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# Effect of Carbonate Additives on Dynamic Filtration Index of Drilling Mud

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ABSTRACT

Filtration index of the drilling fluid is an important parameter of well drilling, especially at drilling-in the reservoirs. Standard parameter in the study of drilling fluids is static filtration index. At the same time, it is more feasible to determine dynamic filtration index, if considering actual conditions of the well. Use of polymer carbonate-weighted drilling fluids is advisable at drilling-in oil and gas formations; but, it is also necessary to take into account fractional composition of the weighting agent. Aim of the work is to study the influence of weighting-bridging agent's fractional composition on drilling fluid's dynamic filtration index. Taking into account main theories of bridging agent selection, such as the theory of Abrams, Kaeuffer and Vickers, will make it possible to define the influence of carbonates "blend" on the filtration losses of the drilling fluid. Dynamic high pressure high temperature (HPHT) filter was used in this research, which allows measuring filtration properties of the drilling fluid as in standard HTHP test, with fluid circulating inside the cell. In order to get results that are closer to real conditions, in addition to the standard paper filter, studies were carried out on ceramic disks with a known porosity. Theories on selection of bridging agents considered in the paper have their advantages and disadvantages. Depending on available data on the reservoir (for example, data availability on porosity and permeability) and access to high-quality bridging material, a more effective theory is chosen and the negative effect of the drilling fluid on the productivity of the formation is reduced.

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## 1. INTRODUCTION

Currently, the issue of ensuring the effective operation of drilling rigs in complex conditions is relevant for many enterprises operating in the field of oil and gas drilling both on land and at sea [1, 2].

Drilling fluids, as one of the important components of the well construction process, must satisfy a large number of different requirements, such as removing the cuttings from the well and transporting it to the surface, cooling and lubricating the bit, creating hydrostatic pressure on the bottom and walls of the well, stabilizing the wellbore and controlling fluid loss [3]. Therefore, the rheological parameters and filtration characteristics (including functions of filter cake formation, to maintain wells stability) of drilling fluids are important aspects that must be chosen and justified before the well drilling

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process taking into account the nature and properties of drilled rocks [4-7]. It is especially important to regulate the filtration parameters of drilling fluids during the drilling-in of a formation; since increased the filtration can reduce the productivity of oil-saturated rocks by several times. According to technical references, the filtration characteristics of drilling fluids are evaluated by two types of tests: static and dynamic filtration. The study of drilling fluid for static filtration is a process that occurs in the absence of circulation, when the drilling fluid does not interfere with the growth of the filter cake. Dynamic filtration is evaluated during circulation (mixing) of the drilling fluid. Here, the growth of the filter cake and the filtrate flow are controlled by blocking and erosive action of the mud flow [8]. Static filtration is a standard parameter of the drilling mud and evaluates the loss of fluid in the event that the circulation of the drilling mud in the well stops. However, the rate of drilling fluids' dynamic filtration is a key process regarding preserving the permeability and

stability of the formations; since dynamic filtration rate is much higher than the static one, and most of the mud filtrate penetrates the formation at the drilling process, during the circulation of the fluid [4, 9, 10]. It is known that drilling-in of a formation with a water-based solution leads to its pollution and a decrease in oil production. Method and quality of reservoir drilling-in determines the choice of enhanced oil recovery techniques to be used later [11]. The pollution is mainly due to the penetration of solids and drilling fluid filtrate into the pore space. Rapid and effective building of a low permeability filter cake helps to reduce contamination of oil formation. Building of a filter cake is mainly affected by the size of the solid phase, as well as the weighting-bridging agents used in the solution [12-15]. There are various methods and theories for selecting the fractional composition of weighting-bridging agents, the main of which are: Abrams' criteria, Ideal Packing Theory (IPT) developed by Kauffer and "Vickers Method" [12, 16].

Therefore, study of the dynamic filtration index taking into account the fractional composition of the solid phase gives a more complete picture of the particular drilling fluid influence on the processes occurring during the drilling-in of the formation. Thus, considered investigation was conducted in the following order: first, methods of the research were defined and needed equipment was chosen, then objects for the study – different types weighting agents were selected. Fractional composition of these substances was evaluated considering most relevant to-date theories. Based on the results of the investigation several recommendations on the selection of each theory were given.

