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LABORATORY EVALUATION OF CALCIUM CARBONATE PARTICLE SIZE SELECTION FOR DRILL-IN FLUIDS

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Key words: fluids, formation damage,bridging agent, particle size distribution, filtration

Abstract

The tehnological developments in horizontal, re-entry and multilateral wells require drilling and completion the reservoir sections of a well inducing as little damage as possible. The trends towards open hole completions places additional emphasis on formation damage avoidance. One of the critical factors in avoiding formation damage during drilling is obtaining surface bridging on the formation face with minimum indepth solids penetration.

In case of overbalanced drilling, this can be done by optimizing the particle size distribution of calcium carbonate used as the bridging agent.

The paper presents laboratory data from tests carried out on selected fluids which show the extent of the changes that occur in fluid filtration properties (spurt loss, PPT value and static filtration rate) when calcium carbonate with different PSD is used. The Permeability Plugging Tester was used to evaluate the filtration and spurt loss of selected fluids. The ceramic disks with permeabilities 0,09 μm^2 (90 mD), 0,13 μm^2 (130 mD) and 0,4 μm^2 (400 mD) were used as a filter medium.

Ključne riječi: fluidi, oštećenje formacije, materijal za stvarnje premoštenja, raspodjela veličine čestica, filtracija

Sažetak

Tehnološki razvoj izrade horizontalnih, bočnih i višekanalskih bušotina usmjeren je na izradu kanala kroz ležište uz minimalno oštećenje proizvodne formacije. Potrebu za izbjegavanjem oštećenja proizvodne formacije još više ističu nastojanja da se horizontalni kanal ostavi nezacijevljen (open hole). Jedan od kritičnih čimbenika za izbjegavanje oštećenja formacije je stvaranje premoštenja na licu raskrivene formacije uz minimalan prodor čestica.

U slučaju izrade kanala bušotine u uvjetima nadtlaka to se može postići optimiranjem raspodjele veličine čestica kalcijeva karbonata kao materijala za stvaranje premoštenja.

U radu su prikazani rezultati laboratorijskih istraživanja utjecaja raspodjele veličine čestica kalcijeva karbonata na filtracijska svojstva odabranih fluida (početna filtracija, PPT vrijednost i brzina statičke filtracije). U tu svrhu korišten je uređaj za ispitivanje sposobnosti fluida da stvori premoštenje na propusnom mediju (PPT). Kao propusni medij odabrani su keramički diskovi propusnosti 0,09 μm^2 (90 mD), 0,13 μm^2 (130 mD) i 0,4 μm^2 (400 mD).

Introduction

The increasing use of open hole completions in horizontal wells also means that more attention has to be paid to the cake forming properties of reservoir drilling fluids. Solids invasion is one of the primary causes of formation damage from drilling fluids (Bailey et al., 1999). During the initial stage of filter cake forming solids are forced into the formation, building an internal filter cake wich plugs the near surface pores and reduces formation permeability. Fine particles penetrate deeply and are not easily removed by back-flushing. Invasion of larger particles is usually localised to near surface. Studies conducted by Bailey et al. (1999) show a strong correlation between invasion and damage, and that particle bridging reduces spurt loss and damage. Because of that, minimising of internal filter cake and quickly forming of external cake is very important for both fluid loss and formation damage control. The low permeable external filter cake can significantly reduce the invasion of the solids and the filtrate.

The main factors that determine formation damage due to solids invasion are: particle size distribution in the fluid, formation permeability/pore size distribution, concentration of mud solids, over-balance pressure, mud circulation rate and rheology. Although some solids invasion and formation damage are inherent to all drilling fluids, it is possible to minimise both damage caused by solids invasion, and the depth of this damage, by correctly sizing the bridging particles in the drilling fluid (Gaurina-Međimurec, 1999; Gaurina-Međimurec et al., 2002). In production sections clay-free fluid is used instead of conventional mud to avoid formation damage caused by invasion of clay particles.

