Influence of Dispersed Systems on Exploratory Well Drilling

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Abstract. Results of theoretical, laboratory and stand study which enabled to recommend solutions of surface active substances while well drilling, taking into account mining and geological conditions of a number of Ukrainian regions are given. It was determined that addition of surface active substances to the drilling fluid during rotary drilling by hard-face and diamond cores makes it possible to increase drilling rate.

Introduction

Thorough analysis of statistic material concerning the wells which have already been drilled is the step preceding the process of a well drilling technique selection. The analysis makes it possible to identify intervals with the highest technique-economic indices. If the data are not available, drilling technique is selected depending upon optimum rotation frequency of a boring bit with the consideration of certain recommendations [1].

Structural design of exploration well on the basis of geological environment analysis and its purpose involve the determination of final drilling diameter, a well diameter within each interval, their period as well as diameter, length, depth, a technique to fasten casing shoe, tamponage areas, cementing of drilling trouble zones to be the first step in the process of a drilling technique design since it determines all its subsequent components.

Design of a well is stipulated by purpose of drilling operations, geological task, type of mineral, complexity of mining and geological conditions of the mineral occurrence, and drilling technique.

Labour productivity increase and drilling cost decrease are the important economic problems. The solution of these problems can be reached by the development and study of dispersed systems. It enables to increase drilling rate and the life of rock destruction tool.

The Main Part

Water solutions of surface-active substances that reduce rock strength properties and power consumption to overcome resistance force in terms of drilling tool rotation are offered in National Mining University (Dnipro, Ukraine) [1 – 3]. Theoretical and experimental investigations as for determining effect of surface tension and lubricating ability on drilling rate, torque, power and energy output while well drilling were performed. Their aim was to study the influence of surface-active substances on well drilling.

Let's consider the operation of rock destruction tool in terms of the single boring bit (Fig. 1).

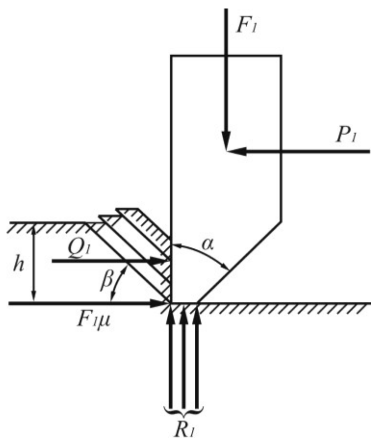

Fig. 1. Diagram of force effect while drilling

Rock behavior in axial direction [4 – 6]:

$$R_1 = (h - y)bR_z tg\alpha \quad (1)$$

where b is the width of cutting ring; h is the rate of sinking per one cycle by single boring bit; y is increase of boring bit dulling; R_z is resistance of rock pressing (hardness) under downhole conditions; α is the taper angle of boring bit.

If $y = 0$.

$$R_1 = hbR_z tg\alpha \quad (2)$$

Projecting all forces on vertical axis we obtain:

$$F_1 - Q_1 f - R_1 = F_1 - Q_1 f - hbR_z tg\alpha \quad (3)$$

Multiplied by a number of boring bits K_p, we obtain for all reactions taking into account that $Q_1 f << F_1$.

$$F_1 K_p - hbR_z tg\alpha K_p = 0 \quad (4)$$

If $F = F_1 K_p$

$$h = \frac{F}{bR_z tg\alpha} \quad (5)$$

Projecting all forces on horizontal axis, we obtain:

$$P_1 - Q_1 - F_1\mu = 0 \quad (6)$$

$$Q_1 = hbK_{ck} ctg\beta \quad (7)$$

$$P_1 - hbK_{ck} ctg\beta - F_1\mu = 0 \quad (8)$$

For all boring bits:

$$P_1 K_p - hbK_{ck} ctg\beta K_p - K_p F_1\mu = 0 \quad (9)$$

By substituting h from (5) we obtain:

$$P_1 = FhbK_{ck}ctg\beta - F\mu = F\left(\frac{K_{ck}ctg\beta}{R_z tg\alpha} + \mu\right) = FP' \tag{10}$$

where P' is general characteristic of rock properties and rock destruction tool. It should be noted that P' will be changed with the change of surface tension and friction coefficient.

