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TASK
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ABSTRACT

Explanatory note: 59 p., 12 tables, 18 sources.

PRODUCTION WELL, FLUSHING FLUID, OPENING.

The object of research is a technical project for drilling a gas well in the Yulievska area.

The purpose of the work is to develop a technology for drilling a gas production well in terms of Yulievska area.

Research tools - literature analysis and theoretical research.

The paper is compiled in accordance with the requirements of the guidelines. It contains information about the drilling area, geological structure, and characteristics of productive horizons. In addition, the design part resolves the following issues of well construction: the well structure has been designed; the equipment of the drilling rig, rock cutting tools, drilling and cementing technology have been selected. Safety precautions are given when drilling wells. The issues of subsoil and environmental protection are highlighted. The estimate for drilling a production well has been substantiated.

CONTENT

INTRODUCTION

The gas industry plays an important role in the national fuel balance. A large number of gas condensate fields with significant gas reserves made it possible to increase gas production in eastern Ukraine in a short time.

In recent years, technical re-equipment in drilling and technology for the operation of gas and gas condensate wells has been carried out. New progressive methods and techniques of exploration, drilling of wells, construction of facilities and exploitation of gas and gas condensate fields, developed and introduced, are used.

The widespread use of gas as a fuel and for technological needs opens up unlimited opportunities for the state economy. It is known that fuel accounts for a significant part of the costs of generating electricity, cement, metal, glass, porcelain, a number of building materials etc. The use of gas in these industries has a significant economic effect.

Positive results of using natural gas for technological needs were obtained in blast furnace and open-hearth shops of metallurgical plants in the country. Gas is successfully used as a process fuel in the furnaces of rolling and tube-rolling shops. The growth of the chemical industry is associated with the development of oil and gas production.

The gas industry of the region is of great importance in the national fuel balance. A large number of gas condensate fields with gas reserves made it possible to increase production in a short time.

1 GEOLOGICAL AND TECHNICAL CONDITIONS FOR CONDUCTING DRILLING WORKS

1.1 Geographical location of the work area

The eastern oil and gas region is located on the left bank of the Dnieper. Administratively, it is part of the Chernigov, Sumy, Poltava, Dnepropetrovsk, Kharkov, Donetsk, and Lugansk regions. It includes the Dnieper-Donets oil and gas region, which takes a leading place in Ukraine in terms of explored reserves, potential resources and the scale of hydrocarbon production. This region is an integral part of the Pripyat-Donets oil and gas province stretching from Belarus through the Dnieper lowland to Donbas and further through its northern outskirts to the border with Russia. Tectonically, the region is located in the basin of the same name (DDD), capturing part of the northern outskirts of Donbas, which is sometimes called the Preddonetsky trough, as well as a strip of the southern margin of the Voronezh anteclise.

Gas condensate deposits, as well as accumulations of hydrocarbon gases, have been identified in a wide stratigraphic range. There are 115 such deposits. Their spatial distribution has its own characteristics. The richest gas condensate deposits are concentrated within a limited area of the northern near-belt zone – Anastasyevske, Talalaevske, Vasilievske and other fields. Recoverable condensate reserves are located at the depths of 3500 – 4000 m (25.8 %) and 4000 – 5000 m (38.5 %); in the depth range of 1500 – 2000 m, the volume of condensate is 4.9%. Transient systems – hydrocarbon fluids with a large amount of dissolved gas or a large concentration of condensate in the gas – are still insufficiently studied and do not have clear criteria for definition and placement.

Yablunivske oil and gas condensate field. It is located in the Lokhvitsky district of the Poltava region, confined to the northwestern part of the near-axial zone of the Far East Region (Glinsko-Solokhovsky Oil and Gas Region). On the rocks of the Devonian and Lower Carboniferous, the uplift was revealed in 1972 – 74. It is a brachyanticline of northwest strike, complicated by fault. Within the boundaries of the isohypse – 5000 m, its dimensions are 11 × 5 km, the amplitude is 600 m. Oil deposits are established in the horizons of the Bashkir and Visean stages, gas condensate – in the Bashkir, Visean, and Tournaisian stages and the Devonian. Accumulations of hydrocarbons are associated with stratal, massive-stratal arching tectonically screened and partially lithologically limited traps, occurring at a depth of more than 3448 m (oil and gas content of 1800 m). Since 1985, it has been in industrial development.

There are 3 rivers flowing through the territory of the district. The main river is Sula.

Natural resources (minerals): forming clays, clays for clay solutions, sandstones, construction and glassworks sands, clays for making bricks, natural gas, reserves of rock salt and potassium-magnesium salts (bischofites).

The area of the deposit is covered with a network of highways and dirt roads, through which year-round cargo transportation can be carried out with the access to highways of national importance. They can also be used for transport communication with railway stations.

The projected well will be supplied with technical water through a 50 m long water pipeline. The projected well will be supplied with power from the power transmission line.

1.2 Geological structure of the site

The oil and gas bearing complexes of the DDD are distinguished in the region by the oil and gas saturated and screening strata of the sections. They are different in their areal distribution and significance. Oil and gas bearing complexes of the Yablunivske oil and gas condensate field are established in the horizons of the Bashkir and Visean stages, gas condensate - in the Bashkir, Visean and Tournaisian stages and the Devonian.

Bashkirian stage, lower stage of a middle share of the coal system. In the stratotype (the Askyn River, Mountainous Bashkiria), it is composed of shallow marine carbonate sediments – limestones with thick interlayers of dolomites being

225 m thick. For the first time, it was singled out by S.V. Semikhatova in 1934 in the South. Ural, within the collecting area of rivers Zilim and Yuryuzan. It is subdivided into the Bogdanovsky, Syuran, Akavassky, Askynbash, Tashastinsky, and Asatau horizons based on the fossil remains of foraminifera, brachiopods, cephalopods, and other organisms. The first 4 horizons are combined into the lower Bashkirian and the 2 upper ones – in the upper Bashkirian substages. Within the territory, platform part of Bashkiria, they are known only from boreholes, where they are represented by limestones and are part of the Middle Carboniferous carbonate oil and gas complex. The most complete exposed carbonate sections of the stage are available along the rivers of Belaya, Zigan, Askyn, where their thickness reaches 195 – 275 m. To the South from the Bolshoi Ik River, lower Bashkirian substage is composed of siliceous-clayey-carbonate deposits of the thickness of 250 – 300 m; and the upper Bashkirian substage is a part of the upper-Moscovian flysch stratum being about 2000 m thick. Within the western slope of the South Urals, organogenic and biogenic limestones of Bashkirian stage are exposed up to 370 m along the rivers of Bolshoi Kizil, Khudolaz and others, where layers of sandstones, siltstones, mudstones are found.

1.3 Characteristics of the horizon

Cenozoic group

Quaternary system, Neogene, Paleogene (0 - 185 m)

The Cenozoic group is represented by brownish clay, brown sandy loam, in the groundmass containing brownish-brown, fine-grained sand and with the inclusion of shell fragments.

Mesozoic group

Cretaceous (185 – 265 m)

Brownish clay, brown sandy loam, in the groundmass containing brownish-brown sand, fine-grained and with the inclusion of shell fragments. Thin limestone layers have been exposed below.

Jura (265 – 750 m)

Interlacing of bluish-gray sandy, non-carbonate, viscous clays, weakly compacted with fine-grained sandstones of medium density and strength.

Triassic (750 – 1140 m).

Clays, micaceous, weakly carbonate ($CaCO_3$ up to 3%), viscous with thin dissemination of pyrite and dark gray, thin-layered, micaceous, silty, dense; with alternating layers of gray and light gray quartz sandstones, uneven-grained (from fine-grained to coarse-grained), weakly cemented with dark gray, silty, carbonate ($CaCO_3$ up to 10%), dense clays.

Paleozoic group

Permian (1140 – 1320 m).

Alternating layers of gray siltstones, different-grained (from fine-grained to coarse-grained), weakly cemented with dark gray, silty, carbonate ($CaCO_3$ up to 10%), dense clays.

Carboniferous (1320 – 2600 m).

Clays are gray, micaceous, highly calcareous ($CaCO_3$ up to 26%), viscous, weakly compacted with a thin dissemination of pyrite, dark gray, dense, thin-layered clays. Also, beds of gray and light gray quartz sandstones, uneven-grained (from fine-grained to coarse-grained), weakly cemented with dark gray, silty, carbonate ($CaCO_3$ up to 10%), dense clays. Interlayers of brownish-gray siltstone, variegated clay and white chalk-like limestone.

1.4 Stratigraphy

Table 1.1 - Lithological-stratigraphic and geochemical characteristics of rocks

Era	System	Stage	Design depth, m
Cenozoic KZ	Quaternary Q		0-185
	Neogene N		
	Paleogene P		
Mesozoic MZ	Chalk K		185-265
	Jura J		265-750
	Trias T		750-1140
Paleozoic PZ	Perm P		1140-1320
	Carboniferous C	Moscovian - C_m	1320-1810
		Bashkirian - C_b	1810-2250
			2250-2600

1.5. Physicochemical properties of the formation fluids

The study of the physicochemical properties of reservoir oils was carried out using reservoir samples in the oil research department and in the analytical laboratory. Below, there is a brief description of oil, water, and gas in terms of stages.

Bashkirian stage

Investigation of the properties of Bashkirian oil in reservoir conditions was carried out using 148 samples taken from 38 wells. The average value of the main parameters of oil obtained from the results of sample analyzes is as follows: saturation pressure – 1.4 MPa, gas content – 5.9 m^3/t, volumetric coefficient – 1.034, dynamic viscosity is 43.63 mPa·s. The density of the reservoir oil is 877 kg/m^3, the reservoir temperature is 23 °C. According to the analysis of surface samples, oils of the Bashkirian stage belong to the group of heavy oils - the density at surface conditions is 908.6 kg/m^3.

In terms of sulfur content – 3.11% of the mass and paraffin – 3.0% of the mass, the oil is high-sulfur, paraffinic. The kinematic viscosity at 20 ° C is 109.9 mPa·s.

In terms of chemical composition, the underground water of the Bashkirian deposits is of the calcium chloride type. The total mineralization of waters ranges from 7.5 to 258.6 g/l, density 1005.0 – 1180.0 kg/m^3, viscosity 1.03–1.84 mPa·s. (Table 1.2)

Table 1.2 – Physical properties of the formation waters of 32 deposits

Name	Range of changes	Average value
Gas content, m^3/t	0.13	0.13
incl. hydrogen sulfide, m^3/t	0.006	0.006
Viscosity, mPa·s	1.03-1.8	1.1
Total mineralization, g/l	7.5587-158.605	56.689
Density, kg/m^3	1005-1180	1040

The composition of the gas is nitrogen. Gas saturation is 0.08 – 0.9 m^3/t. Hydrogen sulfide is present in the amount of 0.006 m^3/t, the volumetric coefficient is 1.0001.

Serpukhovian Stage

Investigation of the properties of oil from the Serpukhovian stage in reservoir conditions was carried out using 91 samples taken from 22 wells. The average value of the main oil parameters obtained from the results of sample analyzes is as follows: saturation pressure – 1.3 MPa, gas content – 4.72 m^3/t, volumetric coefficient – 1.032; dynamic viscosity is 52.87 mPa·s. The density of the reservoir oil is 883.8 kg/m^3, the separated oil is 906.8 kg/m^3, the reservoir temperature is 23 °C. According to the analysis of surface samples, the oils of the Serpukhovian stage belong to the group of heavy oils - the density at surface conditions is 917.3 kg/m^3. By sulfur content – 2.6% of the mass, and paraffin – 5% of the mass, the oil is high-sulfur, paraffinic. Kinematic viscosity at 20 °C is 109.4 mPa·s. The underground waters of the Serpukhov deposits are of two types: sodium sulfate and calcium chloride (according to V.A. Sulin).

