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DRILLING MUD FOR SHALE GAS DRILLING***

1. INTRODUCTION

Nowadays, obtaining natural gas from shale formations generate a lot interest from oil companies. One of the main issues during drilling in this kind of rock is the use of proper drilling fluid characterized by good rheological parameters and a high level of shale hydration inhibition. Drilling in shale formation causes a lot of difficulties. This is due to hydration, swelling and shale rock dispersion, resulting in a loss of stability of the wall of the hole. This leads to a reduction the hole diameter, erosion of the wall or even clamping hole, which may result in the stuck of drilling string, causing failure. Therefore, it is necessary to use congruent chemical substances with inhibitive properties. Selecting the relevant components of the drilling mud can reduce the occurrence of negative physical-chemical phenomena observed between shales and drilling mud. Proper drilling fluid allow for drilling in layers of shale and preform of a hydraulic fracturing [5, 6, 8, 10, 11, 15].

Oil-based muds are characterized by the best inhibition properties. Unfortunately, these muds have an adverse impact on the environment and have high a cost of production. Therefore, carried out research on the development of new water dispersive muds characterized by inhibition properties similar to oil-based muds. The most commonly used drilling mud to shale formation is a potassium/polymer muds containing anionic polymer. However, these muds have a negative impact on reservoir rocks. To improve inhibition properties used of novel polymer inhibitors and eliminated bentonite from drilling mud composition. Performed laboratory tests confirmed the usefulness of cationic and amphoteric polymer, polyglycol and silicate in drilling mud compositions. By using these polymers established a new type of drilling mud i.e. polysilicate – potassium mud, glycol – potassium mud, cationic and amphoteric mud. Developed drilling mud are characterized by a higher level shale hydration inhibition than in the case of traditional KCl – PHPA mud inhibition system [2–6, 8–10].

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To investigate the adverse of phenomena taking place in contact the shale rocks – drilling mud used appropriate laboratory methods. We can determine the effectiveness of the impact of inhibitors on the drilled formations. Shale swelling measurement and analysis of the dispersion of shale rocks are basic laboratory research enabling the effectiveness of the inhibiting impact drilling mud on the shale rock. Alsoby these methods, we can determine the amount and type of the inhibitor that effectively inhibits swelling.

The purpose of the laboratory examination was to estimate the impact of different polymer inhibitors for the hydration of clays and shales. Laboratory tests were performed in order to estimate the concentration of polymer inhibitors in preventing the phenomena taking place in contact with the shale rocks – drilling mud. Also, to research the influence a drilling fluids containing different kinds of hydration inhibitors on swelling and clays and shales dispersion. Laboratory tests to determine inhibitory properties of used drilling mud were carried out on samples of clay-shale rocks represented by Miocene shale, characterized by high dispersion and swelling.

Laboratory examination was conducted for the basic drilling mud used in the petroleum industry:

– potassium – polymer mud,
– glycol – potassium mud,
– polysilicate – potassium mud,
– amine mud.

KCl – PHPA mud

For drilling in shale formations is commonly used potassium-polymer mud, wherein inhibitory function fulfill KCl – PHPA system. In drilling mud of this type the reduction of hydration is achieved by the interaction of the two inhibition systems:

– ion inhibition (K^+) by using of KCl,
– polymer inhibition by using a encapsulation polymer [2–4, 8, 10].

Polysilicate – potassium mud

In polysilicate – potassium drilling mud used sodium silicate and KCl system, which asct as function of hydration inhibitors on swelling and clays and shales dispersion. In the beginning, the silicate mud contained 30–70% of sodium silicate. At present, in the in the composition of the silicate mud using 3–7% of silicate, it is possible by using a new type of polymers. In order to enhance the inhibitory impact of silicate and to control the osmotic flow of mud filtrate using different amounts of NaCl and KCl [2, 6, 8–10].

Glycol – potassium mud

Glycol – potassium drilling mud used for drilling in the shale formations is water dispersive mud. The main components of this mud are polyglycol. Polyglycol used together with an ion inhibitor provides a high inhibition degree of shale hydration. The function of the ion inhibitor can act on potassium inorganic salts (KCl, K_2SO_4) and organic salts (HCOOK, CH_3COOK). The combined effect of polyglycol and potassium chloride is difficult to explain. This synergistic effect may be associated with the properties of K^+ ion, having a lower energy of hydration compared to the sodium ion or calcium ion. It is expected that the impact of the polyglycol on potassium cations involves interaction between K^+ ion and the inner part of the chain polyglycol molecules, which leads to repel of water and the formation of a stable waterproof complex [6, 8, 10].

Cationic polymer mud

The components of the cationic polymer mud suitable inhibiting properties are the two cationic polymers: low molecular weight and high molecular weight. The inhibitory action of cationic muds based on the fact that the polymers bind by electrostatic forces to the negatively charged surface shale rock. This leads to neutralization the negative charged and the displacement of the weakly bound inorganic cations. The result of the interaction between the drilling mud and shale rock is the process of ion exchange and the process of encapsulating the borehole wall by the high molecular weight cationic polymer. The reduction of osmotic hydration is achieved by using low molecular weight cationic polymer [2–4, 6, 8].

