Specifics of drilling wells in the abnormally-high-pressure rock beds in the oil-and-gas fields of Eastern Siberia

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Abstract. Eastern Siberia is Russia’s most promising region as a potential high-capacity oil-and-gas source of the country. Its territory includes large provinces that are promising in terms of oil and gas reserves. Opening-out of the oil and gas deposits is restrained by the deposits’ complex geological structure hindering the hole-making. This includes: saliferous deposits, abnormally high rock pressure in the intervals containing highly mineralized waters, unstable caving-in clay rocks, etc. Many of these problems can be solved using highly-mineralized Siberian brines occurring all over the Siberian craton, one of the largest world’s hydro-mineral provinces. The paper deals with the research on the preparation of weighted and hydrogel-magnesium drilling muds based on the salt from the Znamensk deposit brine. The muds have been processed with Flo-Vis Plus biopolymer and Flo-Trol starch that have a wide-range resistance to high mineralization. The mud weighting has been done with barite and hematite. Based on the Znamensk deposit brine, hydrogel-magnesium drilling muds have been prepared. The research shows that the fluid-loss reducing agents (i.e. Sulfacell and Camcell) should be infused as a 5% solution because they are fixed in the hydrogels when in a dry state. Samples 7 and 8 are not recommended as stabilizers because the solutions have high filtration and viscosity values. The use of the brine helps to prevent cavernosity and salt-bearing rocks’ solubility as well as to prevent the complications connected with the brine recrystallization in the reservoirs and on the surface of the drill tool.

1. Introduction

Oil-and-gas fields of Eastern Siberia are quite promising sources though there are certain difficulties in their development i.e. their remoteness and complicated mining-and-geological conditions of well construction [6].

The geological cross-section of the wells in the Irkutsk region is represented with three geological structure systems (super-salt, salt and sub-salt) with conflicting drilling conditions (South-Kovykta, Balagansk, Kovykta and Znamensk deposit).

The main problem in drilling is connected with the salt-system rocks that are bedded as geologic units of rock salt interlayers with dolomite- and dolomite-anhydrite stringers. Depending on the drilling site location, the salt-bearing beds’ thickness varies from 300 to over 2,000 m. The drilling of the super-salt and sub-salt systems is hindered by the loss zones confined to the Angara-Lena under-
ground-water basin. On certain field sections, there are brine lenses with an abnormally high rock pressure (AHRP) in those geological units, the anomaly index \((K_m)\) of the brine beds being 2.2 and higher [1].

The most common complicating factors in the well-drilling are: sticking of the drilling tool as a result of the salt complex crystallization; deformation of the casing columns; brine attack; hydrogen sulphide and carbon dioxide that cause fast destruction of the casing columns and cement stone; partial or complete well bore loss; brine flow, etc. [2] The AHRP manifestations cause difficulties in the well-drilling process in the sedimentary rock mass.

The main complicating factors in drilling-out the brine-bearing beds are: high mineralization of the brine (up to 600 g/l and higher), high flow capacity of the brine (7000 m³/day and higher) high brine density (up to 1.45 g/cm³). The drilling-out of the salt-bearing sections in some areas is accompanied with a spontaneous shed of the highly-mineralized underground waters from the natural caverns and lenses [5].

With all the available methods used for dealing with the brine problems, it has been very rare that a well is drilled to the planned depth; it is only the case when the brine afflux is reduced to a minimal level. In certain cases, either the wells are dismantled for technical or geological reasons, or a new bore hole is spudded in. The working team training is of a crucial role in preventing open brine flows, when every team member has to learn the signs of the wells’ pre-blow state in case of the brine flow [7,10].

In Eastern Siberia, multiple brine flow shows have been opened with probe holes and prospecting wells with the rate of 5 to 7,500 m³/day (№№3, 5 South-Kovykta field, №№ 3,18,52 Kovykta field, №№ 131,100 Verkhnelensk field, №№ 2, 3 Balagansk field, №№1B, 3 Znamensk deposit, №1 Beryambinsk wells) [3]. The seismic survey data shows that the broaching wells are located within the haloid-carbonate complex with an abnormally high electric resistivity (intensive structure deformation, oblique incidence and fault zones) [4].

