

川西须家河组致密砂岩气藏水平井钻井关键技术

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摘 要 四川盆地西部上三叠统须家河组储层具有埋藏较深、非均质性、岩石致密、破裂压力高等特性。对于该类致密砂岩气藏要获得较好的开发效果需钻遇裂缝发育带,然而常规直井、定向井钻遇裂缝概率小,很难获得理想产能,因而水平井钻井便成为高效开发该类气藏的重要手段。钻井周期长、事故率高、钻井成本高是目前该区水平井钻井面临的瓶颈难题。为此,从三压力剖面、井壁稳定性以及实钻资料分析入手,提出了利于该区须四段和须二段水平井安全、快速钻井的井身结构方案;从技术、经济两方面分析了旋转导向钻井技术在须家河组水平井应用的可行性,推荐在造斜段应用旋转导向、在水平段采用常规随钻测量(MWD)施工的轨迹控制方案,并配套与之相适应的轨迹设计方案;提出了利于润滑防卡和保障井壁稳定的钻井液配套技术方案;通过分析钻井液排量、密度等因素对井眼净化的影响,提出了6条具体的井眼净化技术措施。所形成的水平井钻井关键技术已成功应用于该区3口井,与第一批完钻水平井相比,机械钻速提高18.94%,钻井周期缩短28.47%。

关键词 四川盆地西部 晚三叠世 致密砂岩气藏 水平井 井身结构 旋转导向 随钻测量 井眼净化

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2009年底,中国石油化工股份有限公司整体提交四川盆地西部新场气田上三叠统须家河组须二段气藏探明储量超过 $1\,000 \times 10^8 \text{ m}^3$,成为2009年度中国地质找矿十大成果之一。川西须家河组致密砂岩气藏已成为中国石化西南油气分公司今后几年在其所属矿权区内的重点开发层位。对于该致密砂岩气藏要获得较好的开发效果需钻遇裂缝发育带,然而常规直井、定向井钻遇裂缝概率小,因而针对须四段、须二段裂缝性气藏采用水平井开发、提高天然裂缝钻遇概率、提高单井产能、实现稀井高产势在必行。针对须家河组水平井钻井速度慢、钻井周期长、轨迹难控制、无经验可借鉴等难题,科技人员从井身结构、钻井方式、轨迹控制、井眼净化等方面开展了大量研究和试验,并成功实施第一批水平井(X21-1H和X10-1H井),2口井替喷测试均获得超过 $30 \times 10^4 \text{ m}^3/\text{d}$ 的高产。在已钻井基础上,对井身结构、轨迹控制等关键技术进行不断改进和完善,最终形成了适合于川西须家河组致密气藏的水平

井钻井关键技术方案,并成功应用于X21-2H等川西3口水平井以及川东北元坝地区多口水平井。

1 水平井钻井难点

川西须家河组尤其是新场气田须四段和须二段地层异常复杂,复杂的工程地质条件导致水平井钻井面临诸多困难,目前该地区实施水平井钻井主要存在以下工程技术难点^[1-3]:

1.1 井身结构优化受到多种因素的制约

须二段上部的须三段—须五段地层压力系数高达1.95,而须二段地层压力系数仅1.60左右,多口直井在须二段顶部发生井漏,势必要在须三段底部设置一个必封点,以缓解须二段地层的钻井难度。这就存在一个矛盾:①若要便于在须二段钻进,就应选择 $\varnothing 203.2 \text{ mm}$ 以上尺寸钻头,上层套管势必较大($\varnothing 244.5 \text{ mm}$ 左右),而大套管不能满足抗内压、抗挤要求,更重要的是不能满足安全钻须二段地层的井控需要,尤其是须

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二段气藏存在高产可能情况下(X851、X856 井无阻流量介于 $100\times 10^4\sim 400\times 10^4\text{ m}^3/\text{d}$), 技术套管需定制; ②若要套管强度满足安全要求, 则应采用高钢级、大尺寸套管封隔须二段以上地层, 须二段地层钻进要用小尺寸钻杆和钻头钻进, 存在钻头寿命短、轨迹不易控制、携岩困难等难题; ③水平井因须二段地层的可钻性差需要花费大量时间, 若油层套管下至须三段底部, 由于须二段目的层离上层套管鞋还有 200~ 400 m 的垂直距离, 长时间浸泡易造成裸眼段井壁失稳。