2. LABORATORY TESTS

All tests carried out dealt with the applicable standards of API [1] and national standards. To research of rheological parameters used Grace M3500 viscometer. Swelling test were carried out using HPHT Linear Meter Swell M4600, and the disintegration test was carried out according to the methodology developed in INIG Krosno.

PHPA polymers

In first phase of research performed in order to estimate the impact concentration of PHPA polymer on the rheological parameters of 3% bentonite suspension and on swelling Miocen shale. Tests were carried out on two PHPA polymers described as: B and P. Research results are shown in Figures 1 and 2.

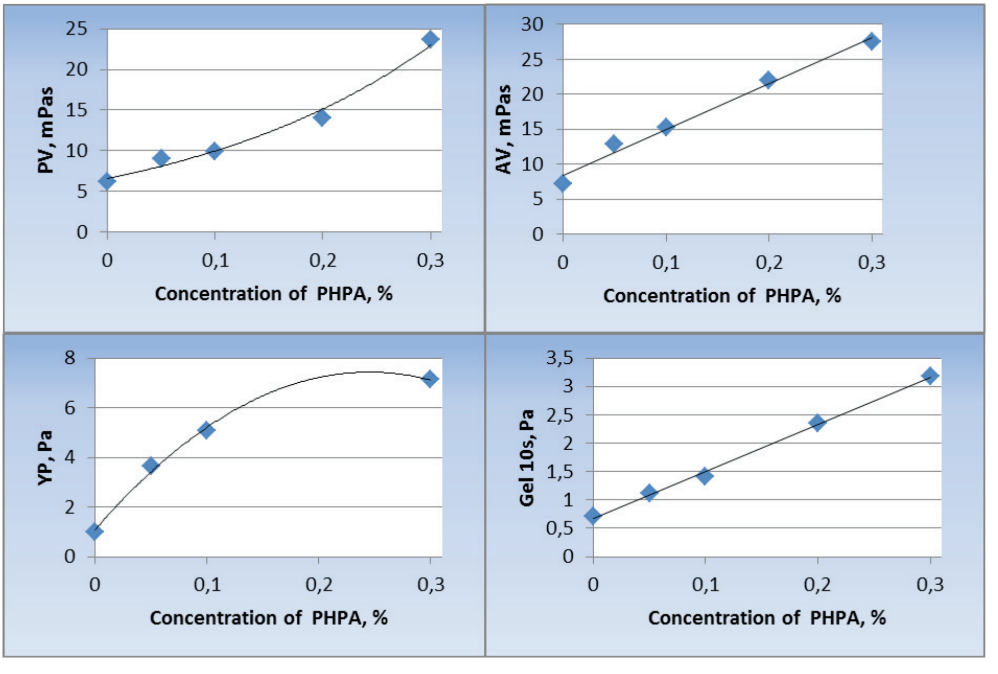


Fig. 1. Polymer B concentration influence on rheological parameters

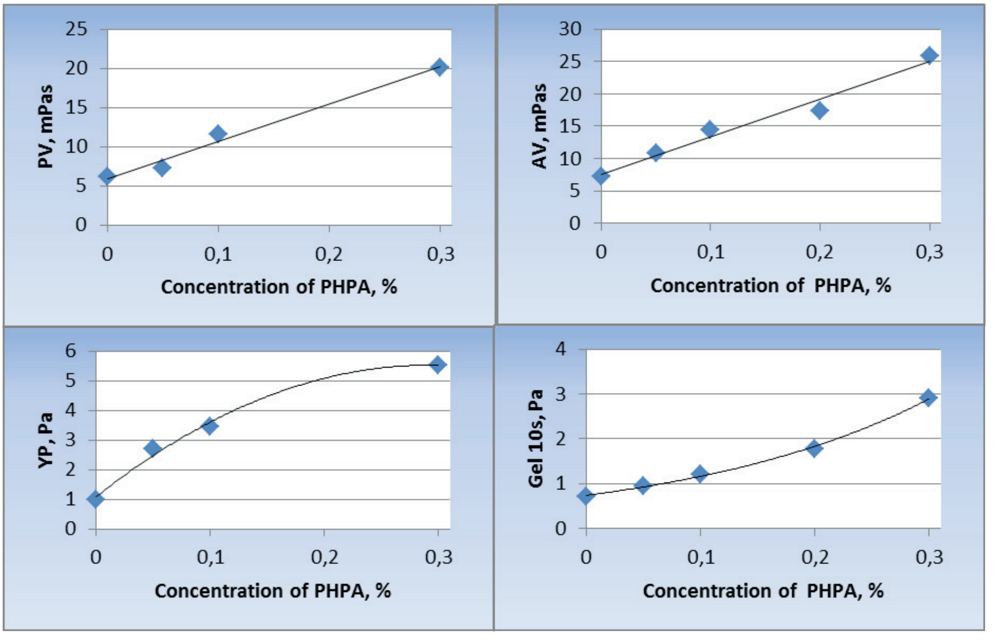


Fig. 2. Polymer P concentration influence on rheological parameters

The study showed that increasing the polymer concentration in mud causes an increase in rheological parameters. At a 0.3% polymer concentration yield point decreased to both polymer B and P. The results of rheological parameters for the B polymer are better than for P polymer.

