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FORMATE-BASED FLUIDS: FORMULATION AND APPLICATION

ISPLAKE NA BAZI FORMIJATA: SASTAV I PRIMJENA

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Abstract

Formate-based fluids has been successfully used in over hunders HPHT well operations since they introduced in field practice. They have many advantages when compared with conventional HPHT drilling and completion fluids such as: minimal formation damage, maintenance of additve properties at high temperatures, reduced hydraulic flow resistance, low potential for differential sticking, naturally lubricating, very low corrosion rates, biodegradable and pose little risk to the environment etc. Formate-based fluids can be applied during deep slim hole drilling, shale drilling, reservoir drilling, salt and gas hydrate formations drilling.

The laboratory research was carried out to evaluate the rheological behavior of formate-based fluids as a function of temperature. Formate-based fluids were formulated using potassium formate brine, xanthan polymer, PAC, starch and calcium carbonate. Experimental results show that potassium formate improves the thermal stability of polymers.

Sažetak

Isplake na bazi formijata uspiješno se primjenjuju tijekom različitim radova u bušotinama s visokim tlakom i temperaturom. One imaju nekoliko prednosti u odnosu na standardne isplake koje se koriste tijekom bušenja i opremanja bušotina s visokim tlakom i temperaturom, kao npr.: minimalno oštećenje formacije, očuvanje svojstava aditiva kod visokih temperatura, smanjenje trenja, smanjenje opasnosti od diferencijalnog prihvata, poboljšana mazivost, smanjena korozivnost, biorazgradivost i neznatan utjecaj na okoliš. Isplake na bazi formijata našle su svoju primjenu tijekom izrade dubokih bušotina malog promjera, bušenja kroz naslage šejla, bušenje kroz ležišta ugljikovodika, te tijekom izrade kanala bušotine kroz naslage soli i plinskih hidrata.

Provedena su laboratorijska ispitivanja kojima je utvrđena ovisnost promjene reoloških svojstva isplaka na bazi formijata u ovisnosti o temperaturi. Isplake na bazi formijata sastojale su se od kalij formijata, xanthan polimera, polianionske celuloze, škroba i kalcijevog karbonata. Ispitivanja su pokazala da kalij formijat poboljšava temperaturnu stabilnost polimera.

Introduction

The formate salts of the formic acid have very high solubilities in water, creating dense, alkaline brines of relatively low viscosity with a range of beneficial properties, such as reduced rate of hydrolytic and oxidative degradation of many viscosifiers and fluid loss agents at high temperatures, which make them ideally suited for use as drilling and completion fluids (Downs, 1992., 1993; Howard, 1995.; Gallino, 1997.). The three monovalent formate salts considered most useful to the oil industry are sodium formate, potassium formate and cesium formate (Table 1) (Downs, 1992. 1993.).

In addition to that, they are biodegradable, have a low toxicity to aquatic organisms and display very little corrosiveness towards ferrous-based metals used in oilfield tubulars and auxiliary hardware.

Formate brines were used as the basis of low-solids drilling fluids for deep and slim hole drilling, as a drilling fluid in drilling through very plastic shales, as a high temperature reservoir drilling fluid, and as a completion and workover fluid (Abou-Sayed, 1996.; Downs 1992.; Sundermann 1996.; Gallino, 1997.; Bungert, 2000.; Gilbert, 200.; Al Otaibi et al., 2008).

Table 1. Typical properties of near-saturated formate brines
Tablica 1. *Osnovna svojstva zasićenih formijata*

Brine	Formate concentration (% w/w)	Brine density	Kinematic viscosity	pH
		Temperature (20 °C)		
		(kg/m^3)	(10^{-6} m^2/s)	
Sodium formate	45	1338	7.1	9.4
Potassium formate	76	1598	10.9	10.6
Caesium formate monohydrate	83	2367	2.8	12.9

The advantages of formate brines in these applications were:

- Effective hole cleaning at high downhole temperatures
- Elimination of solids sag at high downhole temperatures
- Excellent polymer stability up to 154 °C
- Minimal circulating pressure losses
- Low differential sticking potential (thin, easily removable filter cakes)
- Low ECD´s in long/narrow boreholes
- Maximum power transmission to mud motors and bits
- Reduced drilling time, time spent for bit balling and time spent on reaming
- Non-hazardous
- Compatible with reservoir minerals and liquid phases (no formation damage)
- Good inhibition of formation clays (increased hole stability and reduction in wastes produced/hole volume)
- Compatible with drilling/completion hardware and elastomers (no corrosion)
- Increased ROP
- Low treatment costs during drilling
- Environmentally responsible and readily biodegradable (savings on waste disposal)

Generally, formate-based fluids can solve the problems routinely encountered with the temperature limited, calcium carbonate weighted, and water-based polymer drilling fluids such as inadequate solids suspension, poor solids transport, stuck pipe, and tight holes.

