

Davarpanah, Afshin; Mirshekari, Behnam

Article

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Research paper

Effect of formate fluids on the shale stabilization of shale layers

Afshin Davarpanah^{*}, Behnam Mirshekari

Department of Petroleum Engineering, Islamic Azad University, Science and Research Branch, Tehran, Iran



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ABSTRACT

Formate fluids are considered as one of the most efficient drilling fluids in petroleum industries, especially in shale to minimize the drilling inefficiencies during the operational performances. The objective of this study is to compare the profound impact of sodium and potassium formate fluids on the rheological properties such as apparent viscosity, plastic viscosity, yield point, fluid loss and shale recovery percentage of different drilling fluid samples. To do this, six samples with different compositions are conducted into the investigation in the laboratory conditions to measure each parameter statistically. According to the results of this experimental evaluation, potassium formate fluid has the lowest shale recovery percent (about 87%), which is indicated the shale preventive property of potassium. The mixture of sodium–potassium has the highest shale recovery (approximately 95%). Addition of Polyanionic Cellulose-Regular (PAC-R) and Polyanionic Cellulose-Ultralow (PAC-UL) has caused to increase the rheological properties of the formate fluids. Consequently, due to the excellent compatibility of formate fluid with reservoir rock, the minimum damaged has occurred to the formation.

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1. Introduction

Due to the geological properties of hydrocarbon reservoirs which are constituted with the stability of formation rock, it is not possible to drill all the reservoirs in the underbalanced circumstances (Davarpanah and Mirshekari, 2019c; Davarpanah et al., 2019c; Moghadasi et al., 2010; Pashin et al., 2018; Perin and Benson, 2010; Pooladi-Darvish and Firoozabadi, 1998). Therefore, predicting and selecting the best drilling scenario for the drilling performances would be one of the main challenges of petroleum industries that should be addressed significantly (Ardila Jaimes et al., 2018; Bello et al., 2018; Davarpanah et al., 2019a; Kakoli et al., 2016; Nasiri et al., 2018; Raza, 2015). Drilling fluids have played a substantial role in the operational performances of petroleum industries. In respect of the way, choosing the optimum drilling fluid which is more adopted with the reservoir characteristics would be a proper choice to eliminate the drilling inefficiencies (Davarpanah and Mirshekari, 2019b; Huang et al., 2019; Keshavarzi et al., 2019; Madruga et al., 2018; Rahman, 2018; Saasen and Løklingholm, 2002). One of the main functions of drilling fluids is the fluids inflow prevention especially in high permeable rocks which substantially controlled by the fluid density (Caenn and Chillingar, 1996; Davarpanah, 2018b; Davarpanah and Mirshekari, 2019a; Razali et al., 2018; Tare et al.,

2002). Viscosity variation of the drilling fluid would play a significant role in cutting's transfer to the surface, which considered as one of the flexible roles of drilling fluids. Sealing features, suspension control property, and lower friction forces are another roles of drilling fluids which should be taken into consideration in drilling procedures (Davarpanah, 2018c; Davarpanah and Mirshekari, 2018a; Ouaer et al., 2018; Rahman, 2018; Zhao et al., 2017; Zhou et al., 2016).

Formate fluids are considered as one of the useful drilling fluids in petroleum industries regarding its appropriate utilization in different operational circumstances. Three main types of drilling formate fluids which are administered in the recent operations are potassium formate fluid, sodium formate fluid, and cesium formate fluid (Davarpanah, 2018a; Fornasier et al., 2017; Hossain and Wajheuddin, 2016; Redburn and Heath, 2017). One of the principal influence of these types of fluids is that they have a robust inhibitory property which is caused to be a proper replacement drilling fluid rather than water-based drilling fluids (Davarpanah, 2018b; Howard et al., 2016; Shirmohammadi et al., 2018). In addition, other advantages of formate fluids are phase trapping/blocking; excellent compatibility of formate fluids with environment; optimize wellbore hydraulic; surficial absorption of chemical materials and wettability changes; solid particle penetration; minimum damage to the formation; increase drilling penetration rate (Davarpanah et al., 2018b; Jin et al., 2016; Tian et al., 2018). The stabilization of shale layers is stated as the following statements; decrease hydraulic fluid flow from the mud to shale layers (Luo and Vasseur, 2016; Struchtemeyer, 2018).

