

Article

Dependence of the Equivalent Circulation Density of Formate Drilling Fluids on the Molecular Mass of the Polymer Reagent

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Abstract: Construction of offshore gas wells is characterized by increased requirements for both the technological process in general and the technological parameters of drilling fluids in particular. Parameters and properties of the used drilling muds must meet a large number of requirements. The main one is the preservation of the permeability of the reservoirs, in addition to the environmental and technological concerns. At the same time, pressures in the productive formation at offshore fields are often high; the anomaly coefficient is 1.2 and higher. The use of barite in such conditions can lead to contamination of the formation and a decrease in future well flow rates. In this regard, the development and study of the compositions for weighted drilling muds is necessary and relevant. The paper presents investigations on the development of such a composition based on salts of formic acid (formates) and evaluates the effect of the molecular weight of the polymer reagent (partially hydrolyzed polyacrylamide) on the equivalent circulation density of the drilling fluid. The result of the work is a formate-based high-density drilling mud with no barite added. Application of such a mud will preserve the permeability of the productive formation.



Citation: Leusheva, E.; Morenov, V.; Liu, T. Dependence of the Equivalent Circulation Density of Formate Drilling Fluids on the Molecular Mass of the Polymer Reagent. *Energies* **2021**, *14*, 7639. <https://doi.org/10.3390/en14227639>

Academic Editor: Hossein Hamidi

Received: 22 October 2021

Accepted: 12 November 2021

Published: 15 November 2021

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Keywords: drilling fluid; equivalent circulation density; formate fluid; weighted mud; polymer reagent; preservation of formation permeability

1. Introduction

The construction of oil and gas wells is currently accompanied by difficult mining, geological and climatic conditions, as it is increasingly moving to the North, including to the Arctic fields. When carrying out drilling operations in these regions, special attention is paid to environmental safety, especially in sea waters [1,2]. Therefore, attention should be paid to the technical and technological requirements for drilling fluids used for well drilling. The main requirements are temperature stability of the solution, the rheological and filtration characteristics necessary to preserve the reservoir properties of the formation, high inhibiting ability of the solution and filtrate, increased transporting and flushing ability (especially in highly inclined and horizontal sections of the wellbore), resistance to contamination by rocks and liquids, compatibility with formation fluids and the possibility of recirculation.

It is known that, as the depth of the well increases, pressure and temperature in the wellbore increase. With increasing pressure, the density of the drilling fluid increases, but at the same time, the density decreases with increasing temperature. These changes could neutralize each other, but this does not happen due to the complexity of the processes occurring during drilling. During underpressure drilling with a density mismatch, influxes and blowouts from the formations can occur; during overpressure drilling, fluid absorption by drilled-in formations. It is especially difficult to predict the pressure and, accordingly, to select the density of the solution when drilling offshore wells, since the permissible range of pressure change, determined by the pore pressure and the fracture pressure gradient, is rather narrow [1,3,4]. Such a narrow window is usually the result of abnormally high pore

pressure and/or low fracture pressure, because the rock layers are under the additional pressure of the seawater column. This requires more casing strings compared to wells of the same depths built onshore. Accordingly, under such conditions, one of the key success factors for drilling operations is equivalent circulation density (ECD) management [5,6]. The working window under dynamic conditions must be accurately estimated regarding ECD in order to avoid the circulation risks associated with the effect of fluid properties on the wellbore walls [7,8].

The following are the factors affecting the final ECD value: type of solution (oil-based solution/water-based solution), static density, rheological parameters of the solution, well design and profile, drilling mode (pump capacity and rate of penetration), drill pipes and bottomhole assembly used, bit type (number and flow area of each nozzle), temperature profile of the well and chemical composition of the solution (salinity, solids content) [9,10].

This study aims to investigate the effect of the rheological parameters of the drilling fluid on ECD. Understanding the relationship between the rheology of drilling fluids and ECD is especially important for ensuring well stability while maintaining the mud density in the well below the fracture pressure gradient, as well as minimizing non-productive time and expenses in countering the complications.

