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SMART BRIDGING AGENT ENHANCED WELL PRODUCTIVITY IN DEPLETED PRODUCTION FORMATION

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Abstract

Sized calcium carbonate is the most common material used in reservoir drill-in fluids for filter cake deposition. Calcium carbonate has numerous advantages relating to to drilling fluids but also some limitations. Research and field works were performed from mid-2018 to late 2019 to develop and implement a new material that can be used as an efficient alternative to calcium carbonate.

This article describes actual results of the research and field works performed to develop and implement an innovative bridging agent for water-base drilling fluids. The chemical is intended to build a filter cake and has a number of unique properties. The new material enables the solution of certain engineering tasks arising when drilling horizontal wells in a producing formation, in particular, preventing formation damage and increasing development efficiency. The article covers main methods used to elaborate the material and results of pilot works.

Introduction

As noted by the authors (Dick et al, 2000), most of recent water-base drilling fluids consist of four basic components – a brine base, viscosifier, fluid loss control agent, and bridging agent. Most common bridging material used in drill-in reservoir fluids is calcium carbonate.

Detailed practice of the application and theoretical justification of calcium carbonate are given in papers (Dick et al, 2000, Smith, 1996, BP 1996, Vickers et al, 2006) and imply a number of clearly defined requirements.

1. Recommended concentration of the bridging agent is 3–5% by volume (BP, 1996)
2. It is recommended to use special approaches to select fractional composition based on Abrahams rules, Kauffer methods, etc., to ensure the most efficient fluid loss control in drilling fluids (Abrmas, 1977, Kaeuffer,1973)
3. It is recommended to maintain the calcium carbonate concentration and minimum solids content to ensure an efficient filter cake removal at the stage of well completion with specialized breakers. It is advisable to use a special calcimeter to control calcium carbonate ratio to drill cuttings and barite in the drilling fluid (OFITE, 2015).

Field experience in calcium carbonate application as a material to build a filter cake identified some limitations of this material. The need to maintain the minimum concentration of 3-5% during drilling necessitates maintaining increased density of the drilling fluid. The calcium carbonate supplied for drilling fluids has the density from 2600 to 2800 kg/m^3 so that the material functions as both a bridging agent and a weighting material. If recalculated the recommended weighting material concentration is 85–140 kg/m^3. For example, if this concentration is maintained for preparation of a 3% KCl drilling fluid with the density of 1.03 g/cm^3, the fluid final density after treatment with calcium carbonate will be 1.09–1.10 g/cm^3. Such density increase in terms of overbalance pressure while drilling will amount to 0.9–1.75 MPa at 2000m (TVD) under static conditions. Therefore, to maintain the recommended minimum concentration, increased overbalance pressure on a producing formation should be considered. In certain cases, even a minor increase of overbalance pressure on a formation during drilling operations is undesirable, especially in mature fields with a low formation pressure as the excess of overpressure increases the likelihood of differential sticking and fluid losses during drilling. When planning and drilling of wells with low formation pressures, geologists and drilling engineers have to seek a compromise decision between maintaining a minimum mud weight and meeting the requirements of efficient use of calcium carbonate. Therefore, one of the directions of an innovative product development for filter cake building was searching for materials with the density close to water or mud base density that would allow maintaining of an optimal concentration without a mud weight-up.

Measurements of actual particle size distribution during drilling demonstrate that after several mud circulation cycles the initial particle size distribution changes significantly (see Diagram 1) for several reasons:

- during drilling, drill solids with minimum particle size continuously enter the drilling fluid; if we take the maximum efficiency of all solids control equipment components, it can be assumed that the drilling fluid will be contaminated with solids with particle size below 2 µm. A customer usually specifies the allowable solids content in reservoir drill-in fluids that usually ranges from 1 to 2%. Maximum solids concentration is determined based on acceptable cost of mud dilution and well stimulation activity planned. The more complex completion equipment and bottom hole treatment fluids are intended for use, the lower solids content is required. Upon completion of drilling, solids particle size distribution in mud will be affected by a fractional composition of both calcium carbonate and drill solids:

- during drilling, the drill string when rotating and contacting wellbore walls functions as a "mill" breaking calcium carbonate into finer particles and therefore, disturbs or changes its particle size distribution;
- solids control equipment also helps remove coarse calcium carbonate fractions, as most current products are not supplied in a single fixed grade. Most manufacturers regulate the particle size distribution with D10, D50, D90 distribution indices that indicate the content of particles of a particular size in a fraction in microns. Graph 1 shows summaries of calcium carbonate particle size distribution measurements performed in an actual well. The graph indicates that after 300m drilled, 100% of coarse fractions are removed from solids content and even additional treatments of mud with coarse fractions fail to bring back the initial particle size distribution.