^{*} Corresponding author.

E-mail address: Afshin.davarpanah@srbiau.ac.ir (A. Davarpanah).

Abbreviations

PAC-R	Polyanionic Cellulose-Regular
PAC-UL	Polyanionic Cellulose-Ultra-Low
HPHT	High-Pressure High Temperature
Na ₂ CO ₃	Sodium Carbonate
PHPA	Partially-Hydrolyzed Polyacrylamide
NaCl	Sodium Chloride
CaCO ₃	Calcium Carbonate

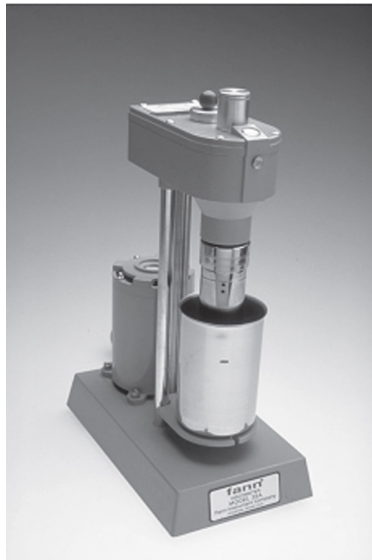


Fig. 1. Viscosity measurement by a direct viscometer (Caenn et al., 2017).

Due to the high salinity of formate, had less water activities that produced an osmotic pressure that may cause to water back flow from the shale to the mud and as a result shale stability was decreased (Davarpanah and Mirshekari, 2018b, 2019b; Davarpanah et al., 2018a; Hickenbottom et al., 2016; Ishika et al., 2018). Reduction in drilling filtrate fluid penetration to the shale layers (Albooyeh et al., 2018; Barroso et al., 2018; Davarpanah and Mirshekari, 2019d).

Although there are numerous studies have widely reported in literature to investigate the importance of drilling fluid on the oil production, in this comprehensive study a set of investigations into the different formate fluids such as sodium and potassium formate fluids were conducted to evaluate the rheological properties such as apparent viscosity, plastic viscosity, fluid loss, and yield point in several material's compositions. Thereby, this experimental test would be beneficial for petroleum industries due to the high potential application of formate fluids and the drilling parameters would be optimized by using them primarily in shale reservoirs.

2. Materials and methods

2.1. Rheological properties measurements

To measure the drilling fluid viscosity, a viscometer as it is shown in Fig. 1 with a capillary glass was utilized to measure specific volume discharge time for the proposed drilling fluids.

To measure the accurate value of the fluid loss, High-Pressure High Temperature (HPHT) filter press was used at the ambient temperature and pressure of 100 psi, which is shown in Fig. 2.

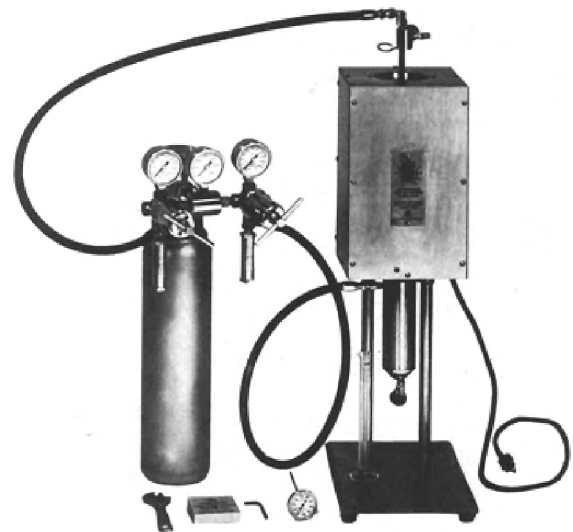


Fig. 2. High-Pressure High Temperature (HPHT) filter press to measure fluid loss (Caenn et al., 2017).