Torque measurement while drilling on the stand was performed by tensometric method with the help of basic loop oscillograph. Measuring system consists of sensors, current collector, repeater, electric power unit and oscillograph. Sensors are wire tensometers with 197 Ohm resistance and 20 mm base. They were stuck on rotatable drill pipe at 20 cm distance from rock destruction tool. It enabled to determine resulting torque with exception of the expenditures connected with friction break within machine unit, redactor and engine. Calibration of measuring circuit was performed directly on the stand with the help of dynamometer. Calibration chart was constructed according to the diagrams. Torque data while drilling was recorded on the oscillogram. Then average values were determined.

Figure 2 shows the chart of mechanical drilling rate concerning sandstone in terms of rotation frequency of hard-face core with 36 mm diameter while water flushing having various surface tension.

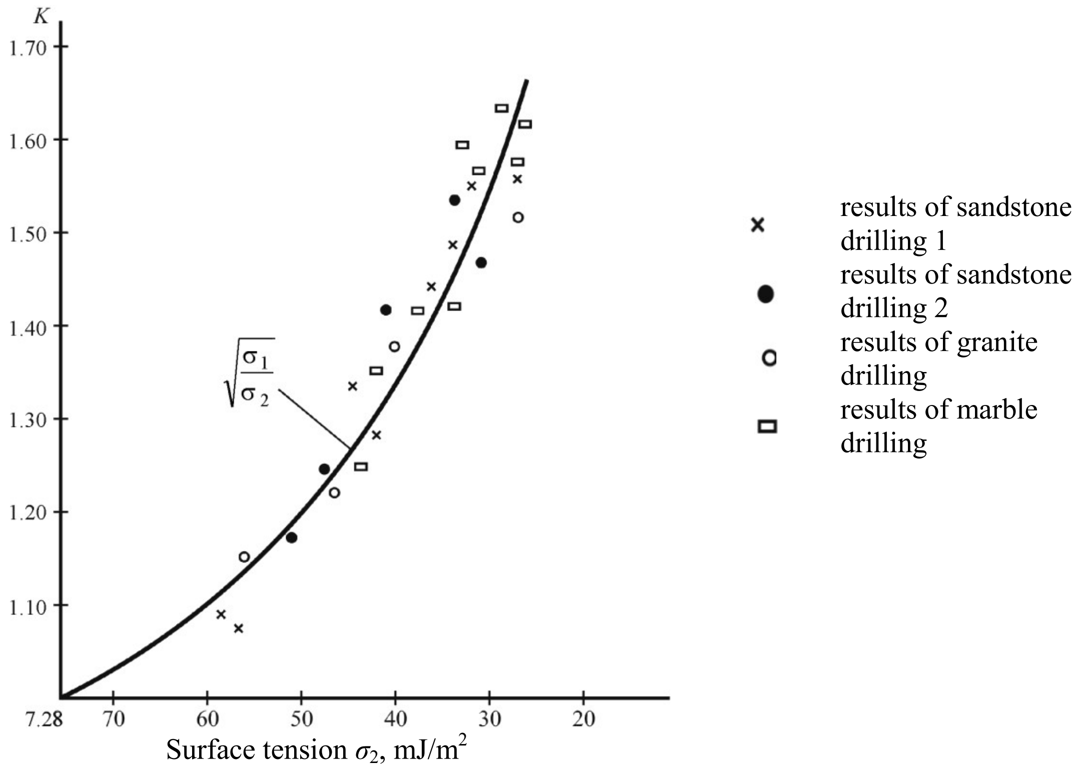

Fig. 2. Experimental test of $K = f(\sigma)$ function

Given data enable to make conclusion that there is close connection between surface tension of drilling fluid and mechanical drilling rate which is perfectly characterized by the criterion:

$$K = \frac{V_2}{V_1} = \sqrt{\frac{\sigma_2}{\sigma_1}} \tag{11}$$

where V_1, σ_1 is a mechanical rate and filter surface tension while drilling using solution of surface-active substances; V_2, σ_2 is a mechanical rate and surface tension while drilling with washing without addition of surface-active substances.