It is feasible to use environmentally safe systems under the conditions of offshore fields [11,12]. Therefore, a formate-based drilling fluid was selected for the study. The solution is characterized by a high density with or without a low solids content. This, as a rule, will provide a lower ECD and pressure loss in the well compared to the traditionally used oil-based mud, which contributes to an increase in the efficiency of drilling, especially in the conditions of a narrow safe corridor in terms of density [13–15]. It is also worth noting that the analysis of the scientific literature proves that formate drilling systems are compatible with formation fluids, which creates preconditions for an increase in ROP and a decrease in NBHZ contamination [16–18]. In addition, such solutions in combination with polymeric reagents have a good inhibitory ability against unstable clay deposits [19–21].

The results of [22] showed that, in comparison with silicates, glycols and potassium chloride, solutions based on formates retain their rheological properties better and have lower liquid losses at high temperatures. In addition, these drilling fluids have better thermal stability at 250 °F for 16 h. Experimental tests in the mentioned work showed that when mud was contaminated with substances such as cement and acids, the rheological properties of the drilling fluid did not deviate much. Potassium/sodium formate fluids retained their properties and did not lead to a sharp deterioration in the rheological properties of the drilling fluid.

Experience [14–16,23,24] with the use of fluids based on the salts of formic acid (formates) is presented in Table 1.

Table 1. Experience in the use of fluids based on formates.

Name of the Field, Location	Enterprise	Number of Drilled Wells	Application	Result
Canada		300+		Stability of the wellbore; High flow rate;
Brigantine, Northern Sea,	Shell	3	Horizontal gas wells	High ROP; High flow rate
Huldra, Northern Sea, Norway	Statoil (now Equinor)	6	Horizontal wells; High temperature (150 °C)	Stability of the wellbore; High ROP; High flow rate; Low ECD
Kvitebjørn, Northern Sea, Norway	Statoil (now Equinor)	7	Interlayered rocks; High temperature (155 °C)	Record drilling time; High productivity; Low skin factor

Table 1. Cont.

Name of the Field, Location	Enterprise	Number of Drilled Wells	Application	Result
Germany	Mobil Germany, M-I Drilling Fluids Germany; ExxonMobile	15+	High temperature (165 °C); Clay and salt formations	High ROP; High productivity; Low ECD
Yuzhno-priobskoye and Prirazlomnoye, Russia	Gazpromneft, Akros	2	Horizontal sections of the wells	Low drilling time; Stability of the wellbore
Dagan, China		20	Clay and unconsolidated formations	Stability of the wellbore; High flow rate

In the solutions presented, compositions of polymeric reagents were used as a structure builder. The most commonly used agents were xanthan gum, starch and polyanionic cellulose. This paper presents the compositions of drilling fluids based on a polymer composition of xanthan gum, starch and polyacrylates.

The aims of the article are the development of the weighted barite-free drilling fluid and investigations to establish the influence of the molecular weight of the PHPA (partially hydrolyzed polyacrylamide) polymer on the rheology of the formate drilling fluid. The optimum composition of the polymer reagent is determined by the calculated ECD. The composition at which the value of the ECD will be minimal can be considered the most effective and appropriate for use in a narrow operational range.

The novelty of the work lies in the establishment of the influence of rheological parameters of the drilling mud based on formates on the equivalent circulating density, as well as in the substantiation of the synergistic effect of polymeric reagents included in the developed mud to improve the efficiency of drilling at offshore wells. The advantage of the developed solution compositions with the addition of PHPA is an encapsulating and inhibiting effect of the reagent. The encapsulating effect will improve bottomhole cutting removal. The inhibiting effect will reduce the intensity of the swelling of clay rocks.

2. Materials and Methods

2.1. Laboratory Equipment

The study was carried out in the laboratory of drilling and cementing fluids at Saint Petersburg Mining University. Investigations involved the development of formulations for drilling fluids based on formates and containing polymer reagents and marble chips. The main properties of the drilling fluid included density (specific gravity), plastic viscosity (PV), dynamic shear stress (DSS), static shear stress (SSS) and filtration index (F30).

A mud balance Fann (Houston, TX, USA) was used to measure the density of the drilling fluid, with a 6-speed Fann rotary viscometer, model 35A, used to determine the rheological characteristics and an HPHT filter press used to measure the filtration rate (Figure 1).



Figure 1. Laboratory equipment.

2.2. Procedures and Materials of the Experiment

The procedure for determining the specific gravity of the drilling fluid [25] is as follows:

1. The measuring vessel is filled with the drilling fluid.
2. Next, the sealing cap of the vessel is installed, displacing some drilling mud through the hole in the cap.
3. The outside of the vessel is cleaned and dried.
4. The graduated lever is placed on the base support.
5. The scale pointer (moving weight) is moved until the graduated arm is level, as indicated by the position of the bubble on the balancer.
6. The density of the mud is measured on the divisions of the lever closest to the measuring vessel.

