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DRILLING FLUIDS FOR DRILLING IN SHALE AND CLAY ROCKS****

1. INTRODUCTION

Clay shale rocks large intervals drilling generates a serious issues caused by hydration, swelling and dispersion of clay rock. Those reactions might lead to break-downs and complications in drilling as the consequences of borehole wall stability loss that have source in cave effect (occurrence of caverns and cavings) and borehole diameter sharp decreasing. In a relation to the above mentioned issues there is still a need to develop new mud formula for clay rock drilling or improvement of existing one.

Oil mud or synthetic mud provides best clay rock's preservation. However, those types of muds have negative influence on the environment. Economical factor plays another vital role in development of drilling mud. Thus extensive cost of oil and synthetic muds is a drawback.

Simultaneously, water-based muds development is evolving. Nowadays the most popular mud of this group is polymeric-potassium mud with dual-inhibition mechanism containing ionic and polymeric inhibitors. The evolvement of such mud represents mud with triple-inhibition mechanism. Along with mentioned inhibitors (encapsulating polymers with high-mass particles) this mud has nanoparticulate polymer or polyglycol addition. Glycolic muds are considered as a separate group of muds.

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Clay rock drilling mud's other substantial assignments, besides rock's hydration prevention, are to provide drill cuttings lifting out of the borehole, drill cuttings maintaining in suspension, etc. [1].

2. DEVELOPMENT OF DRILLING MUD FORMULAS FOR THE RESEARCH

Firstly, regarding to conducted analysis of obtained data (geological profiles, mud reports) four types of drilling mud were selected for the research:

1) bentonite mud – intended for depth to 350 m interval,
2) chloride-polymeric mud – intended for 350–1100 m interval,
3) polymer-inhibited (glycolic) mud – intended for 1100–2940 m interval,
4) mud with triple-inhibition mechanism – intended for over 2940 m depth interval.

Following interpretation of the data formed a possibility for development of selected mud formulas intended for the preliminary research. Suggested mud formulas are presented below.

Bentonite mud – intended for 0–350 m interval
Technological assumptions:
Density – 1.05–1.30 g/cm^3.
Filtrate loss < 20 ml.
Yield point – YP = 12–20 Pa
Environment temperature around 20^{o}C

Suggested mud formulas:

Reagent	Concentration [%]
Bentonite	4.0
CMC LV	0.5
Na_2CO_3	0.4
$NaHCO_3$	0.1
NaOH	0.2

Reagent	Concentration [%]
Bentonite	4.0
CMS	0.5
Na_2CO_3	0.3
$NaHCO_3$	0.1

In case of bentonite mud, two formulas were suggested: first with application of low viscosity value caroboxymethyl cellulose, second with application of caroboxymethyl starch.

Chloride-polymeric mud – intended for 350 – 1100 m interval

Technological assumptions:

Density – 1.15–1.32 g/cm^3.

Filtrate density – 1.22 g/cm^3.

Filtrate loss < 8 ml.

Yield point – YP = 7–14 Pa

Chlorides – max. 195 g/l

Environment temperature around 20–40^{o}C

Suggested mud formula:

Reagent	Concentration
CMC LV	1.3%
XCD	0.2%
PAC LV	0.3%
PHPA	0.3%
KCl	7.0%
NaCl	266 g/l
Blok M-25	130 g/l
Drill cuttings	10%

Polymer-inhibited mud – intended for 1100–2940 m interval

Technological assumptions:

Density – 1.15–1.20 g/cm^3.

Filtrate density – 1.14 g/cm^3.

Filtrate loss < 5 ml.