Tables 1 and 2 show torque values (M_0) and total characteristic (P') depending on surface tension of drilling fluid while changing drilling modes. Given data show good precision:

$$\frac{P_1'}{P_2'} = \frac{\sigma_1}{\sigma_2} \quad (12)$$

Table 1. Values for hard-face core

Rotation frequency, [min^{-1}]	Forward pressure, [kg]	Surface tension, [MJ/m^2]					
		72.8		54.2		30.8	
		M_0, [kgm]	P'	M_0, [kgm]	P'	M_0, [kgm]	P'
102	800	19.2	0.71	13.2	0.49	10.	0.38
	1100	23.8	0.64	17.3	0.47	12.2	0.33
	1400	30.4	0.64	2.2	0.45	1.5	0.37
237	800	15.6	0,58	9.7	0.36	6.8	0.25
	1100	18.4	0.49	11.9	0.32	8.0	0.21
	1400	21.5	0.46	14.8	0.31	11.3	0.24
480	800	13.8	0.51	8.5	0.1	6.6	0.24
	1100	15.5	0.42	10.	0.27	6.9	0.187
	1400	17.7	0.38	10.8	0.23	7.9	0.167

Table 2. Values for diamond core

Rotation frequency, [min^{-1}]	Forward pressure, [kg]	Surface tension, MJ/m^2					
		72.8		45.9		32.8	
		M_0, [kgm]	P'	M_0, [kgm]	P'	M_0, [kgm]	P'
102	800	4.75	0.178	3.27	0.122	2.15	0.080
	1100	5.18	0.140	3.56	0.096	2.40	0.064
	1400	5.90	0.126	4.05	0.084	2.83	0.060
237	800	4.35	0.162	2.90	0.108	1.75	0.064
	1100	4.59	0.124	3.08	0.082	1.90	0.052
	1400	4.89	0.104	3.32	0.070	2.07	0.044
480	800	4.19	0.156	2.74	0.102	1.68	0.062
	1100	4.32	0.116	2.85	0.076	1.79	0.048
	1400	4.51	0.096	3.00	0.064	1.88	0.040

Table 3 shows the torque value as for rock destruction by hard-face and diamond cores under various drilling modes.

Table 3. Torque under various drilling modes

Rock destruction tool	Drilling fluid, [MJ/m^2]	Friction torque, M_t, [kgм]	Moment in terms of rock destruction $M_p = M_0 - M_m$								
			102 min^{-1}			237 min^{-1}			480 min^{-1}		
			800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg
Diamond core	Technical water, (72.8)	3.9	0.85	1.28	1.90	0.45	0.69	0.99	0.29	1.42	0.61
	Sulfonic water solution, (45.9)	2.5	0.77	1.06	1.55	0.40	0.58	0.82	0.24	0.35	0.50
	Sulfonic water solution, (32.8)	1.5	0.65	0.90	1.33	0.25	0.40	0.57	0.18	0.29	0.38
Hard face core	Technical water, (72.8)	12.0	7.2	11.8	18.4	3.6	6.4	9.5	1.8	3.5	5.7
	Sulfonic water solution, (54.8)	7.0	6.2	7.5	14.2	2.7	4.9	7.8	1.5	3.0	3.8
	Sulfonic water solution, (30.8)	4.5	5.8	7.2	12.5	2.3	3.5	6.3	1.1	2.4	3.4

Graphic display $M_0 = f(V_M)$ (Fig. 3, 4) enables to divide the torque value into two constituents; the moment of friction force and rock destruction as well as to determine the effect of surface tension of its drilling fluid.

