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The impact of modern drilling fluids on improving the hydraulic efficiency of water wells

Introduction

Drilling through aquifers using improperly adjusted drilling mud may lead to formation clogging. Penetration of the solid phase into porous space of the rock causes a change of the porous medium initial physical properties (Houben and Treskatis 2004; Wysocki et al. 2017). In consequence, a decrease of the total well capacity can be observed (Civan 2009; Gonet and Macuda 2004; Misstear et al. 2006).

Likewise, drilling mud circulating in the well generates a clay deposit on wellbore wall and similarly impacts the hydraulic resistance of the water stream flowing into the well by increasing it (Bielewicz 2009; Bieske et al. 1998; Placer and Guaroco 2012). During hydrogeological drilling, apart from formation clogging in near-well zone, the clogging of filter active surface during its installation in the well filled with drilling mud also takes place. This is additional factor which increases the resistance of water flow into the well and depends significantly on the type and size of the filter active surface (Houben 2015).

In the current industrial practice, there is no effective method for substantial limitation of near-well zone clogging during well drilling, especially in the view of the wide use of bentonite muds treated with various kinds of polymers. One of the key methods is low-head drilling through aquifers. However, this method may be used only for drilling in compacted

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formations where problems related to wellbore wall instability do not occur (Misstear et al. 2006; Placer and Guaroco 2012). Loose aquifers, to preserve the stability of the wellbore wall, require to be drilled with the maintenance of mud column overpressure in the well in relation to the hydrostatic pressure of the water column.

The cleanout of filtrate and solid phase in near-filter zone, apart from the enhancement of well hydraulic efficiency, have a significant impact on well capacity increase and exploitation time extension (Bieske et al. 1998; Roscoe 1990; Schnieders 2003). A wide range of laboratory studies have been performed in order to improve the current situation, including the development of drilling mud which fulfills both criteria: technological and limiting its negative impact on the permeability of drilled aquifers in near-well zone. One of the key assigned criterion was the development of mud based entirely on biodegradable polymers.

1. Research methodology

Rheological properties were measured using viscometer M3500 Grace Instruments controlled by a computer. 600 rpm and 300 rpm readings as well as structural strengths were measured. The following values were further calculated:

- $PV = \phi\ 600 - \phi\ 300$ [mPas],
- $AV = \phi\ 600 / 2$ [mPas],
- $YP = (\phi\ 300 - PV) \cdot 0.4788$ [Pa].

The surveys were performed according to current international standards (API Spec. 13B-1) in standard conditions (temperature of 25°C and pressure of 0.1 MPa).

Materials used in the research:

- GG – guar gum, technical grade, supplier: PSPW Krosno;
- XCD – xanthan gum, technical grade, supplier: PSPW Krosno;
- CMS – carboxymethyl starch, technical grade, supplier: PSPW Krosno;
- PAC LV – low viscosity polyanionic cellulose, technical grade, supplier: PSPW Krosno;
- CMC LV – low viscosity carboxymethyl cellulose, technical grade, supplier: PSPW Krosno;
- Rotomag – modified starch, technical grade, supplier: PSPW Krosno;
- CAGEx – biodegradable base mud for hydrogeological drilling, technical grade, supplier: Mud Busters Projekt;
- Carbonate bridging agent Mikhart 40 µm, technical grade, supplier: BDC Poland;
- Potassium carbonate, technical grade, supplier: Avantor Performance Materials Poland SA.

2. Laboratory research

2.1. Guar gum

The rheological properties of mud influenced by different concentrations of guar gum were studied. A test was conducted for the guar gum concentration range of 0.0–0.4% w/w. Additionally, CMS in a concentration of 1.5% and XCD in a concentration of 0.5% were applied in the mud formula. The results are presented in Fig. 1.

