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Investigation of the Fractional Composition Effect of the Carbonate Weighting Agents on the Rheology of the Clayless Drilling Mud

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P A P E R   I N F O

A B S T R A C T

The article considers the issue of reducing the influence of clayless mud components on the filtration parameters of the reservoir. In the composition of such solutions, calcium carbonate of various fractions is often added as a weighting and colmatizing additive. It is generally accepted that weighting bridging agents are sufficiently inert substances and their addition does not affect the rheological parameters of drilling fluids. Assessment of the fractional composition effect of carbonate weighting agents on the structural-rheological parameters of the biopolymer drilling mud used for drilling productive reservoirs was made in the paper. Six types of carbonate weighting agents with an average particle size of 5 to 150 μm were evaluated during the study. Rheological curves were constructed and the obtained results are analyzed. Also the article reviews four main methods for selecting fractional composition of the weighting agents.

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1. INTRODUCTION

In the process of drilling oil and gas wells in conditions of high reservoir pressures, occurrence probability of various complications increases. To prevent the occurrence of complications during drilling, such as oil, gas and water backflows, cavings and collapses of the wellbore walls and etc., it is necessary to create pressure in the well that exceeds the hydrostatic pressure. The primary method of creating the necessary pressure is to increase the density of the drilling mud. For this purpose, special weighting materials are used.

Currently more than 20 weighting materials are used in world market. Barite and carbonate weighting agents are most often used. However, more and more materials are being created for weighting. Sometimes it is required to increase the density of the drilling mud to 2500 kg/m^3 and higher, at the same time maintaining structural-rheology and filtration parameters. For this purpose, more thorough and comprehensive analysis of weighting agents' composition and properties is required, as well as their effect on the properties of washing fluids.

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Several scientists studied the properties of bridging agents and their influence on the process of formation drilling [1-5]. In their research, they considered various theories on the fractional composition of the weighting agent particles and their interaction with the pore volume of the formation. Ishbaev et al. [1] investigated ways to reduce the contamination of the productive reservoir with a filtrate and a solid phase of drilling solution. Dick et al. [6] determined the optimum content of the bridging agents in the drilling mud to seal the permeable zones.

The aim of this article is to assess the effect of the carbonate weighting agent dispersion on the rheological parameters of the drilling fluid.

2. THEORIES OF THE BRIDGING AGENT'S FRACTIONAL COMPOSITION SELECTION

Drilling-in with a water-based solution results in contamination of productive reservoir and reduction in oil recovery rates. Basically, the pollution is caused by penetration of the solid particles and mud filtrate into the pore volume. Quick and efficient formation of low-

permeable filter cake leads to reduced contamination of the oil reservoir (Figure 1).

The permeability of the filter cake, which is formed on the wall of the wellbore, is significantly influenced by the grain composition and the amount of the bridging agent contained in the solution. Fractional calcium carbonate is most often used as a bridging agent since it is easily soluble in acid with subsequent hydrochloric acid treatment.

If the colmatage mixture consists of particles that are significantly larger in size than the pore openings, they will not be able to form an effective filter cake. Some of them will be carried away by the flow of drilling mud, and channels will form between the particles, through which the drilling mud is easily filtered (Figure 2 a). Particles that are much smaller than the pore openings will penetrate the pore volume of the formation unhindered and contaminate it (Figure 2b). Optimal selection of particles by their size in the bridging agent leads to the formation of a filter cake with minimal penetration of the filtrate and solid particles into the formation (Figure 2c).

Dick et al. [6] revealed that most effective sealing of permeable zones occurs when the content of the bridging agent in the drilling mud is about 60-90 kg/m^3. Over the years, Abrams' criteria were used to calculate the fractional composition of the bridging agent [2]. According to these criteria, the size of particles capable of forming arched bridges in the pore volume of the permeable formation should be equal to or greater than 1/3 of the average pore size of the formation, and their content should be at least 5% of the solid particles volume in the drilling mud.
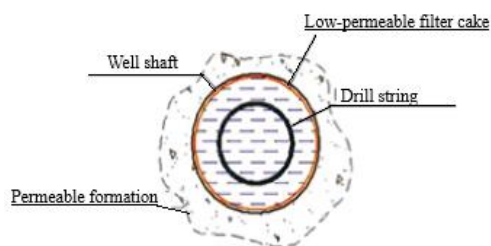
These criteria allow to determine only the particle size, which is necessary to start colmatation, but do not determine the requirements for particle size distribution in the mixture to ensure their effective packaging [2].

