

The integrated method to select drilling muds for abnormally high pressure formations

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Abstract. The article describes the method for choosing a drilling mud for drilling abnormally high pressure formations. A carefully selected drilling mud formulation would not only enhance an array of interrelated fluid properties, but also minimize the impact on the pay zones when the drill bit first penetrates the pay. To ensure a better assessment of drilling mud impact on the pay zone, it is reasonable to carry out the study focused on the analysis of technological parameters, involving filtration, acid and drilling mud tests, as well as formation damage analysis. This would enable evaluating the degree of mudding off, reservoirs acid fracturing effect and the risks of pipe sticking at significant depth. The article presents the results of the above-described study with regard to the currently used drilling mud and new experimental formulations developed at National Research Tomsk Polytechnic University (Drilling Mud and Cement Slurry Laboratory).

1. Description of drilling mud formulations and experimental data

As it was mentioned previously, several types of drilling mud have been proposed as initial formulations. The critical parameters and characteristics of these drilling muds were analyzed in terms of their thermal stability. The colmatation ability of drilling muds was determined; the return permeability tests were carried out. In addition, drilling mud inhibition properties were evaluated. As initial formulations, the following types of drilling muds were considered:

2. Materials and Methods

2.1 Drilling muds with barium salts without additional acid soluble weighting additives

Despite wide application stipulated by low price, the type of drilling mud formulation that dates back to at least the beginning of the 1980s and even earlier is currently outdated. It involves a great amount of barite that adversely affects the reservoir properties. Thus, this drilling mud can cause significant pollution of the bottom-hole formation zone when the drill bit first penetrates the pay.

2.2 Drilling muds with heavy-soluble barium salts

Drilling muds containing siderite and heavy barium salts in low concentrations are considered next-generation formulations as the solid phase added into the drilling mud and negatively affecting reservoir properties is not significant. The use of highly mineralized brines should be mentioned due to their inhibitory ability and almost full absence of bentonite clay, which, in turn, has a positive effect on penetrating strongly cemented shales and other rocks of hard clay. [3]

2.3 Heavy biopolymer drilling muds with sodium and potassium formates

Drilling muds with sodium and potassium formates demonstrate no fundamental differences from the drilling fluids made of heavy salts except for one factor. Unlike heavy salts, formates increase the mud density without using additional weighting agents [4, 5].



The experiment was carried out during the 24-hour period, 48-hour period and 72-hour period. The time periods were defined on the basis of statistical observations, i.e. most commonly encountered time periods when the drilling mud is in the borehole without additional processing. The results of the mud thermal stability are presented in Tables 1-3.

Table 1. Process parameters of drilling mud with barite weighting agent.

Parameters	units	Parameters after 24 hours	Parameters after 48 hours	Parameters after 72 hours
Mud density	g/sm ³	1.68	1.68	1.68
Relative viscosity	St	40-45	56	60
Shearing strength 1/10	pound/100 pounds ²	15/19	13/15	12/13
Water loss by API	sm ³ /30 min	5.0	5.3	5.4
Filter cake	mm	0.5-0.6	0.6-0.7	0.6-0.7
Plastic viscosity (PV)	cps	15-30	17	15
Yield point (YP)	pound/100 pounds ²	45-80	42	42
pH	-	9	9	9

Table 2. Process parameters of drilling mud with heavy-soluble barium salts after aging chamber.

Parameters	units	Parameters after 24 hours	Parameters after 48 hours	Parameters after 72 hours
Mud density	g/sm ³	1.68	1.68	1.68
Relative viscosity	St	60	56	60
Shearing strength 1/10	pound/100 pounds ²	15/19	13/15	12/13
Water loss by API	sm ³ /30 min	4.0	4.3	4.4
Filter cake	mm	0.5-0.6	0.6-0.7	0.6-0.7
Plastic viscosity (PV)	cps	25	17	15
Yield point (YP)	pound/100 pounds ²	41	42	42
pH	-	9	9	9

Table 3. Process parameters of drilling mud with potassium formate after aging chamber.

Parameters	units	Parameters after 24 hours	Parameters after 48 hours	Parameters after 72 hours
Mud density	g/sm ³	1.68	1.68	1.68
Relative viscosity	St	57	68	69
Shearing strength 1/10	pound/100 pounds ²	2/3	2/3	3/4
Water loss by API	sm ³ /30 min	6	6	6.3
Filter cake	mm	0.6	0.3	0.6-0.7
Plastic viscosity (PV)	cps	36	43	45
Yield point (YP)	pound/100 pounds ²	4	4	42
pH	-	10.5	10.5	10

The obtained formate-based drilling mud contains polysaccharide reagents for regulation of filtration and rheology properties. In addition, it includes marble chips for temporary colmatation of the bottom-hole formation zone. Compared to heavy inorganic salts, formates have a number of advantages, precisely: environmental safety, excellent inhibition capacity towards shale, increased thermostability, low corrosivity, compatibility with formation fluids. All these factors positively affecting the penetration conditions lead to the conclusion that the drilling muds formulated using potassium formate are the most suitable for abnormally high pressure formations (AHPF).

