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Issue **Article**

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DESIGN OF DRILLING MODE FOR OPERATIONAL EVALUATION OF DIRECTIONAL WELLS

Abstract*: the proposed article discusses the design of calculation and selection of technological parameters of the drilling mode of a directional production and evaluation well for the purpose of successful drilling of well No. 707 at the Western Cheleken field in the coastal zones of the coastal waters of the Caspian Sea. For the design calculation and selection of technological parameters of the drilling mode were used:*

- the results of studies of drilling support wells on a given area or on areas with similar geological conditions.

- if drilling has not yet been carried out on the well area, statistical data are insufficient and the ability to represent the properties of rocks is only approximate, then axial loads can be approximately set in accordance with the selected bits, their passport data and drilling experience with similar geological conditions.

- data on the durability of the bits and the mechanical speed obtained from the results of working out the bits in this area from previously drilled wells.

This work can be used to perform the tasks set when drilling directional wells and to design the calculation and selection of technological parameters of the drilling regime in extremely difficult mining and geological conditions at abnormally high reservoir pressures.

Key words*: drilling mud, hardness, abrasiveness, plasticity, downhole motor, flushing holes of the bit, manifold, downhole, profile, drilling mode.*

Language*: English*

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Introduction

The drilling mode of a well is a factor regulated and created during the drilling process on which the successful completion of the well depends.

Consider the indicators of the drilling mode.

- the consumption of drilling mud, ensures the operation of downhole engines, which is determined by the technical indicators of the type of engines used. The amount of drilling mud is necessary to clean the well from the drilled rock, which is determined by the velocity of the upward flow of drilling mud, depending on the drillability of the rock.

- the axial load on the bit is determined taking into account the type of bits used and the physical and mechanical properties of the rock (hardness, abrasiveness, plasticity, etc.), lithological section, rock movement, etc. In addition, it is necessary to know the intervals of core sampling and the characteristics of the selected rocks (loose, loose, hard, strong, etc.). When choosing the drilling mode, it is also necessary to take into account data on the possible durability of the bits and the mechanical speed obtained from the results of working out the bits in this area (by area); at the same time, the wear of the bits should be taken into account. If such materials are not available for this deposit, then in this case it is possible to use information on other areas with similar geological conditions [1].

- the frequency of rotation of the bit is due to the fact that energy costs for idle rotation of the column are reduced, the time of working out of bits and drill pipes is increased, vibrations and breakage of the drill tool are reduced. Soft rocks are drilled at high bit rotation frequencies and in small axial loads, in hard rocks, on the contrary, the rotation frequency decreases, and the load on the bit increases.

Let's consider the design of technological indicators of the drilling regime of the operational and estimated directional well No. 707 Western Cheleken.

First of all, we will consider the volume flow of drilling mud (pump supply) for drilling the well in question. Drilling of a well is designed from the wellhead to 800 meters by a rotary method, and from a depth of 800 meters to a design 2764 meters (along the hole) by a rotary controlled system (RCS).

During rotary drilling, the drilling fluid flow rate is determined based on the upstream velocity, the value of which should be at least 0.8 – 1.2 m/s. In soft rocks, the formation of sludge is greater and therefore the value of the upstream velocity of the drilling fluid should be greater than when drilling hard rocks.

In the interal from 0 m – up to 50 m under the elongated direction, the flow rate of drilling mud is 58 l/sec and in the interal from 50 m – up to 800 m under the conductor is 42 l/sec;

Calculate the volume flow rate of drilling mud (pump supply) for drilling a well with downhole motors up to the design depth of 2764 m (along the hole) under the following conditions.

Table 1. Drilling mud density by intervals:

Drilling interval, m	0-200	200-800	800-2119	2119-2764
Mortar density, g/cm^3	1,4	1,47	1,68	1,81

The drilling rig is equipped with two F-1600 pumps.

We determine the maximum supply of drilling pumps when drilling from "zero" ($L=0$) according to the formula (1).

$$Q = \sqrt{\frac{N_{usef.}}{(A_d + A)\rho_{dr.m.}}} \qquad (1)$$

where $N_{usef.}$ is the useful power of the drilling pump, kW;

A_d is the coefficient of pressure drop in the downhole engine;

A is the coefficient of pressure drop, independent of the depth of the well;

$\rho_{dr.\,m}$ is the density of drilling mud, g/cm^3.

Table 2 shows the technical characteristics of the F-1600 drilling pump.

$$A_{d.} = \rho_{tabl.} / \rho_{dr.m.} Q^2{}_{tabl.} \qquad (2)$$

where ρ_{tabl} is the pressure drop in the downhole engine (MPa) when feeding Q_{tabl} (dm^3/s).