Along with the selection of the fractional composition of the bridging agent according to Abrams' criteria, a method aimed at the coverage of the largest range of particles ("Shotgun") is widely used. The essence of this method consists in mixing bridging agents of different fractional composition in proportions providing the widest range of particle sizes. This method is usually applied when the specific characteristics of the formation are unknown, and is not always effective [3].

Another method for determining optimal fractional composition of the bridging agent is based on the Ideal Packing Theory (IPT) developed by Kauffer [4]. Initially, it was used in the paint industry for the ideal pigment-dimensional distribution of particles in paints; later, it was found application in drilling industry. According to this method, the bridging agent forms an ideal package, if the particle size distribution ensures effective clogging of all pores, including the pores formed between the solid particles. Ideal packaging is achieved if the total distribution of articles in the mixture is directly proportional to the square root of the particle size, i.e. graphically represented as a straight line (ideal mixture) (Figure 3) [1].

Drilling mud with a bridging agent, which has fractional particle distribution in accordance with the theory of ideal packing, is capable of forming the filter cake with a minimum permeability.

One of the most recent methods for selecting fractional composition of the bridging agent is the "Vickers Method" (Figure 4). The authors of this method established that in order to increase the effectiveness of colmatation, it is necessary that the fractional composition of the drilling fluid colmatage mixture should correspond to the size of the reservoir pore throats [5, 7]. This correspondence is represented by five target criteria, which carry basic information on the porosity of the particular reservoir and are defined by the following:

D50 – the size of the main pores of the formation, ± 1/3 of their size, µm;
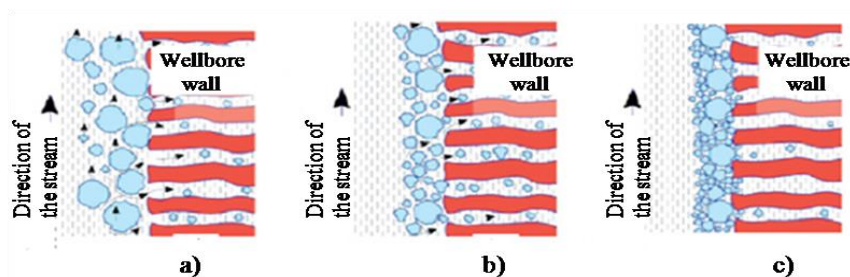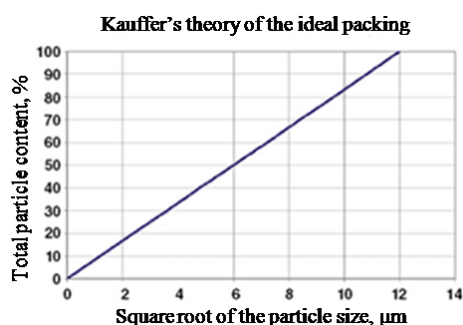

Figure 1. Formation of filter cake on the wellbore walls

Figure 2. Influence of the bridging agent's fractional composition on the filtration properties of the drilling mud

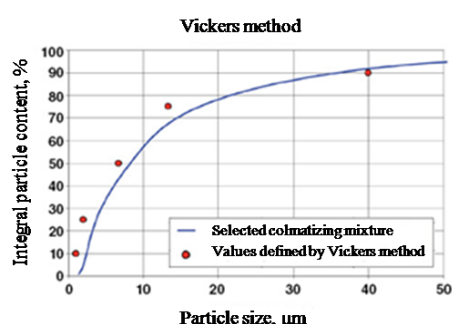**Figure 3.** Graphical representation of the Kaeuffer's theory of the ideal packing

Figure 4. Graphical representation of Vickers method

D10 – is the size of the smallest pores of the formation, μm;

D25 – 1/7 of the size of the main pores, μm;

D75 – < 2/3 of the total porosity, μm;

D90 is the size of the largest pores of the formation, μm.

3. SELECTION OF DRILLING MUD FOR RESEARCH

Current requirements to drilling muds for drilling-in productive reservoirs exclude the possibility of deep penetration of drilling mud filtrate, particles of the solid phase and other elements into the formation, that can reduce its permeability [6, 8]. Therefore, the drilling mud which is used for drilling-in productive reservoirs must comply with the following points:

• The filtrate of the washing fluid should not cause the swelling of clay particles, increase in hydrophilicity of the rocks and the amount of physically bound water in the pores of the formation;

• The composition of the filtrate should be such that, when it penetrates into the formation, no physical or chemical interactions occur, which can lead to creation of insoluble precipitation;

• The grain composition of the washing fluid solid phase must correspond to the structure of the productive

formation pore volume. Surface tension at the interface of the filtrate and hydrocarbon content in the formation should be minimal;

• Fluid loss at the borehole bottom thermobaric conditions should be minimal, density and rheological properties should be so that the differential pressure during drilling of the productive reservoir would be close to zero;

• The degree of mineralization and salt composition of the filtrate should be close to degree as at reservoir, and the osmotic pressure is minimal.