A Fann model 35A 6-speed rotary viscometer was used to determine the properties of the developed and investigated drilling muds. Compositions of the investigated formate drilling fluids were tested by rotating the outer cylinder at 600, 300, 200, 100, 6 and 3 rpm.

The procedure for measuring PV and DSS of drilling fluids using a Fann 6-speed viscometer is as follows:

1. The fluid sample is placed in the beaker of the viscometer and placed on the mobile mount; the fluid level in the beaker should coincide with the graduated line of the outer cylinder.
2. The stirring mode is switched to the HIGH position, i.e., the cylinder rotation rate is set to 600 rpm.
3. After waiting for the arrow to stabilize at this rotation rate, the measured parameter is recorded at 600 rpm.
4. The stirring mode is switched to the LOW position, i.e., the cylinder rotation rate is set to 300 rpm.
5. After waiting for the arrow to stabilize at this rotation rate, the measured parameter is recorded at 300 rpm.

The procedure for determining the SSS of drilling fluids using a Fann 6-speed viscometer is as follows:

1. The viscometer is switched to the “STIR” mode by setting the switch to the “HIGH” position, i.e., cylinder rotation rate is set to 600 rpm.
2. Thorough agitation of the fluid is carried out at 600 rpm, and the viscometer is switched off for 10 s.
3. After 10 s, the device is switched on, and the maximum deviation of the arrow before gel destruction is recorded at a rotation rate of 3 rpm ($SSS_{10\text{ s}}$).
4. Steps 1 and 2 are repeated; at this stage the unit should be switched off for 10 min.
5. The device is switched on, and the maximum deviation of the arrow before gel destruction is recorded at a rotation rate of 3 rpm ($SSS_{10\text{ min}}$).

Drilling fluid engineers use the API methodology to estimate the filtration rate of the drilling fluid at ambient temperature and 100 psi (690 kPa). Analysis consists of

determining the velocity of fluid flow through the filter paper. The result is the volume of filtrate produced (mL) in 30 min.

The measurement procedure on the API filter press is as follows:

1. The filter press cell is assembled using the filter paper supplied with the device.
2. A sample of the drilling fluid to be tested is poured into the cell, approximately 1.5 cm short of the cell top.
3. The cell is placed on the frame support of the filter press. The gas valve is set in the operating position.
4. The measuring cylinder is positioned to receive solution filtrate, the pressure relief valve is closed, and the pressure is set as 100 ± 5 psi and is maintained for 30 min.
5. The pressure is released after 30 min, and the volume of filtrate in the measuring cylinder is determined (in milliliters).

2.3. Research Object

The research object is an environmentally safe, high-density, barite-free drilling fluid (1.45 g/cm^3) based on sodium formate and potassium formate. The solution is used for drilling a directional well with a horizontal ending, located in the Arctic gas offshore field of the Russian Federation. Its composition is presented in Table 2.

Table 2. Component composition of formate-based solution.

No.	Component	Concentration	Function
1	HCOONa/sodium formate (dry)	800 g/L	Mud basis
2	HCOOK/potassium formate (liquid)	30% ($\rho = 1.57 \text{ g/cm}^3$)	Mud basis, inhibitor
4	K ₂ CO ₃ /potassium carbonate	20 g/L	pH buffer
5	Xanthan	4 g/L	Structurant
6	Starch	10 g/L	Filtration reducer
7	VPRG (Hydrolyzed polyacrylonitrile)	4 g/L	HT Filtration reducer
8	CaCO ₃ MEX-CARB F	50 g/L	Bridging agent
9	CaCO ₃ MEX-CARB M	20 g/L	Bridging agent
10	CaCO ₃ MEX-CARB VF	10 g/L	Bridging agent

Complicated conditions are associated with a narrow safe drilling window in terms of mud density and with unstable clay deposits in the geological section, causing problems with the stability of the wellbore. The characteristics of the well selected for the study are presented in Table 3.

Table 3. Characteristics of the selected well.

