Vertical section construction of wells at Kuyumbinsky oil field via percussive-rotary drilling with DTH hammer.

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Abstract. The article presents the analysis of sequential use of mobile percussive-rotary drilling sets with DTH hammer and bottom-hole cleaning by foam mud in construction of vertical sections along with at Kuyumbinsky oil field. On the basis of the analysis, an engineering solution is proposed to prevent disastrous mud loss that is the key factor of efficiency in implementation of resource-saving technologies.

1. Introduction

The analysis of the current situation in Russian oil and gas sector demonstrates a considerable shift in its development towards the regions of Eastern Siberia and Yakutia. During 2006-2014, JSC Rosneft discovered six fields at the license blocks of Irkutsk Region: 2 oil-gas condensate fields (Severo-Danilovskoye and Savostyanov fields); 1 gas-oil field (Lisovsky field); 2 oil fields (Sanarskoye and Mazur fields); 1 gas field (Yuzhno-Danilovskoye field).

On January 1, 2015 the total reserves of the above-mentioned fields amount to 477 million tons of oil and condensate and 192 billion m^3 of gas [1]. At present, Irkutsk and Yakutia gas production centers, with PJSC Gazprom as the main investor, are being built. To ensure the efficiency of the implemented projects, particularly at times of difficult macroeconomic situation, there is an urgent need to use resource-saving technologies [2].

One of the perspective engineering solutions for oil and gas drilling with mud loss is a sequential use of mobile percussive-rotary drilling sets with fixed drilling rigs and drilling mud circulation.

2. Material and Methods

The analysis of modern experience, including foreign (the USA, China, Canada), has shown high technological efficiency of applying air, nitrogen, fog, foam and gas-liquid muds in similar geological conditions [3].

In 1999-2015, 963 wells were drilled in China using gaseous fluids, including 676 wells in Szechuan, in partnership with experts from Chuanqing Drilling Engineering Company (CCDC) [4].

Bottom-hole cleaning with gaseous muds was applied at various depths. In particular, drilling of 508 mm, 426mm, and 324mm sections with percussive-rotary drilling was considered the most successful in Shangluo field with the casing depths of 60m, 350m and 600m respectively. Depending on the size of water inflow and reservoir properties it is advisable to drill 245mm and 168mm sections to the depths of 1,450m and 2,800m using foam, gas-liquid mud or aerated mud.

In 2014, LLC Intes initiated pilot works on the construction of vertical 426mm and 324mm sections along with down-the-hole drilling of water wells and bottom-hole cleaning with foam mud at Kuyumbinsky oil field (Krasnoyarsk Region).

The chosen design and engineering solution was caused by specific characteristics of the geological structure, namely incompatibility of drilling conditions within the field marked by disastrous mud loss in the interval ranging from 6 to 540 meters [5].

Investigating drilling conditions incompatibility alongside with lost circulation and factors contributing to their origin, as well as nature of existence and statistics of elimination, allowed experts of LLC Intes to make the following conclusions:

1. Disastrous mud loss was observed in the gross interval of the Evenkiiskaya Suite (6-540 meters) characterized by fractured dolomites (75%), laminated marls and marlstones (15% and 10% respectively) with high alteration and heterogeneity of rocks through the section.
2. Well deepening accompanied by lost circulation begins at the required capacity of mud pumps (36 hp) thus ensuring high-quality bore-hole cleaning and stability of PDM motors DRU-240.

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3. Application of various wall packing materials and fractions, profile packers, reduction of the drilling mud specific weight, as well as introduction of visco-elastic mud did not bring any positive results within the drilling interval under study. Only repetitive cement plugs are productive (on average 3-5 per interval).
4. Intensive mud loss while deepening a well with surface rotor drive lead to drilling rate limits of up to 2-3 m/h, including due to presence of hard streaks. In case of DDM drilling it is necessary to provide bottom-hole continuous supply of industrial water, taking into account 50 m^3/hour absorption [5].

Development of the individual drilling program for vertical intervals of wells of Kuyumbinsky oil field with the use of DTH hammer became one of the key measures in design and implementation of the aforesaid technology: the analysis of drilling patterns for studied sections, justification of the chosen equipment and development of recommended drilling parameters.

Geological structure of the Evenkiiskaya Suite determines the presence of well walls taluses and collapses in poorly cemented shattered terrigenous deposits along with mud loss. For design purposes it was decided to consider 35 meters as the instability boundary of terrigenous deposits. Besides, the statistical analysis allowed the specialists to reveal common lost circulation patterns and sharp drilling rate decrease within the range of 60-80m in depth. Water inflow of up to 12 m^3/h observed within the studied interval was also taken into account.

Relevance and novelty of engineering solutions that ensure borehole stability, maintenance of the required drilling rate and implementation of the most suitable well construction program are caused by the construction of 426mm vertical sections 35m in depth and 324mm conductors to the depth of 550m by applying the mobile drilling complexes with DTH hammers.