Yield point – YP = 9–11 Pa

Chlorides – max. 120 g/l

Environment temperature around 40–90^{o}C

Suggested mud formula:

Reagent	Concentration
CMC LV	1.3%
XCD	0.2%
PAC LV	0.3%
PHPA	0.3%
KCl	7.0%
NaCl	143 g/l
Glycol GP	4.0%
Blok M-25	100 g/l
Drill cuttings	10%

Mud with triple-inhibition mechanism – intended for over 2940 m depth interval
Technological assumptions:
Density – 1.15–1.20 g/cm^3.
Filtrate density – 1.1 g/cm^3.
Filtrate loss < 5 ml.
Yield point – YP = 9–11 Pa
Chlorides – max. 90 g/l
Environment temperature around 40–90^{o}C

Suggested mud formula:

Reagent	Concentration
CMC LV	1.7%
XCD	0.2%
PAC LV	0.3%
KCl	5.0%
NaCl	109 g/l
Glycol GP	3.0%
Blok M-25	120 g/l
Drill cuttings	10%

3. STANDARD TESTS AND STUDIES ON INFLUENCE OF DRILL CUTTINGS ON DEVELOPED DRILLING MUDS

Preliminary research contains technological parameters measurement of chosen muds, performed according to API specification standard [2] and Polish industry standards. Results are presented on Figures 1–4.

Bentonite mud – CMC LV based

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1025	17.9	27.5	9.5	7.7/18.3	9.7	10

Bentonite mud – CMS based

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1025	15.6	26.5	10.3	9.2/19.7	9.9	10

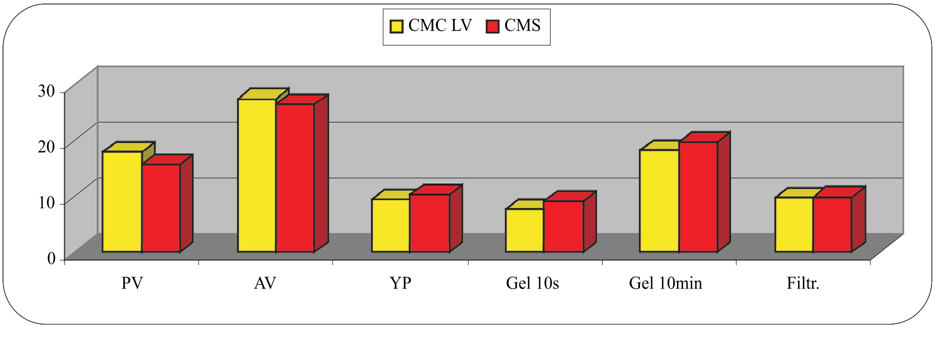

Fig. 1. Technological parameters of bentonite mud depending on formula

Due to test results it can be concluded that CMS based bentonite mud reveals slightly better technological parameters than CMC LV based bentonite mud. As can be seen in Figure 1 CMS based mud exhibits lower viscosity parameters values (PV and AV) and higher gel strengths parameters values (YP and Geles). Both muds filtrate loss comparability has been noticed.

Chloride-polymeric mud – without drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1240	40.4	73.2	32.7	5.4/7.4	14.5	9

Chloride-polymeric mud – with drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1300	40	59	18.2	3.4/4.8	2.8	9

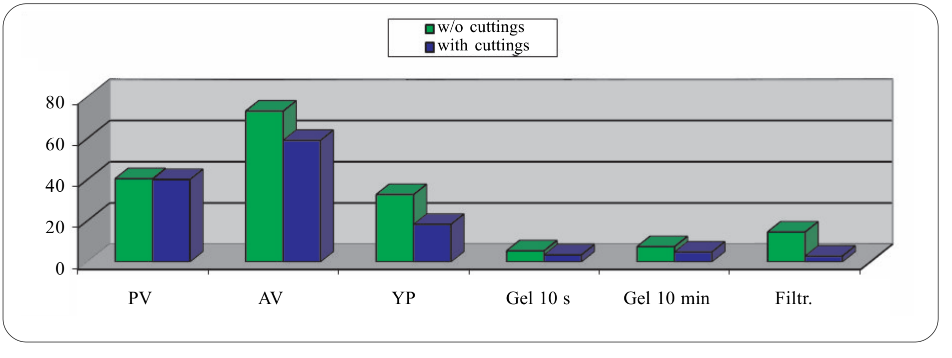

Fig. 2. Influence of drill cuttings on technological parameters of chloride-polymeric mud

On the basis of above tests outcomes it has been found that addition of drill cuttings to studied muds causes decrease of chloride-polymeric mud's technological parameters. Although plastic viscosity marginally changed its value. Major reduction of filtrate loss has been observed, which is advantageous.