1.2 钻遇地层复杂, 起下钻阻卡严重, 斜井段钻井周期长

无论是须二段还是须四段, 主要目的层并不是均匀的单一岩性, 常常钻遇砂泥岩互层、煤层、煤线等。井斜大于 80° 后, 0.1 m 厚的泥岩或煤线将水平穿行 7~ 8 m, 且易导致该井段岩石剥落等。钻遇夹层等复杂情况后, 普遍采用划眼、循环、稠浆洗井等技术措施来加以解除, 但由此导致频繁起下钻, 增加钻井辅助时间和钻井周期。X10-1H 井第 4 次开钻单是处理井塌和卡钻的划眼时间就达 17%。

1.3 岩石致密, 造斜率低, 造斜速度慢, 纯钻率低下

须家河组岩石致密, 可钻性级值高(介于 5~ 8 级), 常规螺杆造斜速度慢, 造斜率低。采用牙轮钻头造斜, 进尺少, 钻速慢; 采用 PDC 钻头造斜, 工具面难以控制, 钻井效率低^[4]。X10-1H 井第 4 次开钻井段长 1 187 m, 纯钻利用率仅 23.25%, 严重制约了钻井提速。

1.4 采用常规钻井方式, 井眼轨迹控制难度大

水平井钻井的关键是轨迹控制^[5,6], 随着井斜的增大, 钻具在重力作用下斜躺在下井壁上, 钻铤施加的钻压很难传递到钻头, 低钻压条件下钻速慢。斜井段特别是水平段摩阻和扭矩随着水平位移的增加迅速增大。采用常规钻井工艺施工川西中深层水平井钻井难度大。若接近目的层时地质预测偏差大于 10 m, 进行轨迹调整难度大, 甚至无法实现地质中靶。如 X10-

1H 井钻至井斜 75° 时, 距离 A 靶点垂深仅 12 m, 地质录井判断地层提前 13 m, 采用常规钻进工艺已不能实现中靶, 只能以安全钻井为主(调整靶点)。国外应用较好的旋转导向钻井系统还没有在川西地区应用。在轨迹监控方面, 目前普遍采用 MWD 和 LWD 随钻测量监测井眼轨迹。

2 井身结构优化

通过对已钻井资料的分析结合对三压力剖面的深入研究, 认为在理论情况下, 以须家河组为主要目的层建立井口后, 采用二开制井身结构即可完成钻井施工, 但实际操作起来却存在很大弊端。为此, 科研人员根据钻井复杂情况分析, 进行工程必封点选择, 考虑到水平井造斜速度慢、起下钻趟数多、钻井周期长以及钻井液长时间浸泡导致裸眼段稳定性变差、井下复杂情况出现概率增加等因素, 井身结构优化时仍以安全钻井和优快钻井为主要考虑出发点。优化结果^[7]如表 1 所示。

第一次开钻 $\varnothing 339.7\text{ mm}$ 套管封剑门关组地层, 为下开钻遇浅气层提供井控支撑; 第二次开钻 $\varnothing 244.5\text{ mm}$ 或 $\varnothing 273.1\text{ mm}$ 套管封沙溪庙组或白田坝组, 为揭开须家河组高压气提供井控支撑, 同时减少大尺寸井眼长度, 利于缩短钻井周期; 须四段水平井设计第三次开钻完钻, 下 $\varnothing 139.7\text{ mm}$ 套管或筛管, 须二段水平井需要在 A 靶点或须二段顶部再下一层套管, 主要是考虑井下安全(须二段压力系数相对较低、水平段长、斜井段井壁稳定性差), 完钻后下 $\varnothing 127.0\text{ mm}$ 套管或筛管。

优化的井身结构在 X21-2H 井、X21-4H 井以及 X8-1H 井成功应用, 从钻井情况看, 未出现因井身结构设计不合理导致的井下复杂情况。与前期完钻井相比, 钻井速度显著提高, 钻井周期同比缩短 15% 以上。

表 1 水平井井身结构优化结果表

项目	开钻次数	钻头程序	套管程序		备 注
		井眼尺寸/mm	套管尺寸/mm	下入井深/m	
须四段水平井	1	$\varnothing 444.5/\varnothing 406.4$	$\varnothing 339.7$	300~ 500	封剑门关组, 建立井口
	2	$\varnothing 311.2$	$\varnothing 244.5$	2 400~ 2 700	封沙溪庙组或白田坝组
	3	$\varnothing 215.9$	$\varnothing 177.8$ 套管 $\varnothing 139.7$ 套(筛)管	4 500~ 5 000	根据完井方式确定管串结构
须二段水平井	1	$\varnothing 444.5/\varnothing 406.4$	$\varnothing 339.7$	300~ 500	封剑门关组
	2	$\varnothing 311.2$	$\varnothing 273.1$	2 400~ 2 700	封沙溪庙组
	3	$\varnothing 241.3$	$\varnothing 193.7$ 套管	4 700~ 5 000	封须三段以上高压层或 A 靶点
	4	$\varnothing 165.1$	$\varnothing 127.0$ 套(筛)管	5 500~ 5 900	根据钻井显示确定完井方式