Correct fluid composition, bridging material selection, and good maintenance of the drilling fluid are the keys to success for better productivity. Careful design is required to minimize spurt loss and solids invasion during drilling and completion operations.

The main objective is achieving minimum solids invasion by quickly forming of adequate external cake. The objective "minimum solids invasion" prevails over "minimum water loss" because drill-in fluids contain salt and have inhibitive filtrate.

Drilling fluid design

A type of especially designed polymer system that very often used in field was selected for evaluation. It is prepared with the base brine (KCl brine), viscosifier (xanthan), fluid-loss additive (starch) and bridging agent (graded calcium carbonate). Fluid´s formulation is given in Table 1, and API properties are shown in Table 2. The concentration of $CaCO_3$ is selected according to literature recommendations (Dick et al., 2000.).

The drill-in fluid was prepered with different PSD of $CaCO_3$ and marked as DIF-A, DIF-B, DIF-C, DIF-D and DIF-E. The mark of fluid is conected with type of calcium carbonate used in the fluid design.

Table 1. Drill-in fluid composition
Tablica 1. Sastav drill-in fluida

Component	Amount
Water	1 dm^3
Xanthan	5 g
Starch	12 g
KOH	1 g
KCl	30 g
$CaCO_3$ (Different PSD)	80 g

Table 2. Drill-in fluid properties (Rheologies at 21 °C)
Tablica 2. Svojstva drill-in fluida (Reološka svojstva na 21°C)

Properties	DIF-A	DIF-B	DIF-C	DIF-D	DIF E
Plastic viscosity [mPa·s]	11,01	11,50	11,50	11,50	11,50
Apparent viscosity [mPa·s]	25,01	25,51	25,51	25,01	25,01
Flow index [-]	0,358	0,368	0,368	0,377	0,377
Consistency index [Pa·s^n]	2,136	2,030	2,030	1,877	1,877
Yield point [Pa]	14,32	14,32	14,32	13,80	13,80
Gel strenghts [Pa/Pa]	6,13/7,67	6,13/7,92	6,65/8,18	6,13/8,18	6,13/7,67
LSRV [mPa·s]	55808	50994	59771	53657	58431
API filtrate [ml]	7,9	6,9	8,2	6,7	7,6
Filter cake [mm]	0,17	0,21	0,19	0,20	0,18
pH	10,82	10,95	10,83	10,88	10,95
Density [kg/m^3]	1066	1070	1070	1067	1063

Selecting an optimum particle size

In sizing solids for use in drill-in fluids attention has been focused on minimizing the invasion of solids into the formation. The drill-in fluid should contain bridging solids of a specific particle size distribution (PSD) that is able to cope with the natural heterogenity encountered in a formation. This plays a critical role in the rapid formation of the filter cake.

There are various guidelines used in the industry to choose the particle size of bridging materials that can form an efficient external filter cake and minimize formation damage:

- A median particle size of the bridging additive equal to or slightly greater than one third of the median pore size of the formation (Abrams, 1977).
- The concentration of the bridging agents must be at least 5% by volume of the solids in the final mud mix (Abrams, 1977).
- The D90 (90% of the particles are smaller than size x) of the PSD of the bridging agents should be equal to the pore size of the rock (Hands et al., 1998).
- $D^{1/2}$ rule (IPT-Ideal Packing Theory) states that ideal packing occurs when the percent of cumulative volume vs the $D^{1/2}$ forms a straight-line relatioship, where $D^{1/2}$ is square root of the particle diameter (Kaeuffer, 1973; Dick et al., 2000).

The rules of thumb stated above ensure that sized solids do not invade the formation and cause permeability reduction. In addition, desired PSD is the bell shaped one (Newhouse, 1991; Dick et al., 2000). Abrams´ rule defines the particle size required to initiate bridging. The ideal packing theory defines the total particle range required to seal all pores, even those created by bridging agents.