Polymer-inhibited mud – without drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1140	27.9	56.5	28.6	4.2/6.1	9.5	9

Polymer-inhibited mud – with drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1220	33	49.5	15.8	2.9/3.8	2.4	9

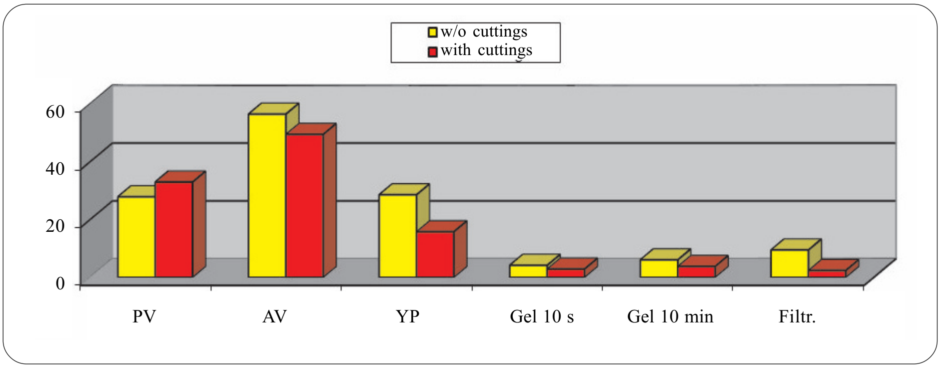

Fig. 3. Influence of drill cuttings on technological parameters of polymer-inhibited mud

The results show that drill cuttings applied to polymer-inhibited mud creates problematic increase of plastic viscosity. Rest of the technological parameters decreased.

In terms of mud with triple-inhibition mechanism, drill cuttings addition affected viscosity parameters by increasing them. Also, decrease of gel strength parameters and filtrate loss has been noticed.

Mud with triple-inhibition mechanism – without drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1090	28	48.5	20.5	3.4/4.7	9	9

Mud with triple-inhibition mechanism – with drill cuttings

Density	Plastic viscosity	Apparent viscosity	Yield point	Gel 10 s/10 min	Filtrate loss	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[Pa]	[ml]	[–]
1190	33	49.5	15.8	2.4/3.8	2.4	9

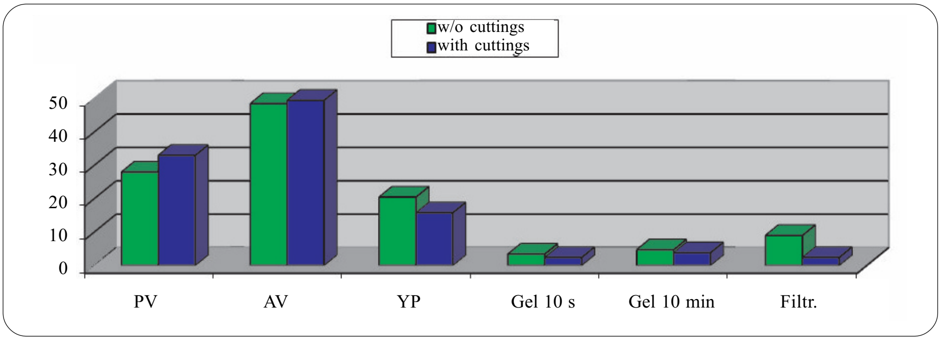

Fig. 4. Influence of drill cuttings on technological parameters of mud with triple-inhibition mechanism

4. TESTS OF DEVELOPED MUDS IN SIMULATED BOREHOLE CONDITIONS

In the subsequent research phase, technological parameters measurement of developed muds has been undertaken under simulated borehole conditions (raised temperature and dynamic) adjusted to each drilling mud intended depth. Tests results are summarized in Figures 5–8.