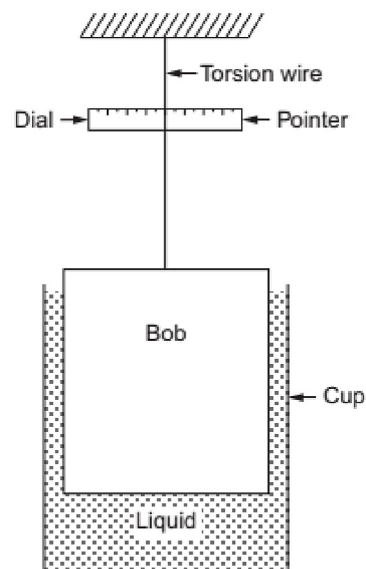


Fig. 3. Torsion Viscometer Schematic to measure yield point and plastic viscosity (Caenn et al., 2017).

Concentric cylinder rotary viscometer was used to measure plastic viscosity and yield point as it is shown in Fig. 3.

To measure the viscosity of proposed drilling fluids which are used in this experiment, a direct viscometer was used and to check the appropriateness of the results; each experiment was repeated three times to compare the measurements and provide the average value. High-Pressure High Temperature (HPHT) filter press device was utilized in this experiment to measure the fluid loss value, and Torsion Viscometer was used to measure the value of plastic viscosity and yield point. To understand the fluids behavior, six samples are used in this experiment to investigate the different types of formate fluids in the presence of several polymers. The properties of utilized materials which is provided for each experiment are statistically explained in Table 1. To give a good agreement with the operational performances of a drilled well, sea water was administered in the experiment.

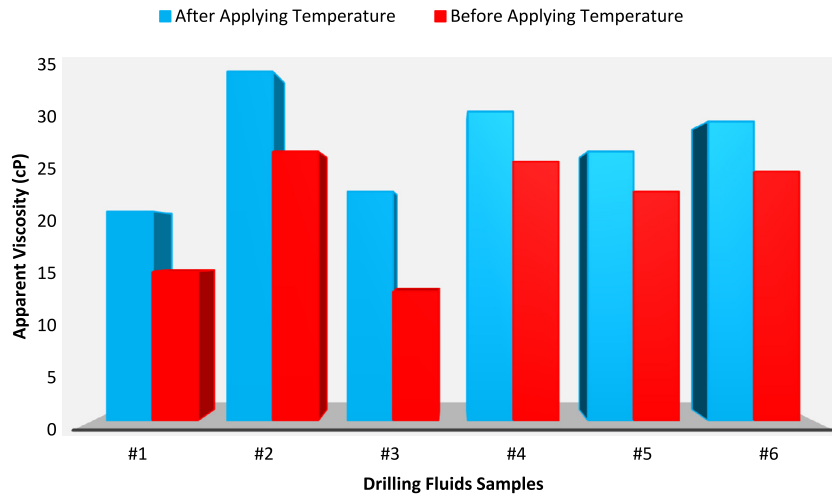


Fig. 4. Apparent viscosity before and after applying temperature.