The results of swelling for the tested muds containing hydration inhibitors P and B have been showed on Figures 3 and 4.

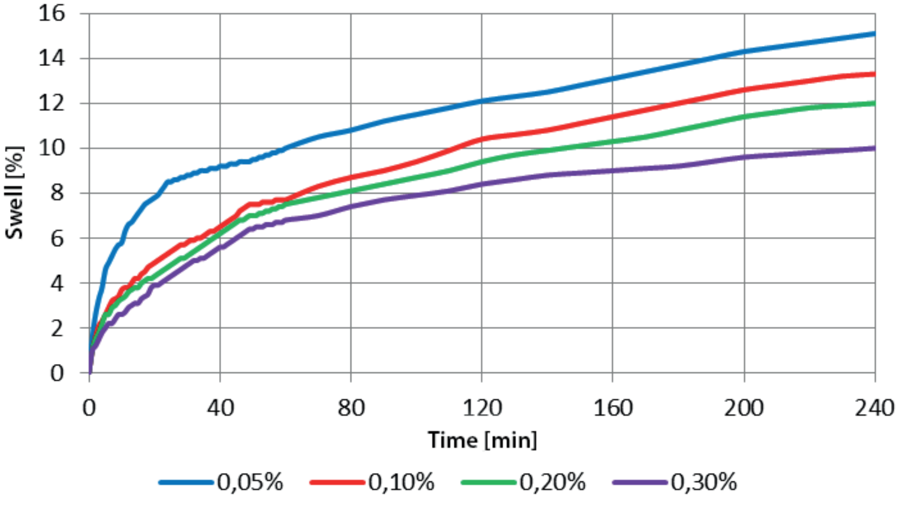


Fig. 3. Linear swelling test results for different concentration of P polymer

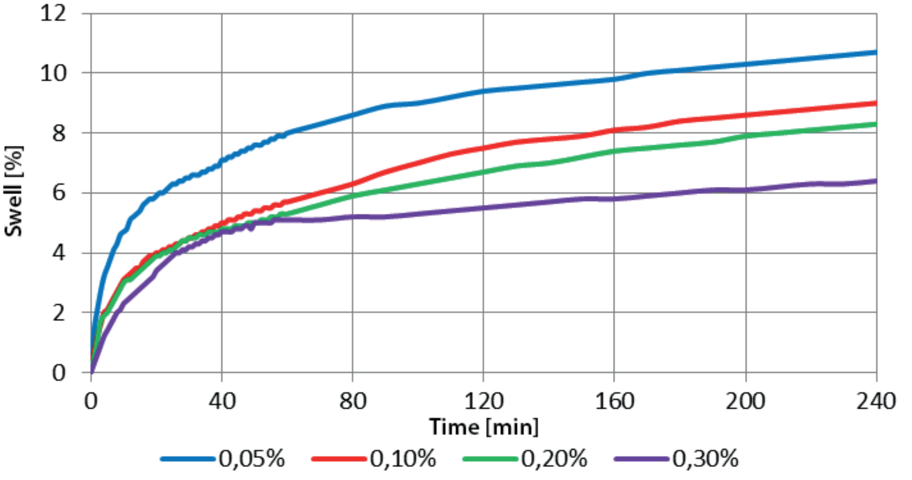


Fig. 4. Linear swelling test results for different concentration of B polymer

The laboratory tests showed that increasing the polymer hydration inhibitor concentration in mud causes a decrease in swelling. Analyzing the results it can be concluded that the polymer B is more effective restriction of swelling as compared to polymer P. The lowest degree of swelling was obtained using the polymer B at 0.3% concentration, and it was equal to 6.4%.

To test the inhibitory properties of drilling mud were also carried out QSE Pellets test. Bentonite pellets were conditioned for 24 hours in the mud filtrate, and then evaluate the degree of dispersion. For this, we purpose, the size of the pellets before and after the test. The result of the test for mud with polymer P showed in Figure 5, results of test for mud with polymer B shown in Figure 6.

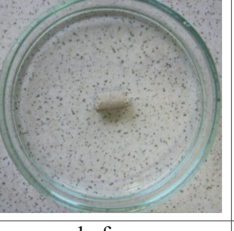
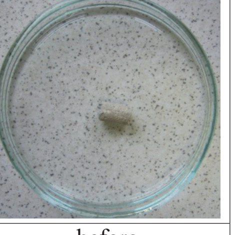
0.05%	0.1%	0.2%	0.3%
			
before	before	before	before
			
after	after	after	after

Fig. 5. QSE Pellets test for mud with polymer P

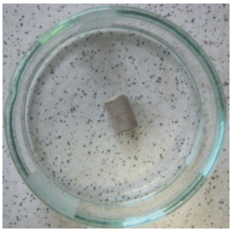
0.05%	0.1%	0.2%	0.3%
			
before	before	before	before
			
after	after	after	after

Fig. 6. QSE Pellets test for mud with polymer B

The test result showed an effective inhibitory effect of the test polymers. The swelling of the bentonite pellet decreases with the increasing of the polymer inhibitor concentration. In the case of polymer concentration of 0.2% and 0.3% the QSE pellets swelled a little and have a relatively high mechanical strength.