## 2. METHODOLOGY OF THE RESEARCH

Dynamic HPHT filter was used to measure the dynamic filtration index. An API filter press was used to measure the static filtration index

OFITE's Dynamic HTHP filter press provides dynamic filtration measurements at high temperatures and pressures. The engine of the device rotates the propeller at different speeds inside a standard cell with a volume of 500 ml. The device allows setting the number of revolutions of the propeller in range from zero to 3900, simulating laminar or turbulent fluid flows in the cell, while changing the length of the propeller shaft, one can adjust the shear stress. The procedure is carried out as in the standard HTHP test for measuring the filtration properties of the drilling fluid. The only difference is that the fluid circulates inside the cell.

Laboratory studies were aimed at to determine the relationship between the particle size of the weighting-bridging agent and its influence on the filtration

properties of drilling fluids. Investigation had the following pattern:
1. Data availability on the reservoir properties of the formation was evaluated;
2. Theory on fractional composition, relevant for available data on the formation was taken;
3. Carbonate weighting agents with corresponding fractional composition were chosen;
4. Dynamic filtration for the selected weighting agents was assessed.

## 3. ASSESMENT OF WEIGHTING AGENTS' FRACTIONAL COMPOSITION INFLUENCE ON DRILLING FLUID FILTRATION INDICATORS

As objects for research, carbonate samples of weighting agents of the brands Baracarb-5 (5 μm), Mex-Carb Fine (10 μm), Baracarb-50 (50 μm), MK-60 (60 μm), MK-100 (100 μm) and Baracarb-150 (150 μm) were chosen. Samples were taken according to the indicator "average fraction size" (D50) [17-19].

For experiments, as in previous works [20, 21] a biopolymer solution was chosen, whose structural agent was BARAZAN (xanthan gum). The composition of the solution and the required amount of reagents for its preparation are presented in Table 1.

The density, as well as the main rheological indicators, static shear stress and filtration indicators of the prepared solutions are presented in Table 2.

As can be seen in Table 2, the biopolymer solution has high initial density of the suspension, which means that to achieve the required density, one need to add less weighting agent.

Advantage of biopolymer solutions is that they increase the effective viscosity at low shear rates with a slight increase in plastic viscosity - this helps to enhance the carrying and suspending characteristics of the drilling fluid and reduce the equivalent density during circulation. Strengthening the viscoelastic properties

**TABLE 1.** Composition of the biopolymer solution

| Drilling mud | | |
|---|---|---|
| Component | Amount used, kg/m$^3$ | Description/purpose of component |
| BARAZAN | 4 | Biopolymer, structurant |
| KCl | 50 | Salt, Weighter |
| PAC HV | 3 | PAC of high viscosity, control of filtration and rheology |
| PAC LV | 3 | PAC of low viscosity, control of filtration |
| NaOH | 1,1 | Caustic soda, pH control |
| Na$_2$CO$_3$ | 0,5 | Soda ash, hardness control |

**TABLE 2.** Main parameters of clayless and thin clay solutions

| Solution parameter | Clayless (biopolymer) solution |
|---|---|
| $\rho$, kg/m$^3$ | 1050 |
| $F_{30}$, ml | 10-11 |
| PV, mPa·s | 16-18 |
| DSS, Pa | 17-18 |
| $SSS_{10s}$, Pa | 4-5 |
| $SSS_{10min}$, Pa | 5-6 |

of drilling agents significantly improves the cleaning of the wellbore from sludge, and also reduces the filtration rate of the liquid phase into the formation.

Furthermore, the biopolymer solution contains smaller amount of insoluble solid phase in the composition than, for example, a clay solution. Therefore, there is less likelihood of formation's contamination during drilling.

For each experiment, a solution sample was prepared; the density of the initial suspension was 1050 kg/m$^3$. Then the density of each solution sample was increased to 1160 kg/m$^3$. Mass content of the weighting agent in the solution was 19% for weighting with calcium carbonate and 15% for weighting the solution with barite.

Figure 1 shows graphs of the static and dynamic filtration dependence on the fractional composition of calcium carbonate in solution.