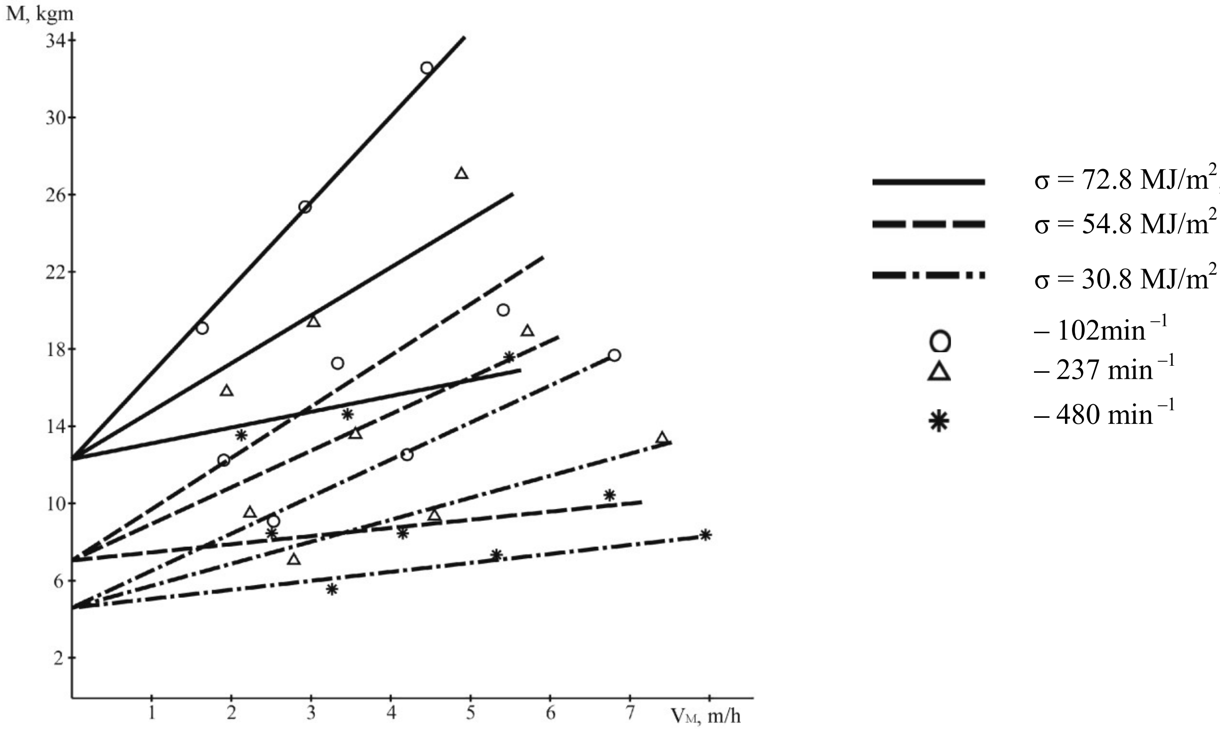

Fig. 3. Function $M_0 = f(V_M)$ while drilling sandstone by hard-face cores

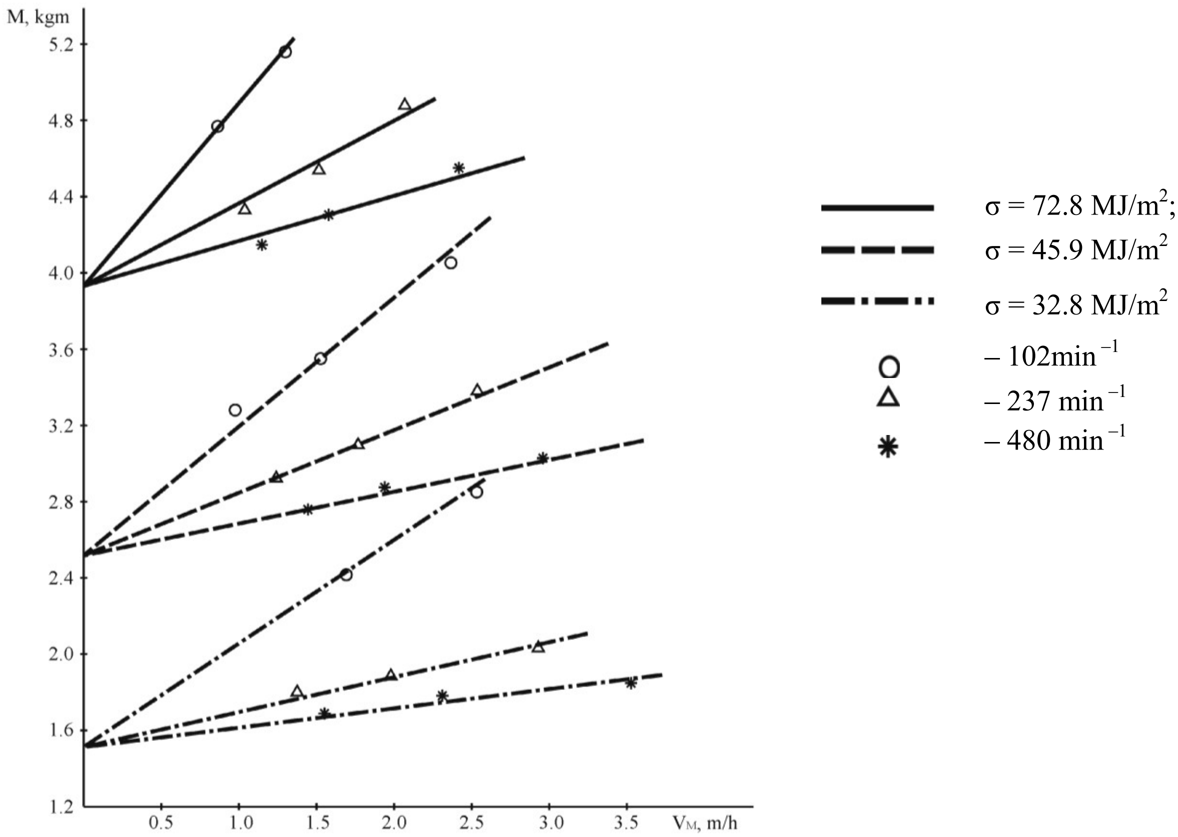

Fig. 4. Function of $M_0 = f(V_M)$ while drilling sandstone by diamond cores

Power drilling can be described in this way:

$$N = \frac{Mn}{975} \qquad (13)$$

On the basis of experimental data the charts $N_0 = f(V_M)$ were constructed. They enable to divide the power into two constituents: friction power and rock destruction and to determine the effect of the surface tension on them (Fig. 5, 6).

