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PDC钻头在普光 10井空气钻井中的应用*

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摘要:长期以来人们一直认为,在气体钻井中 PDC钻头机械钻速没有牙轮钻头高,而且气体散热能力差,易损坏 PDC钻头的复合片而使钻头早期失效,因此,在气体钻井中绝大多数使用牙轮钻头。在普光 10井空气钻井中应用 PDC钻头,主要目的是验证 PDC钻头的适应性,并探索在高陡构造、岩石可钻性差的地层控制井斜和提高钻井效率的方法。在该井空气钻井施工中,利用 PDC钻头加较低的钻压便可获得较高机械钻速,配套应用塔式防斜钻具,达到了有效控制井斜和提高钻井效率的目的,最大井斜 2.59°,比邻井空气钻井井斜小 13.6%~75.4%,PDC钻头钻进进尺 1517.08 m,机械钻速 8.63 m/h,比邻井普光 101井机械钻速高 67.1%。通过分析认为,气体的散热效果并不是影响 PDC钻头寿命的根本原因,而只影响井眼环空的畅通和单位时间通过钻头的气量;PDC钻头+塔式钻具可有效地控制井斜,提高钻井效率。

关键词:空气钻井;PDC钻头;机械钻速;应用

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在用钻井液钻井的过程中,钻头不会出现过热现象,而在气体钻井中,由于气体的比热容很小,热传导性能也不好,那么气体钻井中能否保证钻头的冷却呢?尤其是 PDC钻头会不会由于温度过高而使钻头提前损坏呢?所以人们普遍担心的问题是气体冷却效果不如钻井液好,有可能“烧坏”钻头。普光 10井应用 PDC钻头的尝试,为今后 PDC钻头的改进和推广应用提供可借鉴的经验。

1 普光地区空气钻井过程中存在的问题

普光地区空气钻井地层为遂宁组、沙溪庙组、下沙溪庙组属陆相地层(井段 600~3500 m),砂、泥、页岩互层,地层砂岩石英含量高、胶结致密,井壁稳定性相对较好,局部区域沙溪庙组有微量出水。但该井段存在以下技术问题。

(1)易井斜。地层局部小褶皱多倾角大(普光 1井测井资料 54°)造斜力强,控制井斜保证井身质量难度大。

(2)机械钻速慢。地层富含硅质的岩石硬度大、研磨性强、可钻性差,牙轮钻头可钻性级值在 5级以上的地层约占 80%,而且岩石的不均质性、多变性,使得钻头选型困难,钻进中憋跳严重,影响了钻头的使用效果,降低了机械钻速。普光地区已完钻 8口探井(钻井液钻井),平均钻井周期 343.58 d,全井平均机械钻速 1.62 m/h,二开遂宁组~须家河组井段(井眼尺寸 311 mm或 314 mm)平均机械钻速 1.53 m/h。

2 钻头选型

空气钻井除取心外,很少用 PDC钻头,主要原因是空气钻井钻头破岩以冲击破碎为主,与钻井液钻井破岩机理有所不同,机械钻速不如牙轮钻头快;另外,怕钻头在与地层岩石间摩擦产生高温“烧坏”钻头。因此,气体钻井应用牙轮钻头居多,并且为了防止钻头的早期损坏,钻头都是金属密封钻头。

普光地区已完钻的空气钻井,除个别井用空气锤外,大多以牙轮钻头为主,牙轮钻头的缺点是为了保证井身质量,加钻压小机械钻速慢,加钻压大容易产生井斜,尤其钻遇高陡构造地层更容易产生井斜。普光地区地层倾角达到 54°,为了保证井身质量必须用小钻压钻进,但机械钻速太慢,经济效益差。

为了达到既控制井斜、保证井身质量,又能提高机械钻速的目的,在普光 10井空气钻井中,尝试应用 PDC钻头。

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3 钻井过程中温度对 PDC钻头的影响

PDC钻头在井底工作时,与岩石摩擦生热使钻头温度上升,与钻头尺寸、钻压、转速以及摩擦因数等因素有关,采用 Memarzadeh提出的热量计算模型

$$Q_h = 0.23667\mu W_e ND \quad (1)$$

式中, Q_h为钻头与地层单位时间摩擦产生的热量, J/min; μ为摩擦因数,取 0.4; W_e为钻压, kN; N为转盘转速, r/min; D为钻头直径, cm。