As can be seen in the graph, the indicators of static and dynamic filtration are inversely dependent on the fractional composition of calcium carbonate. However, the obtained values of dynamic filtration are higher due to simulated flow of the solution during the experiment. In contrast to static filtration the growth of the filter cake during dynamic filtration is limited by erosion
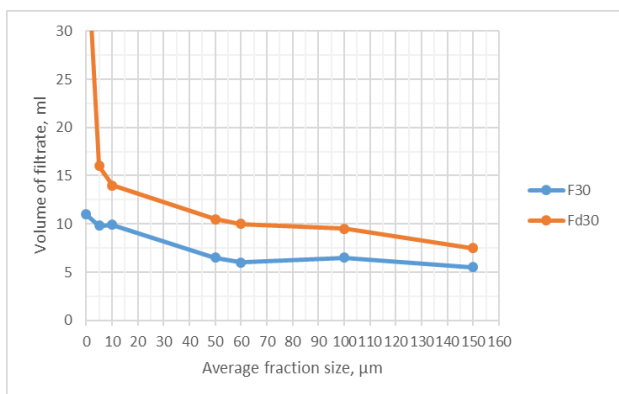


**Figure 1.** Dependence of static ($F_{30}$) and dynamic filtration rate ($F^d_{30}$) on fractional composition of calcium carbonate in solution

processes. The thickness of the filter cake remains constant after its growth rate becomes equal to the rate of erosion due to the flow of mud.

Most intense decrease in the dynamic filtration of a solution is observed when calcium carbonate with a particle size of up to 50-60 µm is included in its composition (> 30 ml in the initial solution and to 10 ml in the weighted one). With a further increase in particle size, significant decrease in the value is not observed.

## 4. RESULTS AND DISCUSSION

Correct selection of the bridging agent's fractional composition at drilling-in of the formation reduces the risk of its contamination by the filtrate and the solid phase of the drilling fluid. The barrier that protects the formation from contamination is the low-permeable filter cake formed on the wall of the well. The rate of its formation, as well as its thickness and permeability, is significantly affected by the particle size distribution of the bridging agent

At the second stage of experimental studies, several theories were tested on the selection of bridging agent's fractional composition. The effectiveness of each theory was evaluated and a comparative characteristic was given.

Three most wide-used theories were compared:
• Abrams' criteria;
• Ideal Packing Theory (IPT), Kaeuffer's theory;
• "Vickers Method".

The essence of the experiment was to determine the dynamic filtration rate of a biopolymer solution when calcium carbonate of a certain fractional composition was introduced into it.

As a porous medium through which the solution was filtered, special ceramic filter disks made by "Fann" were used. They are stronger and more durable than natural materials, which allows them to be used when testing under high pressure and counter-pressure. A disc with pore diameter of 10 µm was selected. For comparison, each sample of the solution was also filtered through a "Blue Ribbon" filter.

**4. 1. Abrams' Criteria**            According to Abrams' criteria [16] at selecting the fractional composition of bridging agents, the following condition must be fulfilled:

$$3d_{par} < d_{por} < 10d_{par} \qquad (1)$$

where $d_{par}$ – particle size, µm; $d_{por}$ – pore diameter, µm.

This means that the particle size of the bridging agent must satisfy the following system of inequalities:

$$d_{par} \in \begin{array}{l} > \dfrac{1}{3}d_{por} \\ < 1 d_{por} \end{array} \quad (2)$$

The total content of particles of this size should be equal to or greater than 5% of the volume of solid particles in the drilling fluid.

Substituting the selected value of the ceramic disk's pore diameter in Equation (2), size range of the required particles of calcium carbonate is obtained.

$$d_{par} \in \begin{array}{l} > 3,33 \mu m \\ < 10 \mu m \end{array} \quad (3)$$

Particle size range (3) corresponds to calcium carbonate of the brand Baracarb-5 with an average particle size of 4-10 µm.

To determine the dynamic filtration index, a biopolymer solution sample with a density of 1160 kg/m$^3$ was prepared. The mass of added calcium carbonate was 77.2 g. According to Abrams' criteria, the entire fraction of bridging agent consisted of Baracarb-5 calcium carbonate.

## 4. 2. Ideal Packing Theory (Kaeuffer's Theory)
According to Kaeuffer's theory ideal packaging is achieved if the total distribution of particles in the mixture is directly proportional to the square root of the particle size, i.e. graphically represented as a straight line (ideal mixture) [22].