At present, several types of solutions are used at drilling-in productive formations: thin clay solutions, clayless (biopolymer) solutions, petroleum based solutions [9]. The latter type of solution is used more often at present when drilling reservoirs, since the degree of mineralization and the composition of such fluid filtrate comply with formation liquids. However, such solutions have several drawbacks:

1. Expensive preparation;

2. Difficulties with preparation and regulation of parameters;

3. Solutions are environmentally unsafe systems.

As mentioned above, two types of water-based solutions were chosen for the experiments: a biopolymer solution, the thin clay of which was BARAZAN (xanthan gum), and a thin clay solution, thin clay - bentonite powder, Duovis.

The composition of solutions and the required amount of reagents for their preparation are summarized in Tables 1 and 2.

TABLE 1. Component composition of biopolymer solution

Drilling mud	
Component	Flowrate, kg/m³
BARAZAN	4
KCl	50
PAC HV	3
PAC LV	3
NaOH	1,1
Na₂CO₃	0,5

TABLE 2. Component composition of thin clay solution

Drilling mud	
Component	Flowrate, kg/m³
Bentonite	30
NaOH	1,1
Na₂CO₃	0,5
PAC HV	1,7
PAC LV	1,7
Modified starche	10,8
Duovis	2

Reagents, presented in the tables, have following functions: BARAZAN - biopolymer, viscosifier; KCl - salt, heaver; PAC HV and PAC LV - polyanionic cellulose of high and low viscosity, used for filtration and rheology control; NaOH – caustic soda, pH control; Na_2CO_3 - calcined soda, hardness control; Bentonite - clay, viscosifier, base of clay drilling mud; Modified starche for filtration control; Duovis - polymer, viscosifier.

Density (ρ), as well as the main rheological parameters, such as static shear stress (SSS) calculated after 10 seconds (SSS_{10s}) and 10 minutes (SSS_{10min}) of rest, dynamic shear stress (DSS), plastic viscosity (PV) and filtration rate in 30 minutes (F_{30}) of the prepared solutions are presented in Table 3.

As shown in Table 3, the biopolymer solution has a higher initial slurry density than the thin clay solution. This means that in order to achieve the required density, less amount of weighting agent is needed.

The filtration indices in both solutions were approximately the same: 11 ml and 10.6 ml - in the biopolymer and thin clay solution, respectively.

Rheological parameters of solutions (PV, DSS) also have approximately the same values.

The SSS of the biopolymer solution has lower values both for 10 seconds and for 10 minutes, rather than for thin clay solution.

The advantage of biopolymer solutions is that they increase the effective viscosity at low shear rates with an insignificant increase in plastic viscosity, which contributes to the enhancement of the carrying and suspending properties of the drilling mud and the reduction of the equivalent density at circulation. Strengthening the viscoelastic properties of drilling agents significantly improves cleaning of the wellbore, and also reduces the rate of filtration of the liquid phase into the formation [10, 11]. In addition, the biopolymer solution contains a lesser amount of an insoluble solid phase in the composition than the thin clay solution [12, 13]. Therefore, there is a lower chance of reservoir contamination during drilling.

After the comparison, clayless (biopolymer) drilling mud was chosen for further studies, since it better satisfies current requirements to drilling muds for productive reservoir drilling.

4. EVALUATION OF WEIGHTING AGENTS' FRACTIONAL COMPOSITION INFLUENCE ON DRILLING MUD MAIN PARAMETERSm

For each experiment, a sample of a solution with a volume of 400 ml was prepared. The density of the base suspension was 1050 kg/m^3 [14, 15]. The drilling mud parameters listed in Table 3. The required amount of reagents for preparing a solution sample summarized in Table 4.

Each sample of the solution weighted to a density of 1160 kg/m^3. The required amount of weighting agent was:

$$C_w = \frac{\rho_w(\rho_{ws} - \rho_{cs})}{(\rho_w - \rho_{ws})} \qquad (1)$$

$$C_w = \frac{2,7 \cdot (1,16 - 1,05)}{(2,7 - 1,16)} = 0,193 \quad \text{g/cm}^3 \rightarrow$$

$$m_\kappa = 0,193 \cdot 400 = 77,2 \text{ g},$$

where C_w - concentration of calcium carbonate, g/cm^3;

m_κ - mass of calcium carbonate, g.