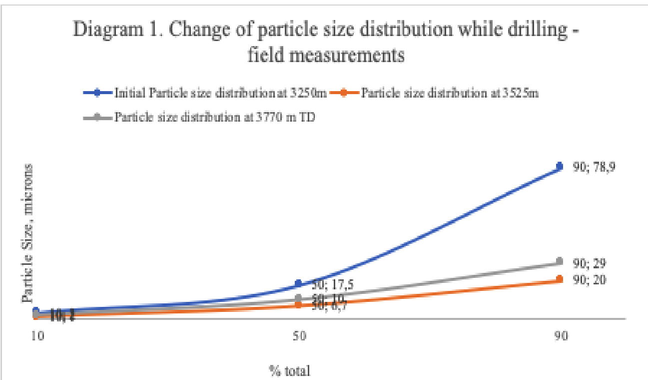

Diagram 1. Change of particle size distribution while drilling - field measurements

In view of the above processes during well drilling, the calcium carbonate particle size distribution naturally shifts toward reducing coarse and increasing fine solids content. Natural "shrinkage" of particle size distribution requires regular mud treatments with coarse fractions to maintain initial particle sizes distribution simulated and selected with the use of particle size distribution models.

Another specific feature of water-base drilling fluids application with calcium carbonate is the need to use specialized breakers to remove a filter cake during completion. Specialized systems including enzymes, chelates, weak organic acids and organic acid precursors are used to remove a filter cake (Smith, 1996). Specialized breakers are recommended if complex screens (i.e. multilayer mesh screens) are used, when drilling wells in formations with low formation pressure and in other cases where maximum efficient bottomhole cleaning from residual filter cake is required. Despite the proven efficiency of such breakers, their use requires time, detailed analysis of formation fluid compatibility with both the breaker composition and reaction products. Bottomhole treatment with a breaker system also increases mud and entire well construction costs that is not always acceptable. For example, during sidetracking in mature fields where minimum drilling cost is an essential condition for well construction cost effectiveness.

Calcium carbonate has become common use in reservoir drill-in water-base muds design and preparation. Given the abovementioned weaknesses and limitations, the development of alternative materials to form an efficient filter cake continues to be relevant.

AKROS LLC development and research activity was focused on development of a material satisfying the following requirements:

1. Be easily available and inexpensive
2. Have minimum density to avoid mud weighting up while maintaining the required concentration
3. Dissolve in hydrocarbon fluids to avoid the need to use expensive bottomhole treatment systems
4. Be compatible with all types of fresh and salt water-base drilling fluids
5. To be supplied in different grades and manufactured with particle sizes from 10 to 400 µм enabling application of best particle size distribution practices (Dick et al, 2000, Abrams, 1977, Vickers et al, 2006)
6. Minimize common to calcium carbonate reduction in particle size distribution during drilling

Reduced friction coefficient and fluid loss relative to standard water-base drilling fluid formulations could be added benefits of this technology development.

Research and development efforts in 2018-2019 contributed to the design and modification of the specialized material to be used in reservoir drill-in fluids as an alternative to or in combination with calcium carbonate.

Product Description and Laboratory Testing

The designed product has the following main properties:

- Dry material compatible with any water-base drilling fluid;
- Can be manufactured in variable particle sizes from 20 to 200 microns;
- Density 950–980 kg/m^3;
- Exhibits thermal plasticity, i.e. at a certain temperature particle deform under the action of pressure; can be manufactured with variable thermal plasticity from 60 to 100ºC;

- Fully soluble both in light hydrocarbon fluids and in crude oil;
- Exhibits hydrophobic property, i.e. it does not get water wet, remains in suspension when used in drilling fluids;

Given the abovementioned properties, this product was assumed to achieve the following advantages when used in drilling fluids:
- maintain required concentration during drilling without weighting up of the mud and, consequently, without increasing overbalance pressure on formation;
- increase well completion efficiency without use of specialized breaker systems;
- reduce fluid loss at bottomhole;
- improve the open hole stability due to micro-sealing effect;
- improve reservoir drill-in quality, reduce the risk of irrecoverable formation damage, optimize the bringing of the well to stable production through the bridging agent complete dissolving in any hydrocarbon fluid.

Based on preliminary laboratory tests, it was decided to conduct an integrated technology assessment in cooperation with LLC "Gazpromneft-STC" including a pilot project of a well drilling at Karamovskoe Field.

The integrated assessment of the material consisted of two stages – laboratory testing and, in case of positive test results, pilot works.

The product modification with softening point 70°C and particle size D50=100 microns was used for the enhanced laboratory testing.

