REPUBLIC OF AZERBAIJAN

On the rights of the manuscript

ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

REGULATION OF RHEOPHYSICAL AND HYDRODYNAMIC PROPERTIES OF DRILLING MUDS BASED ON MULTIPHASE TECHNOLOGIES

Speciality:	2523.01 – “Well drilling technologies”
Field of science:	Technical sciences
Applicant:	**Amrah Parviz Gulubayli**

BAKU – 2026

The dissertation work was performed at the Petroleum Engineering Department at the Azerbaijan State Oil and Industry University PLE.

Scientific supervisor:
Doctor of technical sciences, professor
Gafar Gulamhuseyn Ismayilov

Official opponents:
Correspondin member of ANAS,
Doctor of Technical Sciences, professor
Galib Mammad Efendiyev
PhD of technical sciences
Piri Mamedpasha Guluzade
PhD of technical sciences
Qabil Abdulla Rzayev

Dissertation council FD 2.03 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industry University PLE.

Chairman of the Dissertation council:
Doctor of Technical Sciences,
professor
Elman Kheyrulla Iskandarov

Scientific secretary of the Dissertation council:
PhD of technical sciences,
associate professor
Yelena Yevgenyevna Shmoncheva

Chairman of the scientific Seminar:
Doctor of Technical Sciences,
professor
Eldar Mamed Suleymanov

I approve the signatures

Scientific Secretary of the ASOIU PLE,
PhD of techncal science, ass.prof **I.N. Aliyev**

GENERAL DESCRIPTION OF THE DISSERTATION

The topicality and development degree of the subject. It is well known that the efficient drilling of oil and gas wells is carried out with the use of drilling fluids, which require regulation of their rheophysical and hydrodynamic properties. Those who emphasize that drilling fluids used during oil and gas well drilling are as important as blood circulating in the human body are not mistaken. The proper selection of drilling fluids is of great importance for the safe and successful completion of the drilling process. Although the rheophysical and hydrodynamic properties of drilling fluids contribute to several drilling parameters — such as cleaning drilled intervals from mechanical rock particles, increasing drilling speed, controlling the effective bottom-hole pressure during fluid circulation, reducing pressure losses in the annulus, and preventing drilling complications — their improper selection may lead to various problems during drilling, including increased drilling time and even loss of the well.

The proper selection of drilling fluid parameters and consideration of their relaxation and structural stability properties are very important for improving drilling efficiency.

Currently, the investigation and regulation of these properties based on the application of a new physical model for multiphase flows, taking into account the interaction of phases, are forming new scientific perspectives.

The physicochemical composition of various water-based drilling fluids, as well as the effect of rock particles added to them, the purification of multiphase drilling fluids, the assessment of their rheophysical properties, and the causes and prevention of complications, including loss of structural stability of the flow, are of great relevance.

Despite the existence of numerous scientific studies in this field, the problem still remains relevant because the characteristics of multiphase flows and phase interactions have not been sufficiently considered.

Purpose of the Research. The purpose of the research is to develop new innovative methods for regulating the rheophysical and hydrodynamic properties of drilling fluids based on multiphase technologies.

The aim and objectives of the research. The object of the research is water-based drilling fluids that play a vital role during well drilling operations. The subject of the research is the regulation of the rheophysical and hydrodynamic parameters of these fluids.

The main objectives of the research consist of solving the following complex issues:

- Characterization and analysis of the purposes of using drilling fluids during drilling, determination of their parameters, and factors affecting their functions;
- Analysis of factors affecting the rheological parameters of drilling fluids during drilling, including contaminants, chemical reagents used, various ions entering the fluid from the drilled formation, and the influence of the solid phase within the fluid;
- Study of the composition of clay rocks causing sharp changes in drilling fluid rheological parameters during drilling, and analysis and application of methods preventing their swelling and mixing with the fluid;
- Investigation of the role of forces generated across the cross-section in cylindrical flows during cleaning of multiphase drilling fluids according to multiphase technology;
- Evaluation of the contamination zone at the contact area during displacement of one fluid by another or drilling fluid by cement slurry under laminar flow conditions, taking into account rheological characteristics;
- Analysis of the influence of water-based drilling fluids being multiphase on stuck pipe is one of the most common complications;
- Investigation of the expression of water-based drilling fluids, assumed to exhibit viscoplastic properties, by the Casson model and development of methods for determining the relaxation time of viscoelastic water-based fluids.

Research Methods. The problems posed in the study were solved using theoretical and experimental methods based on actual drilling fluid data, rheological testing and modeling, in accordance with the new physical model of multiphase flows, as well as through the application of standard laboratory equipment and computer modeling.

Main clauses defended:

- Regulation of the rheophysical properties of water-based drilling fluids using multiphase technologies;
- The role and evaluation of the migration of mechanical particles and rock cuttings toward the flow axis in multiphase drilling fluids in causing stuck pipe during oil and gas well drilling;
- Methodology for determining the relaxation properties of water-based multiphase drilling fluids based on diagnostics of loss of structural stability.

Scientific innovations of the research:

- The role of phase interaction in regulating the rheophysical properties of water-based drilling fluids has been determined;
- The cause of the displacement of mechanical impurities and rock cuttings toward the center of the flow in multiphase water-based fluids and its contribution to stuck pipe has been substantiated;
- A methodology for determining the relaxation time of water-based multiphase drilling fluids based on their structural stability during flow has been developed.

Theoretical and practical significance of the research. The regulation and prevention of drilling complications occurring or expected during drilling, as well as the selection and application of prevention methods, are associated with the regulation of both rheophysical and hydrodynamic parameters of drilling fluids. In this regard, the methods and technologies developed and proposed in the work are of significant importance. The main significance of these methods lies in the fact that they are based on multiphase technologies and consider the new physical model of flow.

Based on the proposed methods, methodological guidelines were developed and approved by SOCAR.

Through calculations, it was determined that multiphase water-based drilling fluids conventionally considered viscoplastic also exhibit viscoelastic properties. Methods for determining relaxation time and structural stability coefficient, considered important parameters for viscoelastic fluids, were presented and calculations were carried out.

Dependencies between various parameters for water-based drilling fluids were determined, and corresponding structural stability coefficient intervals were calculated.

International Scientific-Technical and Scientific-Practical Conferences. Dissertasiya işinin nəticələri aşağıdakı konferanslarda müzakirə edilmişdir:

1. XVIII Международной научно-практической конференции, УФА, 2023
2. Ümummilli lider Heydər Əliyevin anadan olmasının 100 illiyinə həsr olunmuş“AZƏRBAYCAN ELMİNİN VƏ TƏHSİLİN İNKİŞAFINDA HEYDƏR ƏLİYEV EPOXASI” adlı beynəlxalq elmi konfrans, Bakı, 2023.
3. Azərbaycan xalqının umummilli lideri HEYDƏR ƏLİYEVİN anadan olmasının 100 illik yubileyinə həsr edilmiş “Neft-Qaz yataqlarının axtarış problemləri və perspektivləri”, Respublika-elmi konfransı, Bakı, 2023.
4. XII International Scientific and Practical Conference «Modern science: theoretical and practical view», Madrid, Spain, 2024.
5. “БУЛАТОВСКИЕ ЧТЕНИЯ” VIII Международная научно-практическая конференция, Краснодар, 2024.
6. The Fifth Eurasion RİSK-2023 Conference dedicated to the 100th anniversary of Heydar Aliyev, Reliability: Theory and Application, November 2023.

7. Reliability: Theory and Application electronic jurnal COP – 29 side event the sixth eurasian risk 2024 conference, Baku, November 2024.
8. Doktorantların və Gənc Tədqiqatçıların XXVII Respublika Elmi Konferansı (NASCO XXVII), Sumqayıt, 10-11dekabr 2024.

Name of the Organization Where the Dissertation Was Performed. Azerbaijan State Oil and Industry University, Department of Oil and Gas Engineering

Volume and Structure of the Dissertation. The dissertation consists of 203 pages and an introduction, 3 chapters, including 28 figures, 19 graphs, 8 tables, conclusions and suggestions, a list of 160 references and appendices.

The dissertation consists of 227145 characters. Including: introduction - 11611 characters, chapter I - 102717 characters, chapter II - 90052 characters, chapter III - 20853 characters, conclusion - 1912 characters.

The introduction presents the relevance of the topic, the purpose of the work, scientific novelty, application, significance, defended provisions, and approbation of the dissertation.

The dissertation discusses the determination and regulation of rheological and hydrodynamic properties of drilling fluids, which are critically important for the effective completion of drilling operations, through the application of multiphase technologies.

In the first chapter of the dissertation, the functions and parameters of drilling fluids, methods of their determination, the composition of chemical reagents used for drilling fluid preparation, selection of drilling fluids for drilling different formations, factors affecting rheological parameters, and the influence of rheological parameters on drilling regime parameters are analyzed.