气体流经钻头将钻头与地层摩擦产生的热量吸收,使钻头冷却。据热平衡理论,气体吸热模型为

$$Q_g = \frac{p\rho_f \gamma C\Delta t}{p_0} \quad (2)$$

式中, Q_g为气体吸收钻头与地层摩擦产生的热量, J/min; ρ_f为标准状态下气体密度, kg/m³; γ为注气速率, m³/min; C为气体比热, J/(kg·℃) (空气 1.4); Δt为钻头与地层摩擦产生的温度, ℃; p为注气压力, MPa; p_0为大气压, MPa。

在钻进过程中钻头产生的热量通过如下 4个渠道转化:

(1)被井底、环空的流体带走,属于直接传热。

(2)传递给钻柱,通过钻柱与循环流体的接触散热;如果散热量小于来自于钻头导热量,则引起钻柱温度升高。

(3)超过水气化点的温度使井下微量水气化,水的气化潜热带走了热量。

(4)热量积累于钻头体造成钻头体温度的逐步升高。

只有当各种渠道的散热能力之和小于钻头的发热能力时,才会造成钻头体温度的逐步升高。这种情况发生在注气量不足、地层出水造成钻头被泥包、井壁和钻具上形成滤饼环使环空不畅通, PDC钻头齿处的局部升温或瞬时高温首先对钻头齿造成损坏,导致钻头的早期失效。

以普光 10井为例:当最大钻压 160 kN,最高转速 90 r/min,井眼尺寸 314 mm,注气压力 1.9 MPa,注气量 120 m³/min时,用式 (1)、式 (2)计算,结果表明钻头与井底摩擦 1 min产生的热量使气体温度升高 15 ℃,如果环空不畅通或注气量太小,钻头温度会上升导致钻头损坏。

4 实际应用及效果分析

4.1 钻具结构

实践表明,气体钻井比钻井液钻井易发生井斜,但原因还不十分清楚,一些学者通过岩石力学分析和钻柱力学计算机模拟仿真计算分析认为可能有 2个方面的原因,一是气体钻井时井底岩石处于受拉状态,地层各向异性比钻井液钻井时表现得突出;二是钻具在空气中的降斜力比在钻井液中要小。为了保证下部钻具具有较大的降斜能力,普光 10井采用了塔式钻具结构 + PDC钻头,钻具结构为:塔式钻具 + PDC钻头钻具结构: Ø314.3 mmWH361USSP—7PDC×0.42 m+630×731+ Ø228.6 mm浮阀 ×0.7m+ Ø228.6 mm单流阀 ×0.5m+ Ø228.6 mm钻铤 ×43.31 m+731×630×0.44 m+ Ø203 mm钻铤 ×35.74 m+631×410×0.46 m+Ø177.8 mm钻铤 ×25.37 m+ Ø127 mm钻杆 +Ø127 mm旋塞 ×0.43 m+Ø127 mm单向阀 ×0.55 m+Ø133.5 mm六方方钻杆。

4.2 技术措施

根据地层变化、测斜数据及时调整钻井参数,钻压控制在 60~160 kN,转速 70~85 r/min。当钻进软硬交界层降低钻压,钻进软地层钻时快时适当控制钻压;每钻进 200~300 m进行测斜,如果井斜小则加正常钻压钻进,如果井斜有增加趋势,则降低钻压钻进。

4.3 钻头的使用情况

该井共用了 3只钻头, 1只 PDC钻头 (2次入井),进尺 1517.08 m,平均机械钻速 8.63 m/h,起出钻头 PDC片、保径齿有轻微磨损,还可继续钻进; 2只三牙轮钻头,进尺 605.83 m,平均机械钻速 6.1 m/h。使用情况分析见表 1。

表 1 不同钻头钻进参数比较

序号	钻头直径 /mm	钻头型号	钻进地层	钻进井段 /m	钻压 / kN	转速 / r·min⁻¹	钻速 /m·h⁻¹
1	314.3	WH361USSP—7(PDC)	遂宁组—上沙溪庙组	881~1585.29	60~80	60~70	11.42
2	314.3	HJT537GK	上沙溪庙组	1585.29~2046.55	100~160	70~75	6.38
1	314.3	WH361USSP—7(PDC)	上、下沙溪庙组	2046.55~2859.34	80~120	75~85	7.12
3	314.3	HJT537GK	下沙溪庙组	2859.34~3003.91	80	75~85	8.55