The enhanced laboratory test program included the following key tasks:

1. Assess product physical state and solubility in water and hydrocarbon media when heated up to the boiling point
2. Assess the effect of acid and alkaline contamination through mixing the reagent with hydrochloric acid and caustic soda with subsequent heating
3. Assess the effect of the product on drilling fluid key parameters
   - 3.1 Measure weight, rheological and filtration properties of biopolymer drilling fluid before and after adding of the new material
   - 3.2 Measure weight, rheological and filtration properties of biopolymer drilling fluid treated with the product after 16 hours of thermostating at 60 and 80°C
   - 3.3 Assess the reagent bridging properties and filter cake characteristics by measuring filter paper and ceramic disc HPHT fluid loss at 65 and 80°C (below and above the softening point)
4. Estimate the probability of the product separation at solids control equipment (decanter centrifuge and hydrocyclones) – gravitational separation in a laboratory centrifuge
5. Estimate the reagent accretion potential on BHA, using the Shale Accretion Test
6. Assess the effect on the change of drilling fluid friction coefficient

Test summary and conclusions are given below.

Physical State and Solubility Assessment

The reagent solubility and physical state were tested by visual assessment of the sample traces after mixing 20 g of unmilled sample in flasks. Comparative results were obtained by measuring relative time of the reagent dissolution in fresh water and diesel fuel. Solubility test summary is given in Fig. 1 below.

Test Finding Conclusions:
The product is insoluble in water, exhibits thermoplastic behavior when heated – softens, returns to its initial solid physical state when ambient temperature reduces. Softening point is 70°C.
The period of full dissolving in diesel fuel without heating amounts to 82 min, at 80°C – 5 min.
The product interacts with hydrochloric acid and caustic soda without visible changes in physical state and signs of reactions of interaction, including when heated to the mixture boiling point.

Assessment of the Product Effect on Key Drilling Fluid Properties

The summary of standard test results of biopolymer clay-free water-base drilling fluid properties is given below:
1 – formulation untreated with oil-soluble bridging agent (OSBA);
2 and 3 – formulations treated with oil-soluble bridging agent (OSBA)
Measurements of key parameters were taken before and after heat aging at 60 and 80˚C.

Assessment of the oil-soluble bridging agent sealing properties was performed by measuring HTHP filtration on ceramic disks at 65°C and 80°C.
Drilling fluid formulations 2 and 3 (Table 1) not exposed to heat aging were used for the measurements.

The filter cake deposited on a ceramic disk during HTHP filtration measurements was put into diesel fuel and heated up to 80°C. The remaining part of the filter cake was exposed to hydrochloric acid (see Fig. 7-9).

The following conclusions were made based on the results of drilling fluid properties and ceramic disc fluid loss testing:

1. Addition of the oil-soluble bridging agent to the biopolymer drilling fluid had a positive effect on the system variation:
    a. API fluid loss reduced by 22% or 1.2 ml
    b. Paper disc HPHT filtration reduced by 55% or 7.2 ml
    c. Drilling fluid weight reduced by 0.015 g/cm^3
2. Addition of the oil-soluble bridging agent does not make a significant effect on the drilling fluid rheological parameters.

After heat aging at 60°C (below the softening point) and at 80°C (above the softening point) the drilling fluid retains its parameters within an acceptable range; additional reduction of fluid loss was observed.

Addition of the oil-soluble bridging agent reduces HTHP fluid loss measured on ceramic discs. At the temperature of measurement exceeding the softening point, a more efficient reduction of fluid loss was observed.

Estimation of the oil-soluble bridging agent accretion potential on BHA (Shale Accretion Test)

A common industry-accepted shale accretion test was used to estimate the potential and quantity of accretion of components of a drilling fluid treated with the oil-soluble bridging agent on BHA (Cliffe et al, 2008). During the testing, measurements were made to assess the change of mass of a metal rod after thermostating in the drilling fluid media.
The test results demonstrated that the quantity of the rod mass increase is negligibly small. Solid particles are easily removed from the rod surface. When calcium carbonate is added to the base sample neither accretion nor the rod mass change was observed.

Assess the Oil-Soluble Bridging Agent Effect on the Change of Drilling Fluid Friction Coefficient

Testing was performed based on method for lubricity tester (OFITE, 2017).
The degree of friction coefficient reduction is determined as metal-metal pair torque reduction after adding a lubricant into a testing drilling fluid. 4% bentonite slurry was used as the comparison base; the oil-soluble bridging agent in the concentration of 50 kg/m3 was used as a friction modifier. The torque reduced by 19% from 5.65 Nm to 4.65 Nm.

Testing Key Findings
During the performed tests main properties of the oil-soluble bridging agent were recorded and the reagent effect on drilling fluid properties was assessed.
The performed tests revealed that:

1. The reagent exhibits thermal plasticity – it softens at a target temperature set during a synthesis process. When the temperature reduces, it returns to its initial solid state.
2. The reagent does not react with hydrochloric acid and calcium hydroxide (cement).
3. The reagent is fully soluble in hydrocarbons, with raising temperature the dissolution rate increases significantly; for the 20 g sample weight the dissolution rate decreased from 82 to 5 min.
4. The reagent added to the drilling fluid does not change mud rheological parameters but reduce API fluid loss, significantly reduces HTHP fluid loss on a filter paper and ceramic disc.
5. Addition of the oil-soluble bridging agent reduces the drilling fluid weight.
6. After thermostating of a drilling fluid with the oil-soluble bridging agent at temperatures both below and above the reagent softening point, no parameter degradation or drilling fluid destabilization occurs.
7. During the drilling fluid filtration through a ceramic disc, a deposited filter cake is partially destroyed in hydrocarbon media. Residual components of the filter cake (mainly calcium carbonate) can be dissolved when exposed to hydrochloric acid.
8. The reagent is partially separated (by gravity) in a laboratory centrifuge with close-cut separation into calcium carbonate and oil-soluble bridging agent.
9. Based on the test results, the risks of the reagent accretion on BHA or increased probability of solids accretion are minimal.
10. Addition of the reagent reduces friction coefficient, therefore the reagent has prominent lubricating properties.

Based on the laboratory tests it was decided to carry out pilot works at the Karamovskoe Field of PJSC «Gazprom neft Oil Company».

Field Trial Overview

AKROS LLC and Gazpromneft-Scientific Technology Centre LLC - defined principal objectives of the oil-soluble bridging agent testing during preparation for the pilot works including:

1. Assess replaceability of calcium carbonate in a drilling fluid
    a. Verification of the possibility of using the oil-soluble bridging agent without weighting up of the drilling fluid
    b. Efficient sealing and filtration loss prevention due to thermal plasticity
    c. Reduction of differential sticking risks
2. Assess the efficiency of the reagent during well drilling under incompatible conditions (when drilling-in several formations with different pressure)

   a. Efficient sealing of underbalanced zones
   b. Avoiding the need of changeover to a drilling fluid with a lower weight
   c. Ability to reduce friction coefficient when drilling without a lubricant
3. Assess the effect of the oil-soluble bridging agent on reservoir drilling-in quality
   a. Zero formation damage
   b. Bringing well to production without using filter cake breakers

4. Assess the effect of the oil-soluble bridging agent on improved wellbore stability – prevention of problems related to wellbore instability

A horizontal section of a well at the Karamovskoe Field was selected as the object of testing with the following specific features of drilling in this field – lower formation pressure, high risks of fluid losses and differential sticking, wellbore wall instability.
Table 4 shows the well design key data.
Prior to field application, a pilot lot of the oil-soluble bridging agent was retested in a field laboratory for compatibility with the drilling fluid; test results of production lot verification are presented in Table 5.

General Data on Field Testing

Drilling out of the production casing cement was performed using process water to ensure better drill cuttings removal. Then the well was transferred to a biopolymer clay-free reservoir drill-in fluid made with the following formulation:

1. Sodium carbonate – 0.5 kg/m^3;
2. Caustic soda – 1.8 kg/m^3;
3. Modified starch – 22 kg/m^3;
4. Xanthan gum – 3.7 kg/m^3;
5. Potassium chloride – 42 kg/m^3;
6. Calcium carbonate – 65 kg/m^3;
7. MEX-CARB F – 23 kg/m^3;

After drilling during one hour the active volume of circulating drilling fluid was treated with the oil-soluble bridging agent in the concentration of 5 kg/m^3, with a sequenced increase to the target concentration of 50 kg/m^3 through staged treatments with 10 kg/m^3.
Increasing concentration of the oil-soluble bridging agent to the target level caused no screen panel blinding and no changes in the drilling fluid flow (see Fig. 15).

Drilling in the 2097-2687 m interval to the target depth was conducted without complications. No signs of balling or solids accretion on BHA components were observed (see Fig. 16)

Drilling fluid parameters during drilling of the interval remained stable without significant changes. Key parameter dynamics are given in Table 6.

During the pilot works the following application features of the oil-soluble bridging agent were verified:

- The reagent does not react with drilling fluid components and hydrochloric acid and therefore has no effect on calcium carbonate content and MBT test results. These methods can be applied with no adjustments, and control procedures require no modifications.
- The oil-soluble bridging agent concentration in the drilling fluid can be assessed indirectly using a retort analysis. The retort analysis demonstrated that hydrocarbon content increased with the oil-soluble bridging agent concentration increase and without adding a lubricant.

Also, during the field tests a minor accretion of the oil-soluble bridging agent on screen panels was observed when circulation was stopped that is most probably related to the reagent thermal plasticity decreasing under cooling conditions.

Analysis of the Oil-Soluble Bridging Agent Effect on Technological Drilling Capabilities

During the field tests, the key drilling parameters, such as ROP, rotary torque, drilling tool weight during tripping operations were monitored and compared against similar wells. The diagrams below show key results of measurements of the oil-soluble bridging agent effect on drilling parameters.