Well Type	Directional Well with Horizontal Ending
Design well depth	4918.65 m (well length) 2506.70 m (well depth)
Wellhead deviation	3597.44 m
Formation type	Carbonate, organogenic-detrital limestone
Possible complications	Problems with wellbore stability
Expected formation pressure	34.0 MPa
Expected temperature	63 °C

2.4. Measurement of the Main Parameters for the Developed Solutions

In order to determine the rheological parameters of the developed formulations, an experiment was carried out on a Fann 35A 6-speed electronic viscometer at rotor rotations of 3, 6, 100, 200, 300 and 600 rpm.

Plastic viscosity in centipoise (cP) or millipascal multiplied by second (mPa·s) is calculated as the difference between the Fann viscometer readings (θ) at 600 and 300 rpm [25]:

$$PV = \theta_{600} - \theta_{300} \text{ [cP]},$$

where θ_{600} and θ_{300} —values for rotation angles of the viscometer scale at rotation frequencies of the sleeve equal to 600 and 300 rpm, respectively, in degrees.

Dynamic shear stress in lb/100 ft² is calculated from the Fann viscometer data using the following formula [25]:

$$YP = \theta_{300} - PV \text{ [lb/100 ft}^2\text{]},$$

where θ_{300} —scale reading at 300 rpm, PV —plastic viscosity.

In order to convert the value obtained into SI units, a coefficient of 0.478 is used.

API Gel 10 s/10 min (or SSS) values of the system are obtained on a rotary viscometer with a rotation of 3 rpm after 10 s and 10 min [25,26].

In order to improve the basic formulation, a partially hydrolyzed polyacrylamide (PHPA) of various molecular masses (from 12 M to 27 M) was proposed as a replacement for VPRG. The concentration of PHPA in each solution is 1 g/L. With an increase in the concentration of PHPA to 2 g/L, the Weissenberg effect was observed (solution was wound on a stirring element). Therefore, it was decided to reduce the amount of PHPA. The main parameters of the developed drilling fluids are presented in Table 4.

Table 4. Parameters of the investigated drilling fluids.

Parameter	Solution 1 (VPRG)	Solution 2 (PHPA 12)	Solution 3 (PHPA 15)	Solution 4 (PHPA 20)	Solution 5 (PHPA 27)
Density, g/cm ³	1.45	1.45	1.45	1.45	1.45
Specific viscosity, s/quarter	45	40	40	41	42
600 rpm	49	43	46	49	52
300 rpm	30	27	30	33	36
100 rpm	15	14	17	18	17
3 rpm	3	3	3	3	3
Plastic viscosity, mPa·s	19	16	16	16	16
DSS, Pa	5.3	5.3	6.7	8.1	9.6
SSS (10 s/10 min), Pa	2.4/3.8	2.4/3.8	2.4/3.8	2.4/3.8	2.4/3.8
Filtration, mL/30 min	3.8	3	2.7	2.6	2.2

2.5. Calculation of Equivalent Circulation Density

The correct selection and control of mud properties are necessary for ensuring efficient drilling of high-inclined and horizontal wells. Because a riser string is used in deep water drilling, the hydrostatic pressure of the mud column can reach or exceed the fracture gradient, especially when circulation is resumed after a static period, tripping in the borehole or running the casing string. In this case, catastrophic losses of the solution can occur, which can lead to problems of pressure control in the well [6,27,28]. ECD control is critical for maintaining borehole stability. Thus, it is one of the key success factors for drilling operations, especially in deep-water areas, where the permissible pressure variation range, determined by the pore pressure and the fracture pressure gradient, is quite narrow [29,30].

Understanding the relationship between the rheological properties of drilling fluids and ECD is essential for its control. The control is needed to ensure well stability while maintaining the mud density in the well below the fracture pressure gradient, as well as to minimize non-productive time and costs for mitigation of complications [31,32].

According to API, the rheological coefficients that are used for calculations within the drill pipe are determined by the following formulas:

$$n_p = \frac{\log(R_{600}/R_{300})}{\log(1022/511)} = 3.32 \cdot \log \frac{R_{600}}{R_{300}}, \quad (1)$$

$$K_p = \frac{5.11 \cdot R_{600}}{1022^{n_p}}, \quad (2)$$

where

R_{600} and R_{300} —viscometer readings at 600 and 300 rpm, respectively;
1022 and 511—shear rates corresponding to 600 and 300 rpm, respectively.