In the first subsection of Chapter One, the functions that drilling fluids must perform and their detailed explanations are presented:

1. Hole cleaning;
2. Counterpressure against formation pressure;

3. Suspension of drilled mechanical rock particles and weighting agent particles when circulation ceases;
4. Filter cake formation — sealing porous formations;
5. Wellbore stability;
6. Prevention of formation damage — not affecting permeability and porosity (skin effect);
7. Cooling, lubricating, and supporting the drill string;
8. Transmitting hydraulic power to drilling bit;
9. Adequate formation evaluation;
10. Preventing corrosion of the drill string;
11. Ensuring effective completion and cementing of the well;
12. Preventing environmental pollution.

In the second subsection of Chapter One, the determination of parameters indicating whether drilling fluids properly perform their functions, as well as the operating principles of the equipment and chemical reagents used for their determination, are presented. The parameters determining drilling fluid functions include specific gravity; rheophysical parameters (plastic viscosity, yield stress, gel strength, structural stability coefficient, and relaxation time); mud cake thickness and filtrate volume; percentage content of the solid phase (sand, clay, weighting agent), water phase, and oil phase; and parameters characterizing the chemical composition of the fluid such as alkalinity, hardness, calcium ion concentration, etc. Various instruments are used to determine each parameter. A mud balance is used to determine fluid density, a viscometer is used to determine rheophysical parameters, and API and HPHT filter presses are used to determine filtrate volume. Chemical reagents (indicators and titration reagents) are essential for determining hardness and alkalinity.

In the third subsection of the first chapter, the chemical reagents required for the preparation of drilling fluids and the functions they perform in the fluid are presented. For the preparation of drilling fluid, it should first be determined whether the fluid will be water-based or oil-based. In water-based fluids, the hardness of the water must initially be reduced below 600 mg/L through the use of caustic soda and bicarbonate. Afterwards, according to the parameters specified in the drilling program, carboxymethyl cellulose, xanthan gum, glycol, and barite should be added. During the preparation of oil-based drilling fluids, depending on the oil-water ratio and customer requirements, diesel or base oil is added first, followed by organophilic bentonite (its organophilic nature facilitates dissolution in non-polar solvents), lime ($Ca(OH)_2$), emulsifiers (amino acids), brine (usually a 20% saltwater solution for oil-based fluids), weighting agents, and gilsonite (to reduce fluid loss).

In the fourth subsection of the first chapter, the influence of drilled formations and external factors on drilling fluid selection, as well as the types of fluids used for efficient drilling, are discussed. The selection of drilling fluid varies depending on the drilled formations and drilling conditions. First of all, the effect of the formations to be drilled is taken into consideration. For example, when drilling limestone formations, the use of KCl/polymer fluid causes a sharp increase in rheological parameters, while using for drilling salt domes leads to salt contamination of the fluid and a sharp increase in rheological parameters. Therefore, it is advisable to use lime-based fluids for drilling limestone formations and saturated saltwater fluids for drilling salt formations.

In the fifth subsection of the first chapter, the factors affecting the rheophysical parameters of drilling fluids are presented. Each component used in the drilling fluid and every mechanical rock particle entering the fluid from the formation affects its rheological parameters. The rheological properties of the fluid are associated with the interaction between negative and positive charges present in the fluid. Drilling conditions, including bottom-hole pressure and temperature, also cause significant changes in the rheological parameters of the drilling fluid. Although pressure has relatively little influence on rheological properties, the effect of temperature is very significant.

The effect of added reagents on the fluid varies depending on its composition. For example, the addition of lignosulfonate leads to neutralization of negative charges surrounding clay particles, which sharply reduces the viscosity of the fluid. Under the influence of

NaOH and KOH, ionization of the carboxyl groups in xanthan gum polymer occurs, resulting in an increase in fluid viscosity.

In the sixth subsection of the first chapter, the influence of drilling fluid rheophysics on drilling parameters and the determination of these parameters for a given well interval are discussed.

The rheology of drilling fluids is one of the important factors affecting drilling parameters during well drilling. These effects significantly influence the efficiency and safety of drilling operations. The drilling parameters affected by the rheological properties of drilling fluids include:

- Hole cleaning while drilling;
- Equivalent circulating density (ECD);
- Surge and swab pressure;
- Rate of penetration (ROP);
- Friction coefficient while drilling.

In the second chapter, the issues of cleaning water-based drilling mud from rock cuttings and mechanical particles, determining the contaminated zone during displacement of one drilling fluid by another, fundamentals of stuck pipe, as well as the relaxation behavior of drilling mud depending on its composition, were examined.

In the first subsection of the second chapter, the reasons for the low efficiency of the operation of hydrocyclones - a device used to clean mechanical rock particles mixed with the drilling fluid from the formation - sand - based on multiphase technologies were analyzed. Accordingly, various forces generated inside the hydrocyclone were investigated[1]. It was determined that the equipment used for solid-phase separation (Figure 1) does not always provide the expected efficiency.

---

[1] Zhang, Y. Understanding the Separation of Particles in a Hydrocyclone by Force Analysis / Y. Zhang, P. Cai, F. Jiang [et al.] // Powder Technology. – Amsterdam: – 2017. – Vol. 322. – P. 471–489

The reason for the low efficiency of hydrocyclones in separating the drilling fluid–rock particle mixture was explained using the theory of gradient-velocity field dynamics, and the mechanism of the interaction force between the phases during separation was clarified[2].

The mentioned force can be expressed based on the change in the pressure gradient as follows:

$$F_{lat} = 0.167\pi d^3(\rho_{rp} - \rho_{df}) \tag{1}$$

Here, $(\rho_{rp}$ və $\rho_{df})$ - respectively, mechanical rock particle and drilling mud density (kg/m^3);
d – diameter of rock particles (m).

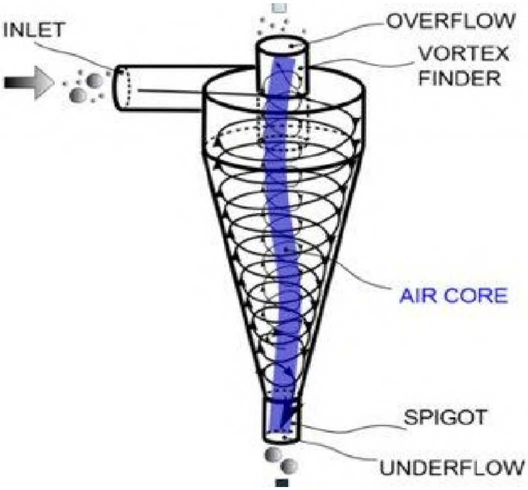


Figure 1. Structure of a hydrocyclone

---

[2] Сиенков, В.Т. Теория градиентно-скоростного поля // – М.: ОАО «ВНИИОЭНГ». – 2004. – 308 с.

According to the working principle of the cleaning device, the driving centrifugal force acting on the particle is determined according to the following expression::

$$F_c = 1.85 \cdot 10^{-3} \pi d^3 \rho_{rp} n^2 r \tag{2}$$

Here, n – number of particle cycles per minute;

r - is the trajectory of the particle's motion (m).

For good separation of rock particles, the centrifugal force must be greater than the lateral-Bernoulli force. Then, taking into account expressions (1) and (2), the following expression can be written to satisfy the above condition:

$$r \leq \frac{92.8\left(1 - \frac{\rho_{df}}{\rho_{rp}}\right) g}{n^2} \tag{3}$$

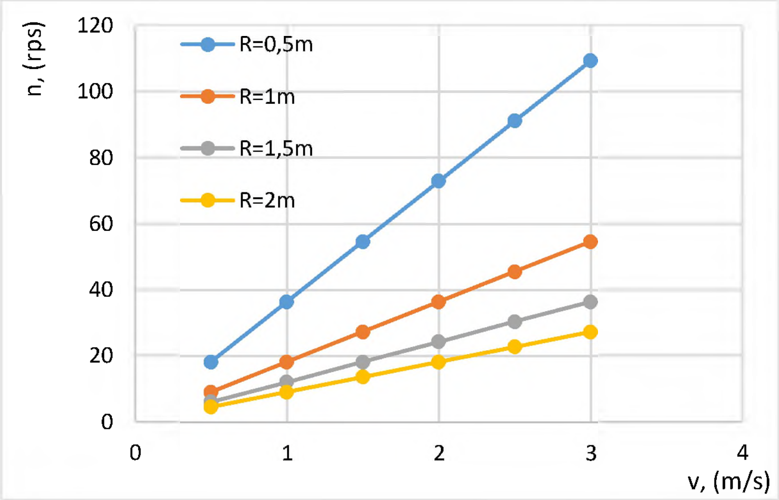
Reports were made and graphs were shown to determine the correct parameters in hydrocyclones (Graphs 1 and 2). The effect of flow velocity (u), hydrocyclone radius (R) and particle to fluid density ratio on the number of cycles (n) was investigated. For this purpose, the calculation of the number of cycles (n=f(u) və n=f(R)) was obtained with the following initial data:

Flow velocity - v=0,5; 1.0; 1.5; və 2,0 m/s.