Practical feasibility of the project challenged engineers and researchers to use tools, which were not applied earlier in Russian oil and gas industry, to solve the problem of mud loss, drilling rate, and optimization of well deepening in geological conditions of oil fields within Eastern Siberia.

The drilling rig “COOPER 550 LTO” was chosen as a plant capacity stock unit aimed to build emergency intervals for vertical sections and conductors. The loading capacity of the rig amounted to 106.5 tons that ensured lowering the 324mm casing to the depth of 550 meters [6].

In order to pass through quaternary deposits it was planned to drill the first ten meters using a 520mm drill bucket KFB-K. In fact, drill bucket footage made 1.2 meters at a time because it required further lifting to clean the drill cuttings. In doing so, the following drilling mode was chosen: axial loading - 1 ton, rotation frequency – 60 rpm, torque – 0.5 kN·m. Table 1 shows the bottom-hole assembly in drill bucket drilling.

Table 1. Bottom-hole assembly within 0-10 m.

Item	Description	Length, m
1	Drill bucket KFB-K 520 No.2606	2.34
2	Drill collar UBT-203 No.05	1.5
3	Drilling tool substitute 3-117x3-121L	0.4
4	Kelly VBT-112	11.4

When reaching 10m bottom-hole and depth of 35m the design implied drilling with a crushing-chipping tool from surface rotor drive with further air-blast cleaning of a well. Drilling without an air hammer in this interval was justified by substantial risks of well walls taluses and collapses. To ensure air-blast cleaning the drilling rig was equipped with three SULLAIR Combo 1150XHH/1350XHDL compressors with 38.2 m^3/min rated capacity and 2.4 MPa developed pressure. The designed bottom-hole assembly is indicated in Table 2.

Table 2. Bottom-hole assembly for surface casing drilling

Item	Description	Length, m
1	Drill bit EBXT1GS III 508 mm s\n 11767592	0.7
2	Drilling tool substitute M 3-177/M 3-152 No.22707	0.56
3	Stabilizer III 444 mm No.512-10	2.28
4	Drilling tool substitute H 3-152/M 3-mm No.104	11.4
5	Drill collar UBT-203 mm	4.5
6	Drilling tool substitute 3-117x3-121L	0.4
7	Kelly VBT-112 mm	11.4

Drilling mode parameters: axial loading - 2 tons, rotation frequency – 40 rpm, torque – 0.5 kN·m.

The air hammer and drill bit selection procedure offered by the Halco Company laid the basis for developing a program section containing technical and engineering solutions for drilling within the interval of 324mm (from 35 to 550 meters) [7, 8]. Figure 1 shows the drill bit selection pattern.