The particle size data for evaluated available calcium carbonates is given in Table 3. Calcium carbonates marked as $CaCO_3$-B, $CaCO_3$-C and $CaCO_3$-D present blends of $CaCO_3$-A (fine) and $CaCO_3$-E (medium).

The conventional particle size distribution of selected and commercially available calcium carbonates is shown in Fig. 1. The curves form S-shape when plotted on semi-log coordinates and only indicate the range of particles present. It does not estimate the packing efficiency of the

Table 3. PSD of selected calcium carbonates
Tablica 3. Raspodjela veličine čestica odabranih kalcijevih karbonata

Grade	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)
$CaCO_3$ – A - fine	2,6	7,6	19,2
$CaCO_3$ – B	2,8	8,8	26,3
$CaCO_3$ – C	3,0	10,1	33,3
$CaCO_3$ – D	3,5	11,5	42,9
$CaCO_3$ – E – medium	4,0	14,6	46,8

particles when they interact to form a filter cake (Dick et al, 2000).

The IPT uses a linear type of graph (cumulative % below vs square root of particles) to optimize particle size distribution for particular reservoir. PSD curves of selected calcium carbonates and the optimum target line based on median pore size of used disks (D_{50}) can be plotted on the same graph (Gaurina-Međimurec et al., 2002). Median pore size – D_{50} (in microns) for each disc can be estimated from disk permeability by taking the square root of the permeability (in miliDarcys). To attain ideal packing, PSD line of the $CaCO_3$ should approximate the slope of the disk´s (or formation´s) line. Fig. 2 shows desirable bell shaped PSD such has $CaCO_3$ - C.

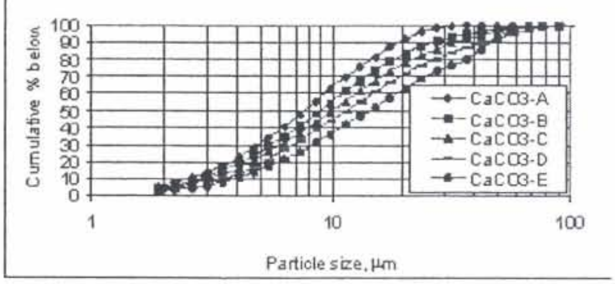

Fig. 1. PSD curves of selected calcium carbonates
Sl. 1. PSD krivulja odabranih karbonata

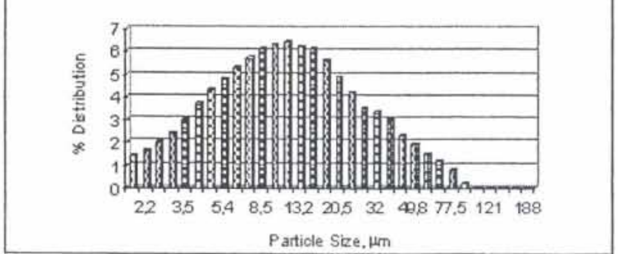

Fig. 2. Desirable bell shaped PSD ($CaCO_3$ –C)
Sl. 2. Poželjan zvonoliki oblik PSD krivulje ($CaCO_3$—C

Test procedure and results

In order to assess the impact of particle size distribution on fluid loss properties, PPT (Permeability Plugging Tester) tests were performed. The main feature of the PPT is the use of ceramic disks as the filtration medium. The laboratory studies discussed here were carried out using the ceramic disks with permeabilities of 0,09 µm² (90 mD), 0,13 µm² (130 mD) and 0,4 µm² (400 mD) as a filter medium. According to manufacturer the selected disks are used for estimated reservoir permeabilities from 0,03 to 0,045 µm² (disk: 90 mD), from 0,043 to 0,065 µm² (disk: 130 mD) and from 0,050 to 0,10 µm² (disk: 400 mD). Fig. 3 shows the surface of ceramic disk with permeability of 0,13 µm² (130 mD).