The selected drilling muds

The second phase of research was to estimate the influence of drilling fluids containing different kinds of hydration inhibitors on swelling and clays and shales dispersion.

Estimate solutions effect on the hydration and dispersive property, density, rheology, API filtration, pH and check the thermal resistance of mud. A laboratory examination was conducted for the following types of drilling mud: potassium-polymer, glycol – potassium, polysilicate – potassium and amine. Potassium – polymer mud prepare in four versions with different anionic polymers PHPA. The drilling muds compositions are shown in Table 1.

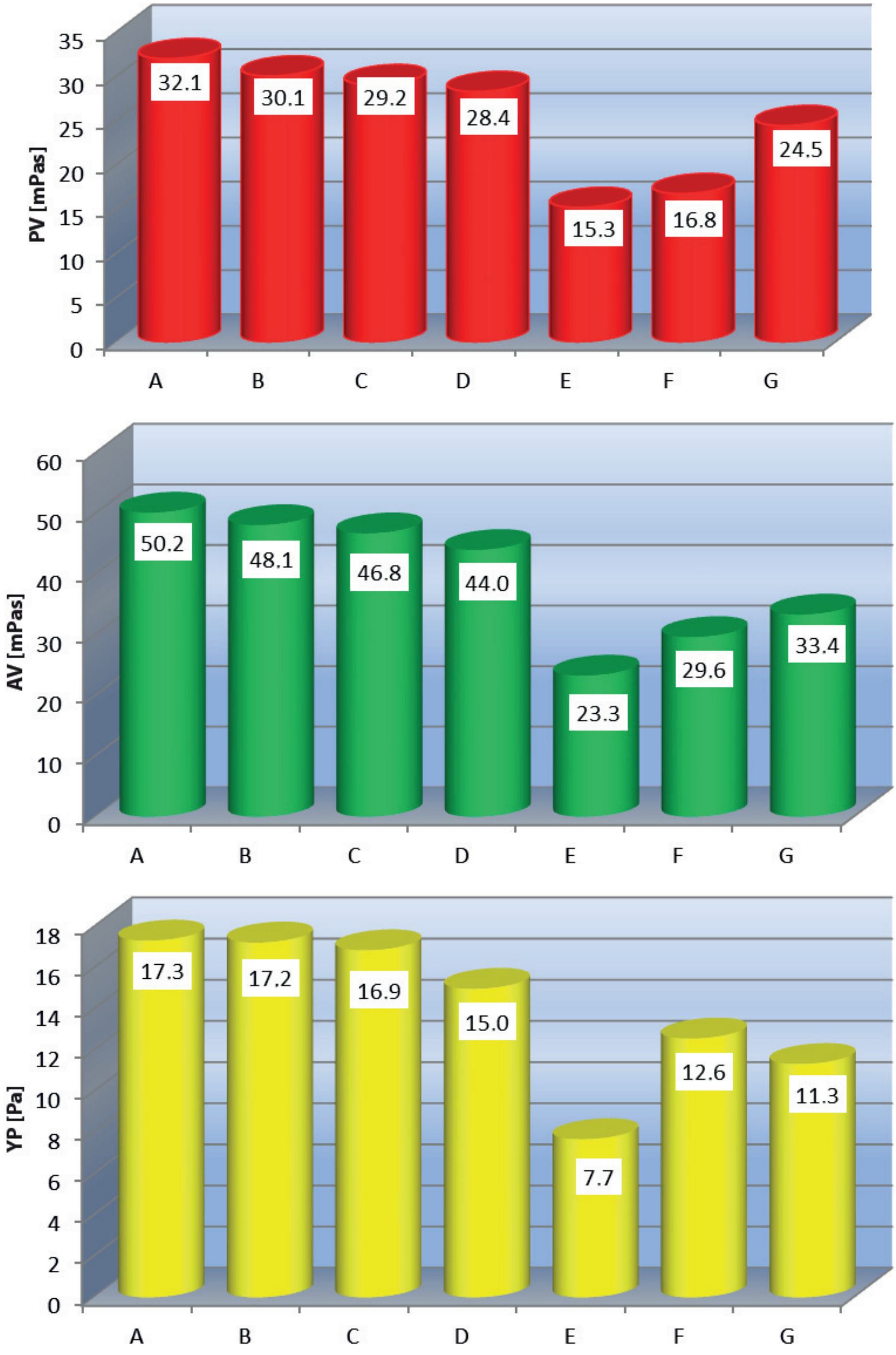
In amine mud used polymer and amine compound systems, which act as a function of hydration inhibitors on swelling and clays and shales dispersion. An amine compound was synthesized at the Institute Oil and Gas in Krosno. On the basis of the laboratory tests, was found that amine compound have inhibiting properties [5, 12].