Bentonite mud studies have been conducted under 20°C, bearing in mind low temperatures of mud's working environment. Filtrate loss comparison for both static and dynamic conditions has been measured. Following muds tests have been carried out in 50°C temperature and filtration has been measured only in dynamic conditions.

Bentonite mud

Bentonite mud	HPHT filtration [ml/30 min]	
	static	dynamic
CMC LV based	10.7	14.3
CMS based	10.5	11.2

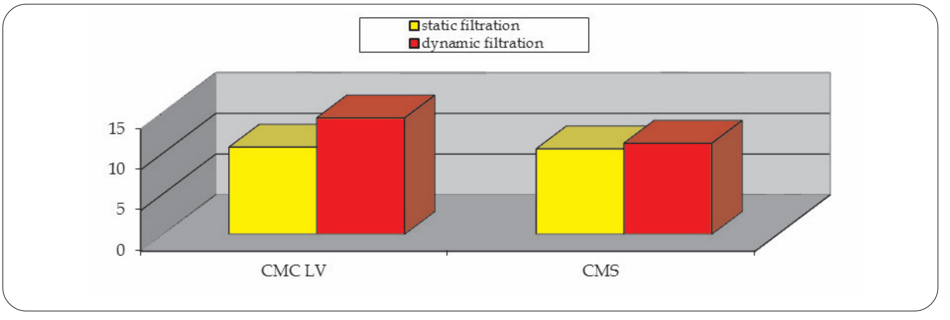

Fig. 5. Influence of dynamic conditions on technological parameters of bentonite mud

Performed test conclusion is that both muds filtrate loss rises in dynamic conditions. As shown in Figure 5 CMC LV based mud increase is more evident

Chloride-polymeric mud

Density	Plastic viscosity	Apparent viscosity	Yield point	Dynamic HPHT filtration	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[ml]	[–]
1300	24	32.5	8.1	5.2	9

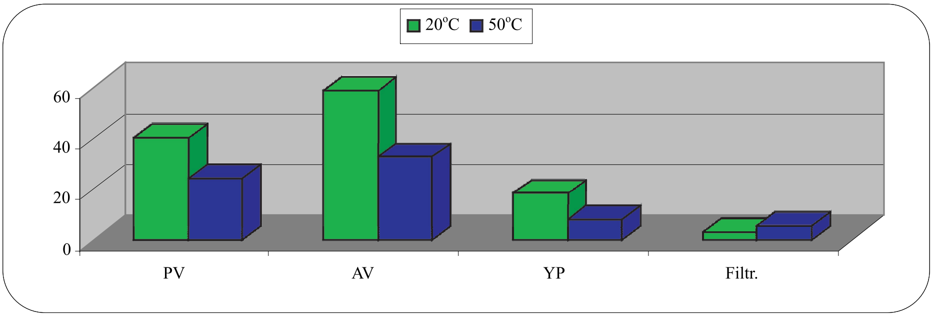

Fig. 6. Influence of temperature and dynamic conditions on technological parameters of chloride-polymeric mud

Polymer-inhibited mud

Density	Plastic viscosity	Apparent viscosity	Yield point	Dynamic HPHT filtration	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[ml]	[–]
1220	20	29	8.6	5.6	9

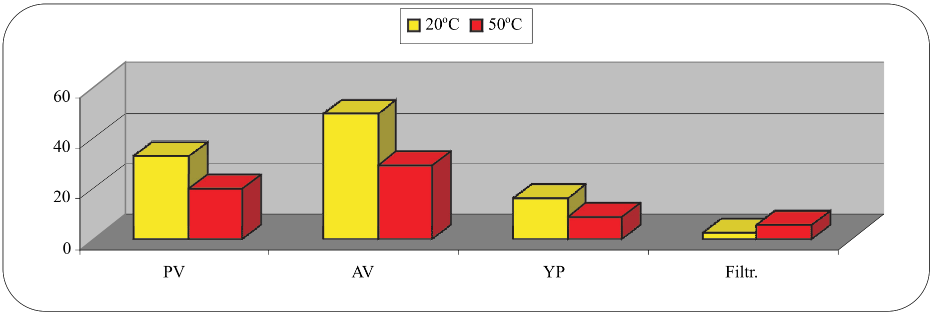

Fig. 7. Influence of temperature and dynamic conditions on technological parameters of polymer-inhibited mud