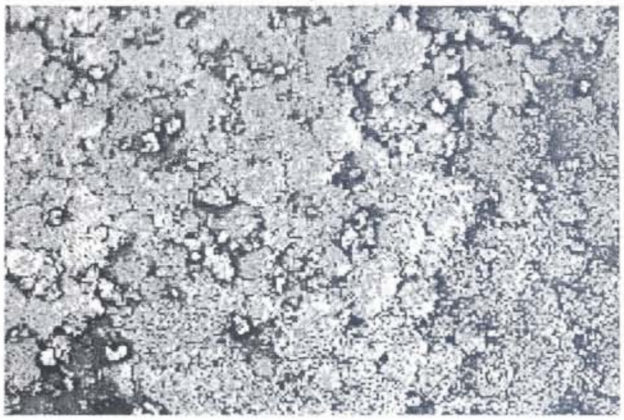

Fig. 3. SEM Photomicrograph of a 130 mD-disk surface
Sl. 3. SEM prikaz površine diska propusnosti 130 mD

The PPT is a very effective tool for determining and modifying the plugging characteristics of drilling fluids. The permeability plugging test can be run on basic fluid systems to determine filtration rates and filter cake thickness which may differ markedly from the API fluid loss tests which uses paper as the filtration medium (Davis et al, 1999). Aditionally, the PPT can be used successfully to evaluate seepage control materials, and minimize the potential for differentil sticking (Newhouse, 1991).

Testing is normally performed on disks that have about twice the peremeability of the formation in question, wich will ensure that adequate plugging is achieved (Newhouse, 1991). The PPT was used to evaluate the filtration and spurt loss of drilling fluids. The permeability plugging tests were performed at room temperature, and at a differential pressure of 500 psi.

Spurt loss is generally defined as the filtrate or fluid loss that elutes through the filter medium before a filter cake is established. Spurt loss is also defined as the intercept on the y-axis of the plot of filtrate (in ml on y-axis) vs square root of time (in min on x-axis). Usually, four measurements were made during the 30 minute test: –1, 7.5, 15, and 30 minutes (Davis et al, 1999).

During the PPT test of drill-in fluids prepared with selected PSD of $CaCO_3$, fluid losses were measured at 0,5, 7,5 , 15 and 30 min, and obtained results are presented in Table 4.

The filtrate volume can be ploted against the square root of time (Gaurina-Međimurec et al., 2002) such as shown in figures from Fig. 4 to Fig. 8. Linear relationships resulted after the sprut loss was collected if the cake was formed at the surface. Conversely, any non-linear

Table 4. PPT filtration results
Tablica 4. Rezultati PPT filtracije

Time, min	DIF-A	DIF-B	DIF-C	DIF-D	DIF-E
Disc permeability: 90 mD					
0,5	2,1	2,1	1,8	2,6	2,0
7,5	4,0	3,8	3,0	4,2	4,0
15	5,1	4,9	3,7	5,4	5,1
30	6,0	5,6	5	6,5	6,5
Disc permeability: 130 mD					
0,5	2,0	2,0	2,3	2,2	1,9
7,5	3,2	3,1	3,9	3,5	3,6
15	4,0	3,8	5,0	4,1	4,2
30	5,1	4,7	5,9	5,1	5,2
Disc permeability: 400 mD					
0,5	1,6	1,8	2,0	2,5	2,2
7,5	2,9	3,3	3,8	3,7	3,8
15	4,0	3,9	5,0	4,4	4,9
30	5,5	4,9	5,9	5,2	6,1