For annular calculations, the non-linearity index and the consistency index are determined using the following formulas:

$$n_a = \frac{\log(R_{100}/R_3)}{\log(170.2/5.11)} = 0.657 \cdot \log \frac{R_{100}}{R_3}, \quad (3)$$

$$K_a = \frac{5.11 \cdot R_{100}}{170.2^{n_a}}, \quad (4)$$

where

R_{100} and R_3 —viscometer readings at 100 and 3 rpm, respectively;
170.2 and 5.11—shear rates corresponding to 100 and 3 rpm, respectively.

ECD calculation consists of several sequential steps, which must be performed for each of the various annulus geometries.

Flow velocity of the drilling fluid in the annulus is determined by the following formula [33]:

$$V_a = \frac{0.408Q}{(D_2)^2 - (D_1)^2}, \quad (5)$$

where

V_a —fluid velocity for a given interval (ft/s);
 Q —flow rate (gal/min);
 D_2 —wellbore diameter, inches;
 D_1 —drill pipe outer diameter, inches.

Calculation of the effective viscosity (μ_{ea}) in the annulus has the following form:

$$\mu_{ea} = 100K_a \left[\frac{144V_a}{D_2 - D_1} \right]^{n_a - 1} \left[\frac{2n_a + 1}{3n_a} \right]^{n_a}, \quad (6)$$

where

μ_{ea} —annular effective viscosity (cP);
 n_a —drilling fluid non-linearity index;
 K_a —drilling fluid consistency index.

Effective viscosity of the solution will be lower at high shear rates in the nozzles or drill pipe, and vice versa, higher at low shear rates in the annulus. In the first case, there will be lower hydraulic resistance, and in the second, the lifting capacity of the solution will be higher, which will facilitate the removal of sludge [34].

The formula for calculating the Reynolds number for the annular interval is as follows [33]:

$$Re_a = \frac{928V_a(D_2 - D_1)\rho}{\mu_{ea}}, \quad (7)$$

where

Re_a —annular Reynolds number (dimensionless value);

ρ —solution density (lb/gal).

The rules for calculating the Fanning coefficient of friction (f_a) are as follows [33]:

If $Re_a \leq 2100$, then the laminar flow equation is used to determine the friction coefficient:

$$f_a = \frac{24}{Re_a} \quad (8)$$

If $Re_a > 2100$, then the equation for the turbulent flow is used:

$$f_a = \frac{a}{Re_a^b} \quad (9)$$

where $a = (\log n_a + 3.93)/50$; $b = (1.75 - \log n_a)/7$

Pressure drop (P_a) is calculated for each of the different annular geometries, and the total annular pressure loss (P_{aT}) is determined by summing the individual P_a values [33]:

$$P_a = \frac{f_a V_a^2 \rho}{25.81(D_2 - D_1)} L, \quad (10)$$

$$P_{aT} = \sum P_a, \quad (11)$$

where L —interval length (feet).

The results are used to calculate the ECD [33]:

$$ECD = \frac{P_{aT}}{0.052(TVD)} + \rho, \quad (12)$$

where ECD —equivalent circulation density of the solution (lbm/gal).

3. Results

The non-linearity index (n) and the consistency index (K) were calculated for the studied drilling fluids according to Formulas (1)–(4). The diagram was constructed (Figure 2) according to the obtained values, presented in Table 5.