Mud with triple-inhibition mechanism

Density	Plastic viscosity	Apparent viscosity	Yield point	Dynamic HPHT filtration	pH
[kg/m^3]	[mPa·s]	[mPa·s]	[Pa]	[ml]	[–]
1190	18	26	7.7	7.0	9

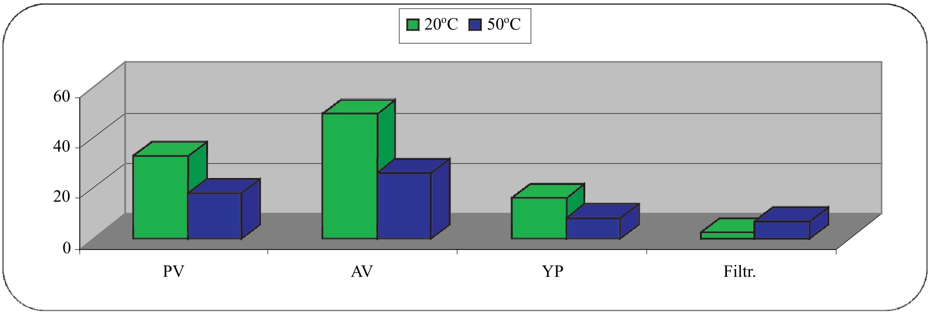

Fig. 8. Influence of temperature and dynamic conditions on technological parameters of mud with triple-inhibition mechanism

Based on research findings, it has been established that increase of temperature generates decrease of developed muds' technological parameters. Another relevant finding is that filtrate loss intensification can be observed during measurement, performed in dynamic conditions and risen temperature.

5. TEMPERATURE RESISTANCE TESTS OF DEVELOPED MUDS

Temperature resistance tests of developed muds was the next focus of the research. Test outcomes are summarized on Figures 9–14.