Field experience

Solids-free formate brines were introduced in practice in the early 1990´s (Downs, 1993.; Bungert et al., 2000.; Al Otaibi et al., 2008.). Formate fluids have been used in hundreds wells across the world since their comercial introduction in 1993. Table 2 presents different data colected from the published literature regarding field experience in formate based fluids application.

Laboratory testing - Fluid formulation and results

In laboratory, three fluids (marked as DIF-1, DIF-2, and DIF-3) were prepared, with 50 % w/w potassium formate and one fluid without potassium formate (marked as WBF) (Table 3). Fluid formulations shown in Table 2 contain base fluid and four components: viscosifying biopolymer, fluid loss polymers (starch and PAC) and sized calcium carbonate. A viscosifying biopolymer (xanthan gum) provides thixotropic properties and solid carrying capacity. Fluid loss polymers provide filtration control. Sized calcium carbonate is necessary as solid particulates for bridging purposes. Dilution water was necessary to decrease the base fluid density. The polymers were hydrated in the dilution water and that mixture was added to the base saturated brine. Water based fluid was chosen and tested to allow comparison of effectivity of formate based fluids.

Table 2 Formate based fluids application data
Tablica 2. Podaci o primjeni fluida na bazi formijata

Year	Country/ Area	Company	Fluid	Purpose	Well type	Formation	Source
1994.	North Sea		Sodium formate	Drill-in and completion fluid	Offshore open-hole horizontal oil wells		Byrne et al. 2002.
1994.	The Netherlands		Sodium/potassium formate	Drill-in and completion fluid	Horizontal open-hole gas wells		Byrne et al. 2002.
1994.	Norway	Statoil	Potassium formate weighted with manganese tetraoxide	Drill-in and completion fluid	Well C-18	The reservoir consisted of relatively shallow, highly porous, poorly consolidated sand. The reservoir matrix contained a significant percentage of reactive clays.	Downs et al. 2005.; Howard 1995.; Svendsen et al. 1995.
1995.	Northern Germany	Mobil Germany and M-I Drilling Fluids Germany	K-formate, saturated NaCl+$CaCO_3$, formate blend, Na-formate	Drill-in fluid (10 wells), workover/completrion (6 wells) and fracturing (1 well)	15 gas wells, deep horizontal gas well	Rotliegend sand formations, Formation temperature - 150 °C	Bungert et al. 2000.; Byrne et al. 2002.; Downs et al. 2006.
1996.-2000.	Germany	ExxonMobile	Biopolymer, fluid-loss agents, $CaCO_3$ (1-3%), Na-formate, K-formate or their blend	Drill-in and completion fluid	More than 15 wells	Blackstone, Fernie and Fort Simpson shales	Downs et al. 2005.
1997.	Ecuador	Oriente	Sodium formate	Drill-in fluid	Several horizontal wells		Downs et al. 2005.
	The Netherlands	NAM	Na-formate and Na/K-formate, $CaCO_3$, purified xanthan biopolymer, modified strach	Drill-in and completion fluid	Gas well (K14-FB 102)	Rotliegend sand formations	Downs et al. 2005.; Howard 1995.
1999.	UK	BP	Na/K-formate, biopolymer viscosifer, modified strach, sized $CaCO_3$	Drill-in and completion fluid	High-angle well	Sand/shale sequences with a high level of reactive smectite clay (80% of the clay content)	Downs et al. 2005.
1999.	UK	Shell	Cesium formate	Perforating fluid		Formation temperature - 185 °C	Downs et al. 2006.
1999.	Western Canada		Potassium formate	Drilling fluid	Over 300 wells		Downs et al. 2005.
1999	UK	Total	Cesium formate	Completion and workover fluid		Formation temperature - 207 °C	Downs et al. 2006.