Sulphate waters are mainly associated with the leaching of gypsum and anhydrite. Total mineralization ranges from 12.6 to 23.0 g/l, density 1009.6-1175.0 kg/m^3, viscosity 1.03-1.8 mPa·s. (Table 1.3)

Table 1.3 – Physical properties of the formation waters of 33 deposits

Name	Range of changes	Average value
Gas content, m^3/t	0.14	0.14
incl. hydrogen sulfide, m^3/t	0.008	0.008
Viscosity, mPa·s	1.03-1,8	1.1
Total mineralization, g/l	17.775-229.0226	47.105
Density, kg/m^3	1009-1175	1036

Hydrogen sulfide is also present in the amount of 0.008 m^3/t. The composition of the gas is nitrogen. Gas saturation is 0.09 – 0.12 m^3/t; volumetric ratio is 1.0003.

Due to the presence of sulfur and hydrogen sulfide in the waters of the Serpukhovian and Bashkirian deposits, it is necessary to provide for the protection of oilfield equipment from corrosion.

The most complete results of studies of oil properties in reservoir and surface conditions, physicochemical properties and fractional composition of degassed oil, physicochemical properties of reservoir waters, the content of ions and impurities in reservoir waters are represented in Table 3 – 6; for each of the horizons the average values of the parameters and the range of their variation are given.

The total mineralization of groundwater in the Serpukhovian and Bashkirian deposits varies during the year from 0.7 to 258 g/l, the specific gravity – from 1005.0 to 1180.0 kg/m^3. From all of the above, it can be concluded that the formation waters of these deposits are heterogeneous.

Table 1.4 - Content of ions and impurities in the formation waters of 32 deposits

Name	Range of changes	Average value
CL^-	55.16-4141.8	893.21
SO_4^{2-}	0-81.51	37.53
HCO_3^-	0.4-13.4	5.39
Ca^{2+}	9.9-77.3	83.21
Mg^{2+}	1.55-168.02	38.48
$K^{2+}Na^+$	93.82-3144.15	731.72

Table 1.5 - Content of ions and impurities in the formation waters of 33 deposits

Name	Range of changes	Average value
CL^-	164.58-3982.5	694.42
SO_4^{2-}	0.03-90.89	50.41
HCO_3^-	0-14.26	5.76
Ca^{2+}	13.06-600	66.44
Mg^{2+}	11.29-162.13	34.84
$K^{2+}Na^+$	218.26-3092.74	601.32

2 WELL DESIGN. SELECTION OF DRILLING EQUIPMENT AND TOOLS

2.1 Selection and substantiation of the drilling method

The selection of the most effective drilling method is due to the tasks that must be solved in the development or improvement of drilling technology in specific geological and technical conditions.

When drilling oil and gas wells, drilling methods have become widespread: rotary, hydraulic downhole motors, and drilling with electric drills. The drilling of the project well will be carried out in a rotary way.

The section for the set of curvature and stabilization of the bend angle is provided for drilling using downhole drilling motors.

2.2. Well design

The well design is determined by the number of casing strings to be run, the depth of their installation, the diameter of the pipes used, the diameter of the bits that are used for drilling under each string, the height of the cement grout rise in the annulus and the bottomhole design.

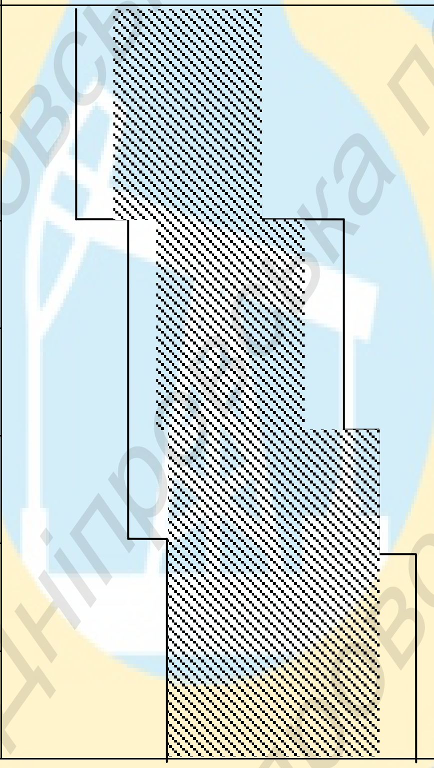
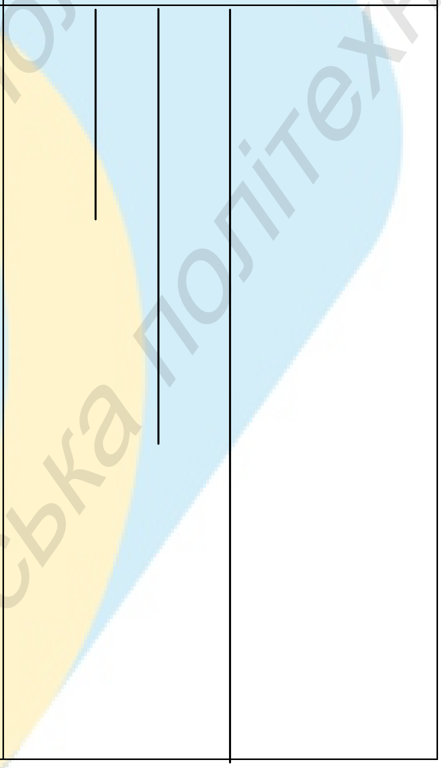
The well design depends on the depth of the productive strata, their productivity and reservoir properties, reservoir and pore pressures, as well as hydraulic fracturing pressure of permeable rocks, physical and mechanical properties and state of rocks.

When designing a well structure, first of all, the number of casing strings and the depth of their lowering are selected, proceeding from the prevention of incompatibility of drilling conditions for individual intervals of the wellbore. In this project, three casing strings are envisaged: under the direction, under the surface, and production casing. The depth of running the production string is determined by the location of the productive formations, the methods of injection and well operation, as well as the design of the bottomhole. In our case, it is 2600 m. The depth of the conductor is 200 m.

The diameters of the casing strings and bits are selected from the bottom up, starting from the production string.

To establish the number of casing strings and the depth of their running, we have built a combined graph of the change in the gradients of reservoir pressure and hydraulic fracturing pressure along the depth of the borehole. On its basis, we have developed the first rough design of a borehole. The final decision on the number of casing strings and the depth of their running is made after analyzing the geological and technical conditions of drilling, taking into account possible complications. Below, there is a combined pressure plot and projected well design.

Table 2.1 - Combined pressure graph

Base depth, m	Pressure gradient, MPa/m		Combined pressure graph	Well design
	Embedded	Hydraulic fracturing		
150	0.01	0.012		
200	0.01	0.012		
750	0.0114	0.014		
1350	0.0108	0.013		
1900	0.0104	0.015		
2350	0.0116	0.017		
2600	0.014	0.018		

1. In accordance with the initial data, the diameter of the production casing

$d_{ek} = 146$ mm.

2. Diameter of a drill bit for production casing

$$D_{d}^{ek} = d_{m}^{ek} + 2\delta, \quad (1)$$

where d_m^{ek} is the diameter of the production casing collar; for a given production casing d_m^{ek} = 166 mm; δ is the size of the gap between the production casing collar and the wellbore wall, since the production casing diameter is equal to d_{ek} = 146 mm, then we take δ = 10 mm

$$D_d^{ek} = 146 + 2 \cdot 10 = 166\,\text{mm}.$$

In accordance with GOST, we take 215.5 mm for drill bits.

3. Determine the inner diameter of the intermediate casing

$$d_{vn}^{pr} = D_d^{ek} + (6 \div 8), \tag{2}$$

$$d_{vn}^{pr} = 190.5 + (6 \div 8) = 196.5\,\text{mm}.$$

We accept in accordance with GOST for casing pipes

$$d_n^{pr} = 219\,\text{mm};\ d_{vn}^{pr} = 210.1\,\text{mm};\ d_m^{pr} = 245\,\text{mm};$$

4. Determine the diameter of the bit for drilling under the intermediate string

$$D_d^{pr} = 245 + 2 \cdot 20 = 285\,\text{mm}.$$

It is accepted according to GOST for drill bits being 295.3 mm.

5. Determine the inner diameter of the conductor

$$d_{vn}^{k} = 295.3 + 6 = 301.3\,\text{mm}.$$

$$d_v^{k} = 324\,\text{mm};\ d_{vn}^{k} = 301.9\,\text{mm};\ d_m^{k} = 351\,\text{mm};$$

6. Determine the diameter of the drill bit for surface drilling

$$D_d^{pr} = 324 + 2 \cdot 30 = 384\,\text{mm}.$$

It is accepted in accordance with GOST for drilling bits being 393.7 mm.

Cementing of casing strings is carried out for the entire length of the string.

The calculation results are summarized in Table 2.2.

Table 2.2 – Summary table of casing cementing

Casing name	Casing running depth, m	Casing diameter, mm	Bit diameter, mm	Cementing interval, m
Conductor	200	324	393.7	0-200
Intermediate column	2350	219	295.3	0-1350
Production casing	2700	146	215.9	0-2600

2.3 Drilling technique

2.3.1 The selection of rock- breaking tools

Taking into account the physical and mechanical properties of rocks and the design of the well, we take the following rock-breaking tools.

For drilling in the range of 0 -200 m – blade bit III-393.7 M-GVU.

For drilling in the interval of 200 -1350 m – roller cone bit III-295.3 M-GVU, III-295.3 S-GVU, III 295.3 SZ-GV - 2.

For drilling in the interval 1350-2600 m – roller cone bit III-215.9 MZ-GAU, III-215.9 MS-GNU, III 215.9 SZ-GAU.

2.3.2 Drill string

1. The diameter of the drill collar is selected taking into account the diameter of the bit based on the following conditions

$$\frac{d_{\text{UBT}}}{D_{\text{d}}} = 0.75 \div 0.85 \text{ if } D_{\text{d}} \leq 295.3 \text{ mm;} \quad (3)$$

Then

$$d_{\text{UBT}} = (0.75 \div 0.85) \cdot D_{\text{d}} = (0.75 \div 0.85) \cdot 215.5 = 162 \div 192 \text{ mm.}$$

In accordance with GOST, at the UBT accept $d_{\text{UBT}} = 178$ mm.

The weight of 1 m of these pipes is $q_{\text{UBT}} = 1030$ H.

The diameter of the drill pipes is selected from the ratio

$$\frac{d_{\text{bt}}}{d_{\text{UBT}}} = 0.75 \div 0.80, \quad (4)$$

Then

$$d_{\text{bt}} = (0.75 \div 0.80) \cdot d_{\text{UBT}} = (0.75 \div 0.80) \cdot 146 = 110 \div 117 \text{ mm.}$$

In accordance with GOST, we accept for drill pipes $d_{\text{bt}} = 114$ mm.

2. The bottom hole assembly is designed taking into account the wellbore profile and the rock tendency to bend the well. Since the well is vertical, we use an above-bit calibrator, one drill collar of the maximum possible diameter (UBTS1-203), a stabilizer and then a drill collar of the calculated diameter.

Since the layout is single-stage, the required length of the drill collar is determined by the formula

$$l_{\text{UBT}} = \frac{KG_{\text{d}}}{q_{\text{UBT}}\left(1 - \dfrac{\rho_{\text{pr}}}{\rho_{\text{m}}}\right)}, \tag{5}$$

where K is the safety factor, K=120 – 1.25;

G_{d} is the axial load, H;

ρ_{pr} is the density of the flushing liquid, kg/m^3;

ρ_{m} is the metal density, kg/m^3;

q_{UBT} is the weight of 1 m of drill collar, N/m.

The resulting length of the drill collar is rounded up to a value that is a multiple of the length of the candle.

$$l_{\text{UBT}} = \frac{1.25 \cdot 100000}{2230 \cdot \left(1 - \dfrac{1500}{7850}\right)} = 179 \text{ m.}$$

We accept a multiple of the length of the stand (23 m) l_{UBT} = 189 m.