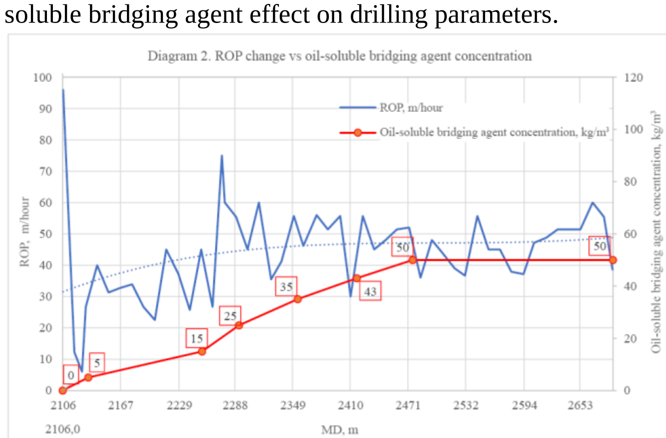

Diagram 2 shows a minor ROP increasing trend when the oil-soluble bridging agent concentration increases.

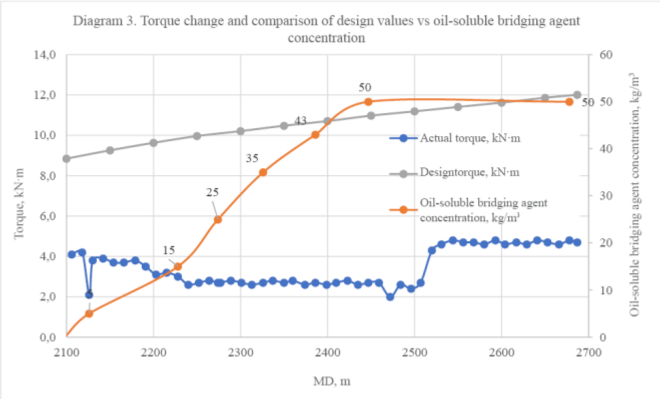

Diagram 3. Torque change and comparison of design values vs oil-soluble bridging agent concentration

Diagram 3 shows torque change and comparison of actual values against design ones for the given well trajectory.

Torque increases at the depth of 2520 m due to the equipment calibration during tripping. Obtained values of torque during drilling are significantly lower than the design values that also gives evidence that the oil-soluble bridging agent reduces friction coefficient.

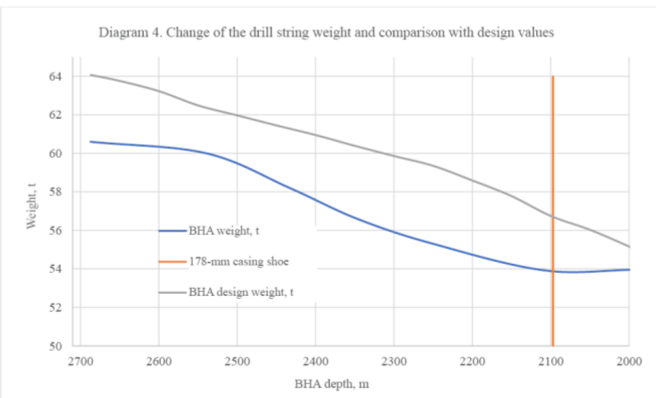

Diagram 4. Change of the drill string weight and comparison with design values

Diagram 4 shows that the actual drill string weight was registered below the plan weight by an average of 10%. Diagram 5 compares ROP with the oil-soluble bridging agent against ROP without the oil-soluble bridging agent when drilling a similar design well.

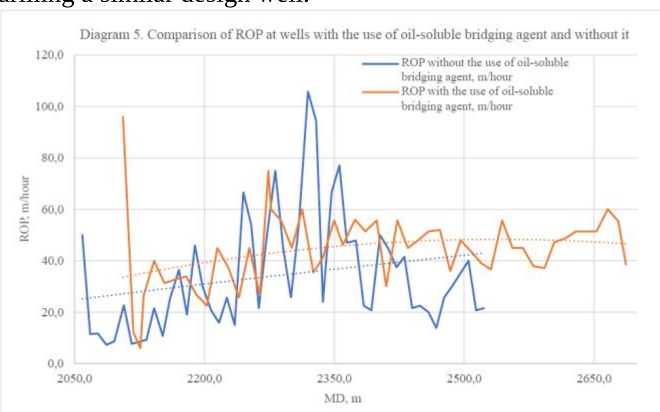

Diagram 5. Comparison of ROP at wells with the use of oil-soluble bridging agent and without it

Average ROP when drilling the liner interval with the oil-soluble bridging agent amounted to 37.3 m/h which is 68% higher than at the adjacent well drilled without the oil-soluble bridging agent (22.2 m/h).

In accordance with the approved well construction program, planned time for drilling the liner interval was 50 h; while the actual time of drilling the 2097-2687m (590m) interval amounted to 40 h 42 min. So ROP increase by 18.6% was recorded during drilling of the liner interval.

By contrast, at the adjacent well the 2042-2523m (481m) interval was drilled for 56 h 12 min while planned drilling time was 48 h, i.e. behind the depth-day schedule by 17.1%.