Table 2 Formate based fluids application data (continued)
Tablica 2. Podaci o primjeni fluida na bazi formijata (nastavak)

Year	Country/ Area	Company	Fluid	Purpose	Well type	Formation	Source
	Norway	Statoil	Cesium formate	Drill-in and completion fluid	6 wells (45°-55° inclination)	Form. temperature - 150 °C	Downs etal. 2005.; Downs et. al. 2006.
2000.-2001.	UK	Shell	Na-formate, and Na/K-formate, KCl+polymer, NaCl+polymer, LTOBM, $CaCO_3$	Drill-in and completion fluid	Three horizontal wells		Downs et al. 2005.
2001.	UK	BP	Potassium/cesium formate	Drilling fluid		Sandstone	Downs et al. 2005.; Downs et al. 2006.
2002.	Norway	Norsk Hydro	Potassium formate	Drilling and perforation fluid	Horizontal HPHT appraisal/developmen t well	Formation temperature - 115 °C	Downs et al. 2005.; Downs et al. 2006.
2002.	USA	BP	Cesium formate	Completion and workover fluid	Offshore HTHP well	Formation temperature - 177 °C	Downs et al. 2006.
2003.	Norway	Statoil	Cesium formate	Drill-in and completion fluid	Gas wells	Formation temperature - 170 °C	Downs et al. 2006.
2004.	Saudi Arabia		Solids-free formate brines - (XC-polymer, strach, polyanionic cellulose, relatively small amount of $CaCO_3$)		Gas wells	Deep sandstone reservoir, Form. temperature -154,44 °C	Al Otaibi et al. 2008.
2004./2005.	Saudi Arabia	Saudi Aramco		Drilling fluid		Hard and abrasive sandstone with interbedding of shale, Form. temperature -121°C - 177 °C	Downs et al. 2005.; Downs et al. 2006.
2004./2005.	Norway		Cesium formate	Drill-in and completion fluid	6 wells	Form. temperature - 145 °	Downs et al. 2006.
2005.		MOL	Cesium formate	Completion and perforating fluid	Onshore well Vetyem-1		Downs et al. 2006.
	UK		Potassium/cesium formate	Completion fluid	HTHP well		Downs et al. 2005.
	USA Alaska			Drill-in and completion fluid	Horizontal sidetracks drilled with couled tubing		Downs et al. 2005.
	North Sea		Potassium/caesium formate blend	Drill-in and completion fluid	HT/HP gas wells		Byrne et al. 2002.

Table 3. Potassium formate based fluid composition
Tablica 3. *Sastav isplake na bazi kalij formijata*

Formulation	Units	WBF	Potassium formate based fluids		
			DIF-1	DIF-2	DIF-3
Water	ml	1000	500	500	500
K-formate	ml	0	500	500	500
Xanthan gum	g/l	4	4	4	4
Starch	g/l	14	14	14	14
PAC	g/l	20	0	10	20
$CaCO_3$	g/l	30	30	30	30
Defoamer	As required				

Rheological properties at temeratures up to 160 °C (plastic viscosity, yield point, gel strenghts, index of consistency, flow index) were determined from readings of shear stress data at different shear rates obtained by using HPHT viscometer - OFITE Model 1000 and presented in the Table 4 and Figures 1 to 6 as well as API fluid loss, filter cake thickness and friction coefficient data presented in the Table 4 and Figure 7.

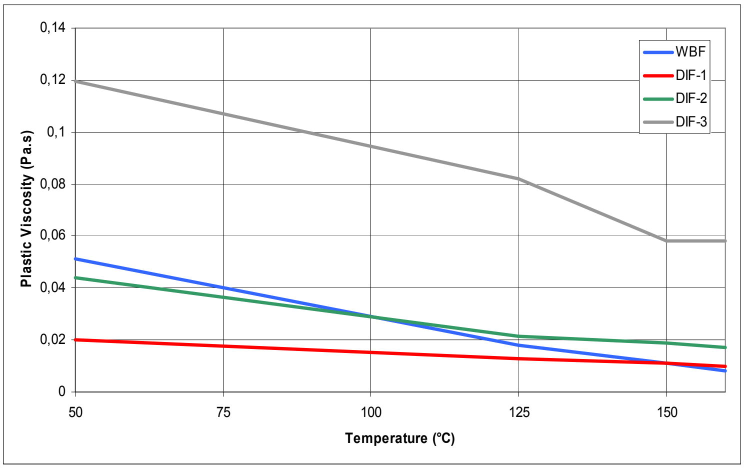

Figure 1 Influence of temperature on plastic viscosity of potassium formate based fluids
Slika 1. *Utjecaj temperature na plastičnu viskoznost isplaka na bazi kalij formijata*