Table 1

Compositions of test drilling muds

Type of mud	Composition of mud [%]	
Potassium – polymer (Mud A)	Biocide Starch XCD KCl Bridging mat. 25μ PHPA “B”	0.10 3.00 0.20 5.00 7.00 0.20
Potassium – polymer (Mud B)	Biocide Starch XCD KCl Bridging mat. 25μ PHPA “P”	0.10 3.00 0.20 5.00 7.00 0.20
Potassium – polymer (Mud C)	Biocide Starch XCD KCl Bridging mat. 25μ PHPA “PP”	0.10 3.00 0.20 5.00 7.00 0.20
Potassium – polymer (Mud D)	Biocide Starch XCD KCl Bridging mat. 25μ PHPA “A”	0.10 3.00 0.20 5.00 7.00 0.20
Glycol – potassium (Mud E)	Biocide Starch XCD KCl Bridging mat. 25μ Polyglycol 400	0.10 3.00 0.20 5.00 7.00 4.00
Polysilicate – potassium (Mud F)	Biocide Starch XCD KCl Bridging mat. 25μ Sodium silicate R-140	0.10 3.00 0.20 5.00 7.00 4.00
Amine (Mud G)	Biocide Starch XCD KCl Bridging mat. 25μ Ultracap Amine compound	0.10 3.00 0.20 5.00 7.00 0.20 3.00

The results of technological parameters tests are shown in Figure 7.



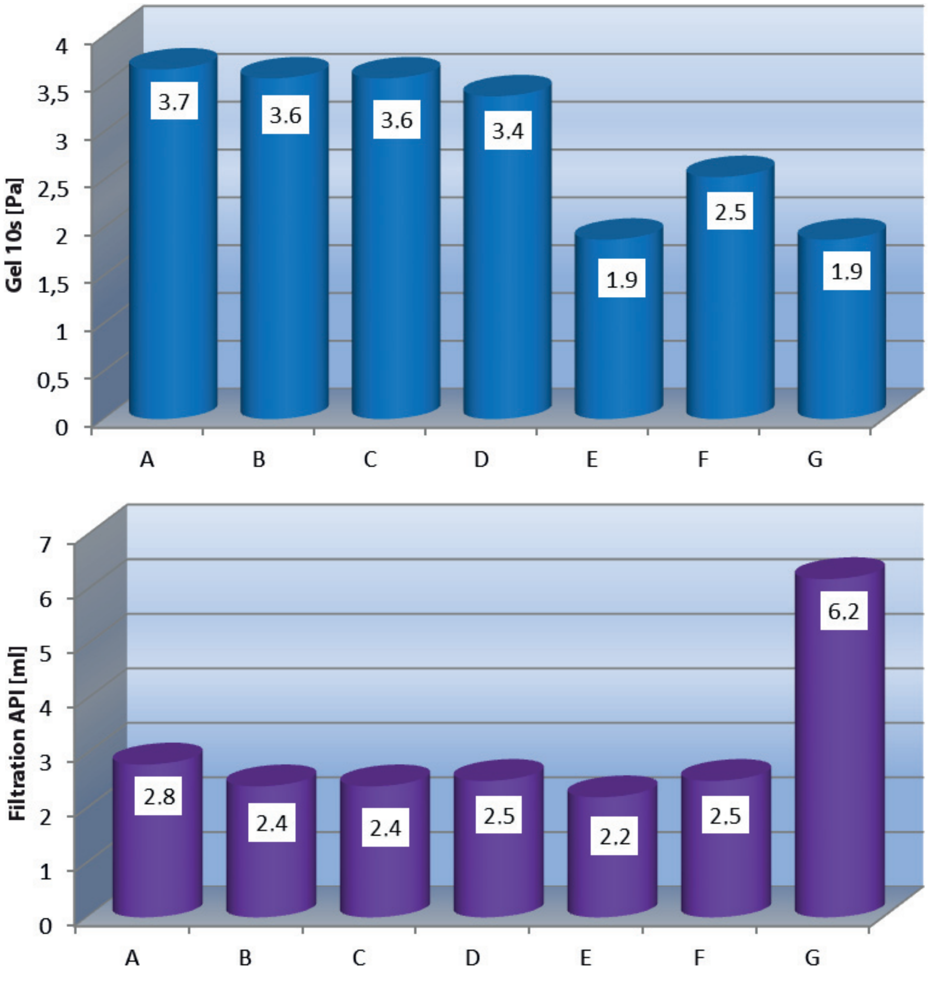


Fig. 7. Technological parameters tested drilling muds

The highest parameters have been noticed for potassium – polymer mud containing B polymer: plastic velocity 32.094 mPa·s, apparent viscosity 50.196 mPa·s, yield point 12.332 Pa, Gel 10s 3.654 Pa. Glycol – potassium and polysilicate – potassium mud are characterized by similar values of viscosity. The lowest rheological properties obtained for glycol – potassium mud. Yield point for this mud was significantly lower the other muds and amounted 7.683 Pa. Comparing the API filtration of drilling muds can be concluded that these muds have a similar filtration, only amine mud has a higher value. Muds are characterized by the same values of density (1.07 g/cm^3) and similar values of pH ~9.5. Polisilicate – potassium mud has elevated pH – 11.20.

Thermal resistance of rheological parameters

Test of the effect of elevated temperature on rheological parameters of drilling muds was carried out using high temperature and pressure viscometer Ofite 77. Mud heated 100°C and the cooled to room temperature, observing the rheological and structural properties during heating and cooling. The results are showed graphically in Figures 8–11.