Conclusions and Recommendations Based on the Results of Pilot Works

Drilling of the liner interval in the pilot well at the Karamovskoe Field was trouble-free:

- The claimed reagent operational performance was verified;

- During drilling of the horizontal section and the liner RIH no complications were registered related to high overbalance pressure, such as mud losses, differential sticking, troubled tripping operations;

- The well was drilled to the target depth with lower torque and drill string load without using lubricants;

- Lower fluid loss values were registered after the drilling fluid treatment with the oil-soluble bridging agent;

- It was established that increased content of the oil-soluble bridging agent does not have a significant effect on the drilling fluid rheological parameters;

- Pilot tests identified good compatibility of the oil-soluble bridging agent with all components of the biopolymer drilling fluid;

- Significant reduction of torque value was registered during drilling with the oil-soluble bridging agent concentration above 15 kg/m^3;

- No negative effect on the drilling fluid parameters was observed;

- No reagent adhesion (accretion) on BHA and equipment components was observed;

- High ROPs were achieved (ROP= 39.25 m/h).

Finally, the well was completed and tested without problems and brought to a planned production regime.

It is unfortunate that the oil-soluble bridging agent effect on well completion performance was not analyzed to the full within the pilot works scope at the Karamovskoe Field. However, the subsequent wells drilled with oil-soluble bridging agent for other customers confirmed that the reagent application improve well completion efficiency as compared to conventional reservoir drill-in fluid systems.

Conclusion and Key Outputs

A novel reagent for water-base drilling fluid was developed and implemented during joint works of AKROS LLC and Gazpromneft – Scientific Technology Center LLC.

The reagent has the following key features:
- fully soluble in hydrocarbon fluids,
- flexible fractional composition,
- fully compatible with standard water-base drilling fluid formulations,
- variable dissolution speed and temperature control.

In 2019 one horizontal section and three sidetracks were drilled with the reagent.
Production tests of the novel reagent demonstrated, among others, the following results:

- improved drilling performance at all sites – well construction rate increased by 20%;
- zero operating problems, mud losses, differential sticking, accident-free casing running-in;
- confirmed replaceability of calcium carbonate as a drilling fluid component and the ability to maintain the drilling fluid minimum specific gravity;
- ability to complete and bring wells to production without conventional acid treatment of bottom hole area.
- actual well production rates exceeded expected values.

Field tests confirmed the reagent efficiency and capability to improve well construction and completion performance. Based on the pilot works results, production of the reagent was organized in Russia.

The results of the oil-soluble bridging agent application in reservoir drill-in fluids allow extension of the reagent scope of application to develop completion and well-killing fluids as well as new LCMs for producing formations. The technology makes it possible to dismiss high cost filter cake breaker systems when using smart completion systems. The novel oil-soluble bridging agent can be used as the base for developing new reservoir drill-in fluid systems.

Acknowledgements
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Tables

Table 1. Comparative data of drilling fluid property measurements when treated with the oil-soluble bridging agent

COMPONENT	UNIT	1	2	3			
Caustic soda	g/l	1.0	1.0	1.0			
Xanthan gum	g/l	4	5	5			
Potassium chloride	g/l	30	40	40			
Modified starch	g/l	18	18	18			
Calcium carbonate	g/l	60	60	60			
Oil-soluble bridging agent	g/l	50	0	50			
PARAMETER	**UNIT**						
Measurement temperature	°C	25	25	25			
600	rpm	60	46	49			
300	rpm	44	32	34			
6	rpm	13	8	7			
3	rpm	11	7	6			
PV	cP	16	14	15			
YP	lbs/100 ft2	28	18	19			
GEL 10 sec	lbs/100 ft2	13	7	8			
GEL 10 min	lbs/100 ft2	17	12	12			
FL, API	мл	4.5	5.4	4.2			
FL, HTHP 80°C 500psi	ml	-	**13.2**	**6.0**			
Density	g/cm3	1.023	1.060	1.045			
THERMAL AGING	**UNIT**	**1**	**2**	**3**			
Time	h			16		16	
Temperature	°C			60		80	
Measurement temperature	°C			25	50	25	50
600	rpm			52	40	52	40
300	rpm			38	30	38	30
6	rpm			11	10	11	10
3	rpm			10	8	10	9
PV	cP			14	10	14	10
YP	lbs/100 ft2			24	20	24	20
GEL 10 sec	lbs/100 ft2			10	8	10	8
GEL 10 min	lbs/100 ft2			14	10	14	10
FL, API	ml			4.1	-	4.1	-

Table 2. Fluid loss measurement data

COMPONENT	UNIT	2		3	
Caustic soda	g/l	1.0		1.0	
Xanthan gum	g/l	5		5	
Potassium chloride	g/l	40		40	
Modified starch	g/l	18		18	
Calcium carbonate	g/l	0		0	
Oil-soluble bridging agent	g/l	50		60	
PARAMETER	**UNIT**	**2**		**3**	
Measurement temperature	°C	65	80	65	80
HTHP filtration on 35 μм disk	ml	**7.2**	**8.0**	3,8	**3,0**

Table 3. Tests performed in three combinations of temperatures and drilling fluid compositions.