2.4. Filtration study

The next stage of laboratory research was to determine the colmatation abilities of the drilling muds. The filtration studies designated to assess the dynamics of core samples permeability exposed to drilling muds were carried out under formation conditions using a laboratory setting PIC-PS.

The schematic diagram of the experiment is shown in Figure 1. Having irreducible water saturation, core samples were placed in a core holder of the setting where the conditions similar to downhole environment were created by applying confining lithostatic pressure. Kerosene was filtered through the core samples in the "forward" direction (from the formation into the wellbore). When permeability to oil was measured, the tested drilling mud was allowed to flow through the core sample in the "reverse" direction (from the wellbore to the formation) in the mode of dynamic filtering imitating the penetration stage.

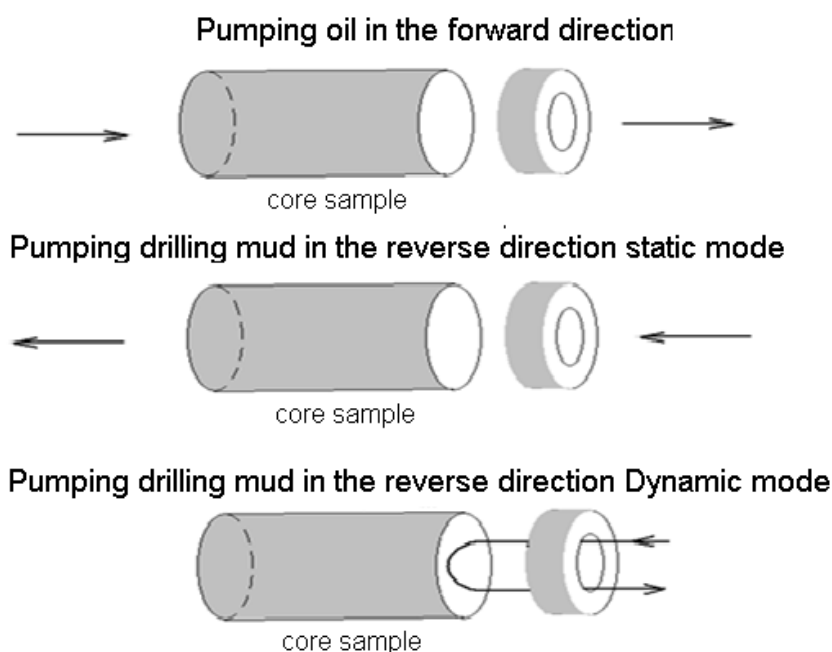


Figure 1. Schematic diagram of the experiment.

At the end of the filtration experiment, kerosene was pumped again in the "forward" direction in order to measure core sample permeability to oil before and after contact with the drilling mud. As a result, the coefficient of return permeability to oil was calculated in % (formula 1).

$$K = \frac{K_{oil1}}{K_{oil2}} * 100\% \quad (1)$$

where K – coefficient of return permeability to oil of core samples, %; K_{oil1} – coefficient of return permeability to oil of core samples before contact with drilling mud, mD; K_{oil2} – coefficient of return permeability to oil of core samples after contact with drilling mud mD.

The composition and basic parameters of the core material used in the laboratory tests are listed in Table 4.

The efficiency of core sample return permeability was investigated by filtrating formation water through the core samples before and after contact with drilling mud. The first experiment involved the

drilling mud containing potassium formate and colmatant. The dependence of pressure drop on the flow rate of fluid filtered through the core sample before and after contact with drilling mud is given in Figure 2.