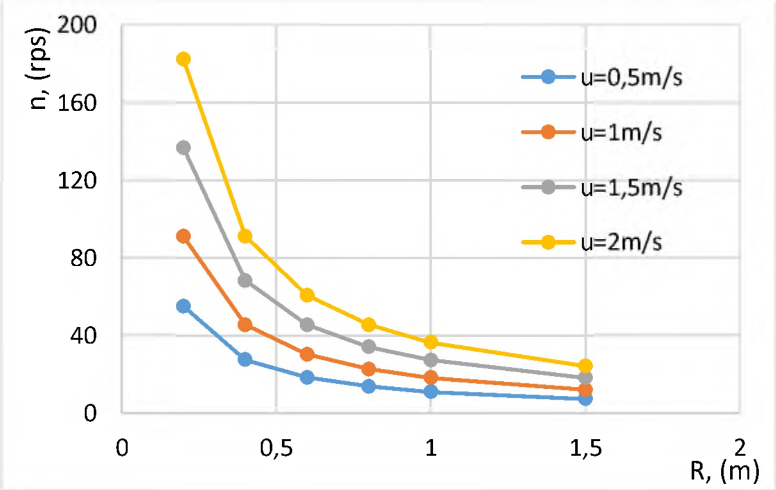
Radius of trajectory - R=0,2; 0,4; 0,6; 0,8; 1.0 və 1.5 m.

Density ratios ρ_{rp}/ρ_{df}= 1,3; 1.5; 2.0; 2.5.

As can be seen from Graph 1, the number of cycles increases proportionally with increasing flow velocity. At the same time, the number of cycles decreases monotonically with increasing radius (R) of the hydrocyclone (Graph 2). With the help of the established dependencies, it is also possible to eliminate the negative effect of the Bernoulli force on the operation of hydrocyclones based on the selection of the above parameters.



Graph 1. Variation of the number of cycles (n) in the cleaning unit depending on velocity (v)



Graph 2. Variation of the number of cycles (n) in the cleaning unit depending on radius (R)

The second subsection of the second chapter shows the basics of displacement of drilling mud with another one or cement with drilling mud and the rheotechnological characteristics of displacement in laminar mode.

During drilling, it is often necessary to displace one type of mud with another type of mud or to displace cement with drilling mud during cementing of a given interval. In this case, contamination occurs as a result of mixing of the two fluids at the contact area. The contamination area varies depending on the parameters of the displaced and displacing mud.

It is known that the maximum velocity (when r=0) along the cross-section of a pipe with radius (R) and length (l) is determined as follows:

$$v_{max} = \frac{\Delta P * R}{4\mu l} \tag{4}$$

Here, ΔP – diffferential pressure (Pa);
μ – drilling fluid viscosity (Pa·s).

Taking into account the irregular - parabolic distribution of velocity across the cross section in the laminar motion mode and using the maximum flow velocity, it is possible to solve important, practical problems (displacement of the mud with cement, cleaning of pipes, etc.). In such cases, ensuring the optimality of technological processes depends on how the fluids are displaced, the degree of their displacement. Suppose that drilling fluid is displaced with cement in a pipe with a radius R. For a simple version, let's assume that the viscosities are the same - (μ) and the displacement is carried out at a pressure difference $\Delta P = P_1 - P_2$ (Fig. 2).

The time it takes for the displaced fluid to reach the final point in a vertical pipe can be calculated as follows according to Figure 2:

$$t_1 = \frac{l}{u_{max}} = \frac{4\mu l^2}{\Delta P R^2} \tag{5}$$

Then, according to Poiseuille's formula, the volume of drilling fluid displaced from the pipe during time t_1 is as follows:

$$V = Q * t_1 = \frac{\pi R^4 \Delta P}{8\mu l} * \frac{4\mu l^2}{\Delta P R^2} = \frac{\pi R^2}{2} * l \qquad (6)$$

In the case under consideration, if we consider that the volume of the bore in length l is $V_0 = \pi R^2 l$, the volume of the compressed drilling mud will be 50%. That is, half of the drilling mud in the pipe of length l will be compressed.

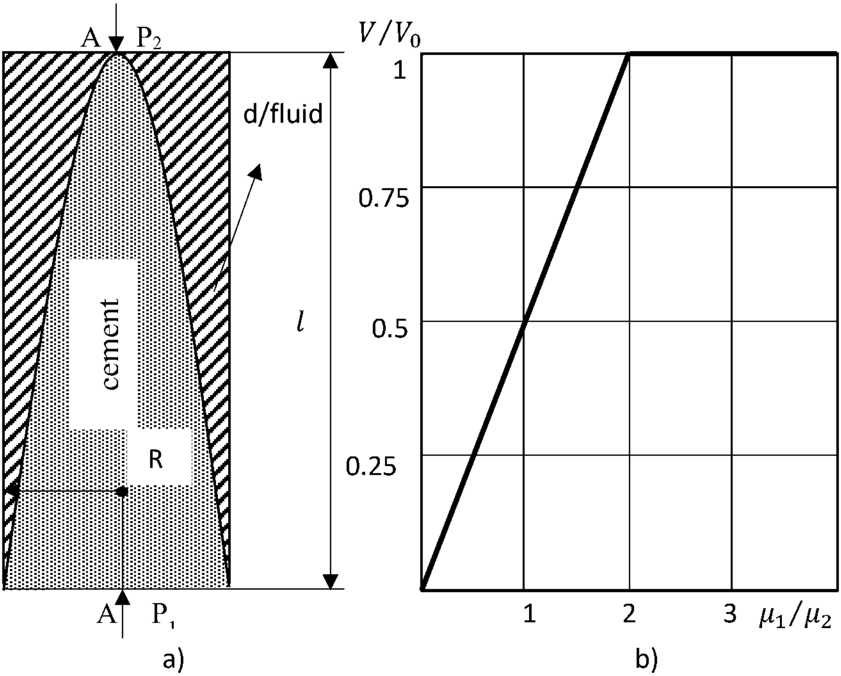


Figure 2. Displace of cement in a vertical pipe

If we assume that the viscosities of the displacing and displaced fluid are μ_1 and μ_2, respectively, then it is clear that the dependence

$\frac{V}{V_0} = f(\frac{\mu_1}{\mu_2})$ is directly proportional and that the contamination zone occurs according to this law. That is, for full displacement, the viscosity of the displacing fluid must be at least 2 times higher (Figure 2b). It should also be noted, since the displacement of various multiphase fluids belong to cylindrical flows, it is important to take into account the lateral force formed in accordance with the new physical model of the flow and directed towards the center along the cross section.

In the third subsection of the second chapter, possible causes of stuck pipe while drilling, methods for eliminating them, and the effect of the side force directed towards the center of the flow cross-section on the compression of the drilling tool are investigated.

Mechanical stuck caused by changes in the wellbore occurs during tool movement. Examples of such stuck include keyseat, undergauge holes due to abrasive formations, and mobile formations – the movement of formations into the wellbore due to high rock pressure. Differential stuck occurs when the differential pressure between the hydrostatic pressure of the drilling fluid and the formation pressure forces the drilling tool into the formed filter cake. Differential stuck usually occurs when the tool is stationary – during the connection of a drill pipe or logging. There are two possible cases for differential stuck[3]:

a. The hydrostatic pressure of the drilling fluid must be higher than the formation pressure;
b. The reservoir must have high permeability in that section – this causes the formation of a filter cake.

In such stuck, circulation is usually observed. The high filtrate of the mud and the high solid phase content in it cause the resulting thicker filter cake, which further increases the risk of stuck pipe.

---

[3] Reid, P. I. Differential-Sticking Mechanisms and a Simple Wellsite Test for Monitoring and Optimizing Drilling Mud Properties / P. I. Reid, G. H. Meeten, P. W. Way [et al.] // SPE Drilling & Completion. – Richardson: – 2000. – Vol. 15, №2. – P. 97–104.

In the fourth subsection of the second chapter, the selection of suitable rheological models (Bingham plastic (BP), force model (GM), Herschel-Bulkley (HB) and casson model[4]) for expressing the rheological parameters of drilling mud and the determination of relaxation properties of water-based fluids were considered.

Initially, various models for the expression of the drilling fluid were investigated. For this purpose, water-based drilling mud samples with different compositions (table 1) were prepared and their parameters were determined. The mud samples are samples used during drilling wells in different fields - Neft Dashlari, Guneshli fields and prepared in laboratory conditions.