3 水平井钻井关键技术

针对上述钻井难点,对井身剖面优化设计、井眼轨迹控制、钻井液、井眼净化等关键技术进行了攻关,提出了配套技术措施和方案。

3.1 井身剖面优化技术

针对须家河组储层埋藏较深、气层多的特点,地质普遍设计多个靶点,如 X10-1H 井要求在 T_{3x2}^4 、 T_{3x2}^5 砂组内穿越分别不得少于 650 m 和 300 m,要实现层间降斜、层内增斜,常规五段制剖面难以满足要求,只能设计为阶梯水平井。轨迹设计时以满足地质中靶和安全钻井为首选。通过对悬链线、圆弧线和侧位悬链线轨道的对比分析,结合定向工具特点以及施工操作难易程度等因素,在轨道设计时主要采用圆弧轨道进行设计^[8],造斜点选择在须家河组,造斜率低于 $18^\circ/100\text{ m}$ ($1.0^\circ \sim 1.5^\circ$ 单弯螺杆或旋转导向均能实现)。

3.2 井眼轨迹控制技术

须家河组特别是须二段及其以深地层的高温高压特征使得常规螺杆钻具和随钻测量仪器难以满足施工需要,急需在满足温度、压力的前提下实现定向和旋转导向钻井的井下工具和数据准确传输的随钻测量仪器。通过对螺杆钻具组合和轨迹测量控制工具(MWD、LWD)的深入研究,优化出了 $\varnothing 311.2\text{ mm}$ 、 $\varnothing 241.3\text{ mm}$ 、 $\varnothing 165.1\text{ mm}$ 井眼的 3 套螺杆钻具和配套钻具组合,形成了抗温 165°C 、抗压 158.6 MPa 的高温高压无线随钻测量设备配套技术。X10-1H、X21-1H、X21-2H 井采用抗高温 MWD 和电子多点均成功实现斜井段轨迹控制,为安全钻井和顺利下套管提供了保障。

针对须家河组水平井轨迹控制难点,调研分析了旋转导向钻井技术的特点和优势^[9],从技术、经济两方面分析了旋转导向钻井技术在须家河组水平井的可行性。推荐在造斜段应用旋转导向,水平井采用常规 MWD 施工的轨迹控制方案,若钻遇复杂地层(夹层、垮塌层)时采用常规 MWD 随钻监测。X21-2H 井采用旋转导向工具造斜钻进,平均机械钻速达 2.21 m/h ,井眼轨迹平滑。同时,根据盈亏平衡原理,结合须家河组深井最新钻井技术指标,分别计算出须四段、须二段水平井应用旋转导向取得直接经济效益的极限机械钻速和最低经济进尺,为今后川西深层水平井应用旋转导向提供了参考。

3.3 保障井下安全的钻井液技术

针对川西地区须家河组水平井钻井难点和特点,

重点对斜井段井眼净化、润滑防卡和护壁性进行了研究。通过深入分析井眼净化影响因素及技术调研^[10],形成了井眼净化技术优化措施:①合理调整钻井液性能,动塑比控制在 $0.6 \sim 0.8$ 之间,同时提高低剪切速率下的黏度(3 r/min 和 6 r/min 下的读数);②提高环空返速,环空返速超过 0.9 m/s (岩屑总浓度控制在 5% 以内)。通过室内研究,形成了钻井液润滑性能优化方案:①优化固控措施,提高离心机的使用率,减少细颗粒岩屑的含量;②优选润滑剂,优选出复合润滑剂 $4\%\text{ RH220} + 1\%\text{ RH102} + 1\%$ 塑料小球。通过室内研究,优选出性能较好的抑制防塌处理剂聚胺 UHIB,作为川西地区须家河组水平井钻井液体系的抑制防塌处理剂,提高井壁稳定性。研究成果应用于 X21-2H 井等 4 口井,较好地指导了现场施工,未出现井壁垮塌和净化不良,与 X21-1H 井相比,起下钻次数减少 13 趟,大大减少划眼时间,缩短了钻井周期。