Table 5. PPT filtration parameters
Tablica 5. Parametri PPT filtracije

Parameter	DIF-A	DIF-B	DIF-C	DIF-D	DIF-E
Disc permeability: 90 mD					
Spurt loss, [ml]	4,0	4,0	2,0	3,8	3,0
30-min. filtration, [ml]	6,0	5,6	5,0	6,5	6,5
PPT value, [ml]	12,0	11,2	10,0	13,0	13,0
Filtration rate, [ml/min$^{1/2}$]	1,46	1,31	1,46	1,68	1,83
Filter cake [mm]	0,21	0,18	0,20	0,30	0,22
Disc permeability: 130 mD					
Spurt loss, [ml]	2,6	3,0	3,8	3,8	4,0
30-min. filtration, [ml]	5,1	4,7	5,9	5,1	5,2
PPT value, [ml]	10,2	9,4	11,8	10,2	10,4
Filtration rate, [ml/min$^{1/2}$]	1,38	1,17	1,46	1,17	1,17
Filter cake [mm]	0,21	0,22	0,26	0,25	0,19
Disc permeability: 400 mD					
Spurt loss, [ml]	1,8	3,4	3,4	4,4	3,0
30-min. filtration, [ml]	5,5	4,9	5,9	5,2	6,1
PPT value, [ml]	11,0	9,8	11,8	10,4	12,2
Filtration rate, [ml/min$^{1/2}$]	1,89	1,17	1,53	1,09	1,68
Filter cake [mm]	0,22	0,23	0,24	0,24	0,26

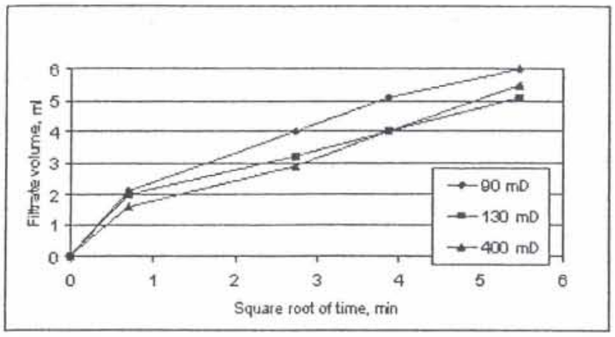

Fig. 4. Fluid DIF-A: The plot of filtrate vs square root of time
Sl. 4. Fluid DIF-A: Odnos volumena filtrata i vremena

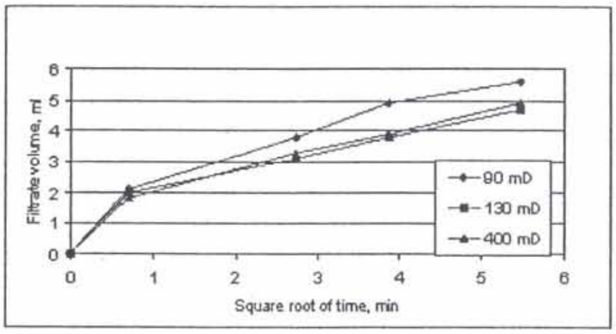

Fig. 5. Fluid DIF-B: The plot of filtrate vs square root of time
Sl. 5. Fluid DIF-B: Odnos volumena filtrata i vremena

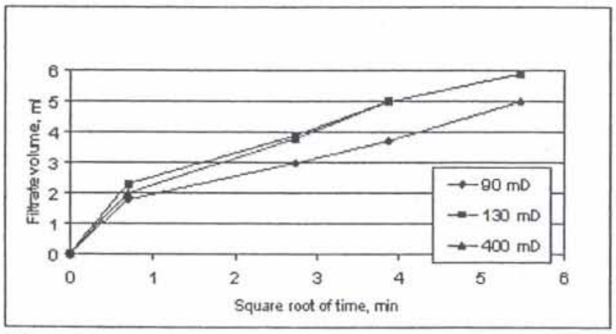

Fig. 6. Fluid DIF-C: The plot of filtrate vs square root of time
Sl. 6. Fluid DIF-C: Odnos volumena filtrata i vremena

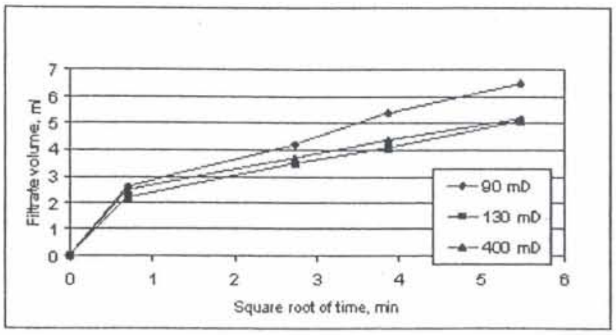

Fig. 7. Fluid DIF-D: The plot of filtrate vs square root of time
Sl. 7. Fluid DIF-D: Odnos volumena filtrata i vremena