The weight of the drill collar is

$$G_{\text{UBT}} = l_{\text{UBT}} \cdot q_{\text{UBT}} = 189 \cdot 2230 = 421470 \text{ N.}$$

The length of the drill collar is checked for stability from the action of its own weight. To determine the critical length of the drill collar by the formula

$$l_{\text{UBT}}^{\text{kr}} = 1.94 \sqrt{\frac{EI}{q_{\text{UBT}}}}, \tag{6}$$

where E is the modulus of elasticity of material (steel), N/m^2;

I is the moment of inertia at bending, m^4

$$I = \frac{\pi}{64}\left(d_{\text{n}}^4 - d_{\text{vn}}^4\right), \tag{7}$$

Where d_{n}, d_{vn} are the outer and inner diameter of the UBT respectively, m.

$$I = \frac{\pi}{64}(0.146^4 - 0.068^4) = 21.25 \cdot 10^{-6} \text{ m}^4.$$

Then

$$l_{\text{UBT}}^{\text{kr}} = 1.94\sqrt{\frac{2.1\cdot 10^{11}\cdot 21.25\cdot 10^{-6}}{2230}} = 127.7 \text{ m.}$$

As $l_{\text{UBT}} \geq l_{\text{UBT}}^{\text{kr}}$, then, to prevent possible borehole curvature, we include centralizers in the drill collar assembly.

Above the drill collar, we place the above-bit set of drill pipes. To do this, we select pipes made of steel of strength group “D” with the greatest wall thickness and a length of 275 m, q_{bt} = 285 N.

Its weight is

$$G_{\text{nk}} = l_{\text{bt}} \cdot q_{\text{bt}} = 275 \cdot 285 = 78375 \text{ N.}$$

3. Drill string design

When determining the design of the drill string, we assume that the drill string has a single-stage design. For the first section, we accept drill pipes of strength group “D” with a minimum wall thickness (8 mm).

The length of the first section is determined from the condition of permissible tensile stresses by the formula

$$l_1 = \frac{Q_{p1} - K_{\text{t}}\left(G_{\text{UBT}} + G_{\text{nk}}\right)\left(1 - \frac{\rho_{\text{pr}}}{\rho_{\text{m}}}\right) - P_{\text{p}}F_{\text{p}}}{Kq_1\left(1 - \frac{\rho_{\text{pr}}}{\rho_{\text{m}}}\right)}; \tag{8}$$

$$Q_{\text{p}1} = \frac{Q_{\text{t}}}{K_1 n}, \tag{9}$$

where $Q_{\text{p}1}$ is the permissible tensile load for pipes of the first section, N;

K_{t} is the coefficient of friction (K_{t}=1,15);

G_{UBT} is the weight of drill collar, N;

G_{nk} is the weight of the above-bit set, N;

P_{p} is the bit pressure loss, Pa;

F_{p} is the flow area of drill pipe, m^2;

q_1 is the weight of 1 m of drill pipes of the first section, q_1 = 214 N/m;

Q_{t} is the tensile load limit determined by the yield point of the pipe material σ_{t}, N for steel grade "*D*" σ_{t} = 380 MPa;

$$Q_t = \boldsymbol{\sigma}_t \cdot F_{tr}. \tag{10}$$

F_{tr} is the cross-sectional area of the drill pipe body, m^2;

n is the safety factor (since rotary drilling n = 1.4);

K_1 is the coefficient that takes into account the effect of torque and bending moment (for rotary drilling K_1=1.04).

Then

$$Q_{p1} = \frac{380 \cdot 10^6 \cdot 0.785\left(0.114^2 - 0.098^2\right)}{1.04 \cdot 1.4} = 695300 \text{ N}$$

Then the length of the first section

$$l_1 = \frac{695300 - 1.15 \cdot (334750 + 78375)\left(1 - \dfrac{1500}{7850}\right) - 11.0 \cdot 10^6 \cdot 0.785 \cdot 0.100^2}{1.15 \cdot 214 \cdot \left(1 - \dfrac{1500}{7850}\right)} = 1145 \text{ m.}$$

In accordance with the length of the stand, we take l_1 = 1125 m.

Since the total length of the KNBK, UBT, drill collar and the first section is less than the depth of the borehole, we install a second, stronger one behind the first section (wall thickness 9 mm, weight 1 m 238 N). The length of the second section is determined by the formula

$$l_2 = \frac{Q_{p2} - Q_{p1}}{kq_2\left(1 - \dfrac{\rho_{pr}}{\rho_m}\right)}. \tag{11}$$

Where

$$Q_{p2} = \frac{380 \cdot 10^6 \cdot 0.785\left(0.114^2 - 0.096^2\right)}{1.04 \cdot 1.4} = 774800 \text{ N}$$

Then the length of the second section

$$l_2 = \frac{774800 - 695300}{1.15 \cdot 238 \cdot \left(1 - \dfrac{1{,}50}{7.85}\right)} = 359 \text{ m.}$$

In accordance with the length of the stand, we take l_2 = 350 m.

For the third section (wall thickness 10 mm, weight 1 m 262 N) we use steel grade “*K”* steel grade “*K*”σ_t = 500 MPa.

$$Q_{p3} = \frac{500 \cdot 10^6 \cdot 0.785\left(0.114^2 - 0.094^2\right)}{1.04 \cdot 1.4} = 112200 \text{ N}$$

$$l_3 = \frac{112200 - 774800}{1.15 \cdot 262 \cdot \left(1 - \frac{1,50}{7.85}\right)} = 1424 \text{ m.}$$

Since while the total length of the sections, UBT and KNBK exceeds the design depth of the well, the length of the third section will be

$$l_3 = L_{skv} - l_{UBT} - l_{nk} - l_1 - l_2 = 2700 - 325 - 275 - 1125 - 350 = 625 \text{ m.}$$

The drill string design is given in the summary table.

Table 2.3 – Drill string design

Indicators	Section number				
	UBT	Above bit kit	1	2	3
Outside diameter of pipes, mm	178	114	114	114	114
Wall thickness, mm		11	8	9	10
Strength group of pipe material		Д	Д	Д	Д
Section length, m	325	275	1125	350	625
Weight 1m, N / m	1030	285	214	238	262
Section weight, N	4211470	78375	240750	83300	163750
Total weight, N	900925				

Based on the proposed flow rate and dimensions of the pumping means, as well as taking into account the established practice of drilling in this area, we take the final drilling diameter of 215.9 mm, the production string diameter – 146 mm.

The casing diameters and directions are selected in accordance with the size of the annular gap between the bit and the running casing string and the annular gap between the casing string and the bit running into it for the next interval. The diameters of the drill and casing bits are 295.3 mm, 393.7 mm, and the diameters of the casing strings are 245 mm and 324 mm, respectively.

The lifting height of the grouting slurry in the annulus is determined on the basis of the current instructional and methodological materials. The lifting height of the cement slurry behind all the columns should be made up to the wellhead [9].

2.3.3 Well flushing

Substantiation of the density of the flushing fluid

We select the density of the drilling fluid according to the combined pressure graph and refine it for each interval of compatible drilling conditions using the formula

$$\rho_{pr} = \frac{\alpha P_{pl}}{gH}; \qquad (12)$$

where P_{pl} is the reservoir pressure in the well interval for which is determined ρ_{pr};

g is the free fall acceleration, m/s^2;

H is the hole top depth, m;

α is the standard coefficient, which, in accordance with the requirements of the rules for conducting drilling operations, determines the pressure reserve in the borehole above the reservoir.

Density in the range of 10-200 m (since H <1200, we take α = 1.12).

$$\rho_{pr} = \frac{1.12 \cdot 400 \cdot 10000}{9.81 \cdot 400} = 1143 \text{ kg/m}^3.$$

We accept ρ_{pr} = 1140 kg/m^3.

Density in the interval 200-1350 m (as 100 < H < 2500 then we accept α = 1.03).

$$\rho_{pr} = \frac{1.03 \cdot 1350 \cdot 11600}{9.81 \cdot 1350} = 1126 \text{ kg/m}^3.$$

We accept ρ_{pr} = 1120 kg/m^3.

Density in the interval 1350 – 2700 m (as H > 1500 then we accept α = 1,05).

$$\rho_{pr} = \frac{1.05 \cdot 2650 \cdot 10000}{9.81 \cdot 2650} = 11180 \text{ kg/m}^3.$$

We accept ρ_{pr} = 1120 kg/m^3.

Hydraulic calculation

Determine the hydraulic pressure loss in the elements of the circulation system

$$P = P_{\text{t}} + P_{\text{kp}} + P_{\text{z}} + P_{\text{UBT}} + P_{\text{kpUBT}} + P_{\text{obv}} + P_{\text{d}}, \quad (13)$$

where P is the total hydraulic pressure loss in the circulation system, Pa;

P_{t} is the pressure loss in drill pipes, Pa;

P_{kp} is the pressure loss in the annular space behind the drill pipes, Pa;

P_{z} is the pressure loss in locks and couplings, Pa;

P_{UBT} is the pressure loss in UBT, Pa;

P_{kpUBT} is the pressure loss in the annular space behind the UBT, Pa;

P_{obv} is the pressure loss in ground piping (riser, drill hose, kelly, swivel), Pa;

P_{d} is the bit pressure loss, Pa.

To determine the pressure loss in the pipes and the annular space, it is necessary to determine the mode of movement, depending on which one or another calculation formula is chosen. To do this, we determine the actual Re and critical Re_{kp}.

$$\text{Re} = \frac{\rho_{\text{pr}} V d_g}{\eta_{\text{pr}}}, \quad (14)$$

where ρ_{pr} is the density of the flushing liquid, kg/m^3;

V is the flushing fluid speed, m/s;

d_{g} is the hydraulic diameter, which is equal to the inner diameter of the pipe d_{v} or difference in diameters $d_{\text{g}} = D_{\text{s}} - d_{\text{n}}$ for annular space, m;

D_{s} is the borehole diameter, m;

d_{n} is the drill string outer diameter, m;

η_{pr} is the dynamic viscosity of the flushing fluid, Pa·s;

$$\eta_{\text{pr}} = 0.033 \cdot 10^{-3} \rho_{\text{pr}} - 0.022; \quad (15)$$

$$\text{Re}_{\text{kr}} = 2100 + 7.3 He^{0,58}, \quad (16)$$

where He is the Helstrom test;

$$He = \frac{\rho_{\text{pr}} \tau_0 d_{\text{g}}^2}{\eta_{\text{pr}}^2}, \quad (17)$$

where τ_0 is the dynamic shear stress, Pa.

$$\tau_0 = 8.5 \cdot 10^{-3} \rho_{\text{pr}} - 7. \quad (18)$$

$$V=\frac{Q}{F}, \tag{19}$$

where F is the cross-sectional area, m^2

a) for drill pipes

$$F=\frac{\pi}{4}d_{\mathrm{v}}^2=0{,}785\cdot 0.100^2=7.85\cdot 10^{-3}\ \mathrm{m}^2.$$

$$V=\frac{0.022}{7.85\cdot 10^{-3}}=2.8\ \mathrm{m/s}.$$

$$\eta_{\mathrm{pr}}=0.033\cdot 10^{-3}\cdot 1500-0.022=0.0275\ \mathrm{Pa\cdot s}.$$

$$d_{\mathrm{g}}=d_{\mathrm{v}}=0.100\ \mathrm{m}.$$

$$\mathrm{Re}=\frac{1500\cdot 2.8\cdot 0.100}{0.0275}=15279$$

$$\tau_0=8{,}5\cdot 10^{-3}\cdot 1500-7=5{,}75\ \mathrm{Pa}$$

$$He=\frac{1500\cdot 5.75\cdot 0.100^2}{0.0275^2}=114050$$

$$\mathrm{Re_{kr}}=2100+7.3\cdot 114050^{0{,}58}=8358$$

As Re>$\mathrm{Re_{kr}}$, then the fluid flow mode is turbulent.