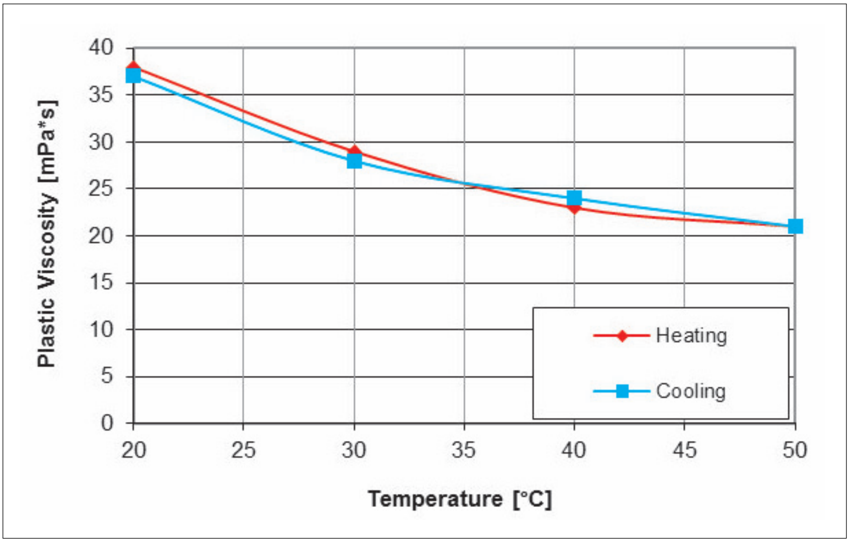

Fig. 9. Plastic viscosity and temperature dependency for chloride-polymeric mud

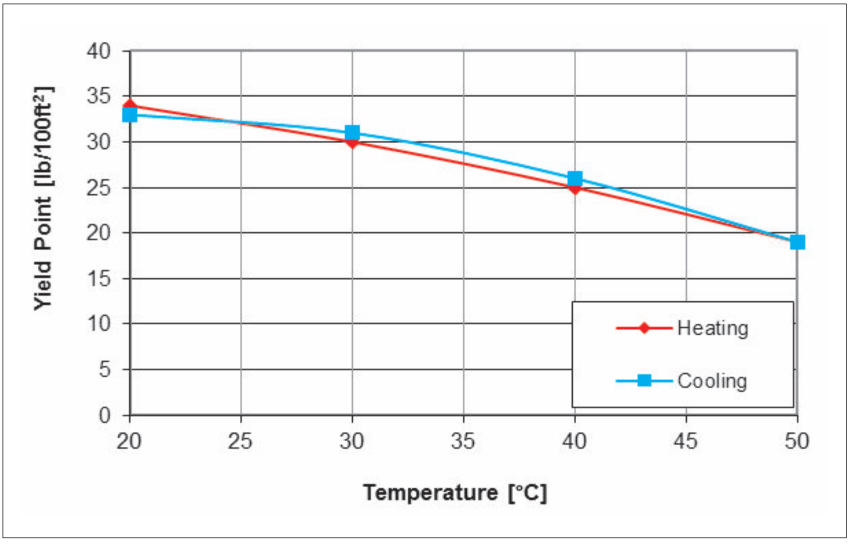

Fig. 10. Yield point and temperature dependency for chloride-polymeric mud

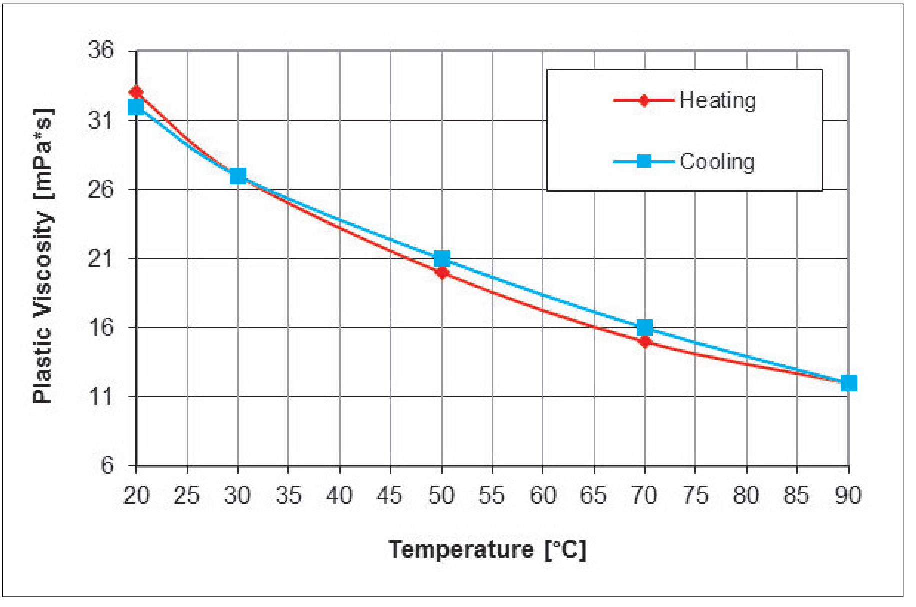