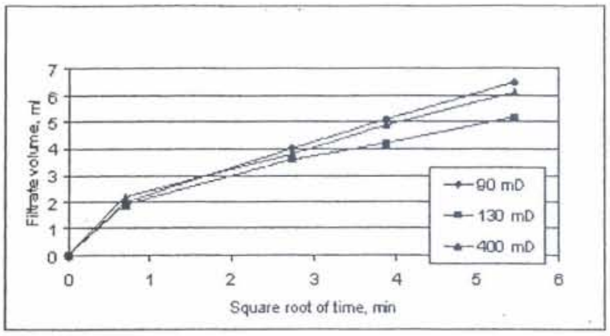

Fig. 8. Fluid DIF-E: The plot of filtrate vs square root of time
Sl. 8. Fluid DIF-E: Odnos volumena filtrata i vremena

According to results fluids DIF-A, DIF-B and DIF-D build an internal filter cake during the initial stage of filtration through 90 mD and 400 mD discs (Fig. 4, Fig. 5 and Fig 7). Fluid DIF-C forms an internal filter cake inside of all selected discs (Fig. 6), and fluid DIF-E builds an internal filter cake inside of 130 mD and 400 mD discs (Fig. 8).

Instead of plotting the data, estimates of the filtration parameters can be made from the data collected at 7,5 and 30 minute intervals according to following formulas (Davis et al, 1999):

- **PPT value,** ml = 2 x EV_{30} where EV_{30} is the total filtrate collected in 30 min.
- **Spurt Loss,** ml = 2 x $[EV_{7.5} - (EV_{30} - EV_{7.5})]$ where $EV_{7.5}$ is the filtrate collected in 7.5 min.
- **Static Filtration Rate,** ml/min$^{1/2}$ = 2 x $[EV_{30} - EV_{7,5}]/ 2.739$

Recommended values of filtration parameters are (Donovan and Jones, 1995):

- Spurt loss: <6,0 ml
- 30-min filtration: < 15,0 ml
- PPT value: < 20 ml
- Filter cake thickness: < 1,0 mm

According to previous formulas the filtration parameters are calculated and given in Table 5. The comparison of the spurt loss, API filtration, filter cake thickness, 30-min filtration and PPT value data obtained for tested fluids with discs of different permeabilities are shown in Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Fig. 13.