The mass content of the heaver in the solution was 19% when weighted with calcium carbonate.

To draw the rheological curves of the solutions under consideration, readings for shear stresses were taken at different shear rates. The obtained data are presented in Table 5.

In accordance with the Herschel-Bulkley model, the rheological curves of the prepared solutions were constructed (Figure 5) [16]. Also, in the course of studying, following parameters of solutions were investigated: density, plastic viscosity, dynamic shear stress, static shear stress for 10 seconds and for 10 minutes, static filtration, dynamic filtration, data obtained for these experiments will be used for future research.

TABLE 3. Main parameters of clayless and thin clay solutions

Solution parameter	Clayless (biopolymer) solution	Thin clay solution
ρ, kg/m^3	1050	1020
F_{30}, ml	10-11	10-11
PV, mPa·s	16-18	16-18
DSS, Pa	17-18	16-17
SSS_{10s}, Pa	4-5	5-6
SSS_{10min}, Pa	5-6	7-8

TABLE 4. Needed amount of reagents to prepare a solution sample of 400 ml

Drilling mud	
Component	Needed amount, g/400 ml
BARAZAN	1,6
KCl	20
PAC HV	1,2
PAC LV	1,2
NaOH	0,44
Na_2CO_3	0,2

TABLE 5. Data for constructing the rheological curves of the prepared solutions

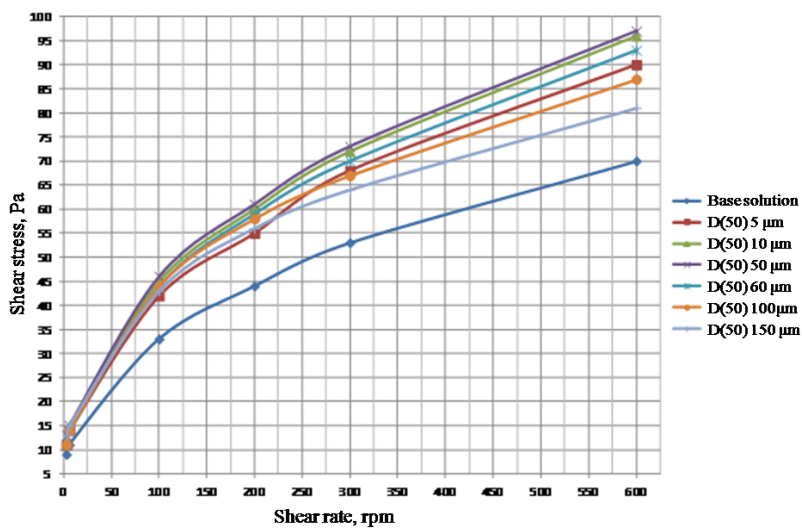| Solution / Shear stress at different shear rates	3	6	$1\cdot\times10^2$	$2\cdot\times10^2$	$3\cdot\times10^2$	$6\cdot\times10^2$	n	K
Base	9	11	33	44	53	70	0,471	2,990
(D50) 5 μm	11	14	42	55	68	90	0,470	3,885
(D50) 10 μm	12	15	45	60	72	96	0,485	3,764
(D50) 50 μm	13	15	46	61	73	97	0,485	3,764
(D50) 60 μm	11	14	44	59	70	93	0,474	3,930
(D50) 100 μm	11	14	44	58	67	87	0,440	4,537
(D50) 150 μm	13	15	43	56	64	81	0,415	4,780

Figure 5. Rheological curves of solutions, constructed according to the Herschel-Balkley model

The proposed rheological model is described by the coefficients of nonlinearity and consistency. Figures 6 and 7 show the graphs of the change in the indices of nonlinearity (n) and consistency (K) as a function of the change in the average particle size of the weighting agent in the solution [17, 18].
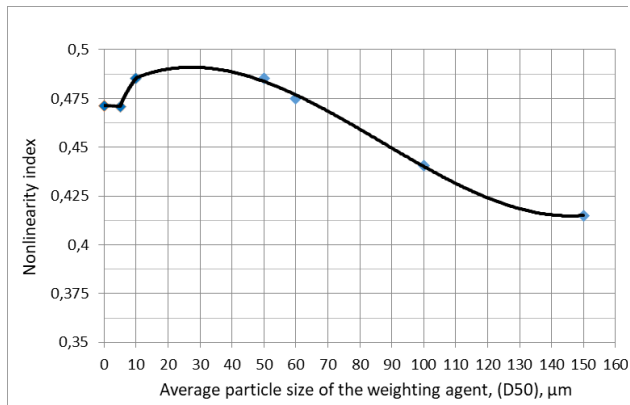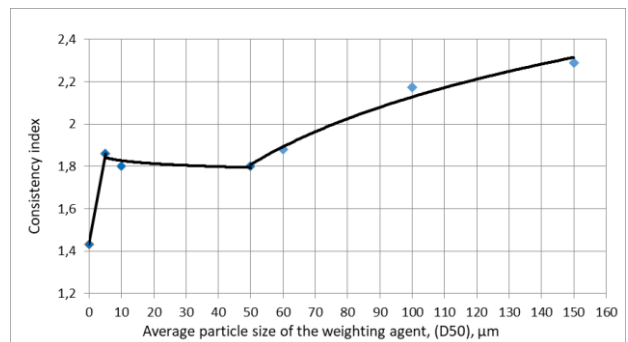