Table 2.

Interval, m		Type of technological operation	Type of drilling pump	Number of pumps	Hydraulic power factor of operation	Fill factor	The sum of the pump capacity at intervals of h/p
from	before						
50	800	Drilling	F-1600	2	0,44	0,8	42
800	2119	Drilling	F-1600	2	0,62	0,8	41
2119	2764	Drilling	F-1600	2	0,53	0,8	28

continuation of table 1

Interval, m		Type of technological operation	Type of drilling pump	Diameter of cylindrical bushings	Maximum working pressure kgf/cm^2	Number of revolutions per minute	Capacity h/p
from	before						
50	800	Drilling	F-1600	178	258	70	21
800	2119	Drilling	F-1600	165	322	78	20,5
2119	2764	Drilling	F-1600	165	322	54	14

The coefficient A is determined by the formula:

$$A = a_{m.} + a_{DC} l_{DC.} + a_{b.} + \alpha_{d.p.} \qquad (3)$$

where am is the coefficient of pressure drop in the manifold. (If a lead pipe with a bore diameter of 85 mm is used, then a_m = 34 10^{-5}; if the bore diameter is 100 mm, then a_m = 30 10^{-5});

a_{DC} is the coefficient of pressure drop in weighted drill collar. For drill collar (DC) with a diameter of 203 mm, a_{DC} = 0,224 · 10^{-5};

a_b is the coefficient of pressure drop in the flushing holes of the bit, which is determined by the formula:

$$a_{b.} = 0{,}12 / F^2 \qquad (4)$$

where F is the total area of the flushing holes of the bit.

We determine the consumption of drilling mud.

The permissible drilling depth with the required feed is determined by the formula:

$$L_{per.} = \frac{N_{НАС} - (A_{d.} + A)\rho_{dr.m.} Q^3}{B \rho_{dr.m.} Q^3}, \qquad (5)$$

where B is the pressure drop coefficient, depending on the drilling depth and determined by the formula:

$$B = a_{c.p.} + a_{lock} / L_{lock} + a_{c.d.}, \qquad (6)$$

where $a_{c.l.}$ is the coefficient of pressure drop in drill pipes.

a_{lock} - pressure drop coefficient in drill locks;

l_{lock} - average distance between locks, m;

$a_{c.d}$ is the coefficient of pressure drop in the annular space.

Based on the interval calculation of determining the maximum supply of drilling pumps and the permissible drilling depth with the required supply, the following results were obtained, which are shown in table 3.

Table 3.

Drilling interval, m	Diameter of cylindrical collars, mm	Drilling mud consumption h/p	Drilling mud density, g/cm^3
0 -50	178	58	1,40
50 - 800	178	42	1,47
800 - 2119	165	41	1,68
2119 - 2764	165	28	1,81

When choosing the optimal values of the axial load on the bit and the frequency of its rotation, it is necessary to use the results of studies of drilling support wells on a given area or on areas with similar geological conditions [2]. In the absence of such information, you can use the method of mathematical statistics, if there is sufficient information.

If drilling is carried out on a new area where the reference wells have not yet been drilled, statistical data are insufficient and rock properties can only be presented approximately, then axial loads can be approximately set in accordance with the selected bits, their passport data and drilling experience with similar geological conditions [3].

The optimal rotation speeds of M-type bits are in the range of (26.2 - 41.9) rad/s or (250-400) rpm; MS-type - (15.7-31.4) rad/s or (150-300) rpm; type C, ST - (10.5-20.9) rad/s or (100-200) rpm; type T - less than 15.7 rad/s or 150 rpm; type K - less than 10.5 rad/s or 100 rpm.

The drilling method and the type of downhole motor are chosen depending on the optimal bit rotation speed (Table 4).

The areas of rational application of rotary drilling are as follows:

-drilling deep intervals of wells with ball bits, where it is necessary to maximize the penetration per voyage and the optimal rotation speed of the bit is in the range of (3.7- 10.5) rad/s or (35-150) rpm;

Table 4.