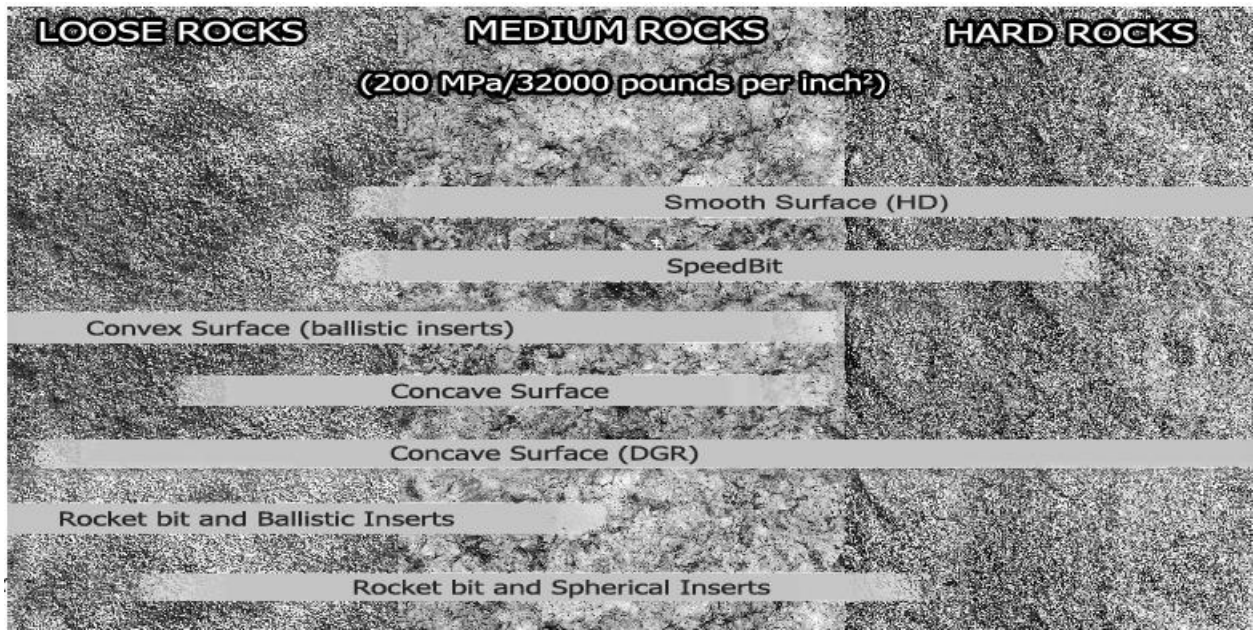

Fig.1. Drill bit selection pattern

A concave drill bit without double gauge teeth (Concave) was selected for standard operating conditions with the maximum control of a wellbore vertical position for rocks of the Evenkiiskaya Suite, mainly for medium rocks. Spherical substrates ensuring the best operational characteristics and length of service at all designed modes recommended by the Halco were selected for drilling extremely hard and abrasive rocks. The diameter of the drill bit was 381mm.

Two fundamental requirements were satisfied while following Halco air hammer selection methodology: the required speed of rock lifting and the maximum similarity of the outer diameter with the diameter of the well. Tables 3 and 4 show the highest lifting speed achieved when applying the air hammer Mach 122/132/142 [2].

Table 3. Air flow rate for Halco hammers (m^3/min.)

Hammer type	0.7 MPa	1.05 MPa	1.2 MPa	1.4 MPa	1.7 MPa	2.4 MPa
Dominator 100	1.6	2.6	3.0	3.5	4.5	-
Mach 20	2	3.8	4.8	5.8	7.6	-
Mach 303	2.8	4.4	5.0	5.9	7.3	10.0
Dart 350	2.5	4.7	5.6	7.0	9.3	13.8
Dominator 350	2.3	4.4	5.2	5.5	8.5	12.5
NT4	4.3	5.5	8.8	11.0	13.2	15.5

Mach 44	4.8	7.0	8.0	9.5	12.0	17.2
Dominator 400/ S-Dominator 400	5.2	7.5	8.5	9.9	12.2	17
NT5/NT5 HD	5.6	9.4	13.2	17.0	20.8	24.6
NT5E	5.6	11.2	15.8	20.4	25.0	29.5
Mach 50	5.7	7.2	8.2	11.0	14.9	23.4
Dominator 500/ S- Dominator 500/ S- Dominator 550	5.5	8.5	9.9	12	15.6	22.65
NT6/NT6HD	5.8	10.8	14,.8	18.8	22.8	26.8
NT6E	8.8	13.5	18.2	22.9	27.5	32.2
Dominator 600/ S- Dominator 600/ S- Dominator 650	-	9.5	12	14.1	19.5	30
Mach 60	5.1	7.9	9.1	12.5	16.4	25.5
Dominator 750	9.9	15.7	18	21.5	27.3	38.5
Dominator 800	5.5	10.8	13.9	15.1	19.3	27.9
Dominator 880	10.9	16.5	18.9	22.4	28.1	39.5
Dominator 880 DeepWell	14.6	23.5	27.1	32.5	41.5	59.4
Dominator 850	11	16.8	19	22.5	28.2	39.5
Dominator 1000	15.6	24	32	40.3	48.5	56.5
Mach 120	-	-	24.35	28.3	35.4	48.1
Mach 122/132/142 S-Dcminaccr 1200	19.8	29.45	33.4	39.05	48.1	70.8

Table 4 illustrates the speed rates (m/min) per each cubic meter of air passing through the hammer for every match of the drilling pipe and the drill bit diameters.

Table 4. Speed rates for 1 m^3 passing through the hammer.

Bit gage (inches/mm)	Drilling pipe diameter							
	2 1/8" 54 mm	2 3/4" 70 mm	3" 76 mm	3 1/2" 89 mm	4" 102 mm	4 1/2" 114 mm	5" 127 mm	5 1/2" 140 mm
2 3/4"/70 mm	642							
3 1/3"/85 mm	295	548	880					
3 1/2"/90 mm	254	420	607					
3 15/16"/100 mm	180	249	304					
4 1/8"/105 mm		208	243	410				
4 1/4"/108 mm		188	218	340				
4 1/3"/110		177	201	305	751			