Graphs were constructed for the fluid samples according to the models. The graph of fluid samples 6 and 7 according to the casson model is shown in Graphs 3 and 4. The expression of drilling fluid 7 with different models is shown below:

$$\tau = 5.6504 + 0.03337\dot{\gamma} \tag{7}$$

$$\tau = 1.854\dot{\gamma}^{0.4114} \tag{8}$$

$$\tau = 3.577 + 0.152\dot{\gamma}^{0.7898} \tag{9}$$

$$\tau^{0.5} = 1.7085 + 0.1417\dot{\gamma}^{0.5} \tag{10}$$

Here, τ – shear stress (Pa);
$\dot{\gamma}$ – shear rate (s^{-1}).

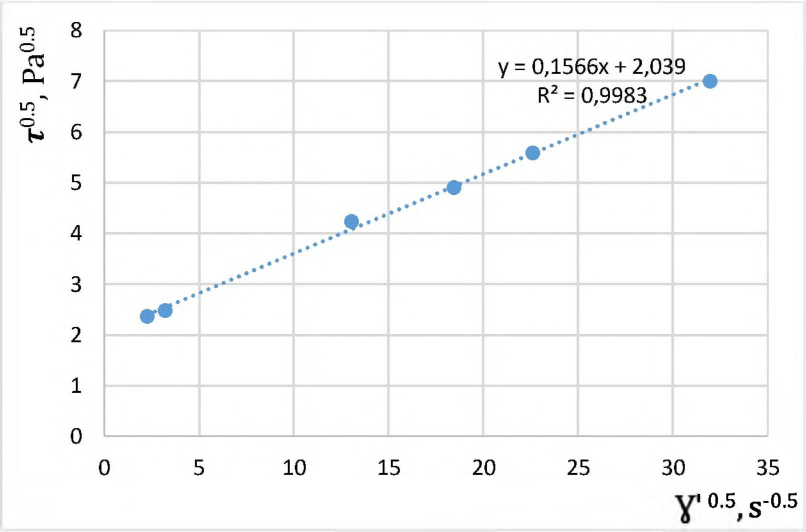
For each drilling mud, the equations shown in expressions (7), (8), (9) and (10) were determined and the values of the shear stress for different shear rate were calculated (table 2).

---

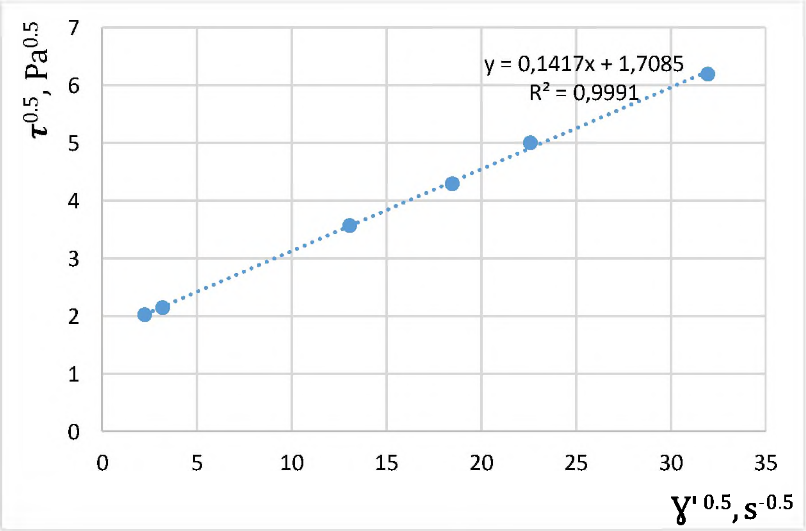
[4] Casson, N. A Flow Equation for Pigment Oil Suspensions of the Printing Ink Type // Rheology of Disperse Systems Conference, – Oxford: Pergamon Press, – September 1957, – 1959, – p. 84–102.

Table 1
Composition of prepared water-based mud samples

1	1ppb caustic soda (NaOH), 2ppb soda ash (Na_2CO_3), 6ppb Pac LV (polyanionic cellulose), 1ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 74ppb barit ($BaSO_4$)
2	1.5ppb caustic soda (NaOH), 3ppb soda ash (Na_2CO_3), 6ppb Pac LV (polyanionic cellulose), 1ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 74ppb barite ($BaSO_4$)
3	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 6ppb Pac LV (polyanionic cellulose), 0.6ppb Xhantan gum, 8ppb KCl, 0.6ppb Ultracap (PHPA), 2% Glydrill, 74ppb barite ($BaSO_4$)
4	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 4ppb Pac LV (polyanionic cellulose), 2ppb PolyPac R, 0.8ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 20ppb barite ($BaSO_4$), 68ppb sand (7%)
5	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 4ppb Pac LV (polyanionic cellulose), 2ppb PolyPac R, 0.2ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 54ppb barite ($BaSO_4$), 24ppb sand (3%)
6	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 5.5ppb Pac LV (polyanionic cellulose), 0.5ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 56ppb barite ($BaSO_4$), 20ppb drilled shale
7	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 5ppb Pac LV (polyanionic cellulose), 0.4ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA), 2% Glydrill, 64ppb barite ($BaSO_4$), 10ppb drilled shale
8	1ppb caustic soda (NaOH), 2.5ppb soda ash (Na_2CO_3), 6ppb Pac LV (polyanionic cellulose), 0.6ppb Xhantan gum, 8ppb KCl, 0.2ppb Ultracap (PHPA),2% Glydrill, 5ppb barite ($BaSO_4$), 20ppb drilled shale, 68ppb sand (7%)



Graph 3. The dependence $\tau^{0.5} = f(\dot{\gamma}^{0.5})$ in the Casson model for WBM №6



Graph 4. The dependence $\tau^{0.5} = f(\dot{\gamma}^{0.5})$ in the Casson model for WBM №7

Table 2

Results obtained for the 6th and 7th drilling fluids sample at various shear rates ($\dot{\gamma}$)

№	$\dot{\gamma}, s^{-1}$	τ, Pa				
		Vgmeter value	BP	GM	HB	Casson
6	5.11	5.62	8.03	4.98	5.66	5.73
	10.2	6.13	8.25	6.56	6.10	6.45
	170.3	17.89	15.02	20.19	15.74	16.67
	340.6	24.02	22.22	26.62	24.17	24.30
	511	31.19	29.43	31.30	31.93	31.13
	1022	49.06	51.05	41.28	53.22	49.64
7	5.11	4.09	5.82	3.63	4.13	4.12
	10.2	4.60	5.99	4.82	4.53	4.67
	170.3	12.78	11.39	15.35	12.37	12.66
	340.6	18.40	17.13	20.41	18.78	18.69
	511	25.04	22.87	24.12	24.52	24.12
	1022	38.33	40.09	32.08	39.78	38.92

For each results, errors - mean absolute error (MAE), root mean square error (RMSE), mean absolute percentage error (MAPE), Symmetrical Mean Absolute Percentage Error (SMAPE), and correlation coefficient (R^2) - were calculated (Table 3).The calculated errors clearly indicate that, for five drilling fluid samples, the lowest error was obtained using the Casson model, whereas for three samples the Herschel–Bulkley (HB) model produced the lowest error. The least suitable model for describing the drilling fluids was the Power Law model. This is explained by the fact that the Power Law model does not take into account the yield stress. The performed calculations demonstrate that the Casson model is the most appropriate model for representing drilling fluids. This is due to the close agreement between the results obtained using the Casson model and those measured by the viscometer.

Table 3

Results of the calculated errors (%) for the models

№	Model	MAE	RMSE	MAPE (%)	SMAPE (%)	R^2
1	BP	1.676	1.681	33.41	26.81	0.9524
	PL	0.545	0.782	4.76	4.44	0.9897
	HB	0.509	0.864	4.03	4.02	0.9874
	Casson	0.804	0.957	9.43	8.71	0.9846
2	HB	2.168	2.288	15.71	13.96	0.9685
	PL	2.551	2.784	16.62	14.95	0.9537
	HB	1.078	1.273	7.06	6.81	0.9889
	Casson	0.990	1.143	6.62	6.33	0.9914
3	BP	1.281	1.332	8.91	8.52	0.9880
	PL	0.923	1.022	6.51	6.25	0.9926
	HB	0.516	0.648	3.84	3.71	0.9965
	Casson	0.533	0.691	3.92	3.79	0.9958
4	BP	2.487	2.564	14.58	13.67	0.9652
	PL	2.306	2.468	12.19	11.56	0.9714
	HB	1.642	1.838	9.21	8.94	0.9857
	Casson	4.359	5.187	22.67	20.41	0.9031
5	BP	1.254	1.326	7.93	7.58	0.9891
	PL	1.348	1.560	8.61	8.09	0.9864
	HB	0.658	0.801	4.37	4.22	0.9962
	Casson	0.615	0.764	4.11	3.98	0.9967
6	BP	1.853	1.954	8.49	8.10	0.9859
	PL	3.509	3.781	16.05	15.21	0.9598
	HB	1.213	1.384	5.79	5.61	0.9932
	Casson	1.143	1.295	5.33	5.18	0.9941
7	BP	1.504	1.602	8.32	7.89	0.9884
	PL	2.962	3.221	15.48	14.36	0.9627
	HB	1.208	1.346	6.78	6.55	0.9931
	Casson	0.934	1.071	5.24	5.06	0.9954
8	BP	2.065	2.214	8.94	8.52	0.9872
	PL	5.172	5.721	19.63	18.44	0.9538
	HB	1.789	1.994	7.31	7.02	0.9916
	Casson	1.128	1.276	4.88	4.69	0.9957

Since the Casson model is a structure-based model for representing viscoelastic fluids, and because the Casson model error is least in drilling fluids, this suggests that they also possess viscoelastic properties.