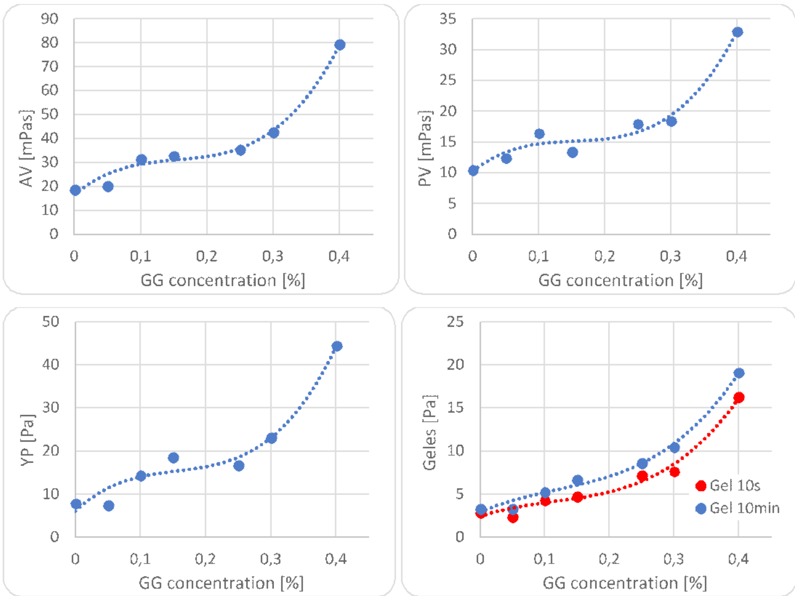

Fig. 1. The influence of guar gum concentration on the rheological properties of base mud

Rys. 1. Wpływ stężenia gumy guar na parametry reologiczne płuczki bazowej

2.2. Xanthan gum

The rheological properties of mud influenced by different concentrations of XCD biopolymer were studied. A test was conducted for the XCD concentration range of 0.05–0.4% w/w. Additionally, CMS in a concentration of 1.5% and XCD in a concentration of 0.15% were applied in the mud formula. The results are presented in Fig. 2.

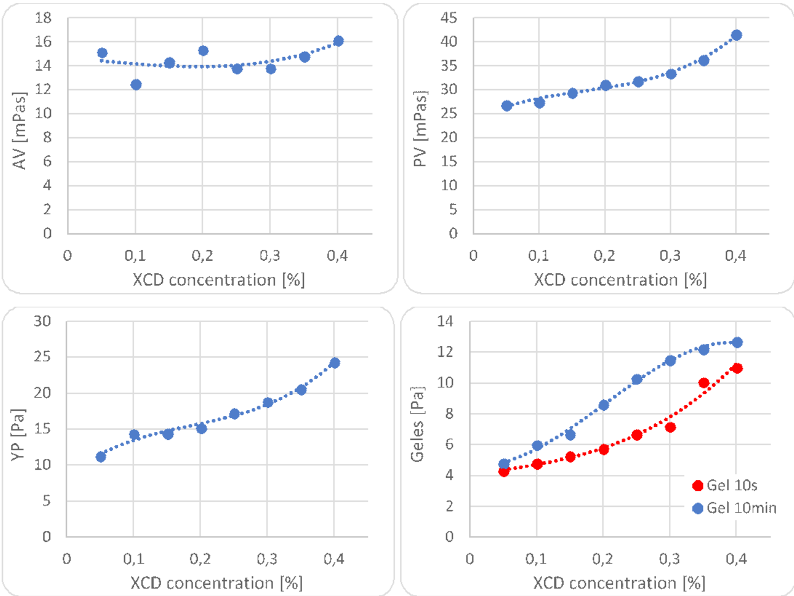

Fig. 2. The influence of XCD concentration on the rheological properties of base mud

Rys. 2. Wpływ stężenia XCD na parametry reologiczne płuczki bazowej

2.3. Rotomag

The rheological properties of mud influenced by different concentrations of Rotomag polymer were studied. A test was conducted for the Rotomag concentration range of 0.5–2.5% w/w. Additionally, CMS in a concentration of 1.5% and XCD in a concentration of 0.15% were applied in the mud formula. The results are presented in Fig. 3.