从表 1可见，普光 10井 PDC钻头加钻压比牙轮钻头小，剔除地层变化的影响因素，机械钻速与牙轮钻头基本接近，而防斜效果比牙轮钻头好，同时钻头使用寿命长，单只钻头进尺多，没有掉牙轮风险。

4.4 防斜效果

881～1585 m为 PDC钻头钻进井段，钻压低、转速受旋转防喷器转速限制控制在 100 r/min以下，增斜率 0.187 (°)/100 m，最大井斜 0.99°。

1585～2046 m井段是牙轮钻头钻进井段，由于钻压比较大，因此增斜快，最大井斜 1.69°，增斜率 0.6 (°)/100 m。

2046～2859 m井段是 PDC钻头钻进井段，钻压中等，最大井斜 2.59°，增斜率 0.195 (°)/100 m，小于牙轮钻头钻进井段的增斜率。

4.5 与邻井对比

PA—2、P6—3、普光 D—1、老君 1、普光 101也是普光地区应用空气钻井的试验井，使用的是三牙轮钻头，与普光 10井进行对比，见表 2。

表 2 与邻井空气钻井比较

井号	钻头尺寸及型号	井段/m	进尺/m	机械钻速/m·h⁻¹	钻井周期/d	钻头数量/只	最大井斜/(°)
PA—2	314 SHT33G、ST537、HJT517GK	649.6～3036	2386.6	4.48	37	10	3.5
P6—3	同上	704～3350	2646	6.41	24	4	3
普光 D—1	同上	564～3002	2438	8.5	20	5	3.6
普光 101	314HJT537GK	642.3～3554	2911.7	4.8	51	10	10.42
老君 1	314HJT537GK	762～3253.7	2491.7	11.4	22	5	10.5
普光 10	314PDC、314HJT537GK	881～3003.91	2122.91	8.02	17.4	3	2.59

从表 2数据可见，普光 10井的机械钻速除了比老君 1井的低，与普光 D—1井基本持平，比其他 4口井都高的多；井斜是最小的。老君 1井是靠高钻压 (140～180 kN)，以大井斜为代价，获得较高的机械钻速，为后续施工埋下了隐患。

在空气钻井中，给牙轮钻头加过大的钻压容易发生断钻具事故，如老君 1井空气钻进井段为 762～3253.7 m，使用牙轮钻头，大部分井段以 120～180 kN钻压钻进，虽然获得了 11.37 m/h的机械钻速，但断钻具 3次，井斜达到 10.5°。而普光 10井只断了 1次钻具。

4.6 PDC钻头存在的问题

PDC钻头钻遇夹层速度较慢，加压不敏感；可供空气钻井选择的 PDC钻头类型少；在使用中要保证足够的注气量保持井眼清洁，特别要注意地层出水时防止钻头泥包。

5 认识与建议

(1)从普光 10井 PDC钻头应用情况看，PDC钻头应用于空气钻井尽管存在一些问题，只要保证井眼清洁，不会发生“烧坏”钻头的现象，机械钻速与牙轮钻头相当，而且有利于控制井斜，也减少了井下钻具事故。

(2)井斜是影响气体钻井速度的最大障碍，采用轻压吊打防斜是比较消极的措施，普光 10井应用塔式钻具＋PDC钻头防斜效果比牙轮钻头好，机械钻速不亚于牙轮钻头；钻头寿命长，单只钻头进尺多，减少了发生井下事故的机会。

(3)目前用于气体钻井 PDC钻头不仅数量少，而且钻进井段也比较短，主要原因是可供选择的钻头类型少，缺乏针对地层个性化设计，影响了 PDC钻头的机械钻速。

(4)根据普光地区井身结构，塔式防斜钻具的钻铤尺寸偏小，下部钻具刚度不足影响防斜效果，建议下部钻具采用：Ø254 mm钻铤×3根 (约 25 m)＋Ø228.6 mm钻铤×6根 (约 50 m)＋Ø203 mm钻铤×6根 (约 50 m)＋Ø177.8 mm钻铤×9根 (约 85 m)。