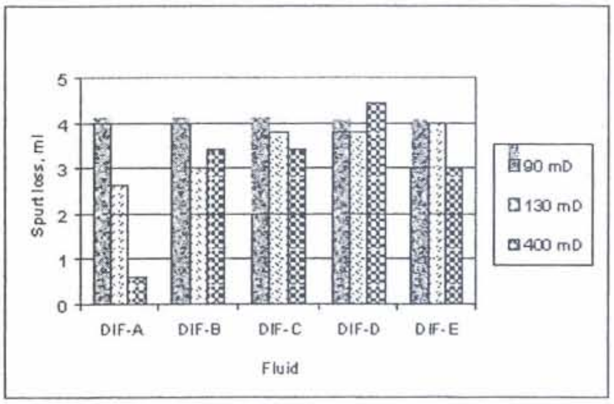

Fig. 9. Spurt loss
Sl. 9. Početna filtracija

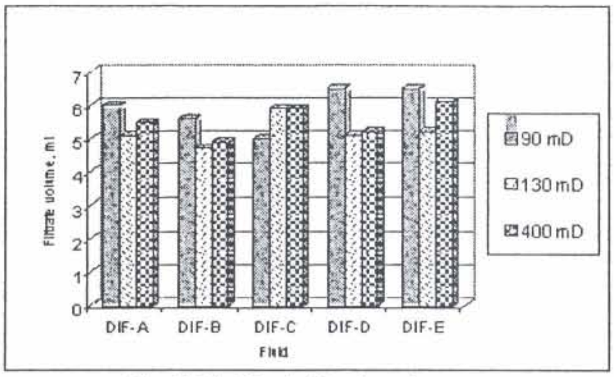

Fig. 10. The 30-min. filtration value
Sl. 10. 30-minutna vrijednost filtracije

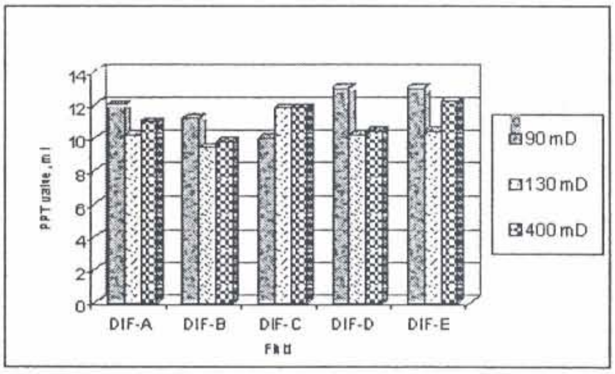

Fig. 11. PPT value
Sl. 11. PPT vrijednost filtracije

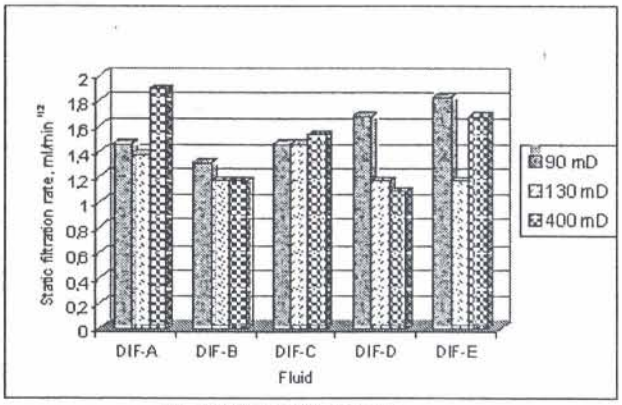

Fig. 12. Static filtration rate
Sl. 12. Statička brzina filtracije

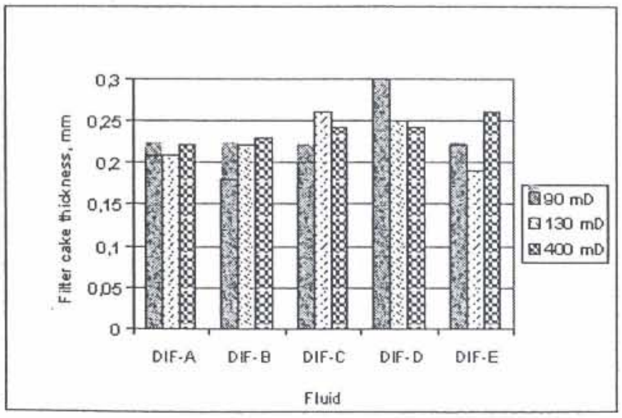

Fig. 13. Filter cake thickness
Sl. 13. Debljina isplačnog obloga

Generally, the values presented in figures from Fig. 9 to Fig. 13 are lower then recommended values in literature. According to test results, there are certain differences between filtration parameters of tested fluids. The reason of that is relationship between PSD of present solids and pore size distribution of discs. The values of filtration parameters for all fluids except for fluid DIF-C decrease with increasing permeability when we compare test results obtained by 90-mD and 130-mD discs or 90-mD and 400-mD discs. The opposite trend is noticed if test results obtained by 130-mD and 400-mD discs are compared. On the basis of presented PTT results is possible to conclude which fluid is the best for given disc permeability.