The chemical composition of the brines includes concentrated mineral salts and rare metals. The Znamensk deposit’s brine composition is shown in Table 1. The deposit’s brines are bedded in the deep stratum of the Siberian craton sedimentary cover (the working seam is at a depth of 1,800-1,830 m). The chemical test of the samples has shown the following results: acidity of 2.00–4.35 pH; total mineralization, up to 590 g/l; density, up to 1.43 g/cm³.

### Table 1. Beneficial component content in the Znamensk brine.

| № | Element | Component content, g/l | № | Element | Component content, g/l |
|---|---------|------------------------|---|---------|------------------------|
| 1 | Na      | 2.54                   | 7 | Sr      | 0.8                    |
| 2 | K       | 4.57                   | 8 | Cl      | 338                    |
| 3 | Ca      | 128                    | 9 | Br      | 10.0                   |
| 4 | Mg      | 28.7                   | 10| B       | 0.09                   |
| 5 | Li      | 0.50                   | 11| J       | 0.013                  |
| 6 | Rb      | 0.009                  | 12| Mn      | 0.12                   |

When drilling the beds in which brine show is possible, it is necessary to consider the section rock constituents’ physical-and-chemical properties that are determined by the salts’ mineralogical composition and occurrence conditions (depth, pressure, temperature) [11].

One of the most effective and promising ways of well-drilling in the brine show conditions is the use of special drilling muds.

Isolation of the water-bearing strataums with cement bridging is a major method of the brine show elimination. Isolation by tamping muds implemented at the Kovykta oil-and-gas condensate field did not give any positive results due to the high rock pressure and highly-mineralized mud flows.

The conventional muds used in well-drilling under the brine show conditions are of little use because when contacting the brines, the muds clot, and their structural, mechanical and filtration proper-
ties are aggravated, which prohibits the mud weighting and thus creates a back pressure. This in turn increases the material consumption for the purpose of the drilling mud processing [9], while the chlorine-potassium and chlorine-magnesium attack limits the usage of the chemical agents such as carboxymethyl cellulose (CMC) and acrylic polymers.

To prevent and eliminate the problem, an experimental study has been done for non-clay muds with a condensed solid phase (hydrogel), oil-based muds [8], salt-saturated polymer-based muds combined with filtration-reducer fillers, as well as polymer-emulsion weighed drilling muds.

2. Materials and methods

The training-and-research laboratory of drilling muds and well cementing, INRTU, has conducted a study on preparation of weighed and hydrogel-magnesium drilling muds based on the Znamensk deposit salt.

In order to prepare weighed muds, the Znamensk brine salt was used (Table 2).

The salt was added to the mud in a dry state or pre-dissolved in water in order to obtain the mud of the required density.

| No | Chemical agent          | Mass concentration, % |
|----|-------------------------|-----------------------|
| 1  | Calcium chloride CaCl₂  | 59.4                  |
| 2  | Magnesium chloride MgCl₂| 0.4                   |
| 3  | Sulphates SO₄²⁻          | 0.018                 |
| 4  | Chlorides CI             | 39.9                  |
| 5  | Boron B                 | less than 0.001       |
| 6  | Bromine Br              | less than 0.02        |
| 7  | pH of 20% mud           | 6.8                   |

In order to obtain the required structural-mechanical and filtration properties, the muds were processed with Flo-Vis Plus biopolymer and Flo-Trol starch having a wide-range resistance to high mineralization.