In a turbulent mode of motion, the pressure loss is determined by the Darcy-Weisbach formula

$$P_{\mathrm{t}}=\lambda\frac{V^2}{2}\frac{\rho_{\mathrm{pr}}}{d_{\mathrm{g}}}l, \tag{20}$$

where λ is the hydraulic resistance coefficient

$$\lambda_{\mathrm{t}}=0{,}1\left(1{,}46\frac{\Delta}{d_g}+\frac{110}{\mathrm{Re}}\right)^{0{,}25}; \tag{21}$$

Where Δ is the roughness of pipes, for pipe walls $\Delta=3\cdot 10^{-4}$ m.

l is the drill pipe length.

Then

$$\lambda_{\mathrm{t}}=0.1\left(1.46\frac{3\cdot 10^{-4}}{0.100}+\frac{110}{15279}\right)^{0{,}25}=0.032$$

Pressure loss

$$P_{\text{т}} = \lambda \frac{V^2}{2} \frac{\rho_{\text{pr}}}{d_g} l = 0{,}034 \cdot \frac{2{,}8^2}{2} \cdot \frac{1500}{0.100} \cdot 2375 = 4.52 \cdot 10^6 \text{ Pa.}$$

b) for annular space behind drill pipes

$$F = \frac{\pi}{4}\left(D_{\text{s}}^2 - d_{\text{n}}^2\right) = 0{,}785 \cdot (0.2011^2 - 0.114^2) = 2.16 \cdot 10^{-2} \text{ m}^2.$$

$$V = \frac{0.022}{2.16 \cdot 10^{-2}} = 1.02 \text{ m/s.}$$

$$\eta_{\text{pr}} = 0.0275 \text{ Pa} \cdot \text{s.}$$

$$d_{\text{g}} = D_{\text{s}} - d_{\text{n}} = 0.2011 - 0.114 = 0.0871 \text{ m.}$$

$$\text{Re} = \frac{1500 \cdot 1.02 \cdot 0.0871}{0.0275} = 4849$$

$$\tau_0 = 5.75 \text{ Pa}$$

$$He = \frac{1500 \cdot 5.75 \cdot 0.0871^2}{0.0275^2} = 86523$$

$$\text{Re}_{\text{kr}} = 2100 + 7.3 \cdot 86523^{0{,}58} = 7432$$

As $\text{Re} < \text{Re}_{\text{kr}}$, then the fluid flow regime is laminar.

Then the pressure loss in the annular space is determined by the formula:

$$p_{\text{kp}} = \frac{4\tau_0 l}{\beta_n \left(D_c^2 - d_н^2\right)}, \tag{22}$$

Where β_{t}, β_{kp} are respectively the coefficients that can be found from the graph by first finding the Saint-Venant parameter *Sen* for annular space

$$Sen = \frac{\tau_0 d_{\text{g}}}{\eta_{\text{pr}} V}, \tag{23}$$

$$Sen = \frac{5.75 \cdot 0.0871}{0.0275 \cdot 1.02} = 18.$$

For such a value of the Saint-Venant parameter $\beta_{\text{kp}} = 0{,}49$.

Then

$$p_{\text{kp}} = \frac{4 \cdot 5.75 \cdot 2375}{0.49 \cdot \left(0.2011^2 - 0.114^2\right)} = 4.06 \cdot 10^6 \text{ Pa.}$$

Similarly, we find the pressure loss in the UBT (RUBT) and the annular space

в) for drill collars

$$F = \frac{\pi}{4} d_{vUBT}^2 = 0.785 \cdot 0.068^2 = 3.63 \cdot 10^{-3}\ m^2.$$

$$V = \frac{0,022}{3.63 \cdot 10^{-3}} = 6.06\ \text{m/s}.$$

$$\eta_{pr} = 0,0275\ \text{Pa} \cdot \text{s}.$$

$$d_g = d_{vUBT} = 0.068\ \text{m}.$$

$$\mathrm{Re} = \frac{1500 \cdot 6.06 \cdot 0.068}{0.0275} = 22469$$

$$\tau_0 = 5,75\ \text{Pa}$$

$$He = \frac{1500 \cdot 5.75 \cdot 0.068^2}{0.0275^2} = 52737$$

$$\mathrm{Re}_{kr} = 2100 + 7.3 \cdot 52737^{0,58} = 6101$$

As $\mathrm{Re} > \mathrm{Re}_{kr}$, then the fluid flow regime is turbulent.

Then

$$\lambda_t = 0.1 \left(1.46 \frac{3 \cdot 10^{-4}}{0.068} + \frac{110}{22469}\right)^{0,25} = 0.032$$

Pressure loss

$$P_{tUBT} = \lambda \frac{V^2}{2} \frac{\rho_{pr}}{dg} l = 0.032 \cdot \frac{6,06^2}{2} \cdot \frac{1500}{0.068} \cdot 325 = 4.26 \cdot 10^6\ \text{Pa}.$$

g) for annular space for UBT

$$F = 0.785 \cdot ((1.2 \cdot 0.1905)^2 - 0.146^2) = 2.43 \cdot 10^{-2}\ m^2.$$

$$V = \frac{0.022}{2.43 \cdot 10^{-2}} = 0.91\ \text{m/s}.$$

$$\eta_{pr} = 0.0275\ \text{Pa} \cdot \text{s}.$$

$$d_g = D_s - d_n = 1.2 \cdot 0.1905 - 0.146 = 0.0826\ \text{m}.$$

$$\mathrm{Re} = \frac{1500 \cdot 0.91 \cdot 0.0826}{0.0275} = 4079$$

$$\tau_0 = 5.75\ \text{Pa}$$

$$He = \frac{1500 \cdot 5,75 \cdot 0,0826^2}{0,0275^2} = 77813$$

$$\mathrm{Re}_{kr} = 2100 + 7.3 \cdot 77813^{0,58} = 7113$$

As $\mathrm{Re} < \mathrm{Re}_{kr}$, then the fluid flow mode is laminar.

Then

$$Sen = \frac{5.75 \cdot 0.0826}{0.0275 \cdot 0.91} = 19 .$$

For such a value of the Saint-Venant parameter β_{kp} = 0.50.

Then

$$P_{\text{kpUBT}} = \frac{4 \cdot 5.75 \cdot 325}{0.50 \cdot \left((1.2 \cdot 0.1905)^2 - 0.146^2 \right)} = 0.48 \cdot 10^6 \text{ Pa.}$$

We use ZU-146 locks to connect drill pipes.

The pressure loss in the locks is determined by the Borda-Carnot formula

$$P_{\text{z}} = \xi \rho_{\text{pr}} \frac{V^2}{2} i , \tag{24}$$

Where ξ is the local resistance coefficient;

V is the average speed of fluid movement in pipes, V = 2.8 m/s;

i is the number of locks.

$$\xi = k_{\text{pk}} \left(\frac{F}{F_{pk}} - 1 \right), \tag{25}$$

Where k_{pk} is the experimental coefficient that takes into account the peculiarities of the configuration of the local resistance in the passage channel;

F is the cross-sectional area of the pipe channel, m^2;

F_{pk} is the the smallest overcut area of the passage channel in the lock, m^2.

$$i = \frac{l}{l_{\text{t}}} , \tag{26}$$

Where l is the length of drill pipes of the same diameter;

l_{t} is the length of one pipe.

Then

$$\xi = k_{\text{pk}} \left(\frac{F}{F_{\text{kp}}} - 1 \right) = 2 \cdot \left(\frac{0.785 \cdot 0.100^2}{0.785 \cdot 0.082^2} - 1 \right) = 0.97 .$$

$$i = \frac{2375}{11.5} = 206 \text{ pc.}$$

$$P_{z} = \xi \rho_{\text{pr}} \frac{V^2}{2} i = 0.97 \cdot 1500 \frac{2.80^2}{2} \cdot 206 = 1.18 \cdot 10^6 \text{ Pa.}$$

The pressure loss in the ground piping is found by the formula

$$P_{\text{obv}} = (\lambda_s + \lambda_{\text{bch}} + \lambda_v + \lambda vt)\rho_{np} Q^2, \tag{27}$$

Where λ_s, λ_{bch}, λ_v, λ_{vt} are the coefficients of hydraulic resistance in the riser, drill hose, swivel, and kelly respectively.

These values for the given conditions are equal

$$\lambda_s = 0.4 \cdot 10^5;\ \lambda_{bch} = 0.3 \cdot 10^5;\ \lambda_v, = 0.3 \cdot 10^5;\ \lambda_{vt} = 0.4 \cdot 10^5.$$

Then

$$P_{obv} = (0.4 \cdot 10^5 + 0.3 \cdot 10^5 + 0.3 \cdot 10^5 + 0.4 \cdot 10^5) \cdot 1500 \cdot 0.022^2 = 0.10 \cdot 10^6 \cdot \text{Pa}.$$

Pressure reserve that can be realized in the bit P_d, defined as the difference between the pressure that the pump (or pumps) develops with the selected diameter of the bushings, and the sum of losses in the circulation system.

$$P_{\text{d}} = b_{\text{r}} P_{\text{n}} - \sum P_{\text{i}}, \tag{28}$$

where b_r =0.75 – 0.8 is the coefficient that takes into account that the continuous working pressure of the discharge of mud pumps should, according to the rules of drilling operations, be less than the passport 20 – 25 %;

P_n is the the pressure that the pump develops for the given conditions $P_n = 32 \cdot 10^6$ Pa;

ΣP_i is the pressure loss in drill pipes, annular space, tool joints, UBT, annular space behind the UBT, strapping.

Then

$$P_d = 0.8 \cdot 32 \cdot 10^6 - (4.52 + 4.06 + 4.26 + 0.48 + 1.18 + 0.10) \cdot 10^6 = 11.0 \cdot 10^6 \text{ Pa}$$

By the value of P_d, we will establish the possibility of using the jetting effect when drilling a given interval of the well.

To do this, we determine the speed of fluid movement in the flushing holes of the bit by the formula

$$V_{\text{d}} = \mu_{\text{d}} \sqrt{\frac{2P_{\text{d}}}{\rho_{\text{pr}}}}, \tag{29}$$

Where μ_d is the consumption coefficient, for jetting bits we take μ_d=0.92.

Then

$$V_d = 0.92\sqrt{\frac{2 \cdot 11{,}0}{1500}} = 111 \text{ m/s.}$$

Since the obtained speed value exceeds 80 m/s, this means that this interval can be drilled using jet drill bits.

Let us determine the total area of the nozzles f_d of the jetting bit according to the formula

$$f_d = \frac{Q}{V_d} = \frac{0.022}{111} = 1.97 \cdot 10^{-4} \text{ m}^2.$$

By f_d value, we select the diameters of the jet bit nozzles according to the formula

$$d_n = \sqrt{\frac{4 f_d}{\pi n}}, \tag{30}$$

Where d_n is the nozzle diameter, m;

n is the number of attachments.

$$d_n = \sqrt{\frac{4 \cdot 1.97 \cdot 10^{-4}}{3.14 \cdot 3}} = 0.0092 \text{ m} = 9.2 \text{ mm.}$$

Drilling fluids perform functions that determine not only the success and speed of drilling, but also the commissioning of a well with maximum productivity. The main of these functions are:

– removal of cuttings from under the bit, transporting it along the annulus and ensuring its separation on the surface;

– keeping the sludge in suspension when the circulation of the solution is stopped;

– cooling the bit and facilitating the destruction of the rock in the bottomhole zone;

– creating pressure from the borehole wall to prevent water, oil and gas manifestations;

– providing physicochemical effects on the walls of the well, preventing their collapse;

– ensuring the preservation of the permeability of the productive formation during its opening;

– power transmission to the downhole hydraulic motor (when used), etc. When drilling the projected well, the following drilling fluids will be used.