2.4. Low viscosity polyanionic cellulose

The rheological properties of mud influenced by different concentrations of PAC LV biopolymer were studied. A test was conducted for the PAC LV concentration range of 0.5–1.5% w/w. Additionally, guar gum in a concentration of 0.4% and XCD in a concentration of 0.5% were applied in the mud formula. The results are presented in Fig. 4.

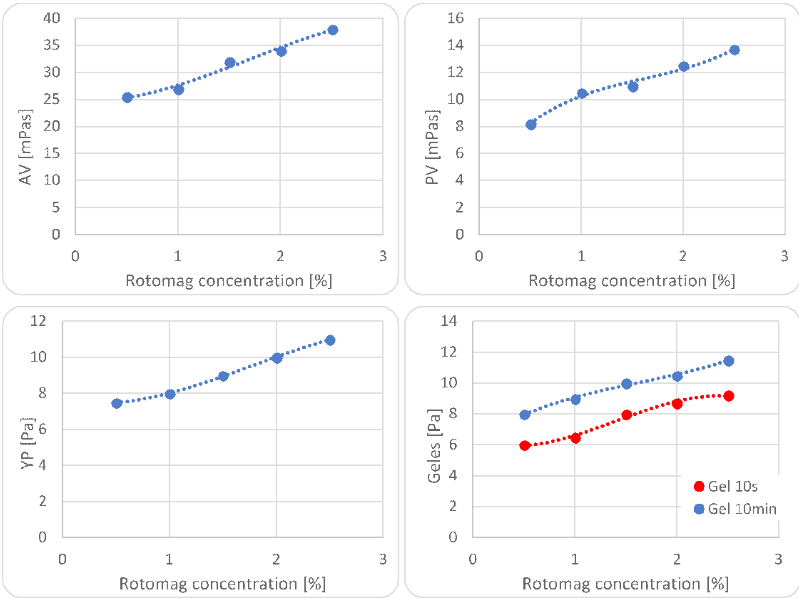

Fig. 3. The influence of Rotomag concentration on the rheological properties of base mud

Rys. 3. Wpływ stężenia Rotomagu na parametry reologiczne płuczki bazowej

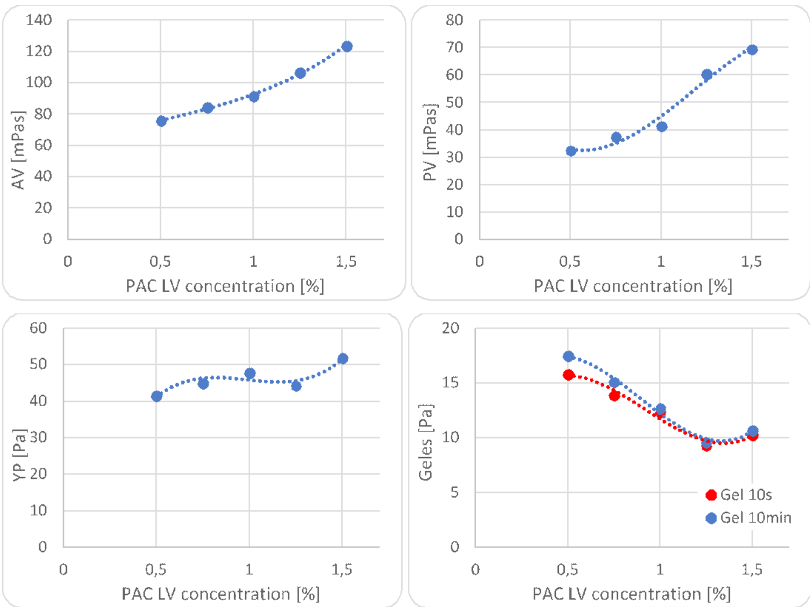

Fig. 4. The influence of PAC LV concentration on the rheological properties of base mud