In the third chapter, the diagnostics and regulation of the structural stability of water-based drilling fluids, as well as the determination of the Bernoulli force, were presented taking into account the characteristics of multiphase flows.

In the first subsection of the third chapter, the role of the side (Bernoulli) force as one of the factors causing drill string stuck was investigated and evaluated through corresponding calculations. In accordance with the new physical model of multiphase cylindrical flow, and taking into account the viscoelastic properties of the drilling fluid, the force formed by the velocity-gradient field across the pipe cross-section during fluid flow in the pipe was analyzed. As can be seen from Equation (1), the particle diameter of the dispersed phase has the greatest influence on this force directed toward the center of the flow. In addition, such parameters as the flow velocity (v), drilling fluid density (ρ_{df}), and the radius of the pipe through which the drilling fluid flows (R) also have significant effects.

Taking into account the expressions for the distribution of velocity and velocity gradient across the cross section and the dependence $(\rho_h - \rho_m)g = \frac{dP}{dr} = \rho_m v \frac{dv}{dr}$, expression (1) can be written as follows:

$$F_{yan} = 4.195\rho_m d^3 {v_{or}}^2 \alpha(1-\alpha^2)/R \qquad (11)$$

Here, v_{or} – avarage flow rate (m/s);
R – pipe radius (m);
$\alpha = \frac{r}{R}$ – is a relative coordinate ($\alpha = 0 \div 1$).

As can be seen from expression (11), the Bernoulli force is equal to zero at the center of the flow (r=0) and at the edges – at the pipe wall (r=R) and takes a maximum value when r=0.577R (Figure 3).

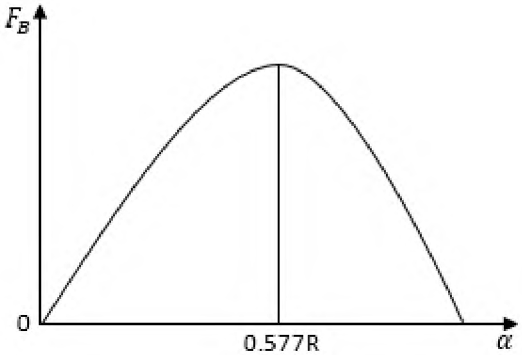
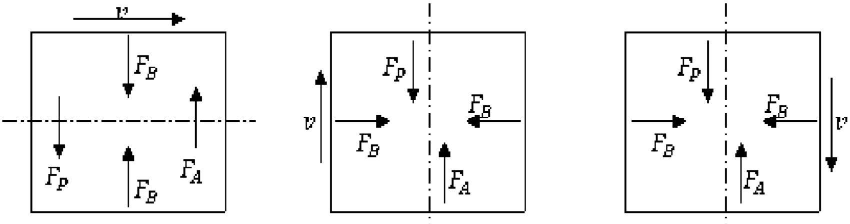


Figure 3. Variation of Bernoulli force across the cross section

To calculate the maximum value of the force, we can write the following expression:

$$F_{B_{max}} = \frac{1.61\rho_m d^3 {v_{or}}^2}{R} \tag{12}$$

As can be seen from Equation (12), an increase in both the size of rock particles and the velocity of the fluid flow leads to a sharp increase in the acting force, thereby significantly increasing the probability of mechanical sticking of the drilling tool by rock fragments. The role and mechanism of the Bernoulli force in drillstring stuck are therefore of considerable importance. According to the law of conservation of energy, a gradient-velocity field is formed not only along the flow direction but also across the cross-section of the flow. Under such conditions, the continuous phase is capable of transporting dispersed-phase particles along the flow axis and concentrating them within the core region of the flow. Due to the action of the Bernoulli force, directed from the core regions of the cylindrical flow toward its center, dispersed particles (mechanical particles, gas bubbles, water droplets, etc.) readily migrate toward the flow axis and continue moving within the core of the continuous phase. It is known that, in such flow systems, the dominant forces governing sedimentation and migration phenomena are gravitational, buoyancy (Archimedes), and Bernoulli forces, while frictional and inertial forces play secondary roles. The directions of these forces under flows of different orientations are schematically illustrated in Figure 4.



horizontal flow vertical (bottom to up) vertical (up to bottom)

F_B – Bernoulli force, F_A – Archimed force, F_P – Gravitation force

Figure 4. Direction of active forces in multiphase flows with different directions

As can be seen from expression (12), despite the high degree of dispersion, the migration of the dispersed phase, even with small diameters of rock fragments to the center of the flow is inevitable. Therefore, due to the intensive migration (transportation) of the excavated rock particles to the center of the flow under the influence of the Bernoulli force created by the changing pressure gradient, the local resistance arising from friction can significantly increase and cause the stuck. The emergence of the Bernoulli force is explained by a new physical model of the flow, and according to this model, even if the static and velocity pressure changes, the total pressure remains constant (Figure 5). During the reports, it was determined that the phenomenon of pipe stuck during the drilling process is often closely related not only to mechanical and geological factors, but also to the hydrodynamic properties of the drilling fluid. In particular, the pressure gradient formed in the velocity-gradient field causes the migration of dispersed phase particles to the central zone of the flow, leading to an increase in local concentration around the tool and, as a result, to an increase in the risk of stuck pipe.

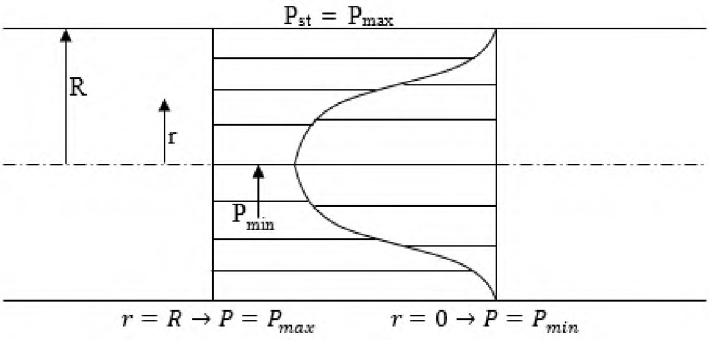


Figure 5. Physical model of flow (static and velocity pressure variation)

Theoretical analyses show that the radial displacement of particles intensifies under the following conditions:

$$\frac{dP}{dr} \geq (\rho_h - \rho_m)g$$

Here, $\frac{dP}{dr}$ – pressure gradient in the cross section (Pa/m);

ρ_h *and* ρ_m – density of rock particles and drilling fluid, respectively (kg/m^3);

g – acceleration due to gravity (m/s^2).

To prevent the stuck pipe because of lateral force, it is advisable to implement the following technological and rheological measures:

- First of all, it is important to maintain the rate of penetration (ROP) at an optimal level.

- The flow regime should be selected in such a way that both the transport of particles is ensured and the pressure gradient does not exceed the critical limit.
- With a decrease in particle diameter, the effect of the pressure gradient weakens and the migration of particles to the center is limited
- As a result of partial weighting of the drilling fluids, the difference $\rho_{m.h} - \rho_m$ decreases, which weakens the relative effect of the pressure gradient. As a result, the migration of particles to the center decreases.
- In addition, the rheological and structural properties of the drilling fluid are of particular importance. The large relaxation time of the fluids creates conditions for migration of particles. High structural stability, on the other hand, ensures that the particles are kept in a network-like structure within the drilling fluids, limiting their free movement.
- Optimization of parameters such as cutting concentartion index (CCI), percentage of particles in the annulus (CC), and cutting transport ratio (CTR) prevents local accumulations by ensuring uniform distribution of particles within the flow.