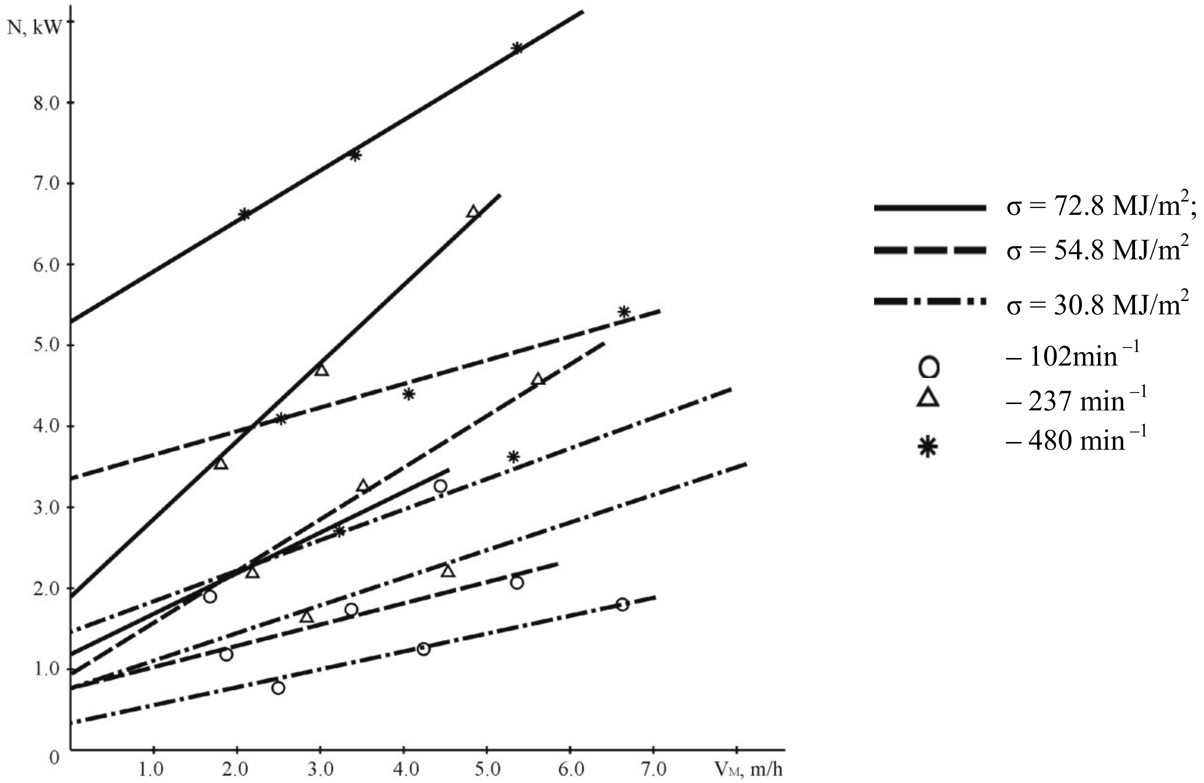

Fig. 5. $N_0 = f(V_M)$ function for sandstone hard-face drilling

Table 4 shows power values in terms of rock destruction while drilling sandstone by diamond and hard face core in various modes.

Table 4. Power values under various drilling modes

Rock destruction tool	Drilling fluid	Surface tension, [MJ./m^2]	N_p, kW								
			102 min^{-1}			237 min^{-1}			480 min^{-1}		
			800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg
Diamond core	Water	72.8	0.086	0.134	0.200	0.109	0.168	0.240	0.143	0.210	0.300
	Sulfonic water solution	45.9	0.080	0.112	0.162	0.097	0.141	0.199	0.118	0.168	0.246
	Sulfonic water solution	32.8	0.068	0.094	0.138	0.060	0.097	0.138	0.089	0.142	0.187
Hard face core	Water	72.8	0.74	1.23	1.92	1.87	1.53	2.31	0.890	0.680	2.80
	Sulfonic water solution	54.8	0.65	0.78	1.47	0.64	1.19	1.90	0.740	1.470	1.87
	Sulfonic water solution	30.8	0.60	0.63	1.31	0.54	0.84	1.54	0.840	1.180	1.67