Rys. 4. Wpływ stężenia PAC LV na parametry reologiczne płuczki bazowej

2.5. Low viscosity carboxymethyl cellulose

The rheological properties of mud influenced by different concentrations of CMC LV polymer were studied. A test was conducted for the CMC LV concentration range of 0.5––2.0% w/w. Additionally, guar gum in a concentration of 0.3% and XCD in a concentration of 0.4% were applied in the mud formula. The results are presented in Fig. 5.

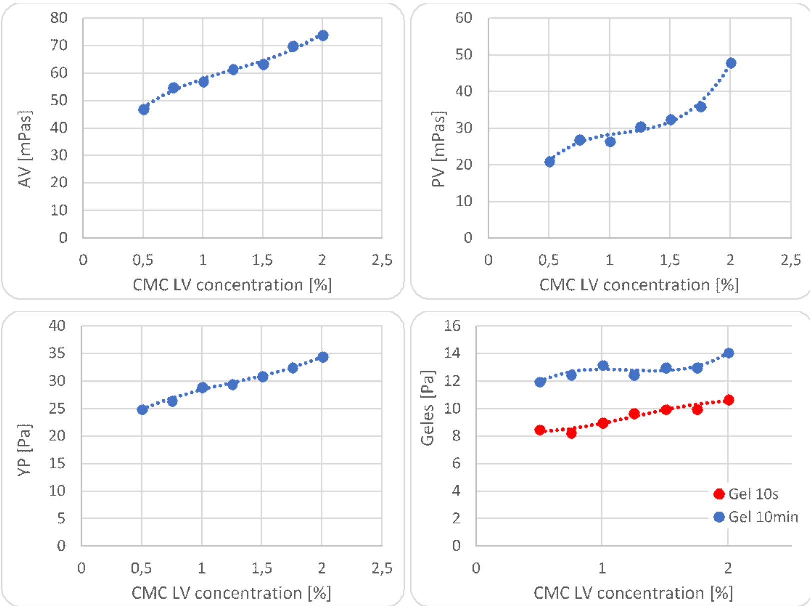

Fig. 5. The influence of CMC LV concentration on the rheological properties of base mud

Rys. 5. Wpływ stężenia CMC LV na parametry reologiczne płuczki bazowej

2.6. Carboxymethyl starch

The rheological properties of mud influenced by different concentrations of CMS biopolymer were studied. A test was conducted for the CMS concentration range of 1.0–3.0% w/w. Additionally, guar gum in a concentration of 0.15% and XCD in a concentration of 0.4% were applied in the mud formula. The results are presented in Fig. 6.

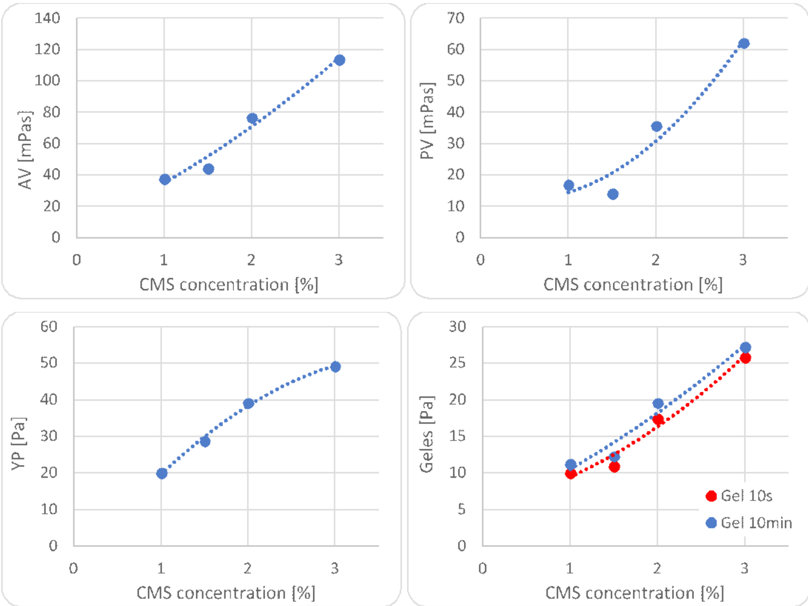

Fig. 6. The influence of CMS concentration on the rheological properties of base mud