The second subsection of the third chapter shows the determination of the loss of structural stability during the movement of water-based drilling fluids. Results from tests conducted on various heterogeneous systems with non-Newtonian properties using the Cross method have shown that in a number of cases, the interpretation dependencies $[\varphi^2 = f(\tau^2)]$ are non-linear rather than linear. The existence of such dependencies can also be explained by structural changes occurring in the system. For the rheological description of systems associated with such structural changes, an extrapolation of an exponential-type rheological model was used:

$$\ln\bar{\varphi} = \frac{\tau^2}{æ}; \qquad \bar{\varphi} = \frac{\varphi_\infty - \varphi}{\varphi_\infty - \varphi_0} \tag{13}$$

Here: æ – structural stability coefficient;;

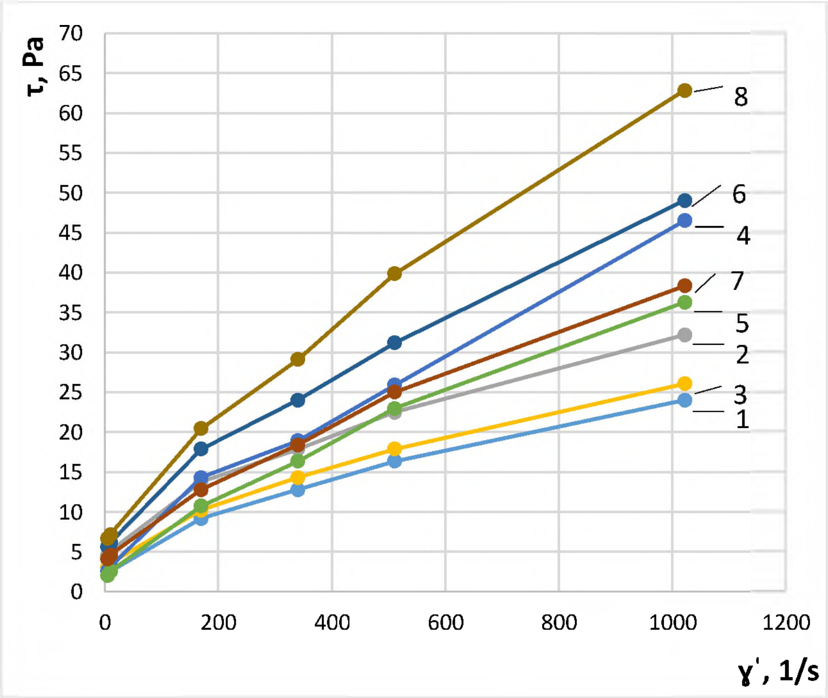
$\varphi = \frac{1}{\eta}$ - fluid fluidity (Ƞ - viscosity);
τ – shear stress (Pa);
φ_0 və φ_∞ - flow at τ = 0 and at the shear stress (τ_∞)

For the determination of the æ coefficient from expression (13), the values of the φ_0 and φ_∞ parameters must also be known.

These parameters are determined from the graph by fitting the $\varphi = f(\tau^2)$ dependence for each tested system. The rheological tests were conducted on eight water-based drilling fluids with different compositions (Figure 5). The compositions of the fluid samples are given in Table 1. Based on the rheological testing of the aforementioned drilling fluids at 120°F or 49°C, the resulting $\tau = f(\dot{\gamma})$ flow curves for each water-based fluid are shown in Figure 5.

As can be seen from Graph 5, despite the tests being conducted at a relatively high temperature (49°C), the $\tau = f(\dot{\gamma})$ flow curves for all fluids are non-linear and differ significantly from one another. These curves intersect the ordinate (stress) axis, with almost none passing through the origin. At first glance, it can also be assumed that the water-based drilling fluids possess pseudoplastic rheological properties. Based on the results of the rheological test, the interpretation using the Cross method [$\varphi^2 = f(\tau^2)$] for each drilling fluid determined that the observed dependencies for the tested systems were not linear but non-linear.

For example, the [$\varphi^2 = f(\tau^2)$] dependence for the №6 water-based drilling fluid is shown in Graph 6. An example of the results of the calculations performed on the provided drilling fluid samples is given in Table 4. Subsequently, the $\varphi = f(\tau^2)$ dependence was established for each drilling fluid tested (graph 7). This table shows the calculated viscosity (Ƞ), fluidity (φ) and the shear stress (τ) of the drilling fluid.



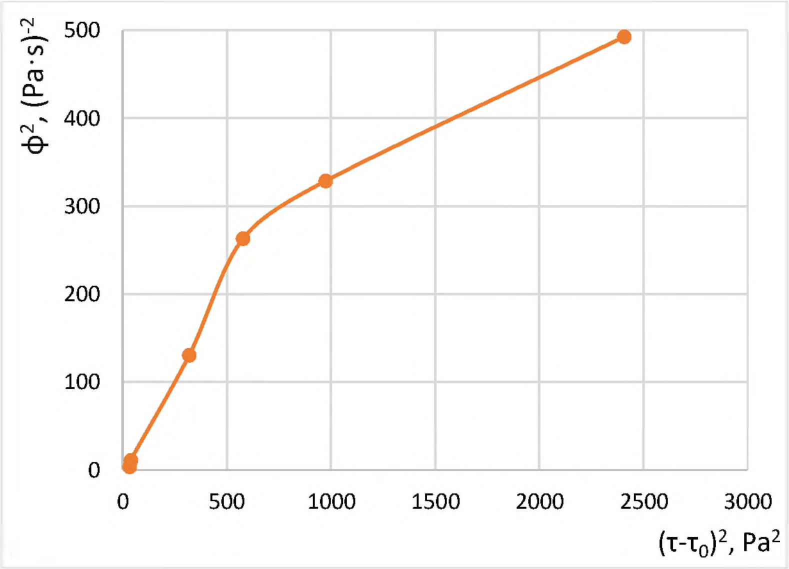
1-8 – water-based drilling fluids of various compositions

Graph 5. $\tau = f(\dot{\gamma})$ **flow curves of water-based drilling fluids**

Table 4

Results of the rheological test of №2 drilling fluid

№2 water based drilling fluid – 1200kg/m^3						
γ', 1/s	τ, Pa	Ƞ, Pa·s	φ, $(Pa\cdot s)^{-1}$	τ^2, Pa^2	$ln\bar{\varphi}$	$1/Ƞ^2$, $(Pa\cdot s)^{-2}$
5,1	4,599	0,900	1,11	21,15	0,035	1,23
10,2	5,11	0,500	2,00	26,11	0,065	3,99
170,3	13,8	0,081	12,32	190,36	0,486	151,87
340,6	17,89	0,053	19,04	319,87	0,904	362,67
511	22,48	0,044	22,72	505,53	1,238	516,33
1022	32,19	0,032	31,74	1036,39	4,812	1007,42



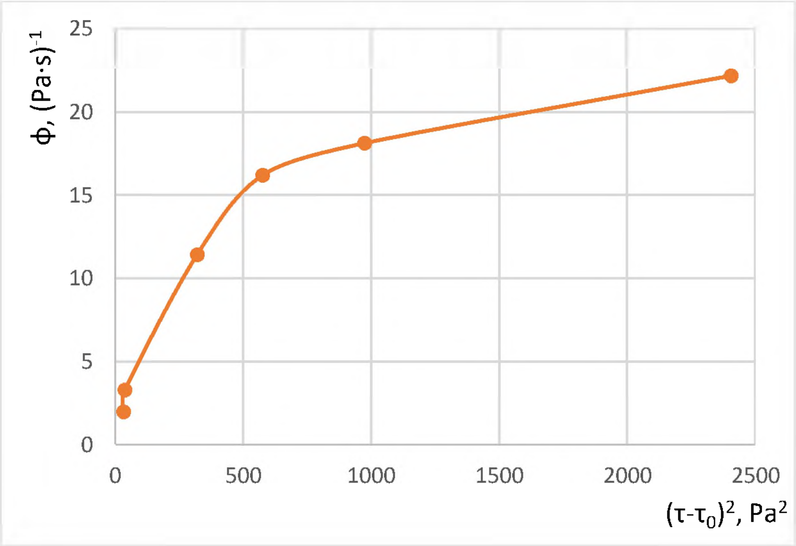
Graph 6. $\varphi^2 = f(\tau^2)$ dependence for №6 WBM

The $\varphi = f(\tau^2)$ nonlinear dependence for the aforementioned №6 water-based drilling fluid is shown in Figure 7, and the extrapolation of ln $ln\bar{\varphi} = f(\tau^2)$ is shown in Figure 8.

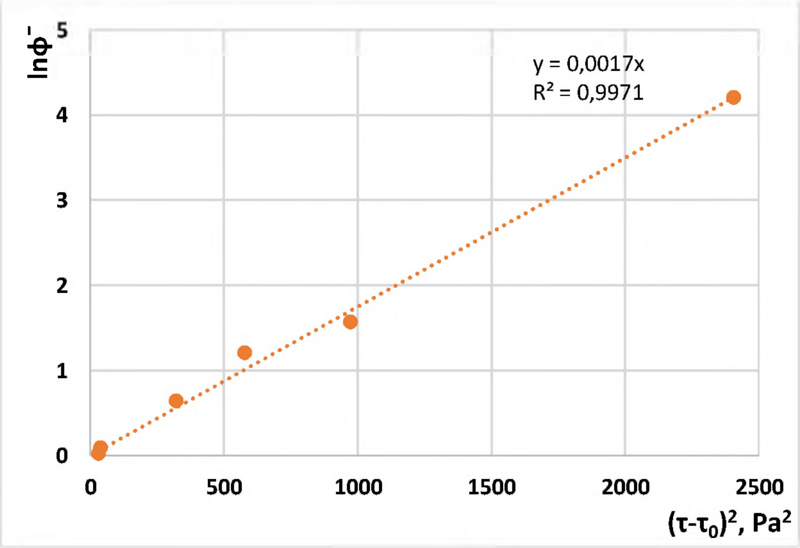
It can be easily shown that the dependence shown above is analogous to the following Maxwell-type rheological model that forms the basis of the Cross method, for which the following mathematical expression has been derived for determining the relaxation time of structuring drilling fluids:

$$\theta = \sqrt{\frac{8(\varphi_\infty - \varphi_0)}{æ{\varphi_0}^3}} \qquad (14)$$

The relaxation time for the tested water-based drilling fluids was calculated based on expression (14).