Fig. 11. Plastic viscosity and temperature dependency for polymer-inhibited mud

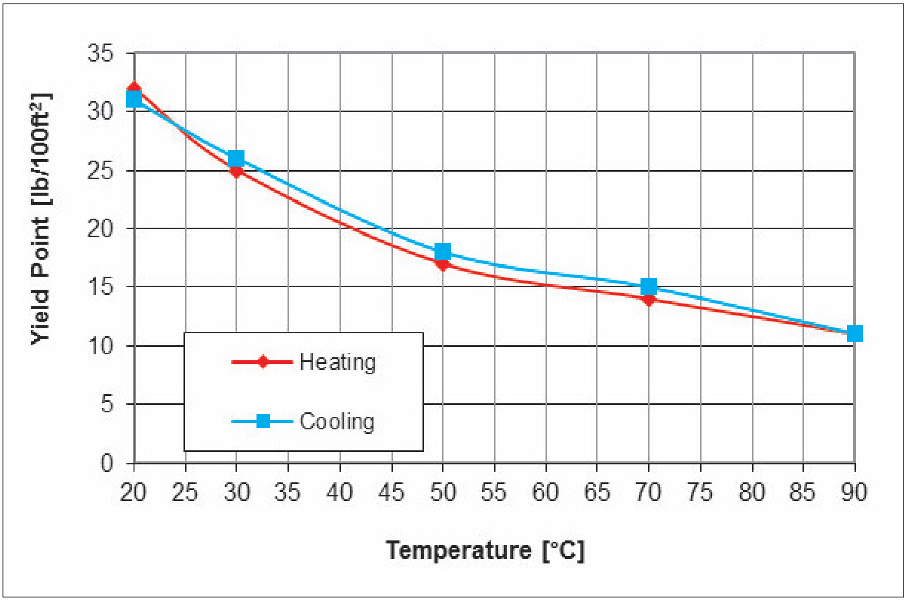

Fig. 12. Yield point and temperature dependency for polymer-inhibited mud

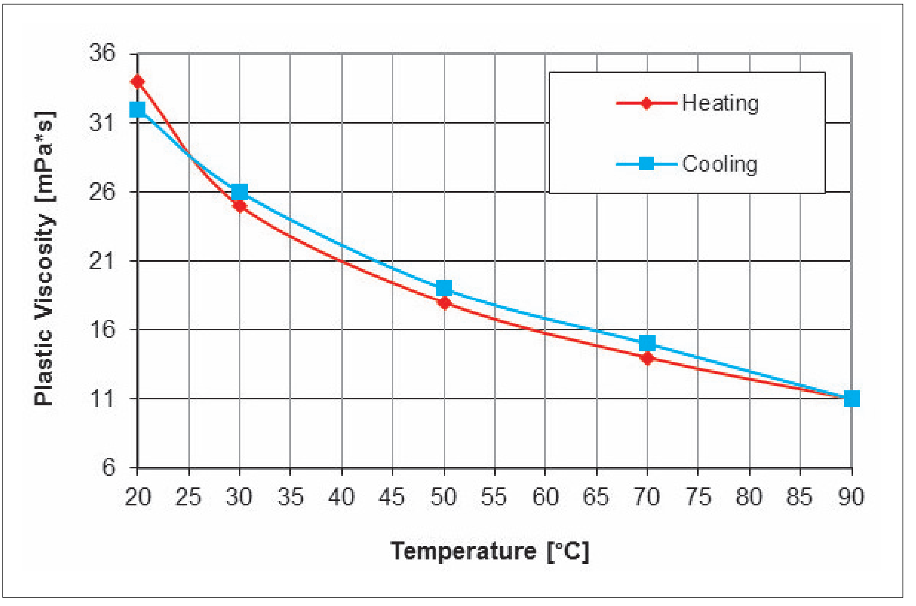

Fig. 13. Plastic viscosity and temperature dependency for mud with triple-inhibition mechanism