Type of bit rotator	Optimal bit rotation speed, rad/s (rpm)
Rotor, electric drill with two gearboxes-inserts	3,7-10,5 (35-100)

Rotor, volumetric hydraulic motor, turbobur with hydraulic braking grilles, electric drill with gearbox insert	10,5-26,2 (100-250)
Spindle turbos with precision casting turbines and turbos with a pressure line falling to the brake, electric drills with a gear-insert	26,2-52,3 (250-500)
Turbo drills and electric drills for diamond drilling	52,3-83,7 (500-800)

- drilling of powerful thicknesses of plastic clays, dense clay shales and other rocks, in which it is advisable to use three-bladed and three-bladed bits with large teeth and a large pitch, it is necessary to create high speeds of drilling mud outflow from nozzles (100-120 m/s) and requires the implementation of a significant part of the hydraulic power developed by drilling pumps in the bit;

- if it is necessary to drill wells with bits with a diameter of less than 215.9 mm, especially deep intervals, except in cases of drilling branched horizontal wells;

- when drilling wells in conditions requiring the use of weighted drilling fluids with a density of more than 1.7-1.8 g / cm^3, when in specific conditions an electric drill has no advantages or there is no possibility to use it;

- when drilling in conditions of high downhole temperatures (more than 140-150 °C) and complications associated with violations of the borehole zone of the well or strong absorption of drilling mud [4];

- when drilling with core sampling;

- when drilling with face blowing with air and flushing with aerated drilling mud with a high degree of aeration (if it is impossible to use an electric drill under these conditions);

- when drilling support wells.

The use of electric drills is rational in the following conditions: drilling wells with a diameter of 190.5-393.7 mm with flushing of the borehole with drilling fluid, including weighted to 2.3 g / cm^3, at a temperature not higher than 130-140 °C, taking into account ensuring optimal values of the bit rotation frequency;

- drilling of support and technological wells;

- drilling of inclined and vertically directed wells in combination with telemetry systems, especially in difficult geological conditions, ensuring optimal values of the bit rotation frequency in all sections of the well profile;

- opening of productive horizons with horizontal and branched-horizontal holes to increase the flow rate of wells and the coefficient of oil recovery from the reservoir [5,13];

Table 5. Technical characteristics of downhole screw hydraulic motors of Russian production

Indicators	Engine size			
	D2-195	D 2-170	D -127	D -85
Liquid flow rate, dm ^{8}/s	35-45	20-36	12-15	5-7
Output shaft rotation speed, rad/s (rpm)	14,65-17,8 (140-170)	12,04-20,93 (115-200)	20,93-26,17 (200-250)	20.93-29,31 (200-280)
Pressure drop, MPa	6,0-7,0	4,5-6,0	3,5-6,0	3,0-3,5
Rotating moment, Nm	6500-8000	2900-4150	1000-1200	340-400
Length, mm	6900	6900	4500	3160
Weight, kg	1140	770	300	90

- drilling with downhole blowing with air and flushing with aerated drilling mud with a high degree of aeration or foams;

- drilling with diamond bits and bits of the ISM type (a bit developed by the Institute of Superhard Materials), except in cases when the temperature of the drilling mud at the bottom exceeds 130 °C.

Table 6.

Type of bit	Bit diameter, mm	Turbine drilling			Rotary drilling		
		bit load, MN	drilling mud consumption, dm³/s	bit rotation speed, rad/s (rpm)	bit load, MN	drilling mud consumption, dm³/s	bit rotation speed, rad/s (rpm)
ISM	149	0,02—0,06	14—20	12,04—23,03 (115—220)	0,03—0,06	25	8,37 (80)
ISM -RG	149	0,0175—0,05	14-20	12,04-23,03 (115-220)	0,02—0,06	25—30	8,37 (80)
ISM	188	0,06—0,08	20—25	26,17—36,63 (250—350)	0,06—0,08	20-25	10,47—12,56 (100—120)
ISM - RG	188	*	**	26,17-36,63 (250-350)	0,04—0,08	20—30	10,47 (100)
ISM	212	0,08—0,10	30—32	36,63—47,1 (350-450)	0.10—0,12	25-30	8,37—12,56 (80-120)
ISM - RG	212	*	**	36.63—47,1 (350—450)	0,05—0,10	25—40	12,56 (120)
ISM	241	0,08—0,10	30—35	41,87—52,3 (400—500)	0,10—0,12	30—35	12,56 (120)
ISM - RG	241	*	**	41,87-52,3 (400-500)	0,08—0,10	35-40	12,56 (120)
ISM	267	0,12—0,14	40—45	47,1-57,57 (450—550)	0,12-0,15	30-40	14,65 (140)
ISM - RG	267	*	**	47,1—57,57 (450—550)	0,07—0,13	30-40	14,65 (140)
ISM	292	0,14—0,16	40—45	47,1-62.8 (450—600)	0,13-0,17	40—60	14,65 (140)
ISM - RG	292	*	**	47,1—62,8 (450—600)	0,08—0,14	45-70	14,65 (140)

* — the maximum value perceived by the engine.
* * - the same, within the limits recommended for the engine.