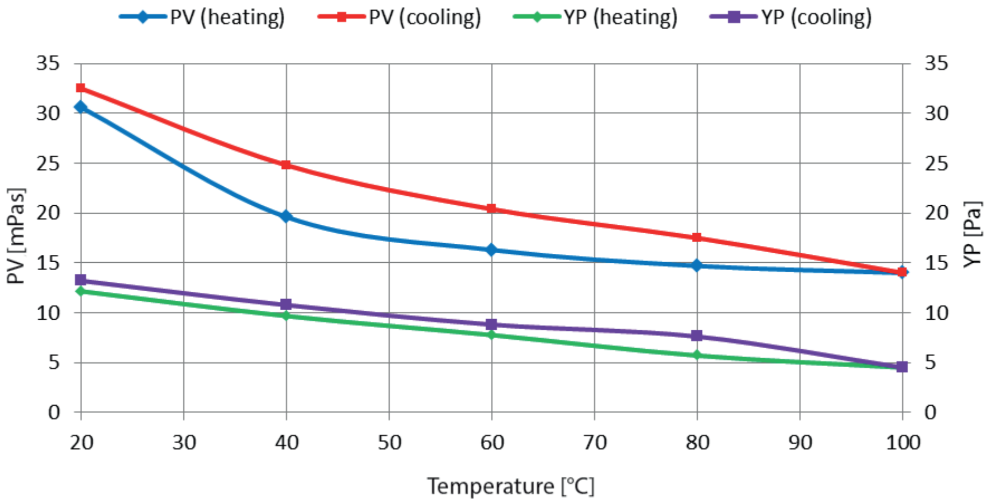


Fig. 8. Plastic viscosity (PV) and yield point (YP) – thermal resistance potassium – polymer mud (Mud A)

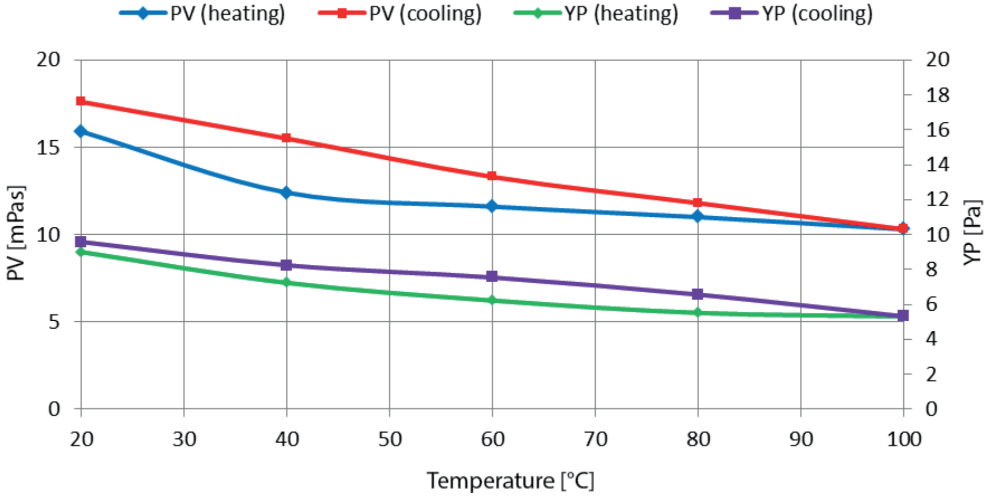


Fig. 9. Plastic viscosity (PV) and yield point (YP) – thermal resistance glycol – potassium mud (Mud E)

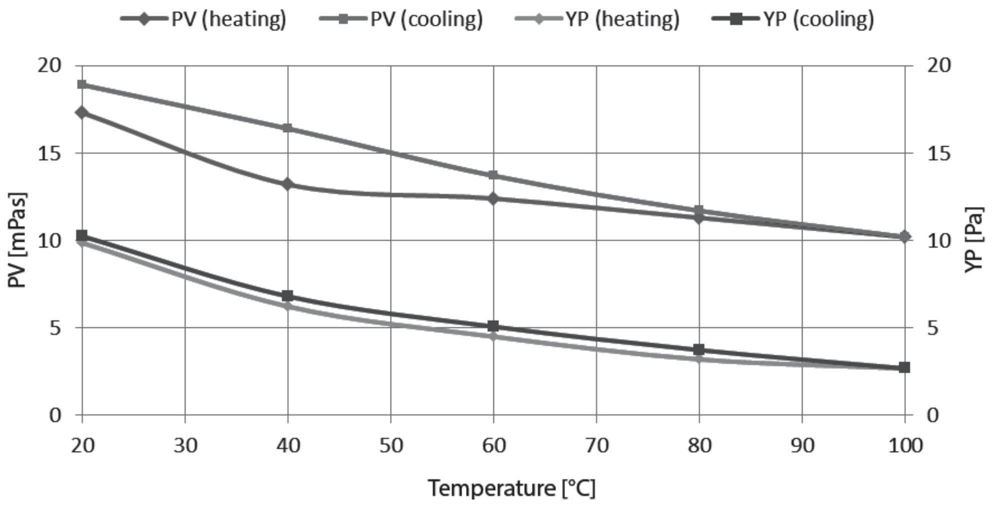


Fig. 10. Plastic viscosity (PV) and yield point (YP) – thermal resistance polysilicate – potassium mud (Mud F)