Figure 7. Graph of the change in the consistency index

Based on the experimental data obtained, the following statements can be made:
- introducing calcium carbonate into a biopolymer solution with an average particle size of up to 50 μm leads to a general increase in the resistance of the solution to the flow;
- Figure 5 shows that the rheological curve corresponding to a solution weighted by calcium

Figure 6. Graph of change in the nonlinearity index

carbonate with a fractional composition (D50) of 50 μm has the highest shear stresses;

- introducing fractions with a size (D50) of 10 μm also leads to an increase in total rheology of the solution;

- drilling mud weighted with calcium carbonate with an average particle size of 150 μm has the lowest index of flow resistance;

- with the rise in the dispersity degree of the weighting agent, the amount of fine fractions increases, the total surface area of the material increases, which contributes to the structure-forming and increase of drilling mud rheology.

5. CONCLUSION

At present, a wide variety of weighting materials are used to weight the drilling muds at well drilling. Most common are carbonate and barite weighting agents.

The degree of dispersion and the fractional composition of the weighting agents affect their weighting ability, process of structure-formation in weighted drilling muds, and also the rheological properties of the solutions. For example, with an increase in weighting agent's degree of dispersion, its weighting ability decreases, and the growth of structural-rheological parameters is observed.

The correct choice of the colmatizing composition at drilling productive reservoir ensures creation of a thin low permeable filter cake on the wellbore wall and minimizes the penetration of the filtrate and the solid phase of the solution into the formation.

By introducing calcium carbonate into the drilling mud with an average particle size of 10 to 50 μm leads to a general increase in the rheology of the solution and, as a consequence, to an increase in resistance to the flow of the solution. With an increase in the degree of dispersion of the weighting agent the amount of fine fractions increases, as well as the total surface area of the material and adsorption of the weighting agent particles by water and polymers, that facilitates the process of structure-formation.

Conducted research showed that the rheological parameters of the drilling biopolymer solution were mostly influenced by the particles of the carbonate bridging agents with an average particle size (D50) of 50 μm, and less influenced by the largest particles of the weighting agents under consideration with the size (D50) of 150 μm.

In order to improve the quality of the reservoir drilling-in, in addition to the filtration characteristics of the drilling mud, it is also necessary to take into account its rheological parameters. Increased shear stress leads to an increase in pressure losses, which in turn causes a decrease in an overall drilling efficiency. Optimum selection of bridging agents in the composition of

drilling muds will allow quick and efficient drilling-in of the formation.

6. ACKNOWLEDGMENT

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	چکیده در مقاله مسأله کاهش تاثیر گل حفاری بدون کانی رسی بر خواص فیلتراسیون مخزن، مورد توجه قرار گرفته است. در ترکیب این گونه گل ها، کلسیم کربنات اغلب به عنوان عامل وزنی با اندازه ذرات مختلف استفاده می گردد. به طور کلی مشخص است که عوامل وزنی مواد خنثی هستند که خواص رئولوژیکی گل حفاری را تحت تاثیر قرار نمی دهند. در این مقاله تاثیر عوامل وزنی کربناته بر خواص ساختاری و رئولوژیکی گل بیوپلیمری که برای حفاری لایه تولیدی توسعه یافته است، مورد بررسی قرار می گیرد. در طول مطالعه شش نوع ماده وزنی کربناته با سایز میانگین ذرات 5 تا 150 میکرومتر مورد ارزیابی قرار گرفته اند. منحنی های رئولوژیکی ترسیم و نتایج مورد بررسی قرار گرفته اند. در مقاله هم چنین چهار روش برای انتخاب اندازه مناسب عوامل وزنی مطرح شده اند. *doi*: 10.5829/ije.2018.31.07a.21