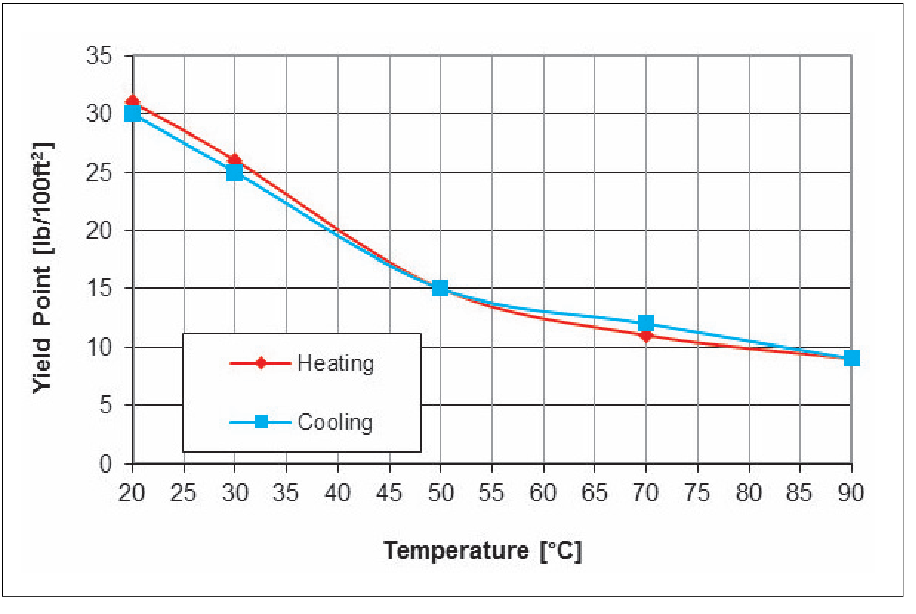

Fig. 14. Yield point and temperature dependency for mud with triple-inhibition mechanism

The results indicate that studied muds' properties decreases with increase of temperature. Those values reached satisfying levels for borehole drilling process. During cooling down of muds, technological parameters return to its initial values. That indicates high resistance of developed muds to temperature (its components do not dissolve while being heated).

6. DISPERSION TEST OF CLAY SHALE ROCK

Dispersion test of clay shale rock is a basic method of inhibition of drilling muds or inhibitors solutions effectiveness assessment. The test has been undertaken at the Oil and Gas Institute in Poland (INIG). Percentage recovery of drill cuttings dispersed in suggested solutions of inhibitors can be estimated with this method.

Dispersion test has been held for developed muds with addition of Miocene shale (Fig. 15).

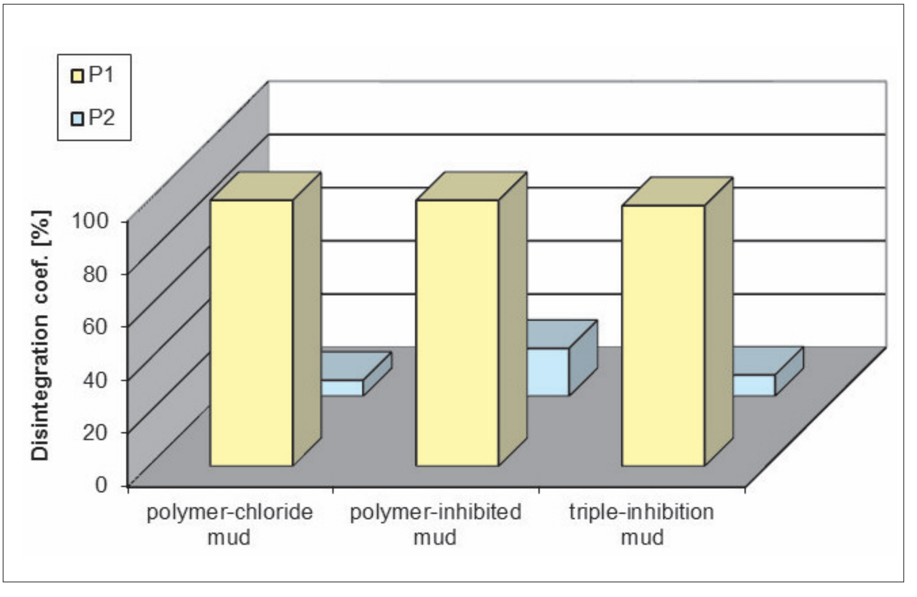

Fig. 15. Properties of inhibition of clay rock (Miocene shale) dispersion of studied drilling muds

On the basis of performed dispersion test, it has been found that rock samples do not disperse after interaction with mud. However, water influence causes disintegration of the rock. For that purpose modification of developed muds formulas is required.

7. CONCLUSIONS

The research shows that drilling mud developed for drilling in intervals of shale rocks are characterized by good technological parameters and effectively protect shale rocks against disintegration.

REFERENCES

[1] Bielewicz D.: *Drilling Fluids*. Wydawnictwa AGH, Kraków 2009.
[2] *API Specification 13B-2*. 5th Edition, April 2014.