Such a wide range of particle sizes implies the presence of at least four different fractions of bridging agent. Five brands of calcium carbonate were selected for the experiment: Baracarb-5, Mex-Carb Fine, Baracarb-50, MK-60, Baracarb-150. According to the theory, the amount of each brand of bridging agent was selected in the following ratio (Table 3).

## 4. 3 "Vickers Method"
When selecting the fractional composition of bridging agents according to the "Vickers method", five basic criteria must be set [23].

These criteria carry basic information on the porosity of the particular formation and are defined by the following:

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

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.

Since the solution will be filtered through a ceramic disk with a pore size of 10 µm, this value was taken as the size of the main pores (D50 = 10 µm). The remaining four criteria were suggested on the basis of

**TABLE 3.** Distribution of calcium carbonate fractions according to Kaeuffer's theory

| Calcium carbonate brand | Mass content, g | Percentage content, % |
|---|---|---|
| Baracarb-5 | 13.9 | 18 |
| Mex-Carb Fine | 5.4 | 7 |
| Baracarb-50 | 27.1 | 35 |
| MK-60 | 6.2 | 8 |
| Baracarb-150 | 24.6 | 32 |

data on a "standard" sandy reservoir with pore sizes, respectively: D50 = 20 µm; D10 = 5 µm; D90 = 60 µm [15].

The final data on the "formation": D50 = 10 µm; D10 = 1 µm; D25 = 2 µm; D75 = 17 µm; D90 = 30 µm.

The amount of each brand of bridging agent was selected in the following ratio (Table 4).

Biopolymer solutions with additives of weighting-bridging agents were filtered through filter paper and through a ceramic disk, the data obtained for each method are presented in Table 5 and in Figure 2.

Conducted research revealed that a solution with a fractional composition of calcium carbonate, selected according to the Vickers Method, showed the best clogging ability and the lowest dynamic filtration rate (Figure 2). A solution with bridging agent selected according to the Kaeuffer's theory also has good colmatizing ability. The highest rate of solution's dynamic filtration is according to Abrams' criteria.

Table 6 shows the data on the quantitative and percentage reduction in the dynamic filtration index at adding fraction of bridging agent calculated in each of the methods into solution.

**TABLE 4.** Distribution of calcium carbonate fractions according to "Vickers Method"

| Calcium carbonate brand | Mass content, g | Percentage content, % |
|---|---|---|
| Baracarb-5 | 19.3 | 25 |
| Mex-Carb Fine | 19.3 | 25 |
| Baracarb-50 | 38.6 | 50 |

**TABLE 5.** Comparison of methods for selecting bridging agents

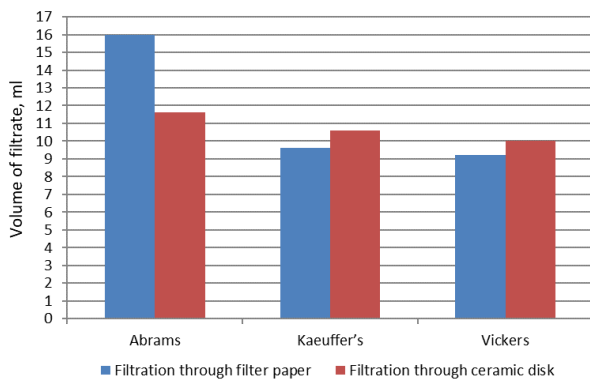| Selection method | Filtration through filter paper, ml | Filtration through ceramic disk, ml |
|---|---|---|
| Abrams | 16 | 11.6 |
| Kaeuffer's | 9.6 | 10.6 |
| Vickers | 9.2 | 10.0 |

**Figure 2.** Comparison of methods for selecting bridging agents

**TABLE 6.** Dynamic filtration of the solutions

| Solution | Volume of filtrate, ml | Difference in volume of filtrate, ml | Difference in volume of filtrate, % |
|---|---|---|---|
| Ceramic disc | | | |
| Initial | 40 | - | - |
| Abrams | 11.6 | 28.4 | 47 |
| Kaeuffer's | 10.6 | 29.4 | 49 |
| Vickers | 10 | 30 | 50 |
| Paper filter | | | |
| Initial | 60 | - | - |
| Abrams | 16 | 44 | 73 |
| Kaeuffer's | 9.6 | 50.4 | 84 |
| Vickers | 9.2 | 50.8 | 85 |

## 5. CONCLUSION

It should be said that all three methods for selecting bridging agents are relevant. Moreover, in each specific case, one of the theories may be most suitable for calculating bridging agent's fractions of the drilling fluid.