3. Research results and analysis

According to the producer’s specification, Flo-Vis Plus is an ultrapure quality biopolymer (fluid loss reducing agent); a natural highly-branched polysaccharide with an extremely high molecular weight; nonionic, completely degradable. It provides the required flow characteristics of the mud and improves its holding and cutting-carrying capacity. Flo-Trol is a particular kind of modified starch used as a filtration-reducing substance for any drilling water-based muds. It has a synergy effect when interacting with the drilling muds and can be used both in unsalted and salt-saturated drilling muds. It is best to be used in combination with filtration reducers (i.e. calcium carbonate or crystalline salt).

The mud weighting was implemented by adding barite and hematite. Using the above chemical agents (i.e. Flo-Trol and Flo-Vis Plus), salt-based stable systems have been obtained. The systems can be used when drilling in the AHRP beds.

The results of the laboratory tests are presented in Table 3.

The main drawbacks of the obtained weighted drilling muds are their high viscosity and low sedimentation stability. The table shows that in the case of the joint use of Flo-Trol and Flo-Vis Plus, there is a synergy effect (i.e. the components mutually increase each other’s effect), which gives a stable mud structure holding the weighting additives in the form of suspension. This in turn helped to increase the mud density up to 2,192 kg/m³.

Thus, further research on sedimentation in the weighted drilling muds is needed, and sedimentation must be taken into account in hole-making.

The hydrogel-magnesium drilling muds were also prepared based on the Znamensk brine.
After the test was completed, the total mineralization level of the Znamensk brine contains the amount of magnesium sufficient for the gel formation.

In order to obtain the hydrogel, the following components are needed: salt that forms the gel (MgCl$_2$); fouciant that precipitates and condenses the solid phase (caustic soda NaOH); salt that keeps the total mineralization level.

The Znamensk brine contains the amount of magnesium sufficient for the gel formation.

In order to obtain the hydrogel, the brine with a density of 1,450 kg/m$^3$ was processed with a 20% caustic soda solution and was intensively stirred for 1.5 hours to a homogenous state. For more effective gel formation and for the purpose of the structure strengthening, the solution was left for 24 hours. After that, stabilizing agents (i.e. Sulphacell, Camcell, Flo-Trol et al.) were added to the solution.

The laboratory test results are presented in Table 4.

### Table 3. Weighted drilling muds based on the Znamensk deposit salt.

| № | Drilling mud composition, % | Drilling mud indices |
|---|----------------------------|----------------------|
|   | Flo-Trol | Flo-Vis Plus | ZDS | Barite | Hematite | ρ, kg/m$^3$ | RV$_{200s}$ | SST$_{1/10}$ | F$_{30s}$ | C, mm | pH | K$_{adh}$ |
| 1 | 0.5      | 0.3          | 70  | -      | -        | 1,273      | 48          | 7/13       | 4        | film    | 5-6 | 0.213   |
| 2 | 0.5      | 0.3          | 70  | 20*    | -        | 1,338      | 51          | 11/15      | 4        | 0.5     | 6   | 0.425   |
| 3 | 0.5      | 0.3          | 70  | 50*    | 50*      | 1,775      | 60          | 24/40      | 5        | 1       | 6   | 0.250   |
| 4 | 0.5      | 0.3          | 70  | 82.5*  | 100*     | 2,192      | 136         | 71/105     | 7.5      | 2       | 6   | 0.213   |

Note: ZDS – Znamensk deposit salt; * - heavier addition to the drilling mud volume, %; RV – relative viscosity; SST – mud static shift tension; F – filtration; C – post-filtration crust; K$_{adh}$ – adhesiveness index.

In order to obtain the hydrogel, the following components are needed: salt that forms the gel (MgCl$_2$); fouciant that precipitates and condenses the solid phase (caustic soda NaOH); salt that keeps the total mineralization level.

The Znamensk brine contains the amount of magnesium sufficient for the gel formation.

In order to obtain the hydrogel, the brine with a density of 1,450 kg/m$^3$ was processed with a 20% caustic soda solution and was intensively stirred for 1.5 hours to a homogenous state. For more effective gel formation and for the purpose of the structure strengthening, the solution was left for 24 hours. After that, stabilizing agents (i.e. Sulphacell, Camcell, Flo-Trol et al.) were added to the solution.