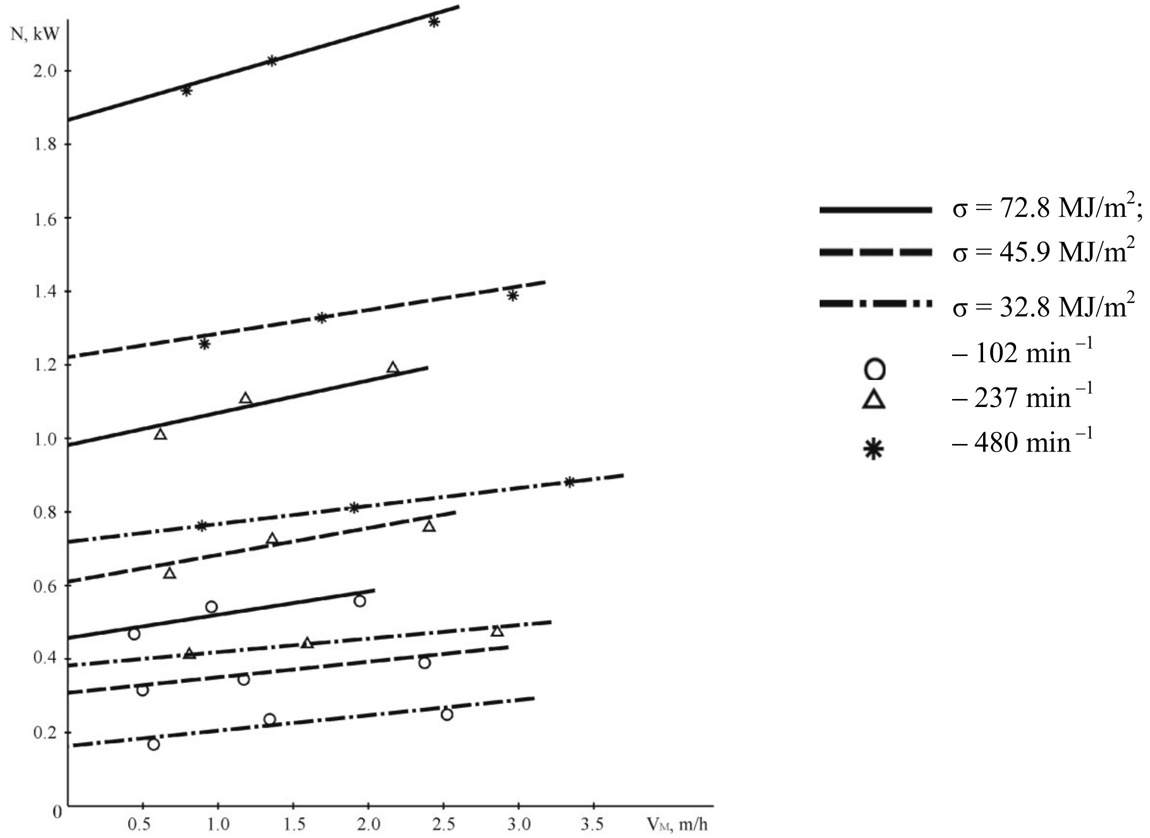

Fig. 6. Function $N_0 = f(V_M)$ for sand stone diamond drilling

Given data enable to make conclusions that decrease of surface tension of drilling fluid can greatly reduce the torque, power as for rotation of drilling tool and rock destruction.

Specific power capacity is an important characteristic of well drilling that shows work expenditure per unit volume of broken rock.

It can be determined in the following way. The work during the time T:

$$A = M\omega T = \frac{Mn}{30}\pi T \tag{14}$$

where M is breaking moment; ω is rotation frequency.

The volume of broken rock during the time T can be determined by the formula

$$W = \frac{V}{n}\frac{n}{60}TS = \frac{VTS}{60} \tag{15}$$

or

$$W = h\frac{n}{60}TS \tag{16}$$

where V is drilling rate; n is rotation frequency; S is the area of the cutting ring; h is the depth of penetration per a single revolution.

Where specific power capacity is

$$E' = \frac{2\pi M}{hS} \tag{17}$$

There is a small amount of works devoted to the study of the forward pressure and rotation frequency effect to the specific power capacity of well drilling and surface tension of drilling fluid [7 – 9].

If we know numerical values of formula (17) input parameters we can determine total specific power capacity of drilling (E'_0) and rock destruction (E'_p).

Figure 7 shows function $E'_0 = f(V_M)$ while drilling sandstone by the diamond core in various modes washed by the fluid with surface active substances. The chart shows that specific power capacity is reduced with sinking increase per a single revolution. Surface tension of drilling fluid is reduced as well.