Test	Drilling fluid treatment chemical	Temperature, °C	Rod mass before/after, g		Increase of mass
1	Oil-soluble bridging agent 60 kg/m³	60	476.6	476.7	+0.02%
2	Oil-soluble bridging agent 60 kg/m³	80	476.6	476.8	+0.04%
3	Oil-soluble bridging agent + calcium carbonate	80	476.6	476.6	0%

Table 4. Well design summary for a well selected for pilot testing

Field	Samotlorskoye
Well type (function)	Production
Well type (profile)	Horizontal
Maximum inclination, °	91
Prior casing diameter, mm	178
Previous casing shoe depth, m	2097
Rated hole diameter below previous casing shoe, mm	155.6
Target hole TVD, hole/vertical, m	2097.77/1735.61
Target TD, hole/vertical, m	2699.08/1743.61
Actual TD, hole/vertical, m	2687.0/1743.62
Interval drilled, m	590

Table 5. Drilling fluid parameters

Parameter	Primary fluid	Primary fluid + 50 kg/m^3 SMART-CASE
Weight, g/ml	1.06	1.06
600/300, rpm	34/24	38/27
6/3, rpm	7/5	7/6
$GEL_{1/10}$ lbs/100 ft^2	6/8	6/8
pV, mPa*s	10	11
YP, lbs/100 ft^2	14	16
pH	11.5	11.5
API fluid loss (30 min)	4.5	3.9

Table 6. MAX-FLOW drilling fluid parameters during drilling and tripping operations

Date	TD, m	Weight, g/cm^3	600 rpm	300 rpm	PV, cP	YP, lbs/100 ft^2	GEL 10", lbs/100 ft^2	GEL' 10, lbs/100 ft^2	pH	API fluid loss, cm3/30 min	Cake, mm	(Cl^-)	Hydrocarbon content in rhetort, %	MBT, kg/m	$CaCO_3$ kg/m^3	Oil-soluble bridging agent concentration, kg/m^3	COF, µ
02.06.2019	2097.5	1.06	36	26	10	16	6	8	11	4.2	0.2	20000	0	0	65	0	0.0699
03.06.2019	2126	1.06	35	25	10	15	6	8	11	3.8	0.2	20000	0	1.4	65	5	0.0656
04.06.2019	2223	1.08	38	27	11	16	6	9	11	3.8	0.2	22000	0.5	3.5	65	15	0.0568
04.06.2019	2274	1.08	39	28	11	17	6	8	11	3.9	0.2	20000	1	3.5	65	25	0.048
05.06.2019	2326	1.10	42	29	13	16	6	8	11.5	3.7	0.2	21000	1.5	5.6	73	35	0.48
05.06.2019	2380	1.08	41	29	12	17	6	8	11.5	4.3	0.2	22000	1.5	4.2	60	43	0.0437
05.06.2019	2440	1.09	43	30	13	17	6	8	11.5	4.4	0.2	22000	2	7	59	50	0.0437
05.06.2019	2531	1.09	45	32	13	19	6	9	11	4.2	0.2	22000	2	10.5	55	50	0.0524
06.06.2019	2617	1.10	42	29	13	16	6	9	11	4.5	0.2	21000	2	13.3	55	50	0.048
06.06.2019	2687	1.09	49	35	14	21	7	11	11	4.2	0.2	18000	2	12.5	53	50	0.0524
07.06.2019	2687	1.09	50	36	14	22	7	11	11	4	0.2	17000	2	12.5	45	50	0.0437

Figures

Figure 1 Physical state of the reagent at 80 °C in water (on the left), in diesel fuel at room temperature (in the center) and at 80 °C (on the right)

Figure 2. HTHP filtration of the drilling fluid treated with the oil-soluble bridging agent

Figure 3. The bridging agent filter paper, exposed side; the center of the filter remained dry due to cake hydrophobic behavior

Figure 4. Visual appearance of the drilling fluid treated with the oil-soluble bridging agent after thermostating for 16 h at 80°C

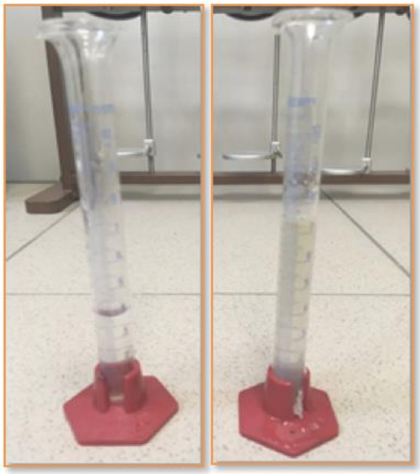

Figure 5. HTHP filtration on a 35 μм ceramic disc at 65°C (on the left – drilling fluid treated with OSBA, on the right – untreated drilling fluid)

Figure 6. HTHP filtration on a ceramic disk at 80°C (on the left – drilling fluid with OSBA, on the right – untreated drilling fluid)

The filter cake deposited on a ceramic disk during HTHP filtration measurements was put into diesel fuel and heated up to 80°C. The remaining part of the filter cake was exposed to hydrochloric acid (see Fig. 7-9).