Rys. 6. Wpływ stężenia CMS na parametry reologiczne płuczki bazowej

2.7. CAGEx

The undertaken studies allowed for the development of a base mud formula marked as CAGEx. Following this, the rheological properties of the mud with different concentrations of CAGEx were studied. A test was performed in the concentration range of 0.5–2.0%. The results are presented in Fig. 7.

3. Discussion of research results

The aim of the undertaken studies was to develop a formula of mud which will be used as a base for muds intended for hydrogeological drilling.

Guar-gum: At low concentrations of guar gum, the rheological properties of the studied muds remains relatively low. The increase of guar gum concentration up to 0.4% generates a rapid increase of all the rheological properties of the studied muds.

XCD: The growth of biopolymer XCD concentration does not cause an increase of apparent viscosity. However, an increase of other rheological properties was noted.

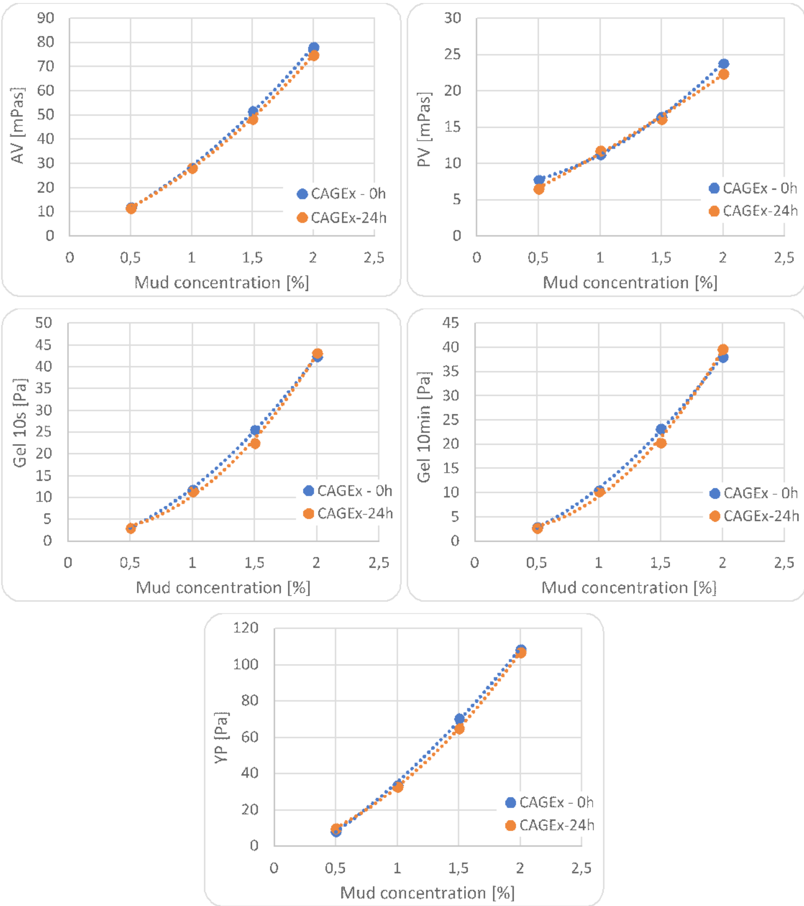

Fig. 7. The influence of CAGEx concentration on the rheological properties of base mud

Rys. 7. Wpływ stężenia CAGEx na parametry reologiczne płuczki bazowej

Rotomag: An increase of the Rotomag concentration slightly impacts the rheological properties of the studied muds. Just a minor increase of parameters values with starch concentration growth can be observed.