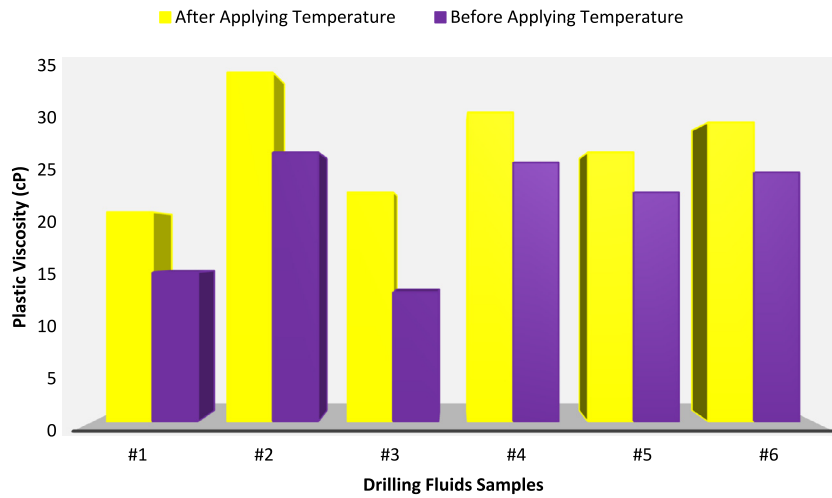


Fig. 5. Plastic viscosity before and after applying temperature.

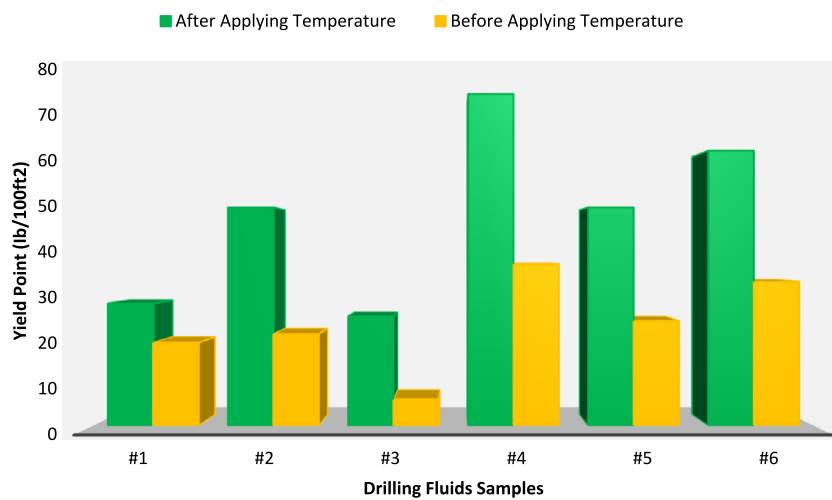


Fig. 6. Yield point before and after applying temperature.

One of the primary purposes of this study was to measure the rheological properties of prepared drilling fluids such as apparent viscosity, plastic viscosity, yield point and fluid loss in each sample. In this experiment, the rheological properties were

measured before and after the applied temperature of 250 °F for 16 h. As can be seen in Figs. 4–6, the value of apparent viscosity, plastic viscosity and yield point before and after applying the temperature was schematically depicted.

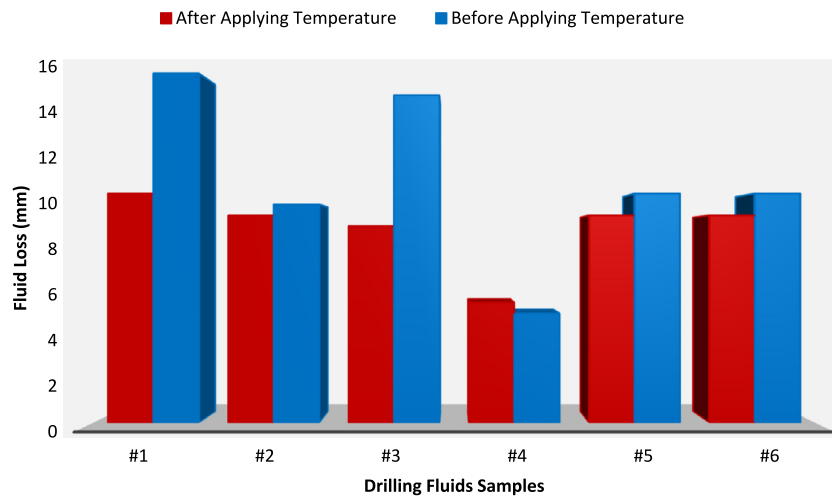


Fig. 7. Fluid loss before and after applying temperature.

Table 1

Six formate fluid samples with combination of potassium/formate fluids.