SEM Photomicrograph of the filter cake built by the selected DIF-B on a 130-mD filter media is shown in Fig. 14. A greater magnification SEM photomicrograph of the same filter cake built by fluid DIF-B shows the polymer coating the calcium carbonate particles (Fig. 15)

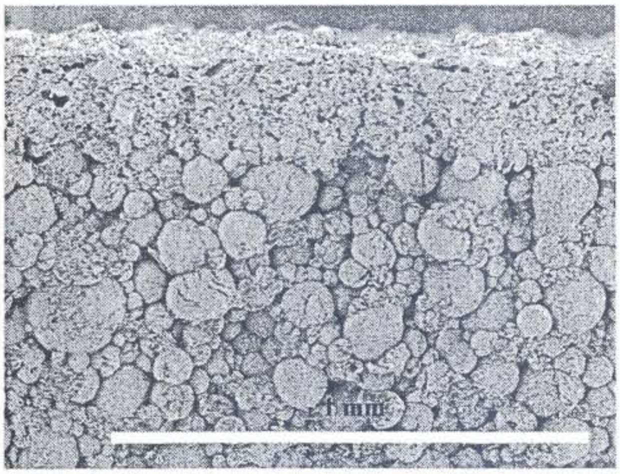

Fig. 14. SEM Photomicrograph of the filter cake built by the selected DIF-B on a 130 mD-dis
Sl. 14. SEM prikaz isplačnog obliga fluida DIF-B na disku propusnosti 130 mD

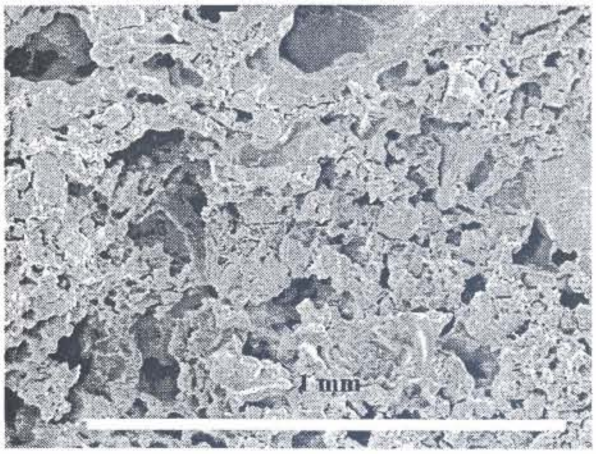

Fig. 15. Greater magnification SEM Photomicrograph of the filter cake built by the selected DIF-B
Sl. 15. Uvećani SEM prikaz isplačnog obloga fluida DIF-B

Conclusions

◆ PSD of selected calcium carbonates does not change rheological properties of evaluated drill-in fluids;

◆ The values of filtration parameters for all fluids except for fluid DIF-C decrease with increasing permeability when we compare test results obtained by 90-mD and 130-mD discs or 90-mD and 400-mD discs;

◆ The opposite trend is noticed if test results obtained by 130-mD and 400-mD discs are compared;

◆ Fluid DIF-C with $CaCO_3$ – C quickly forms adequate filter cake (the smallest spurt loss) on 90-mD disc, shows the smallest values of 30-min filtration and PPT value, and can be recomended for formation with permeability from 0,03 μm^2 to 0,045 μm^2 (from 30 to 40 mD);

◆ Fluid DIF-A prepared with $CaCO_3$-A has the smallest spurt loss during filtration through 130-mD disc but according PPT filtration parameters fluid DIF-B prepared with $CaCO_3$ - B shows very good results also, so both fluids can be suitable for reservoirs with permeability from 0,043 μm^2 to 0,065 μm^2 (from 43 to 65 mD);

◆ Fluids DIF-A and DIF-B shows good results for 400 mD–disc (estimated reservoir permeability from 0,05 μm^2 to 0,10 μm^2); fluid DIF-A shows smaller spurt loss value than fluid DIF-B, but other obtained values are better for fluid DIF-B.

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