mm								
4 1/2"/115 mm		153	171	240	451			
4 3/4"/120 mm		134	148	196	319	907		
5"/127 mm		113	123	155	222	407		
5 1/8"/130 mm		106	114	142	196	326		
5 1/2"/140 mm		87	92	109	138	193	367	
6"/152 mm		70	73	83	99	125	179	
6 1/8"/156 mm		66	69	78	92	114	158	
6 1/4"/159 mm		63	66	74	86	105	140	
6 1/2"/165 mm		57	59	66	76	89	115	
6 3/4"/171 mm		52	54	59	67	78	96	
7"/178 mm				54	60	69	82	105
7 1/2"/191 mm				45	49	55	63	90
7 7/8"/200 mm				40	43	47	53	62
8'/203 mm				38	41	45	51	58
8 1/2"/216 mm				33	35	38	42	47
8 7/8"/225 mm				30	32	34	37	41
9 5/8"/245 mm				24	26	27	29	32
10"/254 mm				22	24	25	26	28
11"/279 mm				18	19	20	21	22
11 7/8"/300 mm				15	16	17	17	18
12 1/4"/311 mm				14	15	15	16	16
13"/330 mm						13	14	14
14 3/4"/375 mm						10	10	11
15"/381 mm						10	10	10
17 1/2"/445 mm						7	7	7
18 1/2"/470 mm						6	6	6
20"/508 mm						5	5	5
22"/559 mm						4	4	4

The required air flow rate for Mach 122 amounts to 70.8 m^3/min under 2.4 MPa air-gauge pressure. Similar diameters (drill bit – 381mm and drilling pipe – 114mm) require 10 m/min per each cubic meter of air passing through Mach 122. Thus, when using a 381mm drill bit, hammer Mach 122 and a 114 drilling pipe the lifting speed for an average particle taken from the bottom-hole makes 708 m/min or 11.8 m/s [2].

It should be noted that the required speed of rock lifting from the well bottom is one of the crucial and complex parameters to be defined during air-blast percussion-rotary drilling. B.B. Kudryashov gave a sound assessment of this parameter, its dependence on the rock type, form and size of cuttings [6].

The outer diameter of Mach 122 makes 273mm, which is the closest to the diameter of wells, according to Halco dimensions range. Bottom-hole assembly for conductor drilling at Kuyumbinsky oil field is presented in Table 5.

Table 5. Bottom-hole assembly for conductor drilling

Item	Description	Length, m
1	Drill bit 381 mm CONCAVE SD 12 BIT No.345732	0.38
2	Hammer MACH 122 No.1100	6.6
3	УБТ-229 mm	9.94
4	Drilling tool substitute Н З-171/М З-152	0.46
5	Stabilizer OD-374 mm	1.5
6	Drilling tool substitute Н З-152/М З-133	0.36
7	Heavy-weight drill pipe SBT-114 mm	as needed
8	Check valve	0.5
9	Kelly VBT-112	11.4

Drilling mode: axial loading – 3 tons, rotation frequency – 20 rpm, air-gauge pressure – 1.7 MPa and air flow rate – 76.4 m^3/min.

The implementation of the developed technical and engineering solutions demonstrated the following results. At 118m bottom-hole and 100 m/h drilling rate in well No. 401 there was a sticky hole situation, which resulted in the losing of drill string mobility.

It became possible to eliminate the emergency only by water injection. To ensure artificial footage constraints and prevent the risk of emergency, further drilling in advance was carried out by MDR rotor drive without a hammer and the drill bit was replaced by a DSD tool. Experts of LLC Intes decided to clean the bottom-hole with industrial water. This entailed lost circulation in well No.402 when passing through 10-81m interval and forced RIH operations of dual selective packer set with bypass and safety valves with subsequent DRILL HLUG hydrogel pumping. A similar hazardous situation occurred when drilling all four subsequent wells.

3. Results and discussion

To avoid the above problems we propose the following methodology: during the analysis and scientific justification of the new design and engineering approach to the solution of the complex problem of failure-free drilling of the specified intervals it is necessary to perform a complete set of calculations based on fundamental laws of rock fracture physics and aerodynamics with regard to well cleaning with gaseous fluids.

In particular, a real success of introducing the technology of surface casing drilling at Kuyumbinsky oil field will be achieved by applying the methods aimed at determining the desired pumping speed of drilled solids and calculating the air supply necessary for high-quality bore-hole cleaning developed by B.B. Kudryashov. Some aspects of practical application of such methods are described in other research works [10 - 12].

The expected recalculation of the flushing mode parameters will result in additional equipment of a mobile drilling rig with 3.5 MPa developed pressure compressors and booster stations to compensate back pressure from water inflow, as well as change of the drilling mode parameters. Modern mobile drilling rigs manufactured by Schramm, Atlas Copco, KERUI are equipped with top power spinner which rotates a column more effectively and prevents substrates from hitting the earlier chipped bottom-hole sections, and as a result, avoids drilling rate drop.

4. Conclusion

Nevertheless, LLC Intes initiative can be considered a “technological breakthrough” in solving problems of well constructions in Eastern Siberia and the Republic of Sakha (Yakutia) due to its

production and engineering advancement. Viability, feasibility and proved applicability of this technology can contribute to its further thorough study.

Acknowledgement

The authors express their sincere gratitude to Andrey V. Petrov, the Director General of LLC Intes, for providing data for the analysis under this research.

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