3.4 斜井段井眼净化技术

井眼净化问题是中深层水平井钻井的难点和关键。岩屑床的存在,增大了钻具上下活动的摩擦阻力和钻进时的扭矩,易产生卡钻、断钻具等井下事故^[11]。针对该区须家河组水平井钻井难点,系统分析了斜井段钻井液性能、井径扩大率、机械钻速、钻具转速、钻井液排量等对井眼净化的影响,提出以下 6 条具体优化建议:

1) 优化钻具结构,减少循环压耗。在地面机泵条件受到限制的情况下,推荐采用旋转导向钻进方式。

2) 合理调整钻井液性能。通过对 3 种钻井液复配性能的分析发现,高密度、高黏度、高切力形成的泵压高,相同井段岩屑床高度最低。实际施工过程中,宜适当降低流性指数,提高动塑比,使处于紊流流态钻进,钻进过程中间断泵入一定量的比原浆黏度低的钻井液,使其成为紊流态循环,再配合泵入比原浆黏度高的钻井液来清除环空岩屑。

3) 加强短程起下钻,清除死角岩屑。

4) 选择合理的钻井方式和钻进速度。通过须二段深井机械钻速和钻具转速的不同配置得出:机械钻速高于 40 m/h 、转速低于 60 r/min 时,岩屑床高度偏差较大。对于致密气藏水平井而言,斜井段机械钻速普遍低于 3 m/h ,应重点考虑钻具转速对井眼净化的影响,建议采用复合钻井方式,钻具转速大于 60 r/min 。

5) 积极研制破坏岩屑床的新工具、新技术。建议采用螺旋钻铤并将斜井段加重钻杆的本体加厚部分加工为螺旋形,在转动钻具的同时搅动底边岩屑床,提高其运移速度。

6) 优化钻井设计, 加强轨迹监控, 降低井径扩大率。开钻前, 充分论证地层稳定性, 避免钻进过程中出现井壁失稳和坍塌掉块; 减少 50° 左右斜井段长度; 优选旋转导向工具, 减少因地质变化带来的轨迹调整, 降低全角变化率。

4 现场应用效果

优化方案应用于 X21-2H、X21-4H、X21-4CH、X8-1H 等井, 目前完钻 3 口井。平均完钻井深 4 640.5 m、平均机械钻速 2.7 m/h、平均钻井周期 142.59 d, 与第一批完钻水平井相比, 完钻井深减少 295.8 m、机械钻速提高 18.94%、钻井周期缩短 28.47%, 同时节约套管约 300 t。X21-2H 井在川西地区首次采用 AutoTraK 旋转导向工具, 20.58 d 顺利完成了造斜段 3 400~4 027.79 m 的井眼轨迹控制, 钻井总进尺 6 27.79 m, 纯钻时间 283.7 h, 纯钻利用率 57.43%, 平均机械钻速 2.21 m/h, 井眼轨迹平滑, 最大全角变化率小于 $18^\circ/100$ m, 未发生任何事故。3 口井合理调整钻井液配方和性能, 斜井段多次采用段塞洗井, 未出现井眼净化不良现象, 起下钻摩阻小于 30 t, 划眼时间缩短 57%。

5 结论与建议

1) 通过 3 口井的应用效果表明, 优化形成的川西须家河组水平井井身结构方案, 在钻井提速、降低环保压力、降本增效方面应用效果良好。

2) 旋转导向钻井技术在技术和经济上均适合于川西须家河组水平井, 在保障井下安全的前提下, 建议延长应用井段并推广应用。

3) 建议将所取得的研究成果推广应用到川东北及国内类似地区, 以提高钻井效率。

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An optimal design for herring bone well trajectory drilling through coalbed gas reservoirs

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NATUR. GAS IND. VOLUME 31, ISSUE 4, pp. 76-79, 4/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: Extremely low permeability of coalbed gas reservoirs will have a negative effect on the coalbed methane development in China. The herring bone wells can effectively maximize the reservoir exposure area to improve the production rate out of each methane gas well so as to be commonly used for coalbed gas development in recent years. However, the conventional 2D trajectory design method is hard to meet the requirements of each horizontal branch for a good herring bone well trajectory design. In view of this, a 2D well trajectory design is first achieved by respective treatment of each branch regarded as an independent unit with the main vertical wellbore. Then according to the features of herring bone wells, a model for the optimization design of herring bone well trajectory is set up and the relationship between each horizontal branch bore and the mother bore is also studied. The results show that with the increase in well depth and the build up rate, the angle between the branch bore and the mother bore will increase, and the offset of the branch bore away from the mother bore will also gradually increase. For such a constant angle, the build up rate is in inverse proportion to the well depth, that is, the higher the build up rate, the shorter the branch; or vice versa.