The laboratory test results are presented in Table 4.

### Table 4. Composition and indices of the condensed-solid-phase drilling muds based on the Znamensk brine ($ρ = 1,450$ kg/m$^3$).

| № | NaOH | Sample№ | Sulphacell | Camcell | Flo-Trol | ρ, kg/m$^3$ | RV$_{200/100}$ | SST$_{1/10}$ | F$_{30s}$ | C, mm | pH |
|---|------|---------|------------|---------|----------|-------------|----------------|-------------|----------|------|-----|
| 1 | 1.7  | 0.2     | -          | -       | -        | 1,440       | 42             | 32/84      | complete | 3.5  | 6.5-7|
| 2 | 1.7  | 0.5     | -          | -       | -        | 1,440       | 105            | 75/120     | complete | 25   | 3   | 6.5-7|
| 3 | 1.7  | -       | 0.1        | -       | -        | 1,440       | 65             | 84/96      | 20       | 3    | 6.5-7|
| 4 | 1.7  | -       | 0.2        | -       | -        | 1,430       | 70             | 30/48      | 13       | 2.5  | 7   | 6.5-7|
| 5 | 1.5  | -       | -          | 2       | -        | d.          | 84/90          | -          | -       | -    | 7   |
| 6 | 1.7  | -       | -          | 2*      | -        | 1,400       | 28             | 36/57      | 25       | -    | 7   |
| 7 | 1.7  | -       | -          | -       | 0.2      | 1,450       | 50             | 46/114     | complete | 4    | 6.5 |
| 8 | 1.7  | -       | -          | -       | 0.625*   | 1,290       | 35             | 28/48      | 18       | 2    | 8   |
| 9 | 1.7  | -       | -          | -       | 1        | 1,450       | no/f.          | 180/190    | complete | 4.5  | 6.5-7|

Note: NaOH was added as a 20% solution; * - Sulphacell and Camcell were added as a 5% solution; sample №7 – hydroxyethyl cellulose (Sulphacell – 2, grade 25, series №1; sample №8 – hydroxyethyl cellulose (Sulphacell – 2, grade 400, series №: 2976; d – drop by drop; no/f – no flow. Samples 7 and 8 are manufactured by PoliceII joint-stock company, Vladimir, Russia.

### 4. Discussion

Using the above chemical agents and brine, stable systems with high viscosity- and static shear stress values have been obtained. The research data shows that the filtration reducing agents (i.e. Sulphacell...
and Camcell) should be added as a 5% solution as they are fixed in the hydrogels when in a dry state. The samples 7 and 8 are not recommended as stabilizers, as the muds have high viscosity and filtration values.

Besides, the research has defined the drawbacks of the solutions: when preparing the hydrogel solutions by the formulas presented in Table 4, the solutions foamed in the process of stirring, which affects the definition of the drilling mud density index. The study has also shown high fluid loss values of the drilling muds.

Moreover, it is necessary to take into account that the process of the hydrogel solutions is quite long and can take a few hours with intensive stirring, which is not convenient in the field conditions of the drill site.

In order to obtain a quality hydrogel from the Znamensk brine (i.e. a hydrogel that can be weighted to a density of 2,000-2,500 kg/m³), it is necessary to continue the laboratory studies designed to select the most efficient stabilizer and defoamer. Which means it is necessary to develop such a method for obtaining the drilling muds with a condensed solid phase that makes it possible to shorten the time needed to obtain the structured system (hydrogel) capable of keeping its stability during a certain period of time without any stabilizing additives.

The use of the available brine makes it possible to reduce the preparation time and the costs connected with the above-ground solution saturation, prevent cavernosity and the saliferous rocks’ solubility, and reduce the probability of the complications connected with the brine recrystallization in the reservoirs and on the surface of the drill tool.