Drilling with hydraulic downhole motors is rational in the following cases:

- drilling of vertical wells with a diameter of 190.5 mm or more with roller bits with a depth of up to 3000-3500 m (in some cases, deeper ones) with a drilling mud density of no more than 1.7-1.8 g/cm³, when the optimal values of the bit rotation speed are selected to the required limit specified in the passport of the downhole engine used [6, 7, 16];

- drilling with diamond bits and bits of the ISM type, except in cases when the density of the drilling fluid exceeds 1.7-1.8 g/cm³, and the temperature in the well is 140-150 °C for engines with rubberized parts [8, 17];

- drilling of directional wells in the intervals of a set of curvature and the formation of a given azimuth, regardless of the optimal values of the bit rotation frequency, and in the intervals of stabilization of the slope and transition to the vertical - provided that their optimal values are provided [9, 10, 14];

- opening of productive layers with horizontal and branched-horizontal wells, as well as drilling of holes in cased wells of the old fund to restore them and increase the flow rate of low-yielding wells [11, 15];

- drilling with plug-in bits without lifting pipes in conditions where the use of this type of turbine drilling method is advisable; in these cases, plug-in downhole motors are used;

- drilling with flushing with aerated drilling mud with a low degree of aeration while ensuring optimal values of the bit rotation speed;

- volumetric screw motors with a diameter of 172 mm are rationally used when drilling vertical or directional wells up to 3000 m deep in hard and strong, as well as abrasive rocks with ball bits with diameters of 190.5 and 215.9 mm, having sliding supports and designed for low rotation speed.

The rotary drilling method for unsupported bits of ISM and diamond types with a fracture mechanism in the form of surface fracture and micro-cutting is economically unjustified in depth ranges up to 4000 m, since the main criterion is the mechanical drilling speed, which is more dependent on the bit rotation frequency, is small compared to the required one.

At great depths, when the mechanical speed of the ball bits decreases sharply, and the penetration into the bit becomes very small, the use of a rotary drilling method with ISM bits may be economically feasible (Table 6).

At the projected operational and estimated directional well No. 707 of the Western Cheleken area, when choosing the optimal values of the axial load on the bit and the frequency of its rotation took into account the data on the durability of the bits and the mechanical speed obtained from the results of working out the bits in this area from previously drilled wells.

Table 7 shows the layout of the bottom of the drill strings (BHA) necessary to create an axial load on the bit in the projected well No. 707 of the Western Cheleken area.

Table 7.

Number BHA	Sequence number	Dimensions, code	Distance from the bottom to the installation site, m	Technical characteristics			Total length of the BHA, m	Total weight of BHA, tons	Note
				Outdoor diameter, mm	Length, m	Weight, kg			
1	1	Bit III 660,4	0	660,4	0,6	670	42	11,7	Getting hole verticality for elongated direction
	2	KLS (calibrator) 660.4	0,6	660,4	1,3	650			
	3	DC - 245	1,9	245	6,5	1735			
	4	KLS 660.4	8,4	660,4	1,3	650			
	5	DC - 229	9,7	229	13	3554			
	6	KLS 660.4	22,7	660,4	1,3	650			
	7	DC - 203	24	203	18	3862			
2	1	Bit 444,5 PDC	0	444,5	0,5	235	84	20	Obtain the verticality of the barrel and create a draft axial load on the bit
	2	KLS 444,5	0,5	444,5	1,3	515			
	3	DC -245	1,8	245	6,5	1735			
	4	KLS 444,5	8,3	444,5	1,3	515			
	5	DC -229	9,6	229	13	3554			
	6	KLS 444,5	22,6	444,5	1,3	515			
	7	DC -203	23,9	203	60	12876			
3	1	Bit 311,1 PDC	0	311,1	0,4	88	84	18,3	Obtain the verticality of the barrel and create a design axial load on the bit
	2	KLS 311.1	0,4	311,1	1,2	350			