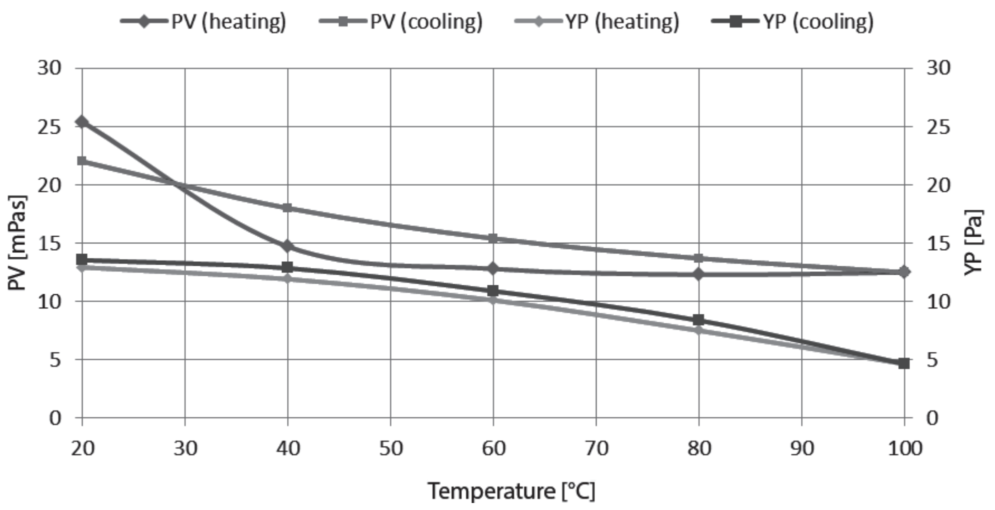


Fig. 11. Plastic viscosity (PV) and yield point (YP) – thermal resistance amine mud (Mud G)

With increasing temperature plastic viscosity and yield point decrease, while across the measurement cycle and lowering temperature to the room temperature rheological parameters increase to values close to baseline. Results show that despite temperature changes in the range of 20–100°C, the rheological parameters are not substantially changed. This indicates its good temperature resistance of using drilling mud.

Linear Swell Test

The Miocene shale swelling test was carried out using Grace M4600 HPHT Dynamic Linear Swell Meter. The research lasted for 20 hours. The Swelling test result shown in Figures 12 and 13.