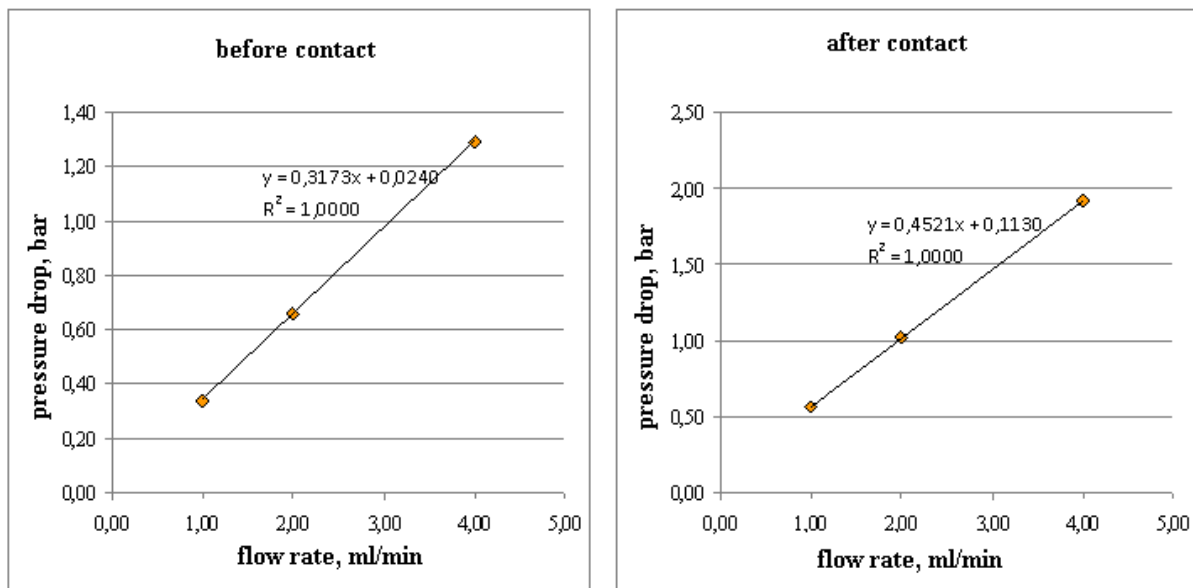


Figure 2. Dependence of pressure drop on the flow rate of fluid filtered through the core sample before and after contact with drilling mud.

The mud cake was disrupted when the reverse pressure drop was 0.213 MPa. Return permeability coefficient – 87.88%.

The second experiment was carried out with the drilling mud containing sodium formate without bridging particles. The dependence of pressure drop on the flow rate of fluid filtered through the core sample before and after contact with drilling mud is given in figure 3.

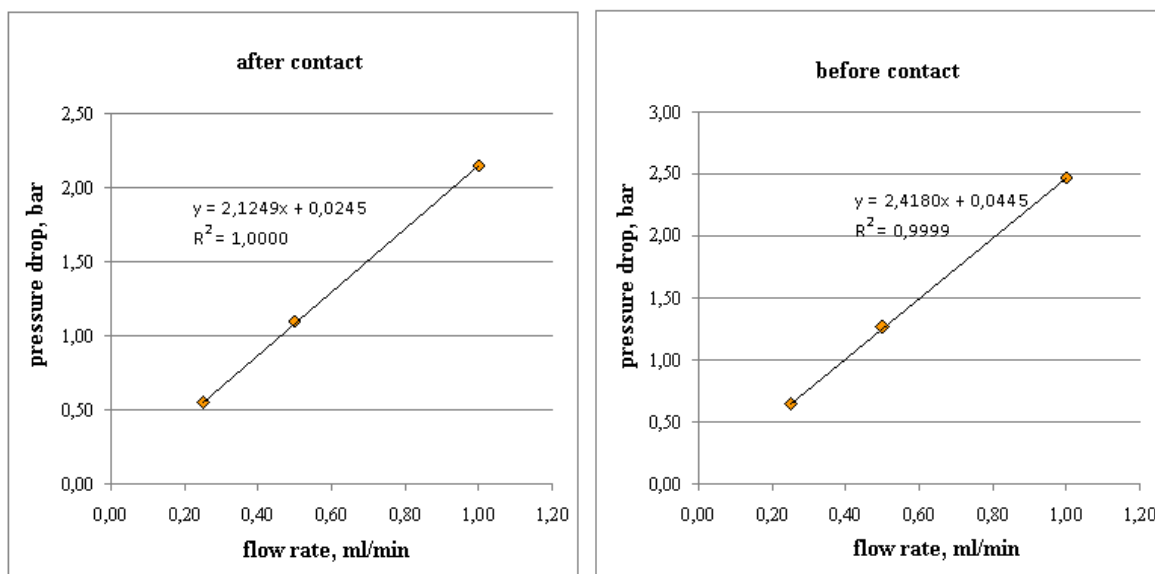


Figure 3. Dependence of pressure drop on the flow rate of fluid filtered through the core sample before and after contact with drilling mud.

3.Results and discussion

The comparative analysis of two drilling muds, the first containing potassium formate and the second with sodium formate colmatant without bridging particles, has showed a significant positive effect in blocking the pore channels by bridging particles. To evaluate the drilling mud inhibition capacity, swell capacity test instrument was used. The analysis results are presented in Table 4.

Table 4. Results of the experiments.