In the process of drilling, a clay mud with a density of 1.07 g/cm^3 treated with Na_2CO_3, graphite will be used under the surface of the conductor, which will ensure drilling without complications in the 0 – 200 m interval, where rock falls are expected.

Clay mud properties:

ρ = 1070 g/cm^3,

T = 60 – 80 sec,

B = 25 – 30 sm^3 /30 min,

CHC = 10 – 20 dPa

K = 1 – 2mm, pH=8-9,

When drilling under an intermediate string, collapses and losses are possible. Therefore, it provides for the use of a humate-acrylic solution based on the PAA + PVLR complex reagent, its characteristics:

ρ = 1.12 g/cm^3,

pH=8 – 9,

T = 20 – 30 sec,

B=6 – 8 sm^3 /30min,

CHC=5 – 15/15 – 40 mgf/cm min,

K = 1 mm, sand =1 – 2%

When drilling under the production casing, collapses and losses are also possible. It also provides for the use of a humate-acrylic solution based on the complex reagent PAA + PVLR, with the treatment of PVLR, PAA, FHLS (imp.), Na_2CO_3, KCl, KOH, and its characteristics with oil:

ρ = 1.12 g/sm^3,

pH=8 – 9,

T = 20 – 35 sec,

$B = 5 – 6\ sm^3\ /30min.$,

CH3 = 15 – 20/30 – 45 mgf/cm min,

K = 1 mm, sand =1 – 2%

2.4 Drilling technology

2.4.1 Calculating the axial load on a bit

The value of the axial load on the bit P_{dol}, which should ensure the volumetric destruction of the bottomhole, taking into account the indicators of the mechanical properties of rocks and structural data on the contact area of the teeth of the bit with the bottomhole, is determined by the formula:

$$P_{dol.} = \alpha * P_{ch} * F_k, \tag{31}$$

Where α is the empirical coefficient that takes into account changes in bottomhole conditions for changes in hardness (α = 0.3 – 1.59);

P_{ch} is the rock hardness according to L.A. Schreiner's method (by stamp); kg/mm^2.

F_k is the contact area of the bit teeth with the bottomhole mm^2, determined by the formula of V.S. Fedorov:

$$F_k = (D_{dol.} * \eta * \delta)/2, \text{ mm.} \tag{32}$$

Where η is the tooth overlap ratio;

δ is the bluntness factor.

In this way, $P_{dol.} = \alpha * P_{ch} * D_{dol.} * \eta * \delta/2$.

For bit diameter 490 mm:

$P_{dol.}$ = 1*250* 490*1.21*1/2 = 74112.5 H = 7.41 t.

For bit diameter 393.7 mm:

$P_{dol.}$ = 1*250* 393.7*1.21*1/2 = 59547.5 H = 5.95 t.

For bit diameter 295.3 mm:

$P_{dol.}$ = 1.2*300* 295.3*1.14*2/2 = 151190.4 H = 15.12 t.

For bit diameter 215.9 mm:

$P_{dol.}$ = 1.59*350* 215.9*1.4*2/2 = 168207.69 H = 16.82 t.

Let us compare the obtained values with the actual values of the WOB, which are calculated by the formula: $P_{dol.f.} = P_1 + P_2 + P_3 + P_4 + P_5 + P_6$,

Where P_1 is the bit weight, P_2 is the adapter weight, P_3 is the weight UBT, P_4 is the drill pipe weight, P_5 is the kelly weight, P_6 is the swivel weight.

For bit diameter 393.7 mm:

$P_{dol.f.}$ = 150 + 15 + 4368 + 1864.5 + 2300 = 8697.5 kg = 8.7 t.

For bit diameter 295.3 mm:

$P_{dol.f.}$ = 150 + 15 + 2180 + 11484 + 1864.5 + 2300 = 37650 kg = 37.65 t.

For bit diameter 215.9 mm:

$P_{dol.f.}$ = 150 + 15 + 29640 + 98890 + 1864.5 + 2300 = 132859.5 kg = 132.86 t.

Since the actual loads on the bit exceed the design values, drilling will be performed at the design value with load compensation through the drilling rig winch.

2.4.2 Calculation of bit speed

It is determined by the following formula:

$$N = 60*V/\pi*D_{dol.}, \text{ (about/min)}, \quad (33)$$

Where V is the average peripheral speed of the bit (V = 0,8 – 2,0).

For bit diameter 393.7 mm:

N = 60*2/3.14*0.3937 = 77.07 about/min, that is, drilling will be carried out at 1 rotor speed.

For bit diameter 295.3 mm:

N = 60*2/3.14*0.2953 = 89.42 about/min, that is, drilling will be carried out at 3 rotor speeds.

For bit diameter 215.9 mm:

N = 60*1.5/3.14*0.2159 = 70 about/min, that is, drilling will be carried out at 2 rotor speeds.

2.4.3 Calculation of the amount of flushing fluid

The technologically required amount of flushing fluid to ensure timely and uninterrupted removal of cuttings from the bottomhole along the annulus and cleaning the wellbore is found from the ratio:

$$Q = 0.785*(d^2_{dol.} - d^2_{nar.b.tr.})*V_{vosh.}, \tag{34}$$

Where V_{vosh} is the minimum permissible upward flow rate from the condition of high-quality cleaning and the wellbore (the smaller the diameter, the higher it is).

For bit diameter 393.7 mm:

$$Q = 0.785*(3.937^2 - 1.4^2)*4 = 42.3 \text{ l/s}.$$

The pump will operate on 150 mm bushings with a capacity 48,0 m/s.

For bit diameter 295.3 mm:

$$Q = 0.785*(2.953^2 - 1.4^2)*8 = 87.9 \text{ l/s}.$$

The operation of 2 pumps will be carried out on 170 mm bushings with a capacity of 80.0 l/s.

For chisel diameter 215.9 mm:

$$Q = 0.785*(2.159^2 - 1.27^2)*16 = 93.3 \text{ l/s}.$$

The operation of 2 pumps will be carried out on 140 mm bushings with a capacity of 100.0 l/s.

2.4.4 Selection of rock-breaking tools

When drilling oil and gas wells, the main tool, with the help of which the rock at the bottom hole is destroyed and the well itself is formed, is the bit.

In Russia, as well as in the United States and other foreign countries, roller cone bits with conical cutters are mainly used for drilling oil and gas wells.

Taking into account the physical and mechanical properties of the rocks of the project section and the established practice of drilling operations in this area, we select the following types of bits for the drilling intervals:

Table 2.4 – The applied rock-breaking tools

Rock categories by drillability	Drilling interval, m	Bit type
I	0 – 350	STSV
I – II	350 – 2400	C-GV (R-175)
III – IV	3000 – 3800	NW-GV (R-162)

2.5. Drilling equipment

2.5.1 Selection of a rig

We select the drilling rig according to the rated lifting capacity in accordance with the largest weight of the drill or casing string in the air.

Drilling rig drive type is selected depending on regional conditions. Taking into account the experience of work in this area, the drilling of the projected well will be carried out using a drive from an internal combustion engine.

To determine the greatest weight of the string, we will compile a comparative table of the weight of the drill and casing strings.

Table 2.5 – Weight of drill and casing strings

Indicators	Drill string	Intermediate column	Production casing
Column length	2600	1350	2600
Weight 1 m, N	–	466	304
Column weight, N	900925	790400	790400

Thus, the intermediate column has the maximum weight.

For well drilling we choose the BU 3000 EUK drilling rig.

Technical characteristics of the BU-3000EUK drilling rig

Drilling depth, m	3000
Permissible hook load, MN	1.4
Tackle system equipment	4×5
The greatest pressure at the pump outlet, MPa	32
Number of pumps, pcs	2
Base height, m	5.5
Candle length, m	25

2.5.2 Selection of a pumping unit

Mud pumps and circulation system perform the following functions:

– Injection of drilling fluid into the drill string to ensure circulation in the well during drilling and effective cleaning of the bottom hole and bit from cuttings, flushing, elimination of accidents, creating a rate of fluid rise in the annulus sufficient to bring the rock to the surface;

– Supply the bit with hydraulic power, providing a high flow rate (up to 180 m/s) of the solution from its nozzles for partial destruction of the rock and cleaning the bottom of the drilled particles;

– Power supply to the downhole hydraulic motor.

A mud pump for flushing a well in specific geological conditions is selected according to the technologically required amount of flushing fluid and the pressure developed at the same time to overcome pressure losses in the elements of the drilling circulation system.

The amount of required flushing fluid when drilling under the production casing is 31.11 l/s. Let us now determine the pressure loss in the circulation system, knowing which it is possible to choose the most rational arrangement of the drilling tool, reasonably select mud pumps and make fuller use of their potential capabilities.

The head loss, kgf/cm^2, in the circulation system of the drilling rig during rotary drilling is determined by the formula:

$$P_{\Sigma} = P_{\text{m}} + P_{\text{b.t.}} + P_{\text{k.p.}} + P_{\text{D}}, \tag{35}$$

where P_{m} is the head loss during the movement of the drilling fluid in the surface pipelines from the pumping section to the drill pipe string, including the standpipe in the drill pipe, the drill hose, as well as the swivel and the leading pipe (pressure loss in the outer piping of the drilling - manifold);

$P_{\text{b.t.}}$ is the head losses during the movement of drilling fluid in drill pipes and tool joints (pressure losses depend on the depth of the well);

$P_{\text{k.p.}}$ is the loss of pressure during the movement of drilling fluid in the annular space of the well (pressure loss depends on the depth of the well);

P_{D} is the head loss during the movement of drilling fluid through the drilling holes of the drill bit;

P_{m}, P_{D} do not depend on the depth of the well, and $P_{\text{b.t.}}$ and $P_{\text{k.p.}}$ increase with the depth of the well.

During the circulation of the cleaning agent, the pressure losses, kgf/cm^2, are different when pumping water and clay solution and depend on their properties and consumption.

$$P_{M} = 82.6 * \lambda * L_{e} * \gamma * Q^2 / d^5, \quad (36)$$

where λ is the is the dimensionless coefficient of hydraulic resistance when moving in pipes;

Q is the drilling mud flow rate, l/s;

γ is the specific gravity of the solution, g/cm^3;

d is the inner diameter of drill pipes, cm;

L_e is the equivalent length of onshore pipelines, which is determined by the formula:

$$L_e = L_H * (d/d_H)^5 + Lc * (d/d_s)^5 + L_{ch} * (d/d_{ch})^5 + L_v * (d/d_v)^5 + L_{v.tr} * (d/d_{v.tr})^5 + L_{e.f.} * (d/d_{e.f.})^5 \quad (37)$$

where d_H, L_H are the internal diameter and length of the discharge line from the mud pumps to the riser;

d_s L_s are the internal diameter and length of the riser with the drill;

d_{ch} L_{ch} are the inner diameter and length of drill hose;

d_v L_v are the swivel shaft inner diameter and length;

$d_{e.f}$ $L_{e.f.}$ are the diameter and equivalent length of the filter installed under the leading pipe;

$d_{v.tr.}$ $L_{v.tr.}$ are the inner diameter and length of the leading pipe.

$$L_e = 30 * (0.107/0.114)^5 + 15 * (0.107/0.114)^5 + 15 * (0.107/0.09)^5 + 2.5 * (0.107/0.09)^5 + 15 * (0.107/0.1)^5 + 2 * (0.107/0.114)^5 = 98.5$$

$$P_{M} = 82.6 * 0.026 * 96.85 * 1.2 * (31.11)^2 / (10.7)^5 = 1.72 \text{ kGs/cm}^2$$

$$P_{b.t} = 82{,}6 * \lambda * \gamma * Q^2 * (l + l_e / l) * L_b / d^5 \quad (38)$$

where L_b is the drill string length, m;

L_e is the equivalent length of the lock connections, m;

l is the distance between locks, m.

$$P_{b.t} = 82.6 * 0.026 * 2.03 * (31.11)^2 * (1 + 3.5/11) * 3800 / (10.7)^5 = 68.5 \text{ kGs/cm}^2$$

$$P_{\text{k.p.}} = 82{,}6 * \lambda_1 * \gamma * Q^2 * L / \left[(D_s - d_H)^3 * (D_s + d_H)^2\right], \qquad (39)$$

where λ_1 is the coefficient of hydraulic resistance when the drilling fluid moves in the annular (annular) space; D_s is the borehole (bit) diameter, cm; d_H is the outer diameter of drill pipes, cm.