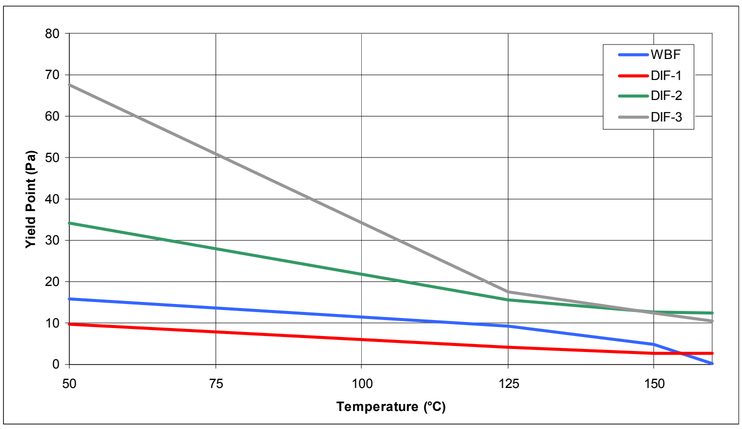

Figure 2 Influence of temperature on yield point of potassium formate based fluids
Slika 2. *Utjecaj temperature na naprezanja pri pokretanju isplaka na bazi kalij formijata*

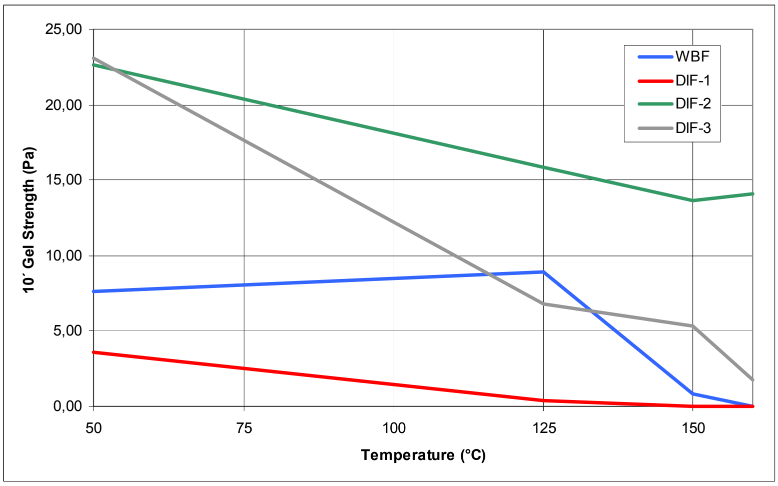

Figure 3 Influence of temperature on 10-s gel strength of potassium formate based fluids
Slika 3. *Utjecaj temperature na deset sekundnu čvrstoću gela isplaka na bazi kalij formijata*

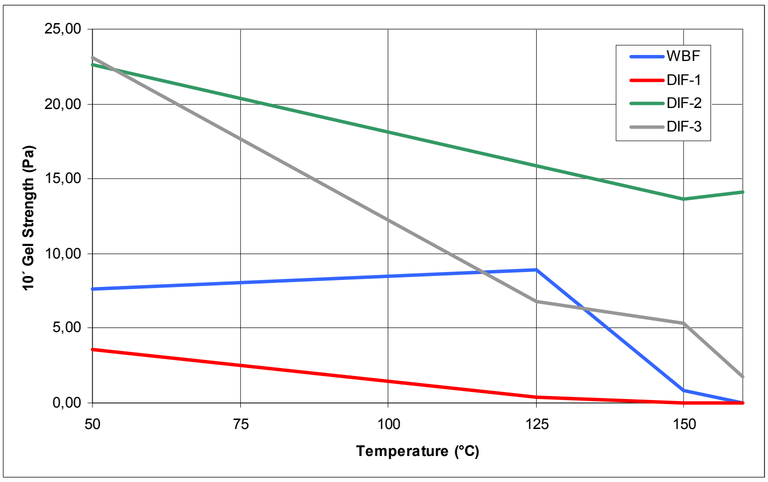

Figure 4 Influence of temperature on 10-min gel strength of potassium formate based fluids
Slika 4. *Utjecaj temperature na deset minutnu čvrstoću gela isplaka na bazi kalij formijata*

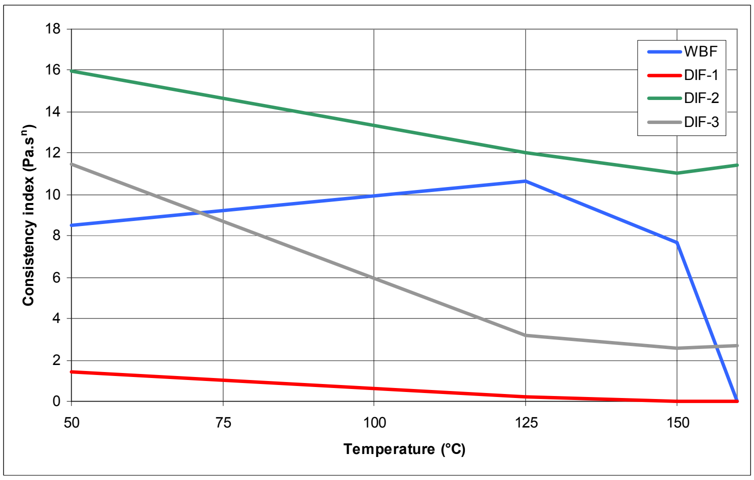

Figure 5 Influence of temperature on flow index of potassium formate based fluids
Slika 5. *Utjecaj temperature na indeks toka isplaka na bazi kalij formijata*

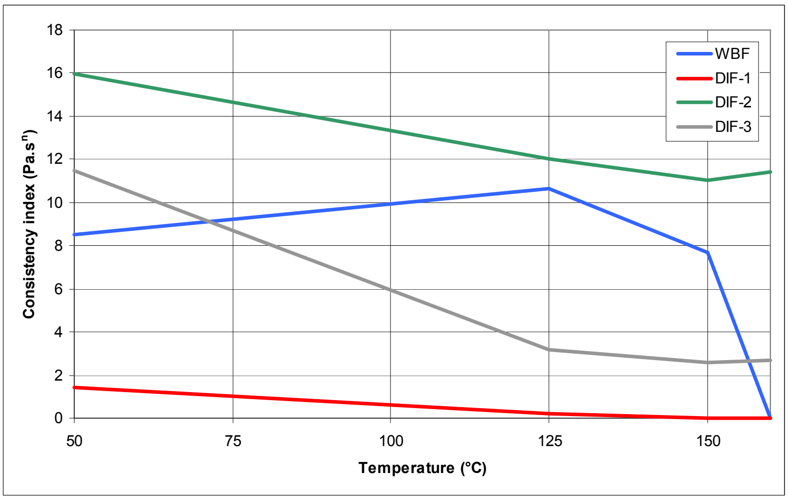

Figure 6 Influence of temperature on consistency index of potassium formate based fluids
Slika 6. *Utjecaj temperature na indeks konzistencije isplaka na bazi kalij formijata*

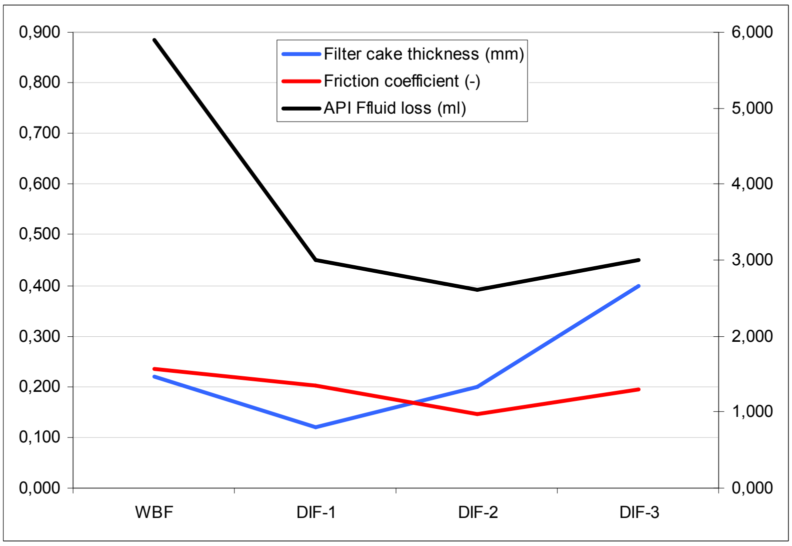

Figure 7 API fluid loss, filter cake thickness and friction coefficient of potassium formate based fluids
Slika 7. *API filtracija, debljina isplačnog obloga i koeficijent trenja isplaka na bazi kalij formijata*

Rheological properties (plastic viscosity and yield point,) of water based fluid (WBF) and potassium formate based fluids decrease with increasing temperature. Potassium formate based fluid DIF 3, that contains the same amount of additives as WBF fluid shows higher values than it that means potassium formate stabilizes polymers at higher temparatures.
Potassium formate based fluid (DIF-1) designed without addition of polyanionic cellulosic polymer (PAC) shows very low values of rheological properties. Increasing of PAC concentration in potassium formate based fluids (DIF-2 and DIF-3) results in higher values of plastic viscosity and yield point at same temperature.

Figure 7 presents API fluid loss, filter cake thickness and friction coefficient data. Potassium formate based fluids show lower values of API fluid loss and friction coefficient than water based fluid. Potassium formate based fluid (DIF-2) with 10 g/l PAC shows lower values of API fluid loss and friction coefficient and thiner filter cake than fluid DIF-3 prepared with higher concentration of PAC. Generally, potassium formate based fluids gave a thin filter cake of <0,5 mm in API fluid loss test.

Table 4. Fluid properties of tested fluids at temperatures up to 160 °C
Tablica 4. *Svojstva ispitivanih isplaka kod temperatura do 160 °C*

	Mud			
	WBF	**DIF-1**	**DIF-2**	**DIF-3**
Temperature	**Plastic Viscosity**			
°C	Pa·s	Pa·s	Pa·s	Pa·s
50	0,05108	0,02006	0,04404	0,11959
125	0,01789	0,01281	0,02142	0,08215
150	0,01125	0,01118	0,01893	0,05815
160	0,00818	0,00976	0,01713	0,05815
Temperature	**Yield Point**			
°C	Pa	Pa	Pa	Pa
50	15,843	9,849	34,025	67,451
125	9,283	4,079	15,729	17,473
150	4,84	2,607	12,645	12,431
160	0,35	2,674	12,382	10,389
Temperature	**Gel Strength (10′)**			
°C	Pa	Pa	Pa	Pa
50	7,64	3,57	22,64	23,07
125	8,93	0,39	15,87	6,77
150	0,87	0,00	13,61	5,30
160	0,00	0,00	14,10	1,75
Temperature	**Gel Strength (10")**			
°C	Pa	Pa	Pa	Pa
50	8,2	3,71	17,63	3,94
125	10,4	0,82	15,37	2,08
150	7,25	0,24	14,36	5,37
160	0	0	14,06	5,12
Temperature	**Flow index**			
°C	-	-	-	-
50	0,323	0,539	0,306	0,493
125	0,177	0,731	0,231	0,505
150	0,144	0	0,219	0,496
160	0	0	0,206	0,471
Temperature	**Consistency index**			
°C	$Pa \cdot s^n$	$Pa \cdot s^n$	$Pa \cdot s^n$	$Pa \cdot s^n$
50	8,525	1,401	15,952	11,448
125	10,637	0,235	12,03	3,195
150	7,704	0	11,054	2,561
160	0	0	11,394	2,666
Temperature	**API fluid loss**			
Room temperature	ml	ml	ml	ml
	5,900	3,000	2,600	3,000
Temperature	**Filter cake thickness**			
Room temperature	mm	mm	mm	mm
	0,220	0,120	0,200	0,400
Temperature	**Friction coefficient**			
Room temperature	-	-	-	-
	0,2342	0,2015	0,1466	0,1943

Conclusions

The comparison of the laboratory research results shows that potassium formate based fluid DIF-3 shows better rheological and filtration properties than water based fluid, especially at higher temperatures. This fact allows to conclude that potassium formate stabilizes viscosifiers and fluid loss polymers enabling better rheological properties at higher temperatures. WBF and potassium formate based fluids without PAC (DIF-1) have inadequate rheological properties at temperatures higher than 125 ºC. Generally, the most acceptable results have achieved with formate based fluid DIF-2 that contain 10 g/L PAC. The better results have not achieved by further increasing of PAC concentration (DIF-3).

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