Type of drilling mud	Swell capacity, mm	Inhibitor additive	Temperature, °C	Composition of the sludge tablets
Mud with barium salts without inhibitor	2.8		63	aleurolite 50% + mudstone 50 %
Mud with barium salts with inhibitor	2.4	Shale inhibitor	64	aleurolite 50% + mudstone 50 %
Formate-based mud without inhibitor	2.1		64	aleurolite 50% + mudstone 50 %
Formate-based mud with inhibitor	2.0	Shale inhibitor	62	aleurolite 50% + mudstone 50 %

The obtained data on clay swelling have shown that the formate-based drilling muds demonstrate the lowest values. The difference in swell capacity can be explained by the absence of bentonite in the drilling muds with salts and formates and by a high content of chlorides that increase inhibition properties of shale. For illustration purposes, the data on clay swelling are presented in Figures 4-5.

**Figure 4.** Swelling curve of sludge tablets contact with mud containing barium salts with inhibitor.

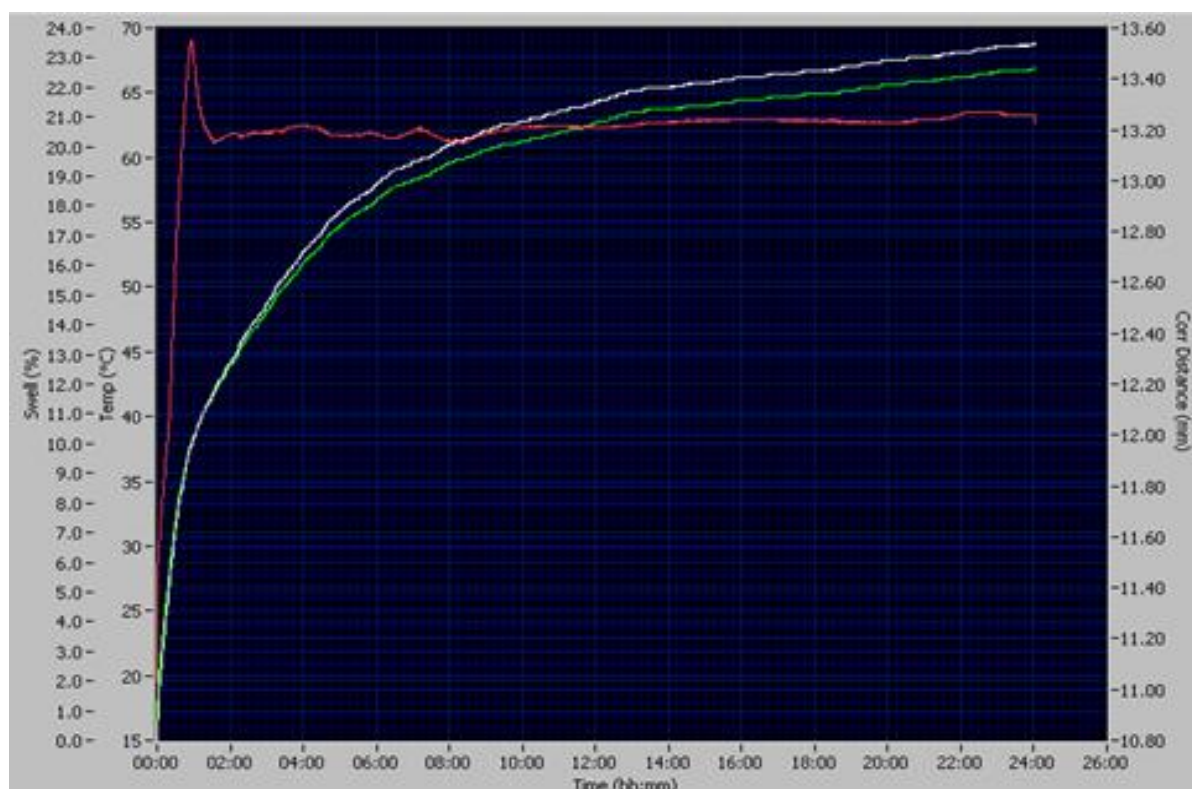


Figure 5. Swelling curve of sludge tablets contact with mud containing barium salts without inhibitor.

4. Conclusion

Compared to the conventional polymer drilling muds, the drilling mud containing formates and barium salts is also proved to be thermostable and efficient for abnormally high pressure formations. The results obtained by means of the swell capacity test instrument have shown that the proposed formulations demonstrate shale swelling reduction of 250% - 300% in comparison with the conventional muds.

Taking into account all the above-mentioned factors that positively influence the conditions of penetration, it can be concluded that the drilling muds containing potassium formate are the most appropriate to penetrate abnormally high pressure formations. Thus, it can be stated that the use of the described method allows engineers to choose the type of a drilling mud that would satisfy specific geological conditions.

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