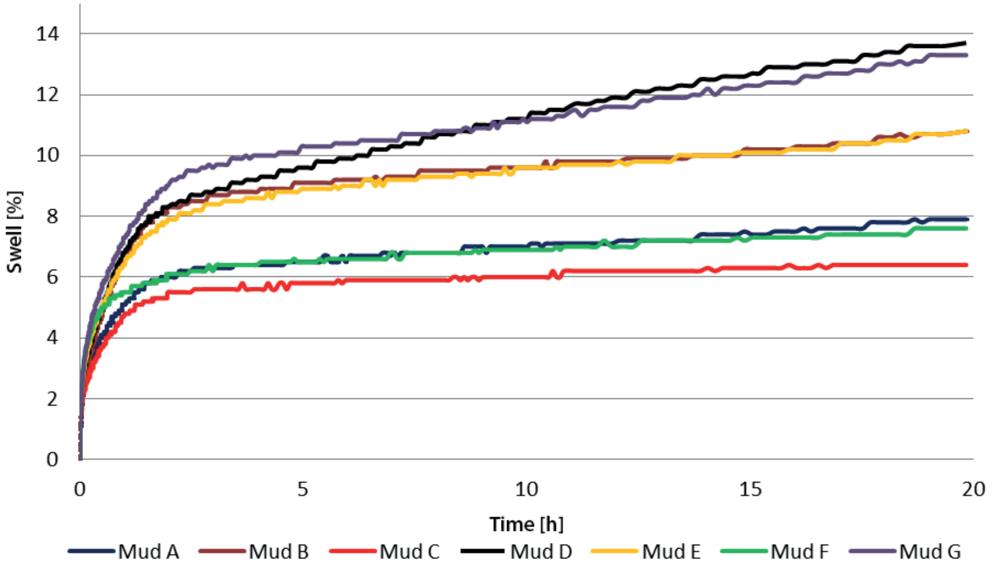


Fig. 12. Linear swelling test results for tested mud, time 20 hour

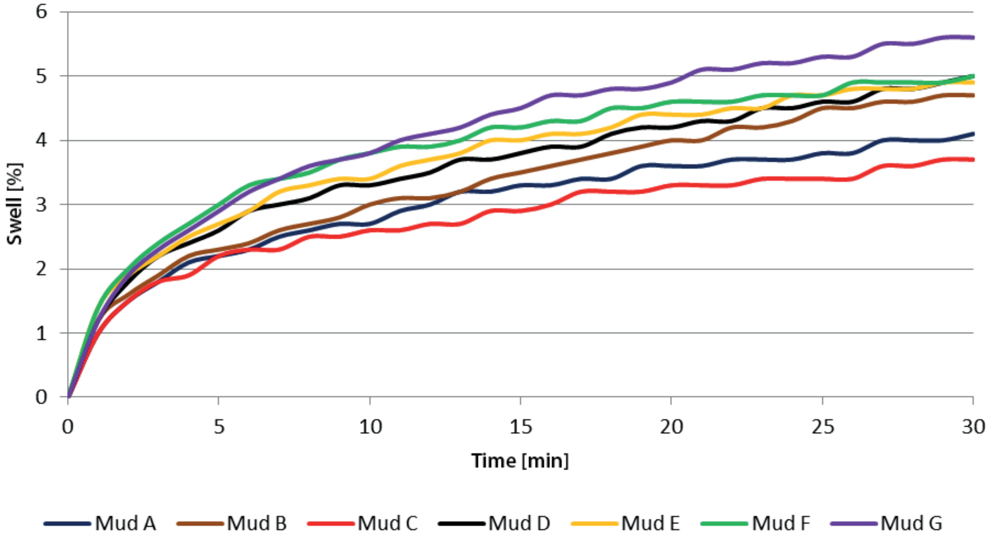


Fig. 13. Linear swelling test results for tested mud, time 30 minutes

The best swelling obtained using a potassium – polymer mud containing polymer PP 6.4% (Mud C), also the low swelling obtained for the polysilicate – potassium mud 7.6% (Mud F). The highest swelling gave using potassium – polymer mud containing A polymer (Mud D) and the amine mud 13.3% (Mud G).

Research in shale dispersion (Miocene)

Research in shale dispersion was performed according to the methodology developed in the Oil and Gas Institute. It is one of the basic methods to evaluate the inhibition effectiveness of the drilling mud on shale rocks. The received results of research in the form of recovered rock samples allow for the evaluation of the inhibitory properties of the mud. It is expressed the size of damage rocks after drilling mud impact on the outer surfaces of the clay minerals. This method allows for choosing the amount and type of polymeric inhibitor for reducing the forces of hydration on the surface. The results are shown in Figure 14. The laboratory test was performed for the Miocene shale.

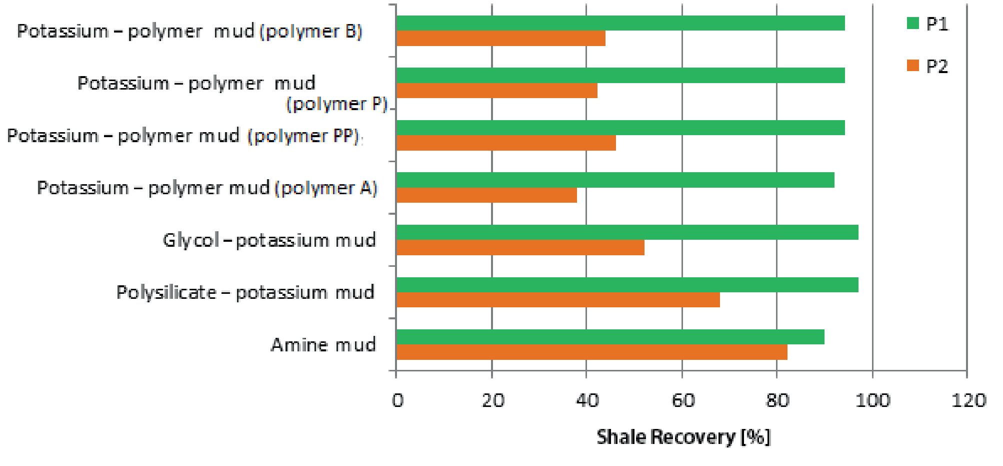


Fig. 14. Miocene shale recovery
P1 – recovery after drilling mud, P2 – recovery after water

Test drilling muds are characterized by high inhibition degree of Miocene shale hydration. Miocen shale recovery values are 90–97%, and after the dispersion in water and pre-impact of drilling mud 38–82%, The highest recovery value of shale after drilling mud interaction obtained for the glycol – potassium mud (Mud E) and polysilicate – potassium mud (Mud F) which was 97%, and the highest recovery after exposure to water achieved for the amine mud (Mud G), equal 82%.

3. CONCLUSIONS

As a result of the laboratory test, it has been concluded that:

1. The increased polymer concentrations in the drilling mud has reduced the swelling of shale rock and improved rheological properties.

2. Polymer inhibitors used in the drilling muds exhibited a high inhibition degree of shale hydration.
3. Glycol – potassium mud and polysilicate – potassium mud are characterized by the best dispergating prevention of drilled shale rocks under the influence of drilling mud.
4. Amine mud are characterized by the best dispergating prevention of drilled shale rock under the influence of water.
5. KCl – polymer mud containing PP polymer and polysilicate – potassium mud are characterized by the best degree of swelling of drilled shale rocks.
6. Drilling muds are characterized by good resistance to elevated temperatures.
7. Test drilling muds have good rheological properties.

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