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serves control. This paper analyzes the characteristic of the reservoirs of Daqing peripheral oilfield, deals with the design and construction of the first staircase horizontal well of Aonan Oilfield-Aonan 242-ping 317, and illustrates some difficulties and countermeasures to construct staircase horizontal wells in thin reservoirs. This well has been successfully drilled, which proves that medium-radius horizontal wells can improve the drilling meeting efficiency of sandstones in thin reservoirs and are suitable for developing Aonan reservoirs. In addition, their application provides technical support for the economic and effective production of low permeability multi-layer reservoirs and lays a solid foundation for the expansion of exploration area and the economic and effective production of the unproducing reserves under complex geological conditions.

Key words: Aonan Oilfield; thin reservoir; staircase horizontal well; drilling

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Adaptability analysis on completion methods of horizontal wells in Liaohe Oilfield. LIU Chun-ze, LIU Yang, LIU Wei. ODPT, **2007, 29 (1): 15-18**

Abstract: According to the status quo and the field application of horizontal well completion techniques in various reservoirs of Liaohe Oilfield, this paper analyzes and evaluates the completion structure and steam injection effect of huge thickness viscous horizontal wells, the completion structure and sand control effect of severely sanding production horizontal wells, and the completion methods of horizontal wells in heavy oil reservoirs with edge and bottom water and thin oil reservoirs with edge and bottom water to analyze the adaptability of horizontal well completion methods applied in different reservoirs. The optimum well completion method selects that can be applied to various types of oil reservoirs is selected. This is very important for improving the development result of the horizontal wells in Liaohe Oilfield and can be referred as a good selection to horizontal well completion methods.

Key words: horizontal well; well completion method; adaptability; analysis and evaluation

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Analysis of mechanics characteristics of deepsea drilling risers. LI Zhong, YANG Jin, CAO Shi-jing, HUANG Yi, GUO Yong-bin, XIE Ren-jun. ODPT, **2007, 29 (1): 19-21**

Abstract: The relatively poor deepsea environmental conditions lead to the complex capacities of the deepsea drilling risers. The strength and stability of the riser can be precisely estimated only by analyzing their mechanics characteristics. Finite element analysis is used to establish a deepsea drilling riser dynamic analysis model under complex marine conditions such as ocean current and wave. During this process, simplified approach to the action modes of ocean current and wave is suggested and it is proposed to ascertain the positive effect of wave by analyzing the forces of riser system under different conditions. It is indicated that the effective depth of wave force is related to the wave height and period, that is, the effective depth of wave force is increasing with increasing wave height and decreasing wave period, and vice versa. In addition, the variation of drilling risers' stresses and strains at different water depth under the influence of various loading modes is analyzed by the means of finite element analysis software ANSYS, providing a scientific basis for the strength design of deepsea drilling riser columns.

Key words: deep sea; riser; wave; ocean current; finite element

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Research on diameter ratio of pilot to enlarger of two-stage bits using bottom-hole stress field. PENG Ye, SHEN Zhong-hou. ODPT, **2007, 29 (1): 22-24**

Abstract: The excavation analysis of the bottom-hole three dimension stress field excavation is carried out on the two-stage bits of three diameter ratio Ø190.5 mm×Ø311 mm, Ø215.9 mm×Ø311 mm, and Ø241.3 mm×Ø311 mm in order to research the diameter ratio of pilot to enlarger. The analysis model, excavating methods, analyzing process, and analysis options of the bottom-hole stress field are applied during the research process. The distribution curve of the bottom-hole stress field is obtained, which shows that the radial stress of the Ø241.3 mm×Ø311 mm bit is more completely released and is favorable for increasing the penetration speed. The difference between radial stress and circumferential stress of the Ø215.9 mm×Ø311 mm bit gets smaller but it still has great potential to improve its penetration rate. The difference of radial stress and circumferential stress of the Ø190.5 mm×Ø311 mm bit is small and the potential to increase penetration speed. Its optimum diameter ratio of pilot to enlarger is 0.7~0.8.