PAC LV: The concentration of PAC LV greatly influences the viscosity parameters of the studied muds. Moreover, a decrease of the studied muds geles can be observed.

CMC LV: An increase of rheological properties of the studied muds with CMC LV concentration growth was noted. In the case of geles, the increase is relatively low.

CMS: Increase of CMS concentration causes significant increase of all rheological properties of the studied muds.

CAGEx: The base mud formula was composed on the basis of abovementioned studies. The mud is marked as CAGEx. The performed tests of CAGEx concentration influence on rheological properties of the mud showed that the developed formula assures good rheological properties even at low concentrations of CAGEx. Simultaneously, a relatively low increase of plastic viscosity and rapid increase of strength parameters with CAGEx concentration growth can be noticed. As a result, mud parameters can be easily adjusted and adapt to borehole conditions achieving this only by changing the base mud concentration. Tests conducted 24 hours after the mud preparation showed that the mud is stable in time even without the addition of biocides.

4. Industrial research of drilling mud for hydrogeological drilling (CAGEx)

Studies on the effective application CAGEx mud in industrial conditions were performed during the drilling of the water intake well in the Quaternary formations with the aquifer formed as medium and small grained sands. Once the well was drilled to the planned depth, a Johnson type continuous-slot well screen was installed and annular space was filled with a gravel pack with a grain size of 2–5 mm. Afterward, cleanout pumping was carried out for 24 h using a pump aggregate at three stages of the pressure drawdown. This pumping was aimed at the cleaning of pore spaces, aquifer near-filter zone, gravel pack and filter out of clogging material deposited from the mud in the form of fine particles of cuttings and clay minerals. The results of the well cleanout pumping are presented in Table 1.

Table 1. Summary of the cleanout pumping results

Tabela 1. Zestawienie wyników pompowania oczyszczającego

Pumping stage	Pump capacity Q [m^3/h]	Pressure drawdown s [m]	Unit pressure drawdown s/Q [h/m^2]
I	24.83	1.5	0.06041
II	41.38	3.0	0.07250
III	52.94	4.5	0.08500

On the basis of the calculations of efficiency coefficient C, within the range 0.00005 to 0.00009 (h^2/m^5) for different pressure drawdown, it can be concluded that the constructed well classifies as a I class well i.e. a properly designed and constructed well without the requirement of additional activation treatment (Dąbrowski and Przybyłek 2005; PN-G-02318:1994; Ramey 1992; Walton 1962).

Table 2. Conversion table

Tabela 2. Przeliczenie jednostek

CONVERSION TABLE				
Unit name	Unit symbol		Unit SI	
Apparent viscosity	AV	1 mPa·s	10^{-3} Pa·s	1 cP
Plastic viscosity	PV	1 mPa·s	10^{-3} Pa·s	1 cP
Yield point	YP		1 Pa	0.02088547 lb/100ft^2
Structural strengths	Geles		1 Pa	0.02088547 lb/100ft^2
Structural strength 10s	Gel 10s		1 Pa	0.02088547 lb/100ft^2
Structural strength 10min	Gel 10min		1 Pa	0.02088547 lb/100ft^2

Conclusions

The undertaken laboratory research has led to the development of a mud formula, that does not cause significant damage of aquifer permeability in near-well zones and can be successfully applied for hydrogeological wells drilled for different purposes. The developed CAGEx base mud is characterized by good technological parameters even in low concentrations. Subsequent modifications and the adjustment of mud rheological properties to geological conditions is easy and done only by changing the concentration of the base mud.

A significant advantage of the developed mud is that it is based on completely biodegradable ingredients. Simultaneously, the mud does not require biocide application, due to the relatively slow biodegradation process. The stability of the developed mud rheological properties is confirmed by tests conducted directly after mud preparation and after 24 hours.