1. For drilling-in of the reservoir, under otherwise equal conditions, it is more efficient to use non-clay biopolymer drilling mud. The biopolymer solution contains less solid phase, and thus reduces the likelihood of reservoir contamination.

2. The dynamic filtration index has the same dependence on the particle size of calcium carbonate as the static filtration index. However, in view of flow initiation of the drilling fluid during measurement, the results have higher values.

3. Abrams' criteria on bridging agents' selection is significantly inferior to theories that are more modern. Despite the simplicity of choosing the necessary

fractions of the bridging agent, the calculations do not take into account information on the largest reservoir pores and pores whose size is above the average value. Therefore, the selected fractions of the bridging agent may not be enough to create a dense, low permeability filter cake during drilling.

4. According to the theory of ideal package (Kaeuffer's) for the selection of the bridging agents, filtration of the solution can be significantly reduced, due to forming of a filter cake with low permeability on the walls of the well. This theory is effective in cases where there is no complete data on the reservoir. However, to apply this theory, it is necessary to have several fractions of the bridging agent, for effective blockage of all pores. In addition, this theory does not take into account the dimensions of the reservoir's largest pores, which can lead to overspending of the bridging agent without positive results.

5. "Vickers Method" for the selection of the bridging agents is one of the newest methods to date. This method allows selection of bridging agent's fractional composition in such a way as to clog almost all pores of the reservoir, at the same time creating a low-permeable filter cake on the wall of the well. This method has shown the best results in reducing the solution's filtration index. However, this method is applicable in conditions when there is complete information about the reservoir.

Each of the considered theories on the selection of the bridging agents has its advantages and disadvantages. In each case, the selection of bridging agents according to one of the theories may turn out to be more effective. It all depends on the available data on the reservoir and the access to high-quality bridging material.

## 6. ACKNOWLEDGMENT

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Persian Abstract

چکیده

ضریب فیلتراسیون سیال حفاری به خصوص در هنگام حفاری لایه های مخزنی یک پارامتر مهم در حفاری چاه است. پارامتر استاندارد در مطالعه سیال حفاری، ضریب استاتیک فیلتراسیون می باشد. در همین زمان، در صورت در نظر گرفتن شرایط واقعی چاه امکان اندازه گیری ضریب دینامیک فیلتراسیون وجود دارد. استفاده از سیال حفاری پلیمری سنگین شده با استفاده از کربنات در حفاری سازندهای نفتی و گازی توصیه شده است، اما در عین حال نیاز به در نظر گرفتن ترکیب جزئی عامل وزنی می باشد. هدف این کار مطالعه ی تاثیر جز پل زننده ی عامل وزنی بر ضریب دینامیک فیلتراسیون سیال حفاری می باشد. با در نظر گرفتن تئوری های اصلی انتخاب عامل پل زننده نظیر آبرامز، کائوفر وویکرز، مشخص کردن تاثیر ترکیب کربناته بر هرزروی سیال حفاری ممکن می شود. دستگاه فیلتر فشار بالا و دما بالا در طول تحقیق قابلیت اندازه گیری خواص هرزروی سیال حفاری در حین چرخش سیال در داخل سلول را فراهم آورد. به منظور گرفتن نتایج نزدیک تر به شرایط واقعی، علاوه بر کاغذ فیلتر استاندارد از دیسک های سرامیکی با تخلخل مشخص استفاده شد. تئوری های انتخاب پل زننده ی مورد مطالعه در این مقاله دارای مزایا و معایب خود هستند. با توجه به داده های موجود از مخزن (به عنوان مثال تخلخل و تراوایی مخزن) و دسترسی به مواد پل زننده ی با کیفیت، تئوری موثرتری می تواند انتخاب شود که باعث کاهش اثر منفی سیال حفاری بر قابلیت تولید مخزن می گردد.