The pressure loss from the tool joints in the annular space is small, therefore it is usually neglected.

$$P_{\text{k.p.}} = 82.6 * 0.027 * 2.03 * 31.11^2 * 3800 / \left[(21.59 - 12.7)^3 * (21.59 + 12.7)^2\right] =$$
$$= 9.32 \text{ kGs/cm}^2,$$

The head loss, kgf/cm^2, in the bit depends on the configuration of the flushing holes, on the number and area of their cross-section, the consumption of the cleaning agent (drilling mud).

$$P_D = C * \gamma * Q^2, \qquad (40)$$

where C is the coefficient characterizing the head loss in the flushing holes of the bit, which can be calculated by the formula:

$$C = 0.51 / (\mu^2 * f_0^2), \qquad (41)$$

where μ is the flow coefficient, f_0 is the total cross-sectional area of the flushing holes, cm^2.

$$C = 0.51 / (0.65^2 * 13.05^2) = 7 * 10^{-3},$$

$$P_D = 7 * 10^{-3} * 1{,}2 * 31{,}11^2 = 8{,}13 \text{ kGs/cm}^2,$$

We calculate the total head loss:

$$P_\Sigma = 1.72 + 62.5 + 9.32 + 8.13 = 81.67 \text{ kGs/cm}^2.$$

Thus, the technologically necessary amount (flow rate) of flushing fluid to ensure timely and uninterrupted removal of cuttings from the bottomhole along the annulus and cleaning the wellbore, taking into account pressure losses, will be provided by the UNB-600 pump.

Description of mud pump UNB-600:

Mud pump UNB-600 (U86MA2) is designed to supply flushing fluid to the bottomhole when drilling wells up to 5000 m deep. Flushing fluid is pumped through the drill pipe string to the borehole bottom to cool and remove the rock destroyed by the bit, as well as to transfer the flow energy to the turbodrill and its associated bit. Water or clay solution with the presence of oil, alkali, soda and other components is used as a flushing fluid.

Two-piston drilling pump UNB-600 in design is horizontal, crank, double-acting.

In the calculation of the main characteristics, it is assumed that the feed coefficient is 1, the efficiency is 0.85.

Mud pump UNB-600 in basic parameters corresponds to GOST 6031.

Table 2.6 - Technical characteristics of the mud pump UNB-600:

Power, kWt	600
Number of double-acting pistons:	2
Frequency of double strokes maximum in min.	65
Piston stroke length, mm	400
Type of gearing of the crank-slider mechanism	helical
Tooth inclination angle, degrees	9°22'00"
Valve box design	L- shaped double action
Connecting dimensions of the valve group in the valve box	#9 API Spec 7K
Inlet fluid pressure, not less, MPa (kgf/cm^2)	0.1 (1)
Coolant supply system for piston rods	Pressurized from an auxiliary electrically driven centrifugal pump
Coolant pressure, not less, MPa (kgf/cm^2)	0.15 (1.5)
Oil supply system to the friction units of the mechanical part:	1. Gravity from collection trays
	2. Dip in an oil bath
Overall dimensions, mm:	
length	5 100
width	3 000
height	4 040
Gearbox housing	Cast
Weight, kg	25 450

2.5.3 Rig selection and tackle system calculation

The tower is used for tripping operations and holding the drill string while drilling. Its choice is carried out according to the height H, m, and according to the carrying capacity *Q*.

Determine the height of the tower (H, m) by the formula:

$$H = k * L_{sv.}, \tag{42}$$

where *k* is the coefficient that prevents the drill string from being pulled into the crown block when it is over-lifted (usually *k* = 1.2 – 1.5);

$L_{sv.}$ Is the length of the plug, depending on the depth of the well, m.

We accept *k* = 1.5; $L_{sv.}$ = 28 m.

$$H = 1.5 * 28 = 42 \text{ m}$$

Thus, the tower BMA-45 / 200P, included in the set of the selected drilling rig, is quite suitable for the design work.

Table 2.7 – Parameters depending on the stroke frequency and piston diameters for the UNB-600 pump:

Piston diameter, mm	Ultimate inlet pressure, MPa	Ideal feed at a double stroke rate per minute, m^3/h					
		65	60	50	40	20	1
200	10.0	186.84	172.44	143.64	114.84	57.6	2,87
190	11.5	164.52	151.92	126.72	99.72	50.76	2,53
180	12.5	151.2	139.68	116.28	92.88	46.44	2,32
170	14.5	129.6	119.52	99.72	79.92	39.6	1,99
160	16.5	113.4	104.76	87.12	69.84	34.92	1,74
150	19.0	99.0	91.44	76.32	60.84	30.96	1,54
140	22.5	83.88	77.4	64.44	51.48	25.92	1,28
130	25.0	70.92	68.04	54.72	43.56	21.96	1,09
Power, kWt		600	554	462	369	185	9.230

The lifting system of the installation is a chain hoist mechanism consisting of a crane block, a traveling (movable) block, a steel rope, which is a flexible connection between the drawworks and the fixing mechanism of the fixed end of the rope.

As the depth of the wells increases, the weight of the drill strings that have to be lowered and raised increases, and the maximum winding speed of the leading string of the wireline on the winch drum remains practically unchanged for drilling rigs of different classes. Therefore, for each installation, a traveling system is used with its own chain hoist ratio from 4 to 14. This is achieved by using various rigs.

We will calculate the rigging and select the wire rope.

Let us calculate the number of working branches by the formula:

$$m = Q_{kr} / P_l * \eta_m, \tag{43}$$

where Q_{kr} is the weight of the drill, N;

P_l is the lifting capacity of the machine winch, N;

η_m is the efficiency of the tackle system, equal to 0.8 – 0.9.

Since the drill string will have the greatest weight (90.09 t) when drilling under the production string, we will calculate only for this string:

$$m = 900925 / (140000 * 0.9) = 5.8 \text{ (accept 6 branches).}$$

The total number of rope branches with a symmetric system is:

$$m_0 = m + 2 = 6 + 2 = 8.$$

Therefore, the rig will be applied 4 x 5.

The length of the wire rope in the equipment $L_{o.s.}$ depends on the number of strings m in it and the useful height of the tower h_P.

$L_{o.s.} = (m + 2)*h_P + l_3$, where $l_3 = 30$ m is the length of the rope wound on the drum.

$L_{o.s.} = (8 + 2)*42 + 30 = 450.$

Then the weight of the rope $G_k = L_{o.s.}*q_k$, where q_k is the weight of 1 m rope.

$G_k = 450*33.8 = 15210$ N = 15.21 kN.

Let us determine the largest statistical load on the moving strings of the rope of the tackle system:

$$P_{ts} = L*q + l_{ubt}*q_{ubt} + G_{ts}, \tag{46}$$

where L is the length of the drill pipes, m;

q is the weight of 1 m of drill pipes, N

l_{ubt} is the collar length, m;

q_{ubt} is the weight of 1 m of drill collar, N;

G_{ts} is the weight of traveling block, rope and hook, N.

Let us calculate G_{ts}:

$$G_{ts} = G_{tb} + G_{rope} + G_{hook} \quad (47)$$

$$G_{ts} = 67000 + 15210 + 35000 = 117210 \text{ N} = 117.21 \text{ kN}.$$

For column with a diameter of 324 mm:

l_{ubt} = 28 m, $q_{убт}$ = 1.56 kN.

P_{ts} = 28*1560 + 117210 = 160890 = 160.89 kN.

Static load per string: $P = P_{ts}/m$,

where m is the number of strings in the tackle system.

P = 160.89/8 = 20.11 кН.

For column with a diameter of 245 mm:

L = 364 m, q = 319 N, l_{ubt} = 136 m, q_{ubt} = 1.56 kN.

P_{ts} = 364*319 + 136*1560 + 117210 = 445486 N = 445.49 kN.

The static load on the string 1: P = 445.49 / 8 = 55,69 kN.

For column with a diameter of 146 mm:

L = 3100 m, q = 319 N, l_{ubt} = 190 m, q_{ubt} = 1.56 kN.

P_{ts} = 3100*319 + 190*1560 + 117210 = 1402510 N = 140.51 kN,

Static load on 1 string: P = 1402.51 / 8 = 175.31 kN.

Taking into account the calculated static loads, we select a steel wire rope of the right cross lay, type LK-RO, with a structure of 6x31 + 1 m with a diameter of 32 mm (according to GOST 16853-88) [2].

2.6 Well cementing

Initial data

When calculating the cementing of wells, the following is determined: 1) the amount of dry cement; 2) the amount of water for mixing the cement grout; 3) the amount of displacement fluid; 4) possible maximum pressure by the end of cementing; 5) allowable cementing time; 6) the number of cementing units and cement mixing machines.

We will calculate the single-stage cementing of each of the casing strings.

Table 2.8 - Initial data for cementing

	Conductor	Intermediate	Production casing
Depth of lowering (N, m)	200	2400	2600
Bit diameter (D, mm)	393.7	295.3	215.9
Outside diameter of casing pipes (d_1, mm)	324	245	146
Inner diameter of casing pipes (d_2, mm)	305.9	230.5	133
Lifting height of cement grout (N_c, m)	350	850	3160
Clay slurry density (ρ_r, kg / m^3)	1070	1100	1100
Density of cement grout (ρ_c, kg / m^3)	1860	1860	1860
Installation height of the stop ring from the bottom (h, m)	5	20	20

2.6.1 Calculation of the volume of cement grout

The volume of cement slurry to be injected into the well is determined by the formula:

$$V_c = (\pi/4)*[K_1*(D_2 - d_1^2)*H_c + d_2^2*h], \text{ m}^3 \qquad (48)$$

where K_1 is the coefficient taking into account an increase in the volume of cement slurry consumed for filling caverns, cracks, and an increase in the diameter of the well against the calculated (nominal).

The value of the K_1 coefficient is determined from the caliper log for each specific well. Typically K_1 ranges from 1.1 to 2.5. In our case, we take K_1 = 1.15.

The direction and conductor will be cemented using pure Portland cement.

For better pumpability of the grouting mixture and in order to raise the cement grout to the design height (to the wellhead), as well as in order to save Portland cement, the production casing in the interval 0 – 350 m will be cemented with a gel-cement slurry with a density of 1.42 g/cm^3 s using clay as a plasticizer. The ratio of clay to cement is 2: 3; water-cement ratio m = 1.1. The interval 200 – 2600 m will be cemented with a solution of pure Portland cement with a density of 1.85 g/cm^3; water-cement ratio is m = 0.5.

For column with a diameter of 324 mm:

$V_c = 0.785*[1.15*(0.3937^2 - 0.324^2)*200 + 0.3059^2*5] = 9.03$ m^3

For column with a diameter of 245 mm:

$V_c = 0.785*[1.15*(0.2953^2 – 0.245^2)*1350 + 0.2305^2*20] = 33.15\ m^3$

For column with a diameter of 146 mm:

Interval 350 – 2100 m:

$V_{g.цс.} = 0.785*[1.15*(0.2159^2 – 0.146^2)*2100 + 0.133^2*20] = 47.95\ m^3$

Interval 2100 – 2600:

$V_c = 0.785*[1.15*(0.2159^2 – 0.146^2)*500 + 0.133^2*20] = 11.42\ m^3$

The total volume of cement slurry for the production casing: 47.95 + 11.42 = = 59.36 m^3.