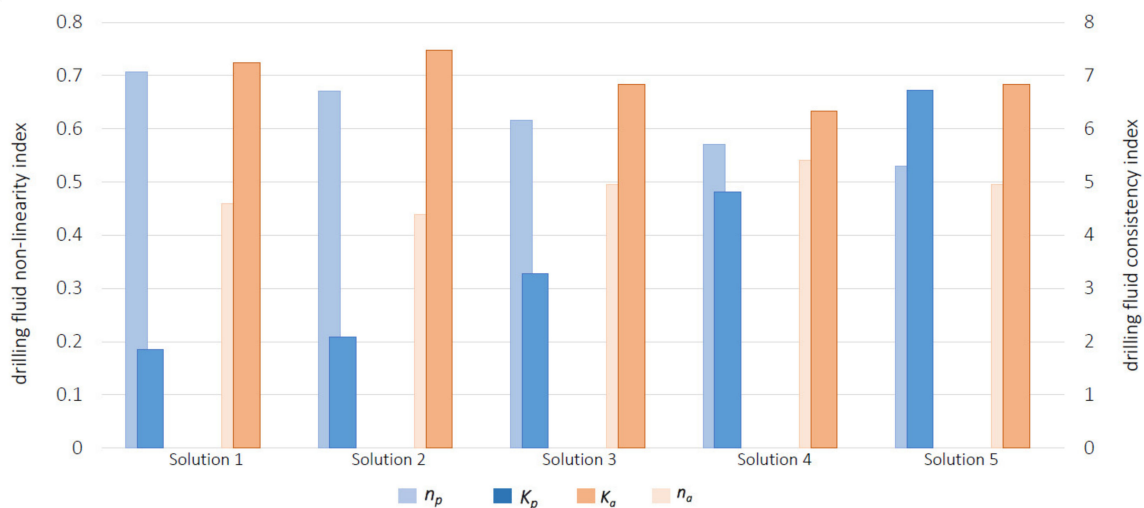
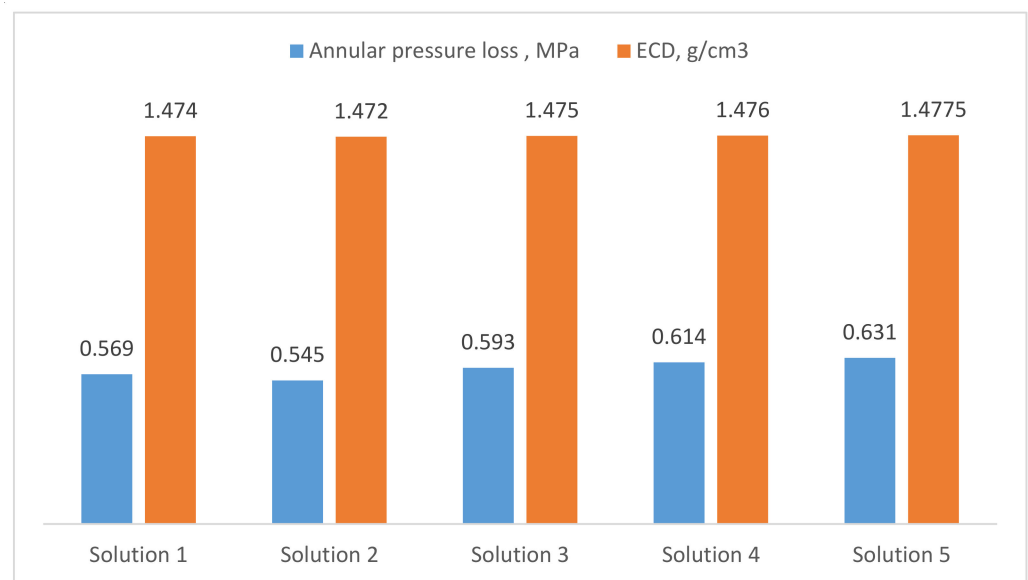


Figure 2. Comparison of the values for the non-linearity index and the consistency index inside the drill pipe and the annulus.

Table 5. Calculated coefficients of the studied drilling fluids.

Solution	1	2	3	4	5
Coefficients for calculating pressure loss in the drill string					
n_p	0.643	0.671	0.616	0.569	0.530
K_p	2.957	2.102	3.284	4.823	6.742
Coefficients for calculating the pressure loss in the annular space and ECD					
n_a	0.459	0.439	0.478	0.495	0.511
K_a	7.244	7.481	7.029	6.834	6.831

All the necessary values to determine the annular pressure drop and ECD are calculated according to Formulas (1)–(9). Annular pressure drop and ECD are calculated according to Formulas (10)–(12). Results are shown in Figure 3.

**Figure 3.** Calculation of pressure loss in the annulus and ECD.

4. Discussion

Analysis of the results obtained shows that the replacement of the VPRG with the PHPA helps to reduce the filtration of the drilling fluid. At the same time, with an increase in the molecular weight of the PHPA, the filtration index decreases, which helps to reduce the likelihood of differential sticking. Furthermore, such drilling fluid is capable of forming a thin impermeable filter cake that will prevent filtrate from penetrating the formation. An increase in the molecular mass of RHPA facilitates an increase in DSS but does not affect the value of plastic viscosity. Obtained SSS values indicate that the structure of the studied solutions manifests itself already after 10 s of being at rest and changes on average by 1.44 Pa after 10 min of being at rest.