The undertaken industrial research of developed drilling mud, while drilling a water intake well, confirmed the great stability of its technological parameters as well as the insignificant influence on rock permeability damage in the filter zone. The water intake well is characterized by high hydraulic efficiency and does not require additional activation treatment.

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THE IMPACT OF MODERN DRILLING FLUIDS ON IMPROVING THE HYDRAULIC EFFICIENCY OF WATER WELLS

Keywords

water well, wellbore skin, hydrogeological drilling, drilling mud

Abstract

During drilling through aquifers using the rotary drilling method with drilling fluid application, the phenomenon of formation clogging in near-well zone takes place. This leads to physical changes in pore spaces in consequence of the deposition solid phase particles originating from the drilling fluid. Due to this fact, filtration velocity in the clogged zones of the aquifer formation decreases, which results in increased pressure drawdown and decreased well hydraulic efficiency. Therefore, it causes a reduction of the well total capacity.

The article consists of studies connected to the development of the mud which will constitute the basis for a complex mud system intended for hydrogeological drilling in different encountered geological conditions.

In the framework of laboratory research, technological parameters of six, commonly applied in oil and gas industry, polymer agents as well as new agent developed at the Drilling, Oil and Gas Faculty AGH-UST in Krakow were examined. The undertaken studies showed that the new agent, marked as CAGEx, provides the required technological parameters and can be applied as a base for drilling muds intended for hydrogeological drilling.

The undertaken industrial research of the new CAGEx drilling mud carried out while drilling water intake well, confirmed the great stability of its technological parameters as well as insignificant influence on rock permeability damage in filter zone. The water intake well is characterized by high hydraulic efficiency and does not require additional activation treatment.

WPŁYW NOWOCZESNYCH PŁUCZEK WIERTNICZYCH NA POPRAWĘ SPRAWNOŚCI HYDRAULICZNEJ STUDNI WIERCONYCH

Słowa kluczowe

studnie wiercone, wiercenia hydrogeologiczne, płuczka wiertnicza

Streszczenie

W trakcie udostępniania użytkowych poziomów wodonośnych metodami obrotowymi z wykorzystaniem płuczki wiertniczej zachodzi proces kolmatacji skał w strefie przyotworowej. Prowadzi on do fizycznych zmian ośrodka porowatego w wyniku osadzania się w nim cząstek fazy stałej z płuczki wiertniczej. Powoduje to zmniejszenie prędkości filtracji wody w zakolmatowanych partiach formacji wodonośnej, co skutkuje wzrostem depresji i obniżeniem sprawności hydraulicznej studni, a w konsekwencji obniżeniem całkowitej wydajności studni

W artykule przedstawiono wyniki badań laboratoryjnych nad opracowaniem płuczki wiertniczej, która stanowić będzie bazę do opracowania kompletnego systemu płuczkowego przeznaczonego do wiercenia otworów hydrogeologicznych w różnych warunkach geologicznych. W ramach badań laboratoryjnych przeprowadzono pomiary parametrów reologicznych sześciu, standardowo stosowanych w wiertnictwie, środków polimerowych oraz nowego środka, którego skład opracowano na Wydziale Wiertnictwa, Nafty i Gazu AGH. Przeprowadzone badania pokazały, że nowy środek, oznaczony jako CAGEx, zapewnia wymagane parametry technologiczne i może być stosowany jako baza płuczek wiertniczych.

Wykonane badania przemysłowe nowej płuczki wiertniczej CAGEx, podczas wiercenia studni ujęciowej potwierdzają dużą stabilność jej parametrów technologicznych i niewielki wpływ na uszkodzenie przepuszczalności skał w strefie przyfiltrowej. Wykonana studnia ujęciowa charakteryzowała się wysoką sprawnością hydrauliczną i nie wymagała wykonania dodatkowych zabiegów uaktywniania.