5. Conclusion
Well-drilling in the conditions of brine flow [12] is a formidable problem requiring a complex solution based on the accumulated expertise, i.e. determination of reliable ways of well cementing, quality zonal segregation of the brine floors, prediction of the mining and geological conditions, development of specific formulas of the drilling muds, etc. [13].

The above-mentioned mud systems are of special interest in connection with the start of the drilling project at the Kovykta gas-condensate field. The project is part of the exploratory wells development program aiming at updating the data on the structure and the volume of the well production and at specifying the geological model of the gas-condensate field.

References
[1] Vakhromejev A G 2008 Geodynamic model of the abnormally-high fluid pressure build-up in the sedimentary cover of the Siberia craton Bulletin of the Siberian Branch of the Earth sciences Section of Russian Academy of Natural Sciences. Geology, exploration and prospecting of ore deposits 12 pp 39–51
[2] Shakirova E V, Averkina E V and Sabirov T R 2016 Influence of the additives on the characteristics of the drilling mud used in well-drilling in Eastern Siberia Bulletin of the Siberian Branch of the Earth sciences Section of Russian Academy of Natural Sciences. Geology, exploration and prospecting of ore deposits 3 (56) pp 86–94
[3] Averkina E V 2009 Analysis of the brine-showing wells at the gas-condensate fields of the Irkutsk region Bulletin of the Siberian Branch of the Earth sciences Section of Russian Academy of Natural Sciences. Geology, exploration and prospecting of ore deposits 2 (35) pp 152–157
[4] Gaisina L.M., Belonozhko M.L, Tkacheva N.A., Abdrakhmanov N. Kh, Grogulenko N.V. 2017 Principles and methods of synergy modeling of management system at oil and gas sector’s enterprises Espacios 38 (33)
[5] Averkina E V, Shakirova E V and Fokin Y V 2017 Study on the defoaming agents in the drilling mud composition Bulletin of the Siberian Branch of the Earth sciences Section of Russian Academy of Natural Sciences. Geology, exploration and prospecting of mineral deposits 3 (40) pp 90–98
[6] Rybkov I I 2011 Prediction of AH RP seam roof depth when drilling horizontal wells *Oil Industry* (4) pp 60–61

[7] Bakhtizin R., Evtushenko E., Burenina I., Gaisina L., Sagitov S. 2016 Methodical approach to design of system of the logistic centers and wholesale warehouses at the regional level *Journal of Advanced Research in Law and Economics* 1(15) pp 16–25 doi: 10.14505/jarle.v7.1(15).02

[8] Shakirova E V, Averkina E V, Sabirov T R and Peryshkina K O 2018 Use of oil as a lubrication additive for the drilling mud (Yaraktinsky oil-gas condensate field) *Gas-and-oil producing industry* 2 (16) pp 12–19

[9] Semeneyakin V S, Semenyak M V and Semenyakin P V 1997 Specifics of the abnormally high rock pressure *Gas industry* 12 pp 50–52

[10] Gaisina L M, Barbakov O M, Koltunova Yu I, Shakirova E V, Kostyleva E G 2017 Social management systems’ modeling based on the synergetic approach: methods and fundamentals of implementation *Academy of Strategic Management Journal* 16 1 pp 83–95

[11] Lambin A I, Ivanishin V M, Sirajev R U, Averkina E V et al. 2015 Study on the influence of emulsion drilling muds on the muds’ properties. *Bulletin of the Siberian Branch of the Earth sciences Section of Russian Academy of Natural Sciences. Geology, exploration and prospecting of ore deposits* 4 (53) pp 58–66

[12] Gaisina L M, Mikhailovskaya I M, Khairullina N G, Pilipenko L M, Shakirova E V 2015 Features of the formation of the corporate identity of the staff *Biosciences Biotechnology Research Asia* 3 (12) pp 2543–2555

[13] Smirnov A S, Gorlov I V, Yaitsky N N, Gorsky O M et al. 2016 Geological-and-geophysical data interpretation as a way to develop a valid model of the Kovykta gas-condensate field *Oil and gas geology* 2 pp 56–66