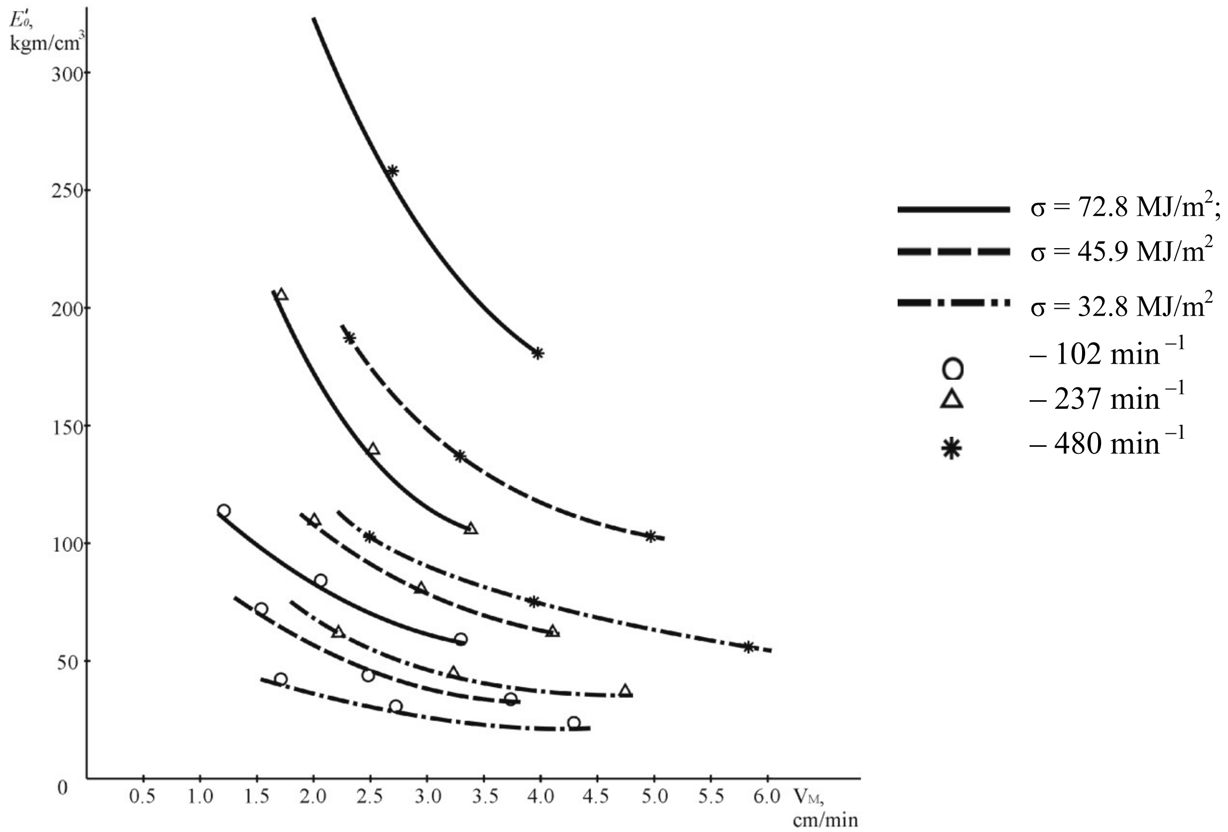

Fig. 7. $E'_0 = f(V_M)$ function while drilling sandstone by diamond cores

Specific power capacity of rock destruction was determined according to the data M_p (Table 5).

Table 5. Specific power capacity of rock destruction

Rock destruction tool	Drilling fluid	Surface tension, [MJ/m²]	E'_p, [kgm/cm³]								
			102 min $^{-1}$			237 min $^{-1}$			480 min $^{-1}$		
			800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg	800 kg	1100 kg	1400 kg
Diamond core	Water	72.8	19.8	20.1	19.4	21.4	22.0	22.6	23.0	24.0	24.0
	Sulfonic water solution	45.9	16.5	15.6	15.1	17.1	15.5	15.7	16.2	17.0	16.3
	Sulfonic water solution	32.8	12.4	11.0	10.5	9.7	9.7	9.3	11.0	11.0	10.4
Hard face core	Water	72.8	90.3	87.0	87.4	91.6	105.8	98.0	83.0	103.0	104.0
	Sulfonic water solution	54.8	56.8	60.0	57.0	58.0	69.0	67.0	58.0	73.0	56.0
	Sulfonic water solution	30.8	49.5	42.0	40.0	40.7	39.0	42.0	33.0	45.0	39.0

As we can see in the Table values E'_p do not practically depend on parameters of the drilling modes and decrease when surface tension is reduced.

According to the experimental data good precision was obtained.

$$\frac{P'_1}{P'_2} = \frac{E'_1}{E'_2} = \frac{\sigma_1}{\sigma_2} \tag{18}$$

That is equal to

$$\frac{\gamma_1}{\gamma_2} = \frac{\sigma_1}{\sigma_2}, \tag{19}$$

where γ_1 and γ_2 are surface energy of a solid body in the water and solution of surface-active substances.

It was obtain theoretically

$$\frac{v_1}{v_2} = \sqrt{\frac{\sigma_1}{\sigma_2}} \tag{20}$$

From the formula

$$\frac{N_{p2}}{N_{p1}} \frac{E'_1}{E'_2} = \frac{v_2}{v_1} \tag{21}$$

$$\frac{N_{p1}}{N_{p2}} = \frac{v_1 E'_2}{v_2 E'_1} = \sqrt{\frac{\sigma_1}{\sigma_2} \cdot \frac{\sigma_2}{\sigma_1}} = \sqrt{\frac{\sigma_2}{\sigma_1}} \tag{22}$$

It is experimentally confirmed by:

$$\frac{v_2}{v_1} = \frac{N_{p2}}{N_{p1}} \frac{E'_1}{E'_2} \tag{23}$$

Conclusions

Given results of theoretical, laboratory and stand study enabled to recommend solutions of surface-active substances while well drilling in geological survey enterprises in Ukraine.

It was determined that addition of the surface active substances to the drilling fluids under rotary movement by the hard face and diamond cores enables to increase drilling rate up to 1.4 – 1.6 times, footage rate per run up to 1.3 – 1.5 times and footage per a rock destruction tool up to 1.2 – 1.3 times.

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