Fluid compound	Unit	#1	#2	#3	#4	#5	#6
1 Water ^a	cc	350	350	350	350	350	350
2 Na ₂ CO ₃	gr	1	1	1	1	1	1
5 PAC-UL MI	gr	-	3	-	3	3	3
6 PAC-R MI	gr	-	1	-	1	1	1
7 HTPM	gr	-	-	4	-	-	-
8 PHPA	gr	1	1	1	1	1	1
7 NaCl	gr	70	70	70	70	30	70
8 Formate Na	gr	17.5	17.5	17.5	17.5	17.5	-
9 Formate K	gr	21	21	21	21	60	40
10 CaCO ₃	gr	5	5	5	50	5	5

^aThe utilized water in this experiment is sea water with the salinity of 30000 ppm to be more adapted to the drilling operational performances.

As it can be seen in Figs. 4–6, the amount of apparent viscosity, plastic viscosity and yield point for the samples of 2, 4, 5–6 which are mixed with PAC-R and PAC-UL are higher than other samples. In sample one regarding the utilization of poly-thin and poly-drill polymers in the mud, the value of viscosity reduction before and after applying temperature is less than other samples. Hence, this reduction would be related to the excellent thermal stability of these polymers. Furthermore, sample five due to the use of more formate salts in its formulation demonstrated that rheological properties reduction would be lower. The high amount of viscosity and yield point in sample four was related to the high percentage of calcium carbonate of this fluid rather than other samples. As it is evident in Fig. 7, fluid loss changes before and after applying the temperature of 250 °F for different fluids during 16 h was schematically plotted. The amount of fluid loss for sample four was noticeably lower than other samples which are caused by the high amount of calcium carbonate in this mixture than other samples and confirmation of bridging properties of calcium carbonate, and it's decreased the fluid loss.

3. Results and discussion

3.1. Shale recovery test

In this part of the study, after the measurement of rheological properties for each sample, 20 g of shale sample with the specific grains of ($5 < \text{grains} < 10$) was added to the samples regarding the API-13I standard. The following steps were done sequentially;

- Exit the samples after reducing its temperature.

- Take samples in the mesh of 35 mm (this should be done correctly).
- Remained shale grains should be washed with saturated salty water.
- Put in the dryer for 4 h.
- Weight samples again. Then shale recovery factor obtains from Eq. (1)

$$\text{Shale recovery\%} = \frac{\text{Weight of dried shale (gr)}}{\text{Weight of initial shale (20 gr)}} \times 100 \quad (1)$$

The shale recovery for potassium/sodium formate fluids through the different formate salts concentration was being schematically plotted in Fig. 8. As it was expected, due to the more preventive property of potassium formate than sodium formate, the shale recovery percentage of potassium formate is more than shale recovery percentage of sodium formate. Moreover, shale recovery percentage increased by the rising of formate salts concentration. Thereby, the percentage of shale recovery for potassium and sodium formate fluids in a high concentration of formate salts approximately reached the plateau.

Regarding tests which were based on the effect of potassium and sodium formate fluids on the rheology properties, it can be demonstrated that potassium formate fluids had more impact on efficient rheology properties and they had more shale recovery percentages. Also, if the concentration was above 100 lb/bbl., the effect of formate salts on the rheology properties was decreased. Subsequently, these salts had the principle role in increasing the fluid density. The rheological properties such as apparent viscosity, plastic viscosity and yield point before and after applying temperature for potassium, sodium and the combination of both formate fluids statistically described in Table 2. As it can be illustrated in Table 2, reduction of fluid rheological properties through 100 grams' sodium formate fluid was more than the other two samples. Even though the minimum reduction of fluid rheological properties related to 100 g of potassium formate fluid. Furthermore, reduction of rheological properties of the mixture of potassium and sodium were less than sodium formate fluid and relatively close to potassium formate fluid. As can be seen in Table 2, a fluid loss for the mixture of potassium/sodium formate fluid is less than other samples.

According to the results of this experiment, shale recovery for potassium formate fluid, sodium formate fluid and the mixture of potