Polymeric structure-forming agent for drilling muds

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Abstract: Recently, studies contributing to development of complete mud system, which would enable drilling the borehole of arbitrary length (including directional and horizontal boreholes) without necessity of mud changing are conducted at the Faculty of Drilling, Oil and Gas AGH-UST Krakow. The article describes technological parameters of developed base mud (BFP) which constitutes ground of developed system. BFP mud will be applied as a structure-forming agent allowing suspension of other components in the drilling mud. BFP mud is characterized by low values of plastic viscosity in wide range of concentrations as well as enhanced strength parameters (Yield Point, Geles). Its parameters are easy to adjust to different geological conditions. The mud is resistant to mono- and divalent ions and to increased temperature. Due to those facts, abovementioned mud can find application in the drilling industry.

Keywords: drilling mud, water-based mud, polymers.

Polimerowy środek strukturotwórczy do sporządzania płuczki wiertniczej

Streszczenie: Opisano parametry technologiczne opracowanej na WWNiG AGH w Krakowie płuczki bazowej (BFP), która stanowi podstawę kompletnego systemu płuczkowego umożliwiającego odwiercenie otworu o dowolnej długości (w tym również otworów kierunkowych i horyzontalnych) bez konieczności wymiany płuczki. Płuczka BFP jest przeznaczona do zastosowania jako środek strukturotwórczy, pozwalający na zawieszenie w nim pozostałych surowców płuczkowych. Płuczka BFP charakteryzuje się niewielkimi wartościami lepkości plastycznej, w dużym zakresie stężeń, i polepszonymi właściwościami wytrzymałościowymi (*Yield Point*, *Geles*), a parametry te można łatwo regulować. Jest odporna na zasolenie jonami jedno- i dwuwartościowymi oraz na podwyższoną temperaturę. Może znaleźć zastosowanie w przemyśle wiertniczym.

Słowa kluczowe: płuczka wiertnicza, płuczka wodnodyspersyjna, polimery.

Until recently, main structure-forming agent in drilling mud was bentonite. As elementary, bentonite muds are frequently used for horizontal directional drilling and shallow hydrogeological drilling (water well drilling), mainly due to its low costs. While deep depth drilling, where raised temperature and probability of salts occurrence should be considered, bentonite mud is not necessarily most effective solution. Despite protective colloids application, appearance of salt ions (particularly multivalent ions) originated from drilled formations or inflowing brines, may effects in coagulation of bentonite suspension, decrease of rheological properties and significant increase of filtration. Continuous advancements in polymers manufacturing as well as decrease of its cost make polymers a noteworthy alternative for bentonite as a structure-forming agent in drilling muds. Due to this, growing number of research centers are carrying out studies on the development of more effective polymeric agents or whole mud systems based on polymeric base. Likewise, at the Drilling and Geoengineering Department of Drilling, Oil and Gas Faculty AGH-UST Krakow are conducted such studies. Essential assumption of the realized project is development of mud system that allows drilling whole depth of the borehole with only one mud without necessity of its change. First stage of the project consist of design of a base mud which permit its rheological properties adjustment to encountered geological conditions [1–6].

The article contains results of studies on new polymeric structure-forming agent intended for water-based mud preparation. Its basic function is to guarantee proper rheological properties and formation of mud structure, in which other components of the mud would be suspended.

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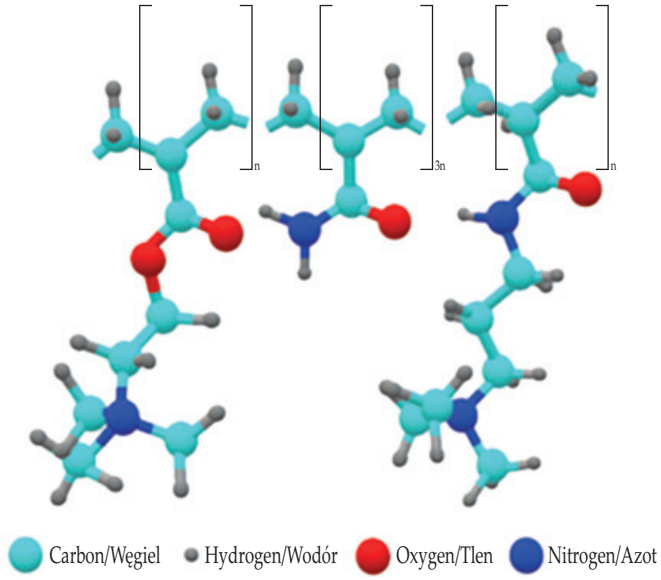
EXPERIMENTAL PART

Materials

BFP – polymeric structure-forming agent, supplier Mud Busters Projekt, Kraków; carbonate bridging agent Mikhart 40 μm, supplier BDC Poland; sodium chloride, calcium chloride, magnesium chloride, supplier Avantor Performance Materials Poland S.A.

Polymeric structure-forming agent BFP is a blend of natural and synthetic polymers. One of BFP agent's basic component is a synthetic polymer – poly[(2-(acryloloksy)ethyl) trimethyl ammonium chloride-*co*-acrylamide-*co*-(3-acrylamidopropyl)trimethyl ammonium chloride] marked as poly[AETAC-*co*-AAm-*co*-APTAC] [Formula (I)]. Synthesis of the poly[AETAC-*co*-AAm-*co*-APTAC] polymer was based on radical polymerization in water solution.



Formula (I)

Terpolymer poly[AETAC-*co*-AAm-*co*-APTAC] is a cationic polymer. Quaternary amine groups with relatively high steric hindrance and amide group originating from acrylamide meres constitute as the function groups in polymer structure. Ratio of [2-(acryloloksy)ethyl]trimethyl ammonium chloride : acrylamide : (3-acrylamidopropyl) trimethyl ammonium chloride meres is 1 : 3 : 1 molar.

Undertaken studies showed that water solutions of poly[AETAC-*co*-AAm-*co*-APTAC] polymer are characterized by high resistance to mono- and divalent ions. Thanks to the possibility of number of hydrogen bonds formation water solutions of poly[AETAC-*co*-AAm-*co*-APTAC] polymer exhibit increased strength parameters (Geles and Yield Point) of the mud, while plastic viscosity (*PV*) and apparent viscosity (*AV*) of the mud remain at low values.

Methods of testing

The surveys were performed according to current international standards: API Spec. 13B-1 [7].

Rheological properties were measured using viscometer M3500 Grace Instruments controlled by computer and fitted with thermal cup that allows carrying out the measurement in temperature range of 20–100 °C. Rheological models of the muds were prepared with computer application – Rheosolution – developed on the Faculty of Drilling, Oil and Gas AGH-UST Krakow [8].

Influence of BFP agent concentration on rheological properties of mud

The rheological properties of mud influenced by different concentration of BFP polymeric structure-forming agent were studied.

Presented mud was applied in further studies. Moreover, Herschel-Bulkley rheological model was prepared for abovementioned mud**.**

Test of thermal resistance

Subsequently, influence of temperature on rheological properties of mud with addition of BFP polymeric structure-forming agent in 1.0 wt % concentration was investigated. Tests were performed in temperature range of 20–90 °C.

Test of resistance to salts – monovalent ions

Impact of monovalent salts on rheological properties of mud with addition of BFP polymeric structure-forming agent in 1.0 wt % concentration was tested. Sodium chloride in concentrations of 5.0–30.0 wt % has been applied in the investigations.

Test of resistance to salts – divalent ions

It was also conducted test of divalent salts influence on rheological properties of mud with addition of BFP polymeric structure-forming agent in 1.0 wt % concentration. Calcium chloride and magnesium chloride in concentration of 0.5 wt % have been applied in the investigations.

Influence of bridging agent on technological parameters of mud

Rheological properties of studied mud were examined for influence of carbonate bridging agent. In the investigations as a bridging agent have been applied carbonate bridging agent with average granulation of 40 μm in 7.0 wt % concentration.

RESULTS AND DISCUSSION

Main functions of BFP polymeric agent are formation of structure and assurance of good rheological properties of base mud. Thus, in first stage of the project, influence of BFP polymeric agent concentration on rheological properties of the base mud was tested. Results are presented in Fig. 1.

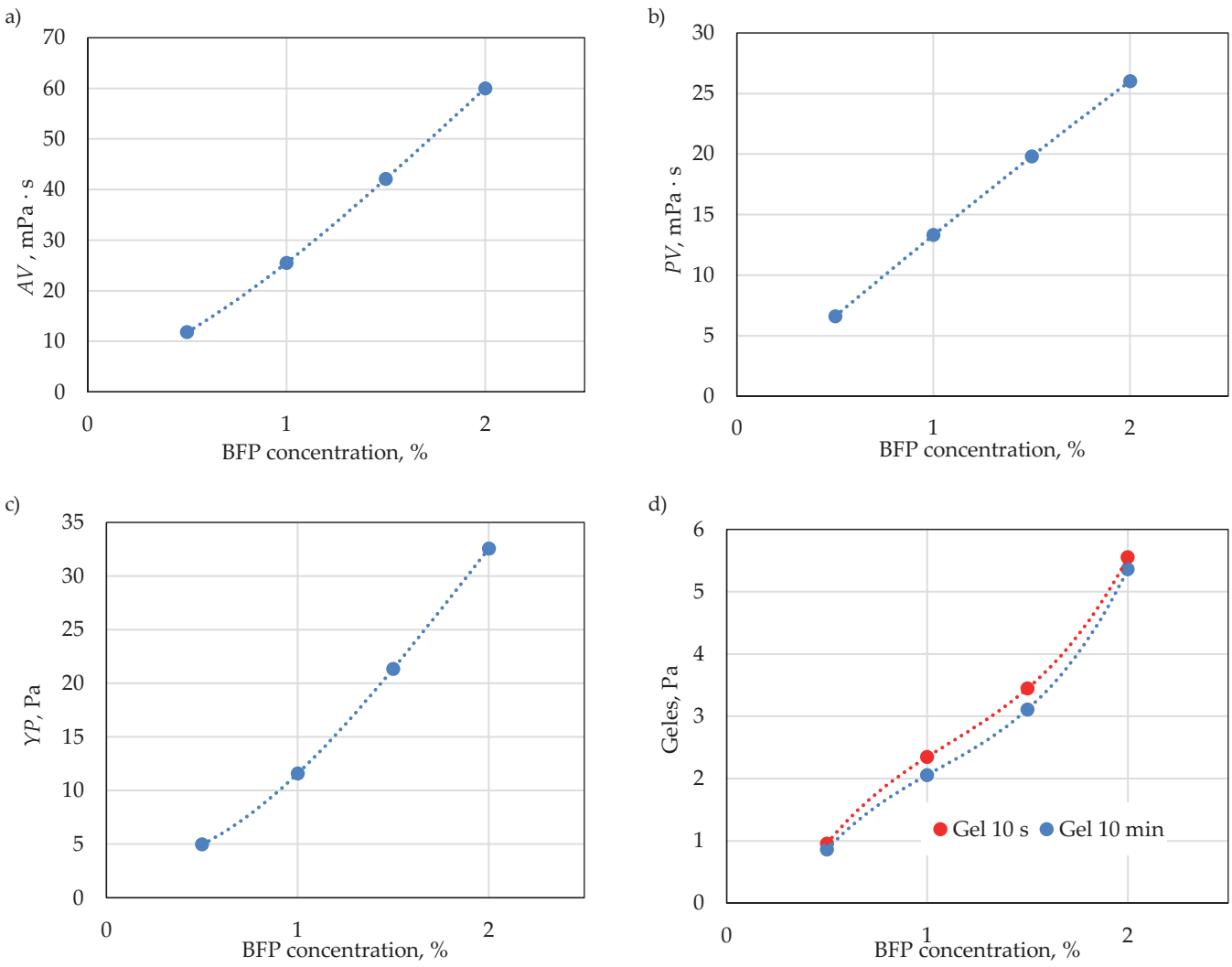
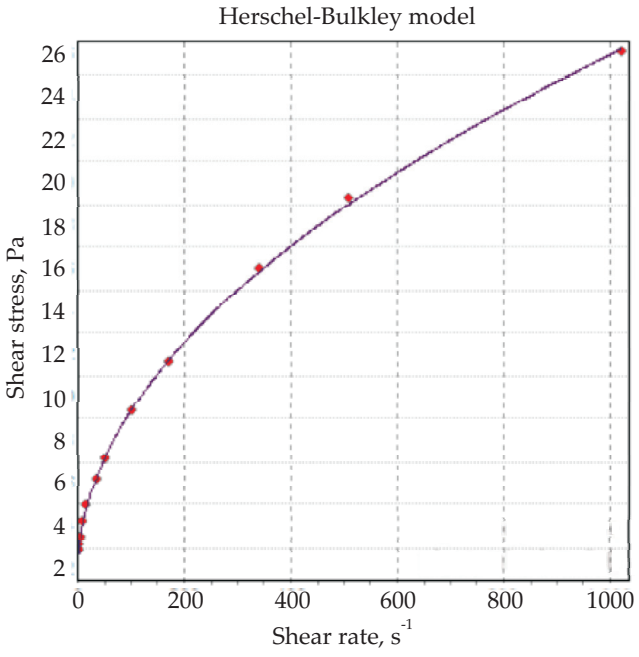


Fig. 1. Influence of BFP concentration on rheological properties of mud: a) apparent viscosity, b) plastic viscosity, c) yield point, d) Geles



Pearson correlation coefficient	R	0.9999	fully correlated
Fischer-Snedecor coefficient	F	52224.9	[–]
Sum of the squares	U	0.11	[–]
Yield point	τ_{yHB}	1.8864	[Pa]
Consistency coefficient	k_{HB}	0.7301	[Pa · $s^{0.5056}$]
Shape factor	n_{HB}	0.5056	[–]

Fig. 2. Rheological model of mud with BFP addition of 1.0 wt % concentration

Results indicate that water-based muds prepared on basis of BFP are characterized by relatively low values of plastic viscosity (*PV*) in wide range of BFP agent concentrations. Other rheological properties of developed muds increase with BFP agent concentration growth. This is beneficial because enables easy regulation of drilling mud parameters (as well as adjustment to geological conditions) by changing only one agent without necessity to apply additional reagents. Studied BFP agent performs effectively even at low concentration of approximately 0.5–1.0 wt %. Mentioned facts cause BFP-based mud relatively inexpensive even in comparison to other water-based muds.

T a b l e 1. Formula and technological parameters of test mud

Mud formula	Technological parameters	
BFP 1.0 wt %	Density	1.02 g/cm^3
	Plastic viscosity	13.3 mPa · s
	Apparent viscosity	25.5 mPa · s
	Yield point	11.6 Pa
	Geles	2.3/2.1 Pa
	API filtration	150 cm^3

Technological parameters of test mud with 1.0 wt % concentration of BFP agent are given in Table 1.

Prepared flow curves of base muds show that all of studied muds are best described by Herschel-Bulkley model (Fig. 2).

For the reason that base mud is intended for drilling whole depth of the borehole, it should be resistant to changing geological conditions. Undertaken research have shown that studied mud is resistant to elevated temperature (Fig. 3) as well as mono- and divalent ions contamination (Figs. 4, 5). Above presented results showed that changes in rheological properties with raising temperature are relatively small and that to achieve as-

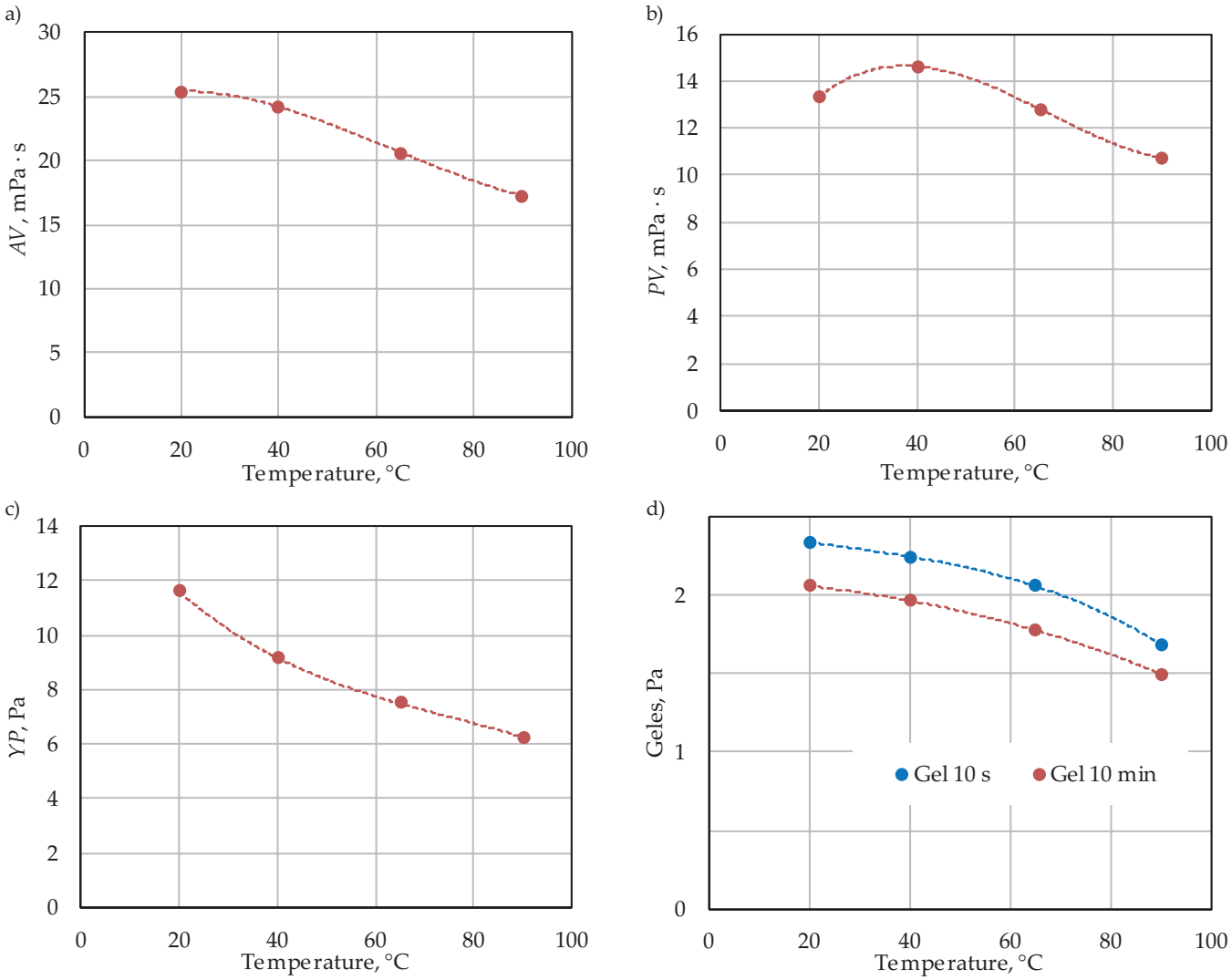


Fig. 3. Thermal resistance of mud with BFP addition of 1.0 wt % concentration: a) apparent viscosity, b) plastic viscosity, c) yield point, d) Geles

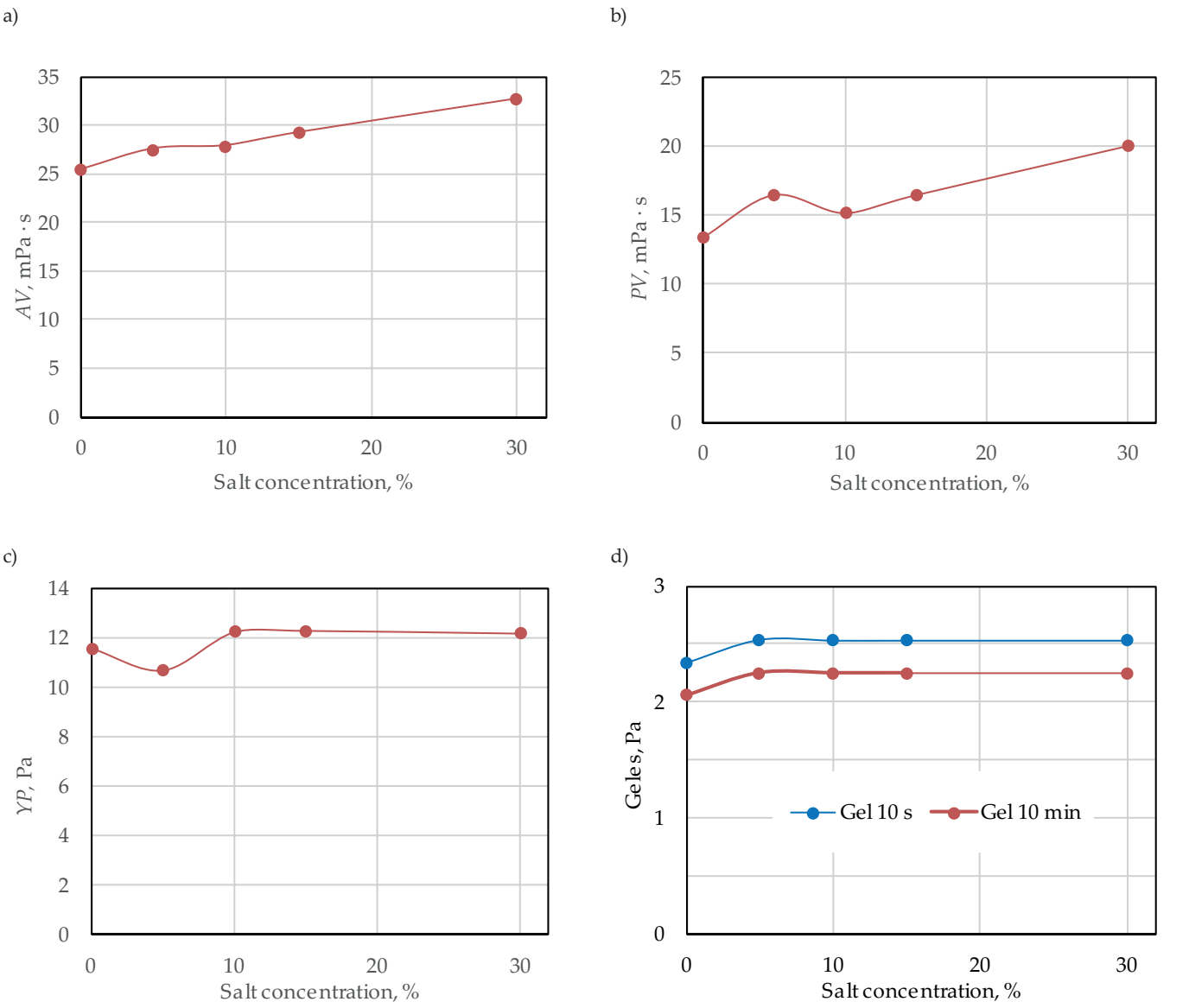


Fig. 4. Resistance of mud with BFP addition to contamination by monovalent ions: a) apparent viscosity, b) plastic viscosity, c) yield point, d) Geles

sumed parameters in raised temperature the only need is to increase BFP concentration during mud preparation. Additional tests conducted using Rollen-Oven oven showed that BFP-based muds are resistant to 120–130 °C temperature.

Particularly positive outcome was noted while performing test of BFP mud contamination with salts. Results have shown that BFP mud is highly resistant to both: mono- and divalent ions contamination.

Moreover, increase of sodium chloride concentration in studied muds causes relatively small increase of plastic and apparent viscosity values and has almost no impact on strength parameters (*YP*, Geles). This is greatly desirable situation, as it enables saturation of mud and drilling salt intervals. Furthermore, preparation of the developed mud is possible in case of offshore drilling, where access to fresh water is difficult. Another advantage of the studied mud is possibility of preparation of mud for drill-in process with addition of salt instead of carbonate bridging agent.

Important benefit of studied BFP mud is its resistance to divalent ions contamination. Tests outcome showed that addition of calcium and/or magnesium ions does not influence rheological properties of studied muds. It is related to resistance of muds to contamination by ions which can spread form drilled formations during brines inflow to the borehole, as well as possible cement slurry contamination.

What is more, undertaken studies showed that muds based on BFP agent are resistant to solid phase (Fig. 6).

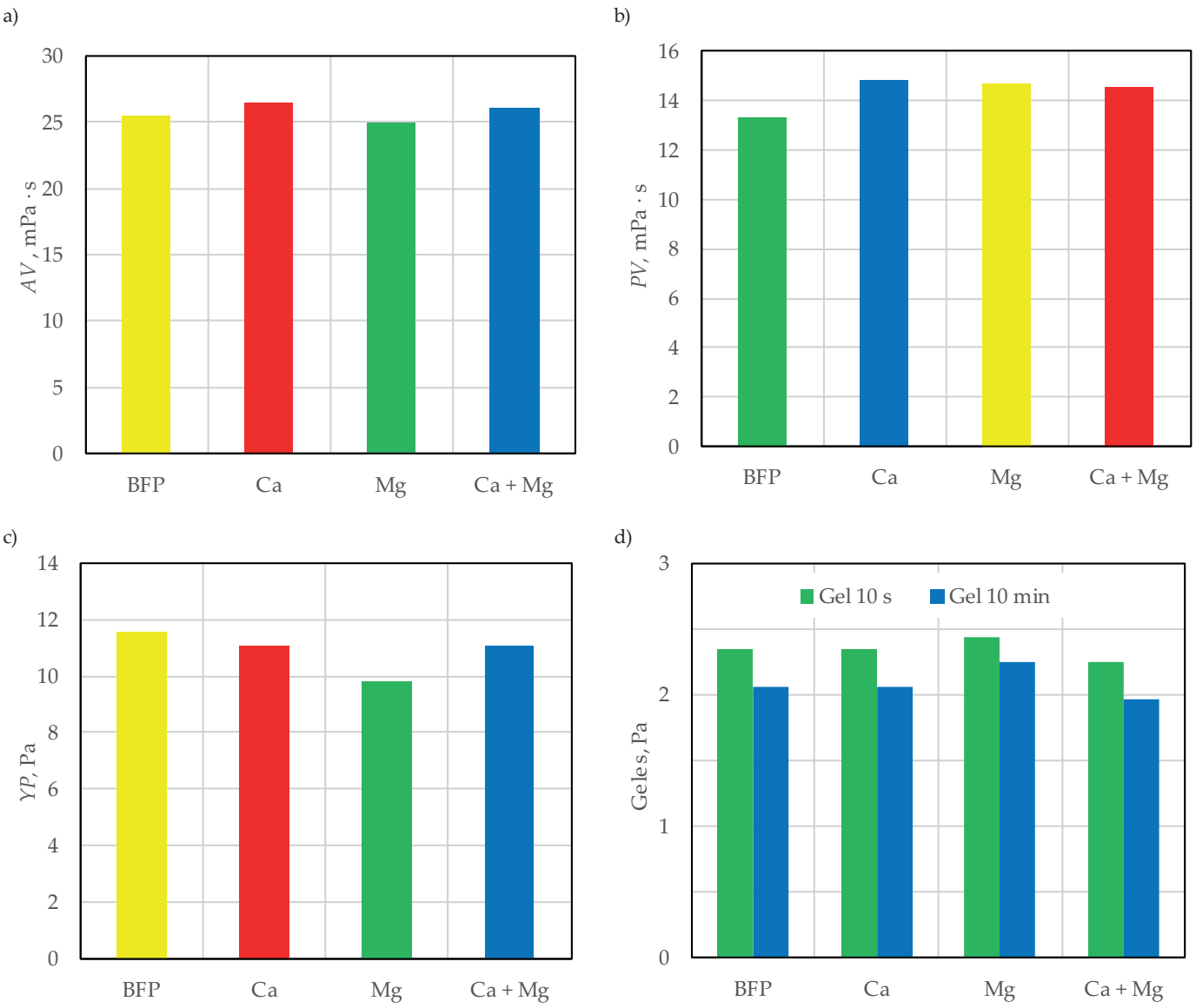


Fig. 5. Resistance of mud with BFP addition to contamination by calcium and magnesium ions: a) apparent viscosity, b) plastic viscosity, c) yield point, d) Geles

Its technological parameters after addition of carbonate bridging agent to the formula of studied muds do not significantly changed. Additionally, filtrate value significantly decreased.

CONCLUSIONS

Based on the outcome of conducted studies, it can be stated that BFP agent as well as drilling muds prepared with its application are characterized by good rheological properties and simplicity of its adjustment to different geological conditions. Furthermore, application of poly[AETAC-*co*-AAm-*co*-APTAC] terpolymer in formula of polymeric structure-forming BFP agent allowed achieving enhanced strength parameters (Geles and *YP*) of the mud, while plastic viscosity (*PV*) of the mud remains at relatively low values. Drilling muds based on BFP agent are resistant to temperature, salts and solid phase. With addition of studied BFP agent can be prepared water-dispersive muds basing on fresh water, sea water and saturated muds.

Thanks to abovementioned advantages BFP agent can find wide range of applications for drilling industry.

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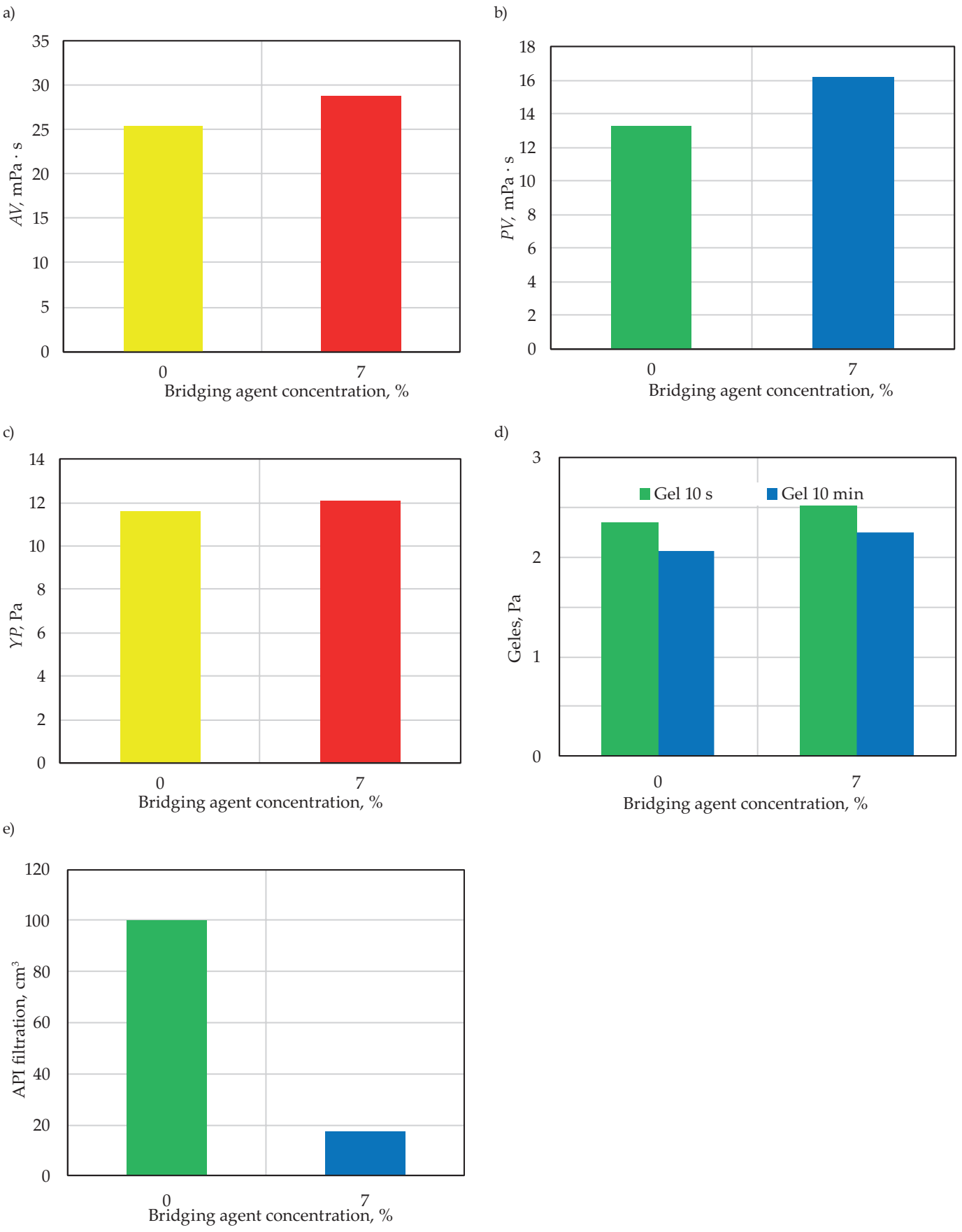

Fig. 6. Influence of solid phase on technological parameters of BFP mud: a) apparent viscosity, b) plastic viscosity, c) yield point, d) Geles, e) API filtration

REFERENCES

[1] Bielewicz D.: „Płyny wiertnicze", Wydawnictwa AGH, Kraków 2009.
[2] Wysocki S., Wiśniowski R., Uliasz M. *et al*.: „Nowe wodnodyspersyjne płuczki wiertnicze do przewiercania skał ilastych", Wydawnictwa AGH, Kraków 2017.
[3] Raczkowski J., Półchłopek T.: „Materiały i środki chemiczne do sporządzania płuczek wiertniczych", Prace INiG, Kraków1998, p. 95.
[4] Chalah K., Benmounah A., Benyounes K.: "Effect of anionic polyelectrolytes on the flow of activated sodium bentonite drilling mud", 2nd International Congress on Materials & Structural Stability (CMSS-2017), Morocco 2017. https://doi.org/10.1051/matecconf/201814901082
[5] Dong W., Pu X., Ren Y. *et al*.: *Materials* **2019**, *12* (*13*), 2115. https://doi.org/10.3390/ma12132115
[6] Yang L., Jiang G., Shi Y. *et al*.: *Journal of Materials Science* **2017**, *52*, *6362*. https://doi.org/10.1007/s10853-017-0870-7
[7] API RP 13B-1, 3rd Edition, December 2003.
[8] Skrzypaszek K.: „Program *rheo solution* jako komputerowe narzędzie doboru modelu reologicznego cieczy wiertniczych", Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004.

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