2.6.2 Calculation of the amount of dry cement

The amount of dry cement for the preparation of cement slurry is determined from the expression:

$$Q_c = \rho_c*V_c*1/(1+m), \tag{49}$$

where m is the water-cement ratio;

ρ_c is the cement slurry density, kg/m^3, it can be calculated by the formula:

$$\rho_c = [(1+m)*\ \rho_{s.c.}*\ \rho_v] / [\rho_v + m*\ \rho_{s.c.}]. \tag{50}$$

where $\rho_{s.c.}$ is the dry cement density, g/cm^3;

ρ_v is the density of water, g/cm^3.

$\rho_c = [(1+0.5)*\ 3.15*\ 1] / [1 + 0.5*3.15] = 1.85$ g/cm^3.

For column with a diameter of 324 mm:

$Q_c = 1.85*9.03*1/(1+0.5) = 11.14$ t.

For column with a diameter of 245 mm:

$Q_c = 1.85*33.15*1/(1+0.5) = 40.9$ t.

For column with a diameter of 146 mm:

Interval 0 – 2100 m:

The amount of gel-cement powder will be:

$Q_{g.c} = 1.85*47.95*1/(1+1.1) = 42.24$ t. (Cement powder: 42.24 t, clay powder: 17.17 t).

Interval 2100 – 2600 m:

$Q_c = 1.85*11.42*1/(1+0.5) = 8915.6$ kg = 14.1 t.

The total volume of cement for the column: $Q_c = 42.24 + 14.1 = 56.34$ t.

The amount of dry cement that must be prepared, taking into account the losses during mixing of the cement slurry, will be calculated by the formula:

$$Q_c^1 = K_2 * Q_c, \qquad (51)$$

where K_2 is the coefficient that takes into account ground losses during mixing of the cement slurry. If mixing is performed without cement mixing machines, $K_2 = 1.054$ – 5-1.15, when using cement mixing machines, $K_2 = 1.01$. In our case, $K_2 = 1.01$.

For column with a diameter of 324 mm:

$Q_c^1 = 1.01*11.14 = 11.25$ t.

For column with a diameter of 245 mm:

$Q_c^1 = 1.01*40.9 = 41.31$ t.

For column with a diameter of 146 mm:

Interval 0 – 2100 m:

$Q_c^1 = 1.01*42.24 = 42.66$ t.

Interval 2100 – 2600 m:

$Q_c^1 = 1.01*14.1 = 14.2$ t.

The total amount of dry cement, taking into account losses for the column:

$Q_c^1 = 42.66 + 14.2 = 56.90$ t.

2.6.3 Calculation of the amount of water

The required amount of water for the preparation of a cement mortar of 50% consistency is found from the expression:

$$V_v = 0,5*Q_c, \qquad (52)$$

For column with a diameter of 324 mm:

$V_v = 0.5*11.14 = 5.57$ m^3.

For column with a diameter of 245 mm:

$V_v = 0.5*40.9 = 20.45$ m^3.

For column with a diameter of 146 mm:

$V_v = 1.1*42.24 + 0.5*14.1 = 53.72$ m^3.

2.6.4 Calculation of the amount of displacement fluid

The required amount of displacement fluid (which is often used as drilling mud) is determined by the formula:

$$V_{pr} = \Delta*\pi*d_2^2*(H - h)/4, \quad (53)$$

where *Δ* is the coefficient taking into account the compression of the clay solution (*Δ* = 1.03 – 1.05).

Substituting the values, we get:

For column with a diameter of 324 mm:

V_{pr} = 1.03*3.14*0.3059^2*(200 – 5)/4 = 14.75 m^3.

For column with a diameter of 245 mm:

V_{pr} = 1.03*3.14*0.2305^2*(1350 – 20)/4 = 57.13 m^3.

For column with a diameter of 146 mm:

V_{pr} = 1.03*3.14*0.133^2*(2600 – 20)/4 = 36.90 m^3.

Very often in practice, the following empirical formula is used to quickly determine V_{pr}:

$$V_{pr} = D_n^2*H_1/2, \quad (54)$$

where D_n is the nominal outer diameter of the string of pipes lowered into the well, in inches;

$D_n^2/2$ is the the amount of displacement fluid required to fill 1 m of lowered pipes, l;

H_1 is the installation depth of the stop ring, i.e. the depth of squeezing the cement slurry.

For production casing:

V_{pr} = 5*2600/2 = 6500 l = 6.5 m^3.

2.6.5 Calculation of injection pressure

The maximum pressure before seating the top plug on the thrust ring is determined from the equation:

$$P_{max} = P_1 + P_2, \quad (55)$$

where P_1 is the pressure required to overcome the resistance caught by the density differences of the liquid in the pipes and the annulus;

P_2 is the pressure required to overcome hydraulic resistance.

$$P_1 = (1/10^5)*[(H_c - h)*(\rho_c - \rho_r)], \text{ MPa} \quad (56)$$

The value of P_2 is usually found using empirical formulas. The most common is the Shishchenko-Baklanov formula; for wells with a depth of more than 1500 m:

$$P_2 = 0.001*H + 1.6 \text{ MPa.} \quad (57)$$

For column with a diameter of 324 mm:

$P_1 = (1/10^5)*[(30 - 5)*(1420 - 1070)] = 0.08$ MPa

$P_2 = 0.001*30 + 1.6 = 1.53$ MPa.

$P_{max} = 0.08 + 1.53 = 1.62$ MPa.

For column with a diameter of 245 mm:

$P_1 = (1/10^5)*[(850 - 20)*(1420 - 1120)] = 2.66$ MPa

$P_2 = 0.001*850 + 1.6 = 2.45$ MPa.

$P_{max} = 2.66 + 2.45 = 5.11$ MPa.

For column with a diameter of 146 mm:

$P_1 = (1/10^5)*[(1500 - 20)*(1420 - 1120) + 1660*(1860 - 1120)] = 15.7$ MPa

$P_2 = 0.001*3160 + 1.6 = 4.76$ MPa.

$P_{max} = 15.7 + 5.26 = 20.96$ MPa.

2.6.6 Calculation of the number of cemented aggregates

The number of cementing aggregates is determined based on the condition for obtaining the rate of lifting of the cement slurry in the annular space at the casing shoe at the time of the start of pumping (at least 15 m/s for the surface conductor and intermediate strings, frost less than 1.8 – 2.0 m/s for production strings); this condition follows from the assumption that an increase in the speed of movement of the cement slurry in the annulus contributes to a more complete displacement of the clay slurry and its replacement with cement slurry.

Often, the wellbore is curved, has local expansion, and the string is not strictly cemented in it. In such cases, it is advisable to displace the cement slurry from the column, while maintaining a low rate of rise of the cement slurry in the annulus (ω = 0.1 – 0.4 m/s). The same should be done if the column is well centered, but it is impossible to create a turbulent flow of the cement slurry in the annulus. Since squeezing almost always begins at the highest speed (as a rule, at IV), the number of aggregates from the condition of ensuring the speed (m v/s) of the cement slurry rise in the annulus is determined by the formula:

$$N_{c.a} = [0.785*K_1*(D^2 - d_1{}^2)*\omega/Q^{IV}] + 1, \quad (58)$$

where Q^{IV} is the cementing unit capacity at IV speed, m^3/s.

We select a cementing unit of the TsA-320M type with 127-mm cylindrical bushings installed in its 9T pump (you can work with these bushings at p_{max} at the end of cementing). The maximum productivity is 0.9 m^3/min at a pressure of 6.1 MPa.

For column with a diameter of 324 mm:

$n_{c.a} = [0.785*1.2*(0.3937^2 - 0.324^2)*1.5/60] + 1 = 2$ aggregate.

Taking into account the established practice of drilling operations in this area, we accept $n_{c.a.}$ = 1 aggregate.

For column with a diameter of 245 mm:

$n_{c.a} = [0.785*1.2*(0.2953^2 - 0.245^2)*1.5/60] + 1 = 3$ aggregate.

Taking into account the experience of work in this area, we accept 2 aggregate.

For column with a diameter of 146 mm:

$n_{c.a} = [0.785*1.2*(0.2159^2 - 0.146^2)*2/(0.9/60)] + 1 = 5$ aggregates.

We accept $n_{c.a}$ = 5 aggregate TsA-320M.

2.6.7 Calculation of cementing performance

The cementing performance (the duration of the cementing process in minutes) can be determined by the formula:

$$t_c = [(V^1/Q_{ca}) + ((V_c + V_{pr} - V^1)/Q_m)] + t_{vsp}. \quad (59)$$

where $V^1 = V_{pr} - \Delta V$, ΔV we take equal 1 – 2 m^3;

Q_{ca} is the total capacity of cementing units, m^3/min;

Q_m is the productivity of cementing units, at which the most complete displacement of the drilling fluid by cement is achieved, m^3/min.

$$Q_m = 0.785*(D^2 - d_1{}^2)*K_1*\omega, \quad (60)$$

t_{vsp} is the time spent during cementing for auxiliary operations, mm (t_{vsp} + 10 – 15 min)

For column with a diameter of 324 mm:

$Q_m = 0.785*(0.3937^2 - 0.324^2)*1.2*1.5 = 0.07$ м^3/с = 4.2 m^3/min.

$t_c = [(0.76/0.9*1) + ((2.02+ 2.26 - 0.76)/4.2)] + 15 = 16.68$ min.

For column with a diameter of 245 mm:

$Q_m = 0.785*(0.2953^2 - 0.245^2)*1.2*1.5 = 0.04$ m^3/s = 2.4 m^3/min.

$t_c = [(19.12/0.9*2) + ((13.63+ 20.62 - 19.12)/2.4)] + 15 = 31.92$ min.

For column with a diameter of 146 mm:

$Q_m = 0.785*(0.2159^2 - 0.146^2)*1.2*1.5 = 0.048$ м^3/с = 2.88 m^3/min.

$t_c = [(47.95/0.9*10) + ((59.36+ 33.15 - 47.95)/2.88)] + 15 = 35.17$ min.

Duration of cementing should not exceed 75% of the time when the cement slurry begins to set. Then the permissible cementing time:

$$t_{dop} = 0.75*t_{n.skhv.} = 0.75*120 = 90 \text{ min.}$$

Thus, the selected number of cementing units and the calculations performed satisfy the conditions for cementing the casing strings [6].

2.6.8 Calculation of the number of cement mixing machines

Based on the condition of providing cement mortar for all operating TsA-320 M aggregate,

$$N_{csm} = n_{ca}*Q_{ca}/Q_{csm} \quad (61)$$

where Q_{ca} is the average productivity of one operating unit when pumping cement slurry into the column, m^3/min;

Q_{csm} is the average productivity of one cement mixing machine 2SMN-20, m^3/min.

Based on the condition of placing the cement powder delivered to the drilling rig in the bunkers of mixing machines:

$$N_{csm} = Q_c^1/q_{cb}, \tag{62}$$

where Q_c^1 is the weight amount of dry cement delivered to the drilling site, taking into account the estimated losses, t;

q_{cb} is the weight amount of cement placed in the hopper of one cement mixing machine

For column with a diameter of 324 mm:

n_{csm} = 11.14/20 = 0.6 = 1 machine 2SMN-20.

For column with a diameter of 245 mm:

n_{csm} = 40.9/20 = 2.1 = 3 machine 2SMN-20.

We accept 3 cement mixing machines 2SMN-20.

For column with a diameter of 146 mm:

n_{csm} = 56.34/20 = 3 machine 2SMN-20.

We accept 3 cement mixing machines 2SMN-20

2.6.9 Cementing equipment

Cementing aggregates

Cementing units are designed:

– for preparation, pumping and squeezing of grouting (or other) solutions into wells;

– for carrying out various types of well flushing through the run-down pipe strings;

– for treatment of the bottomhole zone of wells, injection of isotope solutions, hydrosand-jet perforation and other technological operations in wells;

– for pumping various liquids or solutions from tanks of wells and reservoirs;

– for hydraulic pressure testing of casing pipes and strings, as well as various equipment.

