment; when the horizontal well away from oil-water boundary farther than 60 m, edge water invasion rarely occurs; when the horizontal well is greater than 20 m away from the fault, the fault will not open; when the dryness fraction of steam at bottom of the well is greater than 50%, the development effect has been significantly improved; when the first circle steam injection is 20 t/m, oil-water ratio and cyclical oil production have a high value, 0.54 t/t and 1 000 t, the effect of huff and puff is better; when steam inject speed is 300 t/d, the optimized injection pressure is about 14 MPa, and the rate of delivery at about 20 t/d is reasonable.

Key words: heavy oil reservoir; thin and shallow beds; edge water; horizontal well; injection-production parameter; Henan oilfield

Yang Xiaopei, Research Institute of Exploration and Development, Henan Oilfield Company, SINOPEC, Nanyang City, Henan Province, 473132, China

Wang Peixi, Liu Renjing. Universal model of stress sensitive coefficient for low permeability reservoir. *PGRE*, 2012, 19(2): 75-77.

Abstract: The study on stress sensitivity in low permeability reservoir has attracted more and more attentions of researchers home and abroad, but, there is so far no common understanding on it. To describe the stress sensitivity of low permeability more accurately, the relationship between permeability and effective pressure and its effect factors are studied by laboratory experiments with variable fluid pressures, while keeping confining pressure steady. On this base, a stress sensitive coefficient is presented according to the definition method of rock compressibility, and combined with fractal theory, a universal model of stress sensitive coefficient is built after taking into account of the effect of pore structure, effective stress and hysteresis effect. The results show that the permeability decreases in step shape with the rise of effective stress, and it is related to pore structure and effective stress loading way. The stress sensitive coefficient of permeability can characterize the rock sensitivity quantitatively: the larger the value, the stronger the stress sensitivity. The model built in this paper, taking into account of the effect of pore structure, the effective stress changes and hysteresis effect, can characterize the stress sensitivity in general, and it can forecast the permeability change laws with the change of effective stress, so, it has a wide adaptability. This result has important significance to the further study of stress sensitivity in low permeability reservoir.

Key words: low permeability reservoir; stress sensitivity; pore structure; universal model; hysteresis effect

Wang Peixi, School of Petroleum Engineering, China University of Petroleum (East China), Qingdao City, Shandong Province, 266555, China

Wang Yong, Wu Xiaodong, Han Guoqing et al. Numerical simulation study on horizontal well in foamy oil reservoir. *PGRE*, 2012, 19(2): 78-80.

Abstract: Foamy oil is a kind of heavy oil containing dispersed little gas bubbles, showing different characteristics from conventional oil flow during natural depletion, and its oil production is high, gas oil ratio is low, and formation pressure declines slowly and recovery is high. The technique for simulating foamy oil using numerical simulation is proposed, and the model of foamy oil is established based on the laboratory study. The result comparison between the foamy oil and dissolved gas drive reservoir proves the reliability of the model qualitatively and quantitatively. An in-depth study of drive mechanism of foamy oil is carried out. The dispersed gas generated from the production of the foamy oil reservoir increases the flow capacity of crude oil, and also increases the expandability of the system, and ameliorates the draw down of the reservoir pressure, therefore, enhancing the elastic recovery.

Key words: foamy oil; cold heavy oil production; numerical simulation; component model; relative permeability

Wang Yong, CNOOC Research Institute, Beijing City, 100027, China

Liu Li. Laboratory study on stress sensitivity of threshold pressure gradient in low permeability reservoir. *PGRE*, 2012,