Graph 7. $\varphi = f(\tau^2)$ dependence for №6 WBM



Graph 8. Extrapolation of $ln\overline{\varphi} = f(\tau^2)$ for №6 WBM

The values of the φ_0, φ_∞, æ and θ parameters, from the graphs showing the obtained nonlinear dependencies, are given in Table 5. As can be seen from the table 5, depending on the composition of the drilling fluids, their structural stability and relaxation time also vary significantly.Thus, when it is not possible to determine the relaxation time by the Cross method, it has been shown that the relaxation time can be determined based on the determination of the structural stability of such multiphase and multicomponent fluids.

Table 5
Calculated values for water-based drilling fluids

Drilling fluids, №	$\varphi_0, (Pa \cdot s)^{-1}$	$\varphi_\infty, (Pa \cdot s)^{-1}$	$æ, Pa^2$	θ, s
1	6,0	45,0	100,30	0.12
2	2,0	35,0	218,90	0.39
3	4,5	43,0	135,26	0.16
4	9,0	23,0	336,19	0.02
5	6,5	29,5	279,80	0.05
6	1,5	22,5	572,57	0.29
7	5,0	29,2	256,60	0.08
8	3,8	17,5	576,97	0.06

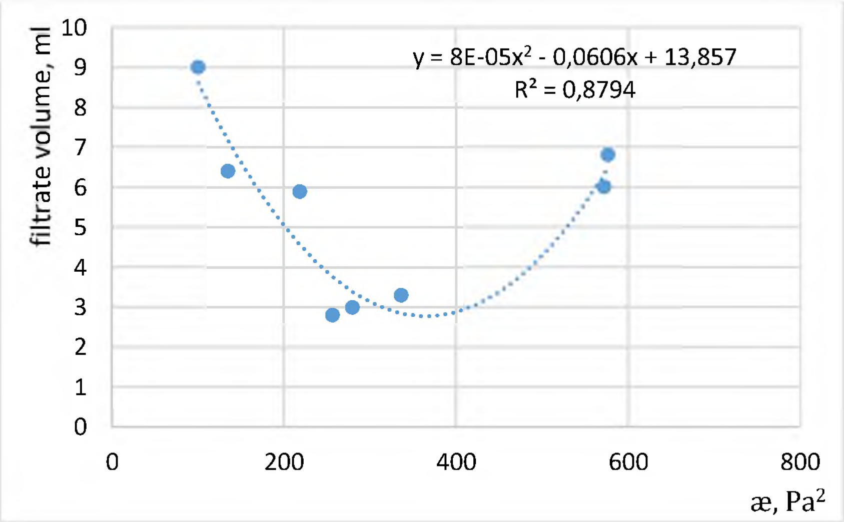
It is possible to determine the relaxation time during the movement of water-based drilling fluids, taking into account the structural stability of the water-based drilling fluids, based on its extrapolation, such as the Maxwell-type equation for linear viscoelastic fluids, which is an exponential-type generalized rheological model that takes into account the structural stability.

The third subsection of the third chapter shows the method of selecting the parameters of water-based drilling fluids taking into account the structural stability coefficient. In order to determine the relationship between the parameters of drilling fluids and their structural stability coefficients, all the parameters of drilling fluid samples prepared in different compositions and their structural stability coefficients were determined and dependencies were established between them. The measured parameters for various water-based drilling fluid samples are shown in Table 6.

Table 6
Parameters of water-based mud №8

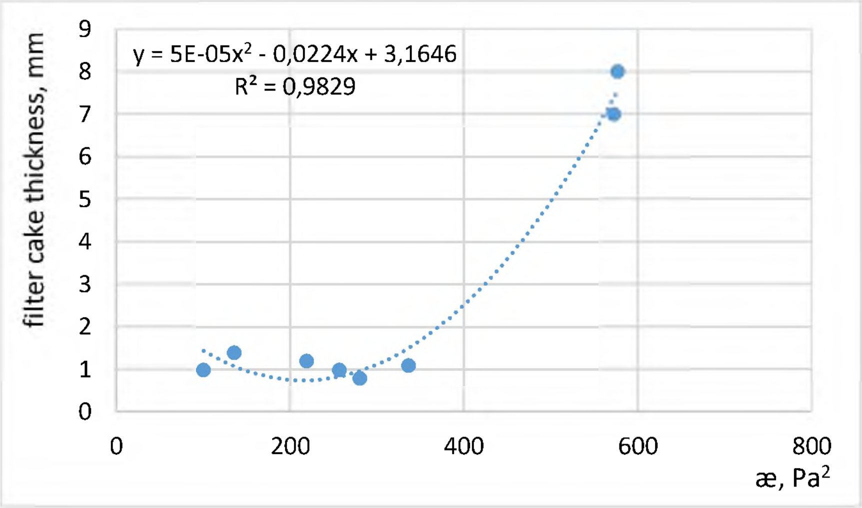
Density (q/sm^3)	1.20
Funnel viscosity (s/l)	103
Reology temperature (°C)	50
R600/R300	123/78
R200/R100	57/40
R6/R3	14/13
Plastic viscosity (sPz)	45
Yiled point(lb/100ft^2)	33
10s/10d/30m Gels (lb/100ft^2)	13/19/31
API fluid loss (ml/30m)	6.8
Filter cake thickness (ml)	8
pH	9.8
Solid (%)	29
Glycoll (%)	2.5
Water (%)	71
Water/solid phase ratio (%)	71/29
Alkalinity (Pm)	1.3
Pf/Mf in filtarte	1.4/3.2
Chlorides (mg/l)	42000
Total hardness/ Ca^{2+} (mq/l)	520 / 160
Sand %	7
MBT kg/m^3	20

From the established dependencies, it was determined that changes occur in the parameters of drilling fluids in accordance with their structural stability coefficients. The relationship between the filtrate and the structural stability coefficient for a water-based drilling mud is shown in Graph 9, and the relationship between the filter cake thickness and the structural stability coefficient is shown in Graph 10.



Graph 9. Relationship between the filtrate of WBM and the structural stability coefficient

As can be seen from Graph 9, an increase in the filtrate volume of the drilling fluid is observed at small (æ < 250Pa^2)and large (æ > 450Pa^2) values of the structural stability coefficient. At an average value of the structural stability coefficient (250 ≤ æ ≤ 450), the filtrate volume for the drilling fluid is within the acceptable range for drillingAs can be seen from Figure 10, at small values of the structural stability coefficient (æ ≤ 450), the filter cake thicness takes small values (t ≤ 3mm). The very thin filter cake thickness and large filtrate volume at small values of the structural stability coefficient are related to the small amount of solid phase in the drilling fluid and the absence of bentonite or clay particles in it that act as a bridge for the rock particles that form the filter cake.



Graph 10. Relationship between filter cake thicness and structural stability coefficient of water-based mud

As a result of the reports conducted, it was determined that for water-based drilling fluids, the structural stability coefficient in the range of 250-400 can be accepted, provided that other parameters of the drilling fluid are suitable for the purpose of drilling.

CONCLUSIONS AND RECOMMENDATIONS

1. The various types of drilling fluids used to drill different intervals and formation, their operating conditions, and the influence of factors affecting their rheological parameters (contaminants, chemical reagents used, various ions entering the fluid from the drilled formation, and the solid phase content of the fluid) have been analyzed [4].

2. The composition of shale rocks that causes a sharp change in the rheological parameters of the drilling fluid during drilling was studied, and methods for preventing their swelling and mixing into the fluid were presented, methods for determining the rheological parameters of the drilling fluid for a given well interval have been proposed, and the feasibility of effectively cleaning drilled mechanical rock particles has been analyzed [5, 7, 19].
3. The negative influence of the side force generated by the gradient-velocity field across the flow cross-section on the operation of equipment used for drilling fluid cleaning and rheological parameter regulation was substantiated, and methods for reducing this influence were proposed [1, 2, 3].
4. The parameters affecting the displacement of the drilling fluid by another one and by the cement slurry during well drilling were investigated, and a method for determining the contamination zone at the interface of the two fluids was presented, taking into account their rheological characteristics in the laminar flow regime [6].
5. The methods for preventing and overcoming stuck pipe, one of the most common complications during drilling, were studied, and the force generated by the gradient-velocity field across the cross-section was determined to be the cause of the stuck pipe [10, 12, 15, 16, 18, 20, 22].
6. It was established that, depending on their composition, water-based drilling fluids exhibit not only viscoplastic but also viscoelastic properties, and the relaxation time was determined using the Cross method [8, 9, 11].
7. As a result of rheological testing of numerous water-based drilling fluids, it was determined that drilling efficiency can be improved through evaluation of their structural stability and relaxation time [11, 13, 14, 17];
8. Taking into account the physicochemical compositions of water-based drilling fluids and the interaction of phases, the possibility of regulating their rheophysical and hydrodynamic parameters was demonstrated [21, 22].