The most widespread in the field practice of oil and gas regions of the country are cementing units TSA-320M and ZTSA-400A.

Cementing units TSA-320M will be used for cementing the project well.

Technological characteristics of the cementing unit TSA-320M:

Mounting base ……………………..……………………..….. car chassis КрАЗ-257
Cement pump:
type …………………………………………………………………………..….9T
hydraulic power, hp ……………………………………………………..….125
piston stroke, mm ………………………………………………….……….250
maximum pressure, kgf/cm^2…………………………………………………..320
maximum flow, l/s ………..…………………………………………………...23
transmission ………………………….……… from the engine of the KrAZ-257
water pump:
type……………………………………………………………………….....1B
plunger diameter, mm ………………………….………………………….….125
plunger stroke, mm ……………………………………………….………..170
flow rate, l/s ………………………………………………………………………13
pressure, kgf/cm^2…………………………………...…………………15
transmission……………………………………….… from the engine GAZ-51A
measuring tank capacity, m ………………………………………..………….6.4
cement tank capacity, m ………………………………………………………0.25
diameter of receiving pipelines, mm ………………………………..……100
diameter of discharge pipelines, mm ……………………………..……..50
total length of the collapsible pipeline, m ….……………………………22
Total weight of the unit, t ……………………………………………...17.5

Cement mixing machines

Cement mixing machines and units designed for transportation of dry grouting materials (clay powders) and mechanized preparation of grouting (clay) solutions.

In field practice, cement mixing machines 2SMN-20, SMP-20, SM-10, SM-4M and units 1AS-20, 2AS-20, ZAS-30 are used.

In this case, cement mixing machines 2SMN-20 will be used.

Technical characteristics of the machine 2CMH-20:

Mounting base ………………………………..……….. chassis KrAZ -257

Transport capacity, t ………………………………………….……….8 – 10

Hopper volume, m …………………………………………….………14.5

Hopper capacity (for cement), t ……………………………..……………20

Solution preparation method …………..……………… mechanical-hydraulic

Productivity in m/min during cooking:

Cement mortar ………………………………………………….…0.6 – 1.2

Cement-bentonite raceствора……………………………..…………0.5 – 1.0

Clay mortar …………………………………………………………1.0 – 2.0

Mixing fluid pressure, kgf/cm^2………………………………………8 – 20

Total weight of the unloaded vehicle, t …………………………….………13.8

Bunker loading method ……………………………………... auger loader

The density of the grouting slurry is regulated by changing the amount of water supplied to the mixer using a device with a set of nozzles and a tap on the bypass line, as well as the amount of dry cement supplied by changing the rotation speed of the engine shaft and two parallel loading augers located in the bottom of the 2SMN-20 hopper [7].

3 LABOUR PROTECTION

General provisions

The heads of the organizations involved in the construction of the well are obliged to ensure that all workers comply with labour protection and safety rules at the facility.

When organizing a construction site, it is necessary to designate hazardous areas for people, within which hazardous production factors act or can potentially act. Hazardous areas and potentially hazardous areas of production factors must be fenced off and marked with signs in accordance with the requirements of GOST 23407-78.

Fire safety must be ensured in accordance with the requirements of GOST 12.1.004-76; electrical safety - according to GOST 12.1.013-78

The operation of construction machines must be carried out in accordance with the requirements of SNiP 3.01.01-85 * on the organization of construction production and SNiP III-4-80 "Safety in construction" and the instructions of the manufacturers.

While drilling it is FORBIDDEN:

- to work with an unshielded drilling rig spindle;
- to push through the plugs formed in the pipelines with a pump;

Start up the pumps after a long shutdown in winter without first checking the pipeline for permeability. Do not repair pipelines, oil seal while the flushing pump is running. All hose connections must be made using standard devices. Using pins, wires, staples, etc. for these purposes is not allowed. During the tripping and lifting operations, it is prohibited to:

1. Work in the presence of a malfunction in the drilling rig winch; stand in the immediate vicinity of descending or ascending pipes or an elevator;
2. Run pipes with unscrewed threaded connections;
3. Hold the tackle system suspended by means of a weight attached to the brake handle or by jamming the handle;

4. Work in the absence of an alarm, a mechanism for over-lifting the traveling block, as well as poor lighting at night.

When extracting a core from a core barrel, it is prohibited to:

- check with your hands the position of the core in the pipe;

- extract the core by shaking or heating the core pipe in a suspended state, it must be held suspended by a brake controlled by the driller. The pipe should be suspended on a swivel - plug or elevator, while the shutter latch should be locked.

The distance from the lower end of the pipe to the drill floor should not exceed 2 centimeters.

Running and lifting of casing pipes, well cementing

Before lowering or lifting the casing string, the driller, together with the drilling foreman and the site mechanic, must check the condition of the drilling rig, equipment, tackle system, instrumentation, foundation and guy wires, and the reliability of the rig attachment to the foundation. Discovered deficiencies must be eliminated prior to starting casing running. The driller records the results of the check in the drill log.

3.1 Accidents and complications

The main complications that can arise when drilling a planned well are rock falls, which usually occur during the passage of compacted clays, mudstones or shales.

The main measures to prevent and eliminate landslides are:

1. drilling in the area of possible landslides with flushing with drilling mud with minimum fluid loss and maximum density;

2. organization of work, ensuring high rates of penetration;

3. implementation of the following recommendations:

- to drill holes of the smallest possible diameter;

- to drill from the shoe of the previous string to the shoe of the next string with bits of the same size;

- to maintain the velocity of the ascending flow in the annulus at least 1.5 m/s;
- to feed the drill string to the bottomhole smoothly, without jerking;
- to avoid significant fluctuations of the drilling fluid;
- do not allow the drill string to remain motionless for a long time.

3.2 Prevention of accidents when running casing strings

The running of heavy casing strings (more than 100 tons) must be carried out using spider-elevators or using the PKRO upper spider.

The supply of casing pipes to the drilling site should be done carefully with the safety rings screwed on, which must be removed when the pipes are fully ready for make-up. A holding device must be installed on the tower gate to prevent the pipes from hitting the rotor when feeding into the drilling room.

Each casing supplied for running must be sieved with an experienced driller assistant assigned to the operation.

All threaded connections of the shoe part of the casing (50 - 60 m), after securing, must be reinforced with an intermittent weld with the obligatory use of special rings or electric rivets.

Welding work must be carried out by qualified welders. Forced cooling of the weld (water or drilling mud) is not allowed.

It is recommended to run the last casing of the string into the well with minimum speed and flushing.

Fastening of threaded connections of all casing strings should be carried out using torque meters.

In order to avoid lost circulation, hydraulic fracturing, disturbance of the stability of the borehole walls, collapse of the casing in the work plan, indicate the permissible rate of running the casing. The running speed of the drill string hanger should not exceed the casing running speed.

To prevent sticking of the casing during filling, restore circulation and intermediate flushes, the casing must be held suspended and paced every 5 minutes.

If, in the process of lowering the column, it became necessary to pace it, then before walking it is necessary to top up the column to the mouth.

IT IS FORBIDDEN TO:

– change design solutions without drawing up an appropriate protocol;

– use for measuring drill and casing pipes corrected tape measures after their repair;

– run the casing without preliminary hydraulic pressure testing of the pipes;

– use casing pipes that had gaps in threaded connections during pressure testing;

– run the casing pipes, in the joints of which, after the bloat in the well, the misalignment of the threads is revealed;

– weld threaded connections for “reinforcement” in case of abnormal make-up of casing pipes;

– forcibly pass the column through the landing zones;

– use a disconnector that does not allow flushing during WOC [5].

3.3 Prevention of accidents and rejects due to poor-quality cementing

Cementing of casing strings, installation of cement bridges, filling of lost circulation zones should be carried out only if there are laboratory analyzes of cement slurries or their mixtures at the drilling rig, carried out by a plugging office (workshop) or laboratory in full accordance with the specified conditions (temperature, pressure, initial water for fluid preparation mixing).

The selection of the grouting formulation must be done 5 days before cementing. If more than 10 days have passed from the day the recipe was selected to the start of cementing, then the recipe should be subjected to a control check and, if necessary, corrected.

The laboratory must verify that there is no negative effect of the spacer fluid on the backfill and drilling fluids. In this case, buffer fluids (composition and rheological parameters) must provide:

– guaranteed separation of drilling fluid from cement, which is achieved by selecting the density of the buffer fluid;

– washing capacity of the mud cake at the “rock – casing” boundaries;

– increasing the adhesion of the wellbore rock and casing metal in relation to cement.

The cementing thickening time, determined on consistometers at the interaction of temperature and pressure, simulated by the cementing process, should be 25% longer than the estimated cementing time, but not less than 30 and not more than 90 minutes.

The required amount of grouting material for cementing the casing should be determined taking into account the fluidity coefficient of the solutions (mixtures), production geophysical data (according to profilometry performed during the final set of geophysical works) and the accumulated experience of cementing wells in this area.

Delivery of cement to the drilling site, as a rule, should be carried out by cement mixing machines and cement trucks in a sealed form with documents on the amount of cement and passport information on it and handed over to the drilling foreman, who must keep records of the imported grouting material.

The design of the cementing head should provide the possibility of preliminary placement of 2 dividing plugs in it, held by stoppers, and exclude the occurrence of a pressure drop across them during cementing.

The cementing head must be pressurized to 1.5 times the maximum pressure expected during cementing, and the top separation plug must be inserted. The cementing head must be equipped with pressure gauges and high pressure taps. Three lines must be connected to the cementing head (two working lines and a third for squeezing out the dividing plug).

The cementing process must be carried out continuously, observing the specified hydraulic program and ensuring the calculated ascending flow rate of the cement slurry in the annulus.

The last 1.0 – 1.05 m^3 of displacement fluid for casing strings with a diameter of up to 245 mm should be pumped with one pump unit with Q = 3 – 4 s^{-1}.

At the end of the cementing of the casing strings overlapping formations with abnormally high formation pressure and gas horizons, as well as in wells prone to gas and oil showings, for the period of WOC, it is necessary to seal the annulus filled to the wellhead and ensure the duty of the cementing unit connected to the wellhead.

IT IS FORBIDDEN TO:

– carry out cementing in the absence of the recipe of the cementing office laboratory (workshop) or the laboratory of the branch;

– cement production strings without performing a control analysis before starting work;

– cement the casing strings without the use of displacement plugs;

– start equipping the wellhead before WOC and determining the height of the cement lift behind the casing (according to the CSD, CBL);

– allow deviations from the standard schemes of the wellhead equipment established by GOST and the current instructions;

– run drill pipes into the well until the BOP piping is complete;

– carry out work on drilling out the cement sleeve, check valve, guide plug until the end of the WCE piping, determining its tightness, as well as using the WCE, including centering devices (calibrator, reamer, etc.);

– rotary drilling or turning the drill string when the calibrator is in the casing shoe [5].

CONCLUSIONS

In this paper, drilling and casing of a production well for gas condensate with a depth of 3800 m are planned at the Yablunivske oil and gas condensate field of the Yulievsky area.

In the general part, the following are given: geographical location, an overview of previously conducted geological and geophysical studies, and the geological characteristics of the work area. The following is described: stratigraphy, tectonics and physicochemical properties of reservoir fluids in the area.

The well will be drilled with a BU 3000 EUK drilling rig in four drilling intervals: for a mine direction with a diameter of 426 mm, for a conductor with a diameter of 324 mm, for an intermediate casing with a diameter of 245 mm and for a production casing with a diameter of 140 mm, using polymer-clay mud. The drilling process will be monitored by the GTI station. Cementing of the well will be carried out using 4 cement mixing machines 2SMN-20, 5 cementing units and a blending tank. Control of the process will be provided by the SKTs-2M cementing control station.

The work provides for all the necessary life safety measures. The measures to prevent accidents and complications are considered along with the ones to protect the subsoil and the environment.

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