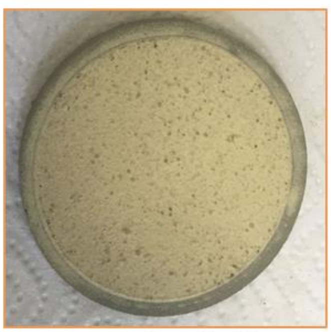

Figure 7. Initial filter cake of the drilling fluid treated with the oil-soluble bridging agent

Figure 8. Filter cake exposed to diesel fuel

Figure 9. Filter cake exposed to a 15% solution of hydrochloric acid

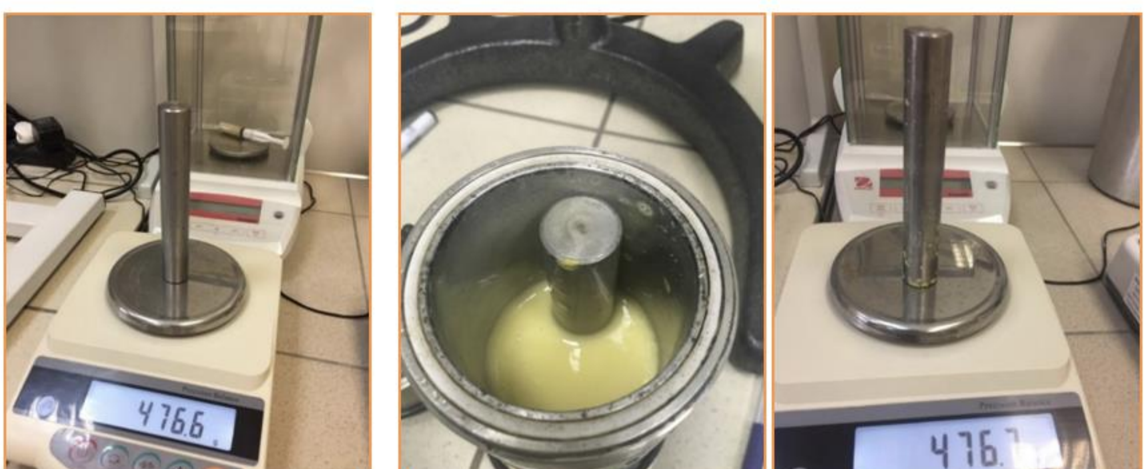

Figure 10-12. Pictures showing Shale Accretion Tests – from left to right: visual appearance of the rod before tests, visual appearance of the rod exposed to thermostating at 60 °C in a cell, visual appearance of the rod on a balance after the removal of drilling fluid residues

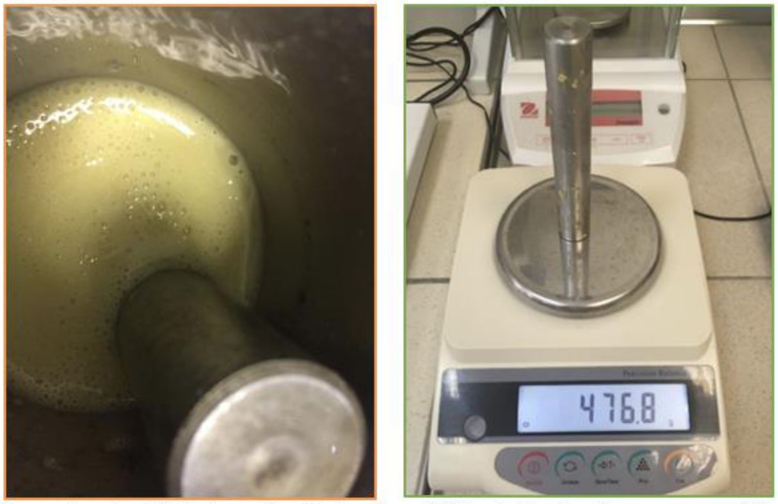

Figure 13-14. Pictures showing Shale Accretion Tests – from left to right: visual appearance of the bar exposed to thermostating at 80 ºC in a cell, visual appearance of the bar on a balance after the removal of drilling fluid residues

Figure 15. Pictures of drilling fluid flow on screen shakers with the oil-soluble bridging agent in concentration = 0 kg/m³ (on the left) and =50 kg/m³ (on the right)

Figure 16. Picture of BHA components during tripping in the drilling fluid treated with the oil-soluble bridging agent in the concentration of 50 kg/m³

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