	3	DC - 203	1,6	203	5	1073			
	4	KLS 311.1	6,6	311,1	1,2	350			
	5	DC - 203	7,8	203	13	2790			
	6	KLS 311.1	20,8	311,1	1,2	350			
	7	DC - 203	22	203	62	13305			

continuation of table 7

4	1	bit 311,1 PDC	0	311,1	0,44	88	138	24,2	Drilling an obliquely-directed shaft at a given angle and create a design axial load on the bit
	2	RCS PD900	0,44	308,.0	4,21	1300			
	3	KLS 308,0	4,65	308,0	1,52	1700			
	4	Telesystem NF	6,17	213,6	7,53	3300			
	5	DC - 203	13,69	203,0	9,40	5500			
	6	K 305,0	23,09	305,0	2,30	6000			
	7	Filter sub	25,39	203,0	1,52	6400			
	8	Sub	26,92	203,0	1,00	6600			
	9	DC - 203	27,92	203,0	28,20	12900			
	10	Sub	56,12	203,0	1,00	13100			
	11	DC - 178	57,12	178,0	28,5	17700			
	12	Sub	85,62	178,0	1,52	18000			
	13	165mm hydraulic jar	87,14	165,0	9,50	18800			
	14	Sub	96,64	165,0	1,52	19000			
	15	DC - 178	98,17	178,0	28,5	23700			
	16	Sub	126,67	168,0	1,52	23900			
5	1	Bit 215,9 PDC	0	215,9	0,23	40	124	13,7	Drilling an obliquely-directed shaft at a given angle and create a design axial load on the bit
	2	RCS PD675	0,7	171,5	4,11	700			
	3	KLS 212,8	0,9	212,0	1,52	900			
	4	Telesystem 675NF	1,8	172,0	7,53	1800			
	5	DC - 172	3,3	172,0	9,42	3300			
	6	KLS 209,0	3,5	209,0	1,52	3500			
	7	Filter sub	3,6	172,0	1,00	3600			
	8	Sub	3,8	172,0	1,00	3800			
	9	DC - 146	6,7	146,0	27,43	6700			
	10	165 mm hydraulic jar	7,4	165,0	4,87	7400			
	11	DC - 146	10,3	146,0	27,43	10300			
	12	Sub	10,5	164,0	1,00	10500			

The calculations of the hydraulic resistances were carried out on the basis of two pumps of the F-1600 type of the ZJ 70 DV drilling rig.

The required flow rate of drilling mud is determined by the specific flow rate of 1 cm^2 at the bottom of the well. It is advisable to keep the specific consumption of drilling mud within 0.035 - 0.05 $dm^3/sec/cm^2$.

Depending on the flow of drilling mud, the number of drilling pumps and the diameters of cylindrical bushings are selected in accordance with the technical characteristics of drilling pumps.

For satisfactory cleaning of the bottom of the well, a nozzle of drill bits is designed, which can create a flow rate of at least 80 m/sec of the washing liquid.

Based on the selected drilling fluid flow rates, pressure losses during circulation are determined.

Calculations are performed in accordance with the "Instructions for drawing up a hydraulic well drilling program", RD 39 – 047009 - 516 - 86.

The pressure drop on the bit and circulation systems should not be higher than 0.8 times the pressure of the selected diameters of cylindrical bushings created by pumps.

The indicators of the distribution of pressure dropes during circulation are given in Table 8.

Table 8. Distribution of pressure dropes during circulation

Interval, m		Type of technological operation	Face pressure on supports, kgf/cm2	Pressure drop at the bottom (kgf/cm^2)				
				On the elements of the BHA		In the drill pipe	In the annular space	On drilling equipment
from top	to bottom			On the bit (nozzles)	On the downhole engine			
1	2	3	4	5	6	7	8	9
50	800	Drilling	113	61	-	44	-	8
800	2119	Drilling	200	40	12	25	-	5
2119	2764	Drilling	170	40	10	27	-	5

During drilling operations, based on actual mining and geological conditions, it is necessary to make a change in the indicators [12].

Based on the calculations, the obtained interval technological parameters of the drilling mode for the projected well are shown in Table 8.

Table 8.

Interval, m		Type of operation	Drilling method	Conditional number of the BHA	Drilling mode indicators			The speed of technological operations, m/hour
from	before				Axial load, ts	Bit rotation speed, rpm	Drilling mud consumption, l/sec	
1	2	3	4	5	6	7	8	9
10	50	Drilling	Rotary	1	4 - 6	30 - 40	58	Actual
50	800	Drilling	Rotary	2	10 - 16	60 - 100	42	Actual
800	1650	Drilling	Rotary	3	10 - 14	60 - 100	41	Actual
1650	2119	Drilling	Rotary	4	5 – 10	120 - 130	40 - 45	Actual
2119	2764	Drilling	Rotary	5	5 - 10	120 - 130	25 - 30	Actual

Note: the projected parameters of the drilling mode can be changed according to the actual conditions during the drilling process.

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