Key words: excavating method; numerical analysis; FEM; stress field of bottom-hole; bit design

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Application of PDC bits in air drilling of Puguang-**10** well. ZHANG Han-lin, LI Ji. ODPT, **2007, 29 (1): 25-27**

Abstract: It has long been held that the penetration rate of PDC bits is lower than roller bits during air drilling. Owing to the poor heat delivery capability of air drilling the compact sleet of PDC bits is easily to be damaged that will result in their early failure Therefore roller bits are more widely used in air drilling than PDC bits The major objectives of applying PDC bits in air drilling of Puguang-10 lie in verifying the adaptability of PDC bits and developing approaches to control hole deviation and improve drilling efficiency in high inclined formation of low rock drillability The penetration rate can be increased by applying PDC with lower weight on the bit In addition hole deviation can be effectively control and drilling efficiency can be improved based on using PDC and tapered inclining prevention drilling tools in air drilling of Puguang10 The maximum deviation angle of Puguang 10 is only 2 59°, smaller than that of its adjacent well while the footage drilled is 1517. 8 m and the penetration rate is 8 63 m/h which is also higher than that of the adjacent well The author believes that heat disseminating capacity of gas is not the basic cause of shortening the life of PDC bits but only affects the hole cleaning and the volume of gas passing through the bits Hole deviation can be effectively controlled and drilling efficiency can be improved by applying PDC bits and tapered inclining prevention drilling tools in air drilling

Key words air drilling PDC bit penetration rate application

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Design on electrical connectors of cable transmission in intelligent wells XIAO Shi-hong LIANG Zheng REN Lian-cheng ODPT 2007 29 (1): 28-30

Abstract Cable transmission has its intrinsic advantages and it is the development tendency of intelligent drilling among all kinds of signal transmission The circuit is required to be automatically switched on electricity as the pin end and box end of drillpipes are screwed together A specially designed electrical connector must be fixed on each end of the cable to carry out the function Based on analyzing various overseas designs of electrical connectors and their working conditions the author redesigns a new type electrical connector The structure of helcial spring of cylindrical compression is adopted which prolongs its service life reduces its contact resistance and improves its sealing capacity Lip structure is designed at the end of the sealing components making the electrical connector has self cleaning function This newly designed electrical connector makes full use of the contact space of the pin end and box end of drillpipes and reduces the energy consumption of drilling fluid circulation It also has the functions of simple structure better sealing property automatic compensation automatic cleaning capability absorbing vibration and anti-torsional capacity etc. What's more it has no special requirement on the types of drillpipes connectors and the drill operating parameters The new design promotes the development of cable transmission technology to a certain extent

Key words intelligent well cable transmission new type electrical connector design promote

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Research on critical sand transportation velocity for low Viscosity liquid flow in vertical well-bore LIU Ai-ping DENG Jin-gen ODPT 2007 29 (1): 31-33

Abstract Afterwell or reservoir sanding critical sand transportation velocity is an important parameter for sand transportation design of vertical well bore It can be worked out by adding a fixed coefficient of correction to the granule free settling terminal velocity Based on theoretical and experimental analysis the problem of shape coefficient measurement is solved through conducting granule settling experiment in virtue of the replacement of the equivalent diameter of equal volume by the equivalent diameter of equal sedimentation velocity In addition the formula of critical sand transportation velocity is established for the Dongying formation reservoir of Chengbei area through sand transportation test The research results show that the correction coefficient of critical sand transportation velocity I increases with the decrease of the granule diameter in low viscosity fluid It varies from 1. 45 to 2. 90 under conditions of the critical sand transportation experiment These results are available to calculate the critical sand transportation velocity of no silting in vertical well bore of low sand grain concentration and can be referred to solve the sand transportation difficulties of vertical well bore in other areas

Key words critical sand transportation velocity vertical well bore coefficient of correction grain settlement sand transportation low viscosity liquid

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Layering oil production technology of rod jet pump ZHANG Hong-lu WU He-xiang ODPT 2007 29 (1): 34-36

Abstract To solve the problems of rod pump such as stroke loss and lower pump efficiency caused by fluid production force deficiency in the formation of the low permeability but high oil saturation the layering oil production technology rod jet pump is developed It is required that a jet pump be added at the end of a rod pump and high permeability formations and low permeability formations be separated through packer As the power fluid of the jet pump the liquid produced from high permeability formations can be utilized to improve the liquid producing capacity of low