Analysis of the data obtained should also consider the rheological model of the drilling fluid presented. Convergence of the rheological model with the properties of the actual drilling fluid minimizes errors in the calculated technological parameters used in oil well drilling. However, it should be taken into account that, to date, there is no rheological model that would give the necessary accuracy of approximation over the entire interval of change in shear rates corresponding to the circulation of drilling mud in the well [35,36]. The authors previously published the results of rheological investigations of these fluids [37]. When selecting the optimal model, a statistical approach was used, in which the rheology of the drilling fluid was characterized by indicators of the model under consideration, which describes its rheological behavior most adequately (with less error). From received

dependencies and results, it was concluded that the Herschel-Bulkley model describes the rheological behavior of investigated drilling agents more accurately than the Ostwald-de Waele model and Bingham-Schwedow model.

It was determined that the modified power law describes the rheological behavior of the studied drilling fluids with the smallest error. However, there is currently no methodology for calculating pressure losses in the well circulation system for the Herschel-Bulkley model. The American Petroleum Institute (API) recommends calculating the annular pressure loss and then the ECD using the rheological parameters (n and K) of the power law (Ostwald-de Waele model), the values of which are calculated from the rotational viscometer data. Higher accuracy will be obtained by using n and K in the shear rate range of 5 to 200 s^{-1} for the annulus and in the shear rate range of 200 to 1000 s^{-1} inside the pipe. However, the power law has a significant drawback—it does not take into account the yield stress of a structured solution, i.e., it does not describe the behavior of the solution at the beginning of circulation (at shear rates lower than 3 s^{-1}).

Further analysis of the results obtained shows that the calculated values of the non-linearity index and the consistency index for the annulus and drill pipe are different from each other in the case of solution 2. This indicates that this system is characterized by ideal rheological behavior—with high shear rates at the exit of the bit nozzles, the solution acquires a viscosity value close to that of water, and when moving in the annulus at lower shear rates, it increases its viscosity in order to lift the cuttings. This phenomenon is called “shear thinning”. Liquefaction is explained by alignment and orientation of suspended unsymmetrical solid particles of suspensions or unfolding of polymer chains in such a way that the flow is at minimal resistance [38,39]. With an increase in the molecular mass of PHPA, the difference between the calculated values of n and K for the annulus and drill pipe decreases. In the case of solutions 4 and 5, the effective viscosity at high shear rates (in the drill pipe) and at low shear rates (in the annulus) will have similar values. In the case of solutions 1, 2 and 3, the effect of “shear thinning” is more visible. At high shear rates, a lower effective viscosity will result in lower hydraulic resistances. At low shear rates, an increased effective viscosity will improve the lifting ability of the drilling fluid, which will ensure the complete removal of cuttings. The rheology of these solutions contributes to an increase in the rate of penetration.

5. Conclusions

The data obtained show that the rheology of the studied drilling fluids does not contribute to a significant increase in ECD; accordingly, these systems are feasible to use in a narrow safe drilling window.

Wellbore cleansing is a priority for large diameter wells (e.g., 311 mm), i.e., if an inclined wellbore is considered, it is necessary to ensure that the wellbore is cleaned efficiently. This will prevent sticking and reduce non-production drilling time and the cost of eliminating complications. Under such conditions, it is advisable to select a drilling mud with a high K_a value, which characterizes viscous adhesion, needed to transfer the sludge into the mud stream. ECD is more important in a well with smaller diameter (for example 216 mm). In this case, it is necessary to choose a solution with lower viscosity characteristics, which will provide a lower ECD value.

Further research will be aimed at studying the effect of temperature on the rheological properties of the developed drilling fluids. It is also necessary to evaluate their inhibitory ability, since reservoirs of complex structure are often accompanied by interlayering of easily hydrating, swelling clay rocks.

Author Contributions: Conceptualization, E.L.; Formal analysis, V.M.; Investigation, E.L. and V.M.; Methodology, V.M.; Project administration, V.M.; Resources, E.L. and T.L.; Software, E.L.; Validation, T.L.; Visualization, E.L.; Writing—original draft, V.M.; Writing—review and editing, E.L. and T.L. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the subsidy for the state assignment in the field of scientific activity for 2021 No. FSRW-2020-0014.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to its storage in private networks.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ECD	equivalent circulation density
ROP	rate of penetration
NBHZ	near-bottomhole zone
PHPA	partially hydrolyzed polyacrylamide
PV	plastic viscosity
DSS	dynamic shear stress
SSS	static shear stress

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