Key words: coalbed methane, development results, herring bone, ML horizontal well, well trajectory, optimization design, drillability, build up rate, well depth

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Key techniques of horizontal drilling through Xujiache tight sandstone gas reservoirs in the western Sichuan Basin

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NATUR. GAS IND. VOLUME 31, ISSUE 4, pp. 80-83, 4/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: The upper Triassic Xujiache gas reservoirs in the western Sichuan Basin are featured by large burial depth, strong heterogeneity, tight sands, high fracture pressure, and so on. To achieve a better result in gas recovery here, the wells have to be drilled through those well developed fractures. However, the previous conventional vertical wells or directional wells could hardly meet with the fractures so the expected productivity was difficult to be obtained. That is why the horizontal well drilling has become an important method for effective development of such gas reservoirs even though its major bottleneck problems include a long drilling cycle, a high accident ratio, and a high cost. In view of this, through an analysis of the 3 pressure profile, the wellbore stability, and actual drilling data, a casing program is developed for safe and fast horizontal drilling through the second and fourth members of the Xujiache formations. And after a feasibility study is made on the application of rotary steering technology in horizontal drilling through Xujiache formations in terms of technology and economics, it is recommended to adopt rotary steering in build up section drilling and conventional measurement while drilling (MWD) trajectory control in horizontal section drilling, with proper matching trajectory designed. A drilling fluid formulation helpful for lubrication and wellbore stability is also developed. In addition, through a deep investigation into the effects of drilling fluid flow rate and density on well cleaning, 6 pieces of well cleaning advices are made. After all the above technical measures were used in 3 wells in this area, in comparison with the previously drilled horizontal wells, the ROP have been increased by 18.94%, and the drilling cycle shortened by 28.47%.

Key words: west, Sichuan Basin, Late Triassic, tight sandstone gas reservoir, horizontal well, casing program, rotary steering, measurement while drilling (MWD), well cleaning

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Application of liner cementing and screen pipes in horizontal section in the Dongfang 1-1 Gas Field, Yinggehai Qiongdongnan Basin

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Abstract: The well B7hSa is a horizontal well drilled by CNOOC Zhanjiang Company at the Dongfang 1-1 Gas Field, Yinggehai Qiongdongnan Basin, with a shallow pay zone, but the drilling process was rather complicated. When the second spud in was drilled to the top of the target zone, where due to poor petrophysical properties, after the cement plug was set to plug back the well, another $\varnothing 311.15$ mm sidetrack was newly drilled, which led to a large trajectory variation and a high friction torque, and before the subsequent $\varnothing 244.5$ mm casing has not been run to the well bottom, there is an uncased length of 677 m. While a water zone existed at the interval between 2930-3015 m to be isolated. After technical advisory work in combination with actual situation, we determined to add liner on the top of the screen pipe in the horizontal section, and then to cement the liner. As a result, the operation has been successful and the well has been effectively completed. On basis of this, we introduce in detail the basic principle, the string configuration, main matching tools, the optimal design of tools, the whole operation process, as well as the key points and measures for each job of this screen top liner cementing technology, and also summarize the experiences for design and field practice of this technology, which will provide reference for future similar operations in other fields.

Key words: Yinggehai Qiongdongnan Basin, Dongfang 1-1 Gas Field, horizontal well, quality sand screen, hanger, staging collar, external casing packer (ECP), blank off sub

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Methods for severe slugging control in a deepwater riser and their simulation analysis

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Abstract: Severe slugging will easily occur in a deepwater riser. If not controlled, it will cause serious safety problems. Accordingly, a comprehensive research has been performed on the deepwater riser severe slugging control methods at home and abroad. The advantages, disadvantages, field application and application scope of them are summarized. The flow regimes of typical years are simulated by means of OLGA, a kind of multi phase transient software, based on the submarine pipe and riser data of a certain deepwater oil and gas field. Choking, gas lift, and gas lift choking methods are adopted to simulate the controlling of severe slugging in the most severe year. Moreover, the relationship between pipeline diameter and severe slugging is discussed. The studies demonstrate that severe slugging occurs in the mature stage of an oil or gas field. The influence of severe slugging should be fully considered in the phase of the pipe diameter optimization and design. Different controlling methods should be chosen according to different situations. For a specific deepwater project, various factors should be taken into consideration during software simulation in order to choose an economic and effective method for slugging control.

Key words: deepwater riser, severe slugging, OLGA, choking, gas lift, pipeline diameter, liquid holdup, wellhead back pressure