The main results of the dissertation were published in the following theses and articles:

1. İsmayılova, F.B., İsmayılov, Q.Q., Qulubəyli, Ə.P., Çoxfazalı dispers sistemlərin ayrılması zamanı hidrosiklonun aşağı səmərəliliyinin səbəbləri haqqında // – Baku: Azərbaycan Ali Texniki Məktəblərinin Xəbərləri jurnalı, -2023, Cild 30, buraxılış 07, – s.278–285.
2. Ismayilov, G., Gulubayli, A., Musayev, S., Musayeva, S. The Estimated Reason for the Low Efficiency of Hydrocyclones in the Petroleum Industry // Reliability: Theory and Application. – The Fifth Eurasian Risk-2023 Conference. Baku, Azerbaijan. – Special Issue No. 5 (75), Vol. 18. – 2023. – p.391–395.
3. Исмайылов, Г.Г., Гулубейли, А.П., Об эффективности разделения мультифазных систем в гидроциклонах // XVIII Международной научно-практической конференции, - России, УФА, -2023, с. 92-93
4. Qulubəyli, Ə. P. Qazma məhlullarının seçilməsinin reotexnoloji əsasları // Ümummilli lider Heydər Əliyevin anadan olmasının 100 illiyinə həsr olunmuş “azərbaycan elminin və təhsilin inkişafında HEYDƏR ƏLİYEV epoxası” adlı beynəlxalq elmi konfrans. Bakı, Azərbaycan, - 4-5 iyul, - 2023, -s.444-448
5. Qulubəyli, Ə. P., Ağırlaşdırıcı agentin qazma məhlulunun reofiziki parametrlərinə təsiri // Azərbaycan xalqının Ümummilli lideri HEYDƏR ƏLİYEVİN anadan olmasının 100 illik yubileyinə həsr edilmiş “Neft-Qaz yataqlarının axtarış problemləri və perspektivləri” Respublika-elmi konfransı. Bakı, Azərbaycan, - 5-6 dekabr, - 2023, - s.115-118
6. İsmayılova, F.B., İsmayılov, Q.Q., Qulubəyli, Ə.P. Laminar Rejimdə Mayenin Hərəkəti və Sıxışdırılmasının Reotexnoloji Xüsusiyyətləri // – Baku: Azərbaycan Ali Texniki Məktəblərinin Xəbərləri.– 2024. – Cild 37 (5), Buraxılış 02. – s.379–387.
7. Gulubayli, A. P. Effect of Rheological Parameters on Surge and Swab Pressure // XII International Scientific and Practical

Conference «Modern Science: Theoretical and Practical View». – Madrid, Spain, – 4–5 June 2024, p.54–56.

8. Gulubayli, A. P. Selection of Best Fitting Rheological Model for Drilling Fluids // – Oslo: Norwegian Journal of Development of the International Science., – 2024. – №134. – p.83–87.
9. Gulubayli, A. Study of the Effect of Drilling Mud Composition on Structural Stability // – Bakı: Azərbaycan Ali Texniki Məktəblərinin Xəbərləri.– 2024. – Vol. 43, №5. – p. 24–33.
10. Ismayilov, G., Valiyev, R., Gulubayli, A. One of the reasons of stuck pipe while drilling // БУЛАТОВСКИЕ ЧТЕНИЯ Материалы VIII Международной научно-практической конференции, - России, Краснодар, - 31 марта 2024, с.255-259
11. İsmayılov, G., Valiyev, R., Gulubayli, A., About Loss of Structural Stability During Movement of Drilling Fluids // – Baku: SOCAR Proceedings.– 2024. – No. 2. – p.90–94.
12. İsmayılov, Q.Q., Vəliyev, R.H., Qulubəyli, Ə.P., Qazma zamanı alətin tutulmasının mümkün olan bir səbəbi haqqında // - Bakı: Azərbaycan Neft Təsərüfatı Jurnalı, -2024, -No.5, s.11-15
13. İsmayılov, G. G., Veliyev, R.H., Gulubayli, A.P. Diagnosis of the Structural Stability of the Flow of Multiphase Oil-Base Drilling Fluids / G. G. İsmayılov, R. H. Veliyev, A. P. Gulubayli, [etc] // Processes of Petrochemistry and Oil Refining. – Baku: – 2024. – Vol. 25, No. 2. – p.622–629.
14. İsmayılov, Q., Vəliyev, R., Qulubəyli, Ə. Neftəsaslı qazma məhlulunun struktur dayanıqlığının diaqnostikası // -Bakı, AVADANLIQLAR, TEXNOLOGİYALAR, MATERİALLAR, - 2024, cild 22 (06) buraxılış 04, s.48-57
15. Исмайылов, Г.Г., Исмайылова, Ф.Б., Велиев, Р.Г., Гулубейли, А.П. О сценариях структурных переходов при мультифазном транспорте // нефтегазовый терминал материалы международный научно-технической конференци транспорт и хранение углевоборогного сырья носьясенной 60-летию ТИУ. - Тюмень, Россия. –4-5 июня, - 2024, ст.162-166

16. Qulubəyli, Ə.P. Neft və qaz quyularının qazılması zamanı alətin tutulmasında Bernulli qüvvəsinin rolu haqqında // Azərbaycan Neft Təsərüfatı Jurnalı. – Bakı: – 2024. – №9. – s.24–31.
17. Ismayilov, G.G., Veliyev, R.H., Gulubayli, A.P. Diagnostics of Structural Stability of Drilling Fluids Based on Physico-Chemical Composition // – Baku: Processes of Petrochemistry and Oil Refining. – 2024. – Vol. 25, No. 4. – p.1204–1217
18. Ismayilov, G., Veliyev, R., Gulubayli, A. About a Risk of Stuck Pipe While Drilling // Reliability: Theory and Application. – The Fifth Eurasian Risk-2024 Conference. Baku, Azerbaijan. – Special Issue No. 6 (81), Vol. 19. – 2024. – p.198–202.
19. Qulubəyli, Ə.P., İsgəndərli, T.T. Qazma məhlullarının reofiziki parametrlərin təyini üçün Binqam-plastik modelin tədqiqi // Doktorantların və Gənc Tədqiqatçıların XXVII Respublika Elmi Konferansı (NASCO XXVII), - Sumqayıt, Azərbaycan. -10-11 dekabr 2024, s.337-342
20. İsmayılov, Q.Q., Vəliyev, R.H., Qulubəyli, Ə.P. Qazma alətinin tutulmasında Bernulli qüvvəsinin rolu // - Bakı: - Elmi Xəbərlər, - 2025, -Vol.17, No.1, s.81-87
21. İsmayılov, Q.Q., Vəliyev, R.H., Qulubəyli, Ə.P. Multifazalı qazıma məhlullarının hərəkəti zamanı struktur dayanıqlığının itirilməsi haqqında // - Bakı: Azərbaycan Mühəndislik Akademiyasının Xəbərləri, - 2025, Vol.17, №1, - s.81-87
22. İsmayılov, Q.Q., Vəliyev, R.H., İsmayılova, F.B., Adıgözəlova, M.B., Qulubəyli, Ə.P. Alətin tutulması və qazma məhlulunun struktur dayanıqlığının diaqnostikası və tənzimlənməsi üzrə metodiki rəhbərlik // -Bakı: Azərbaycan Respublikası Dövlət Neft Şirkəti, -2025, -42s

Personal contribution of the applicant:

[4, 5, 7 - 9, 16] works were performed independently,

[11, 13, 14, 17, 21] in the preparation of drilling fluid samples and conducting research;

[1-3, 6, 12, 15] in the preparation of reports and analysis of results;

[10, 18-20, 22] in the analysis and generalization of results.

The defense will be held on 25 June 2026 at 11:00 at the meeting of the Dissertation council FD 2.03 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industry University PLE.

Address:AZ1010. Baku city, D. Aliyeva str., 227

Dissertation is accessible at the Azerbaijan State Oil and Industry University Library.

Electronic versions of dissertation and its abstract are available on the official website of the Azerbaijan operating at Azerbaijan State Oil and Industry University PLE

Abstract was sent to the required addresses on "22" May 2026.

Signed for print: 20.05.2026
Paper format: A5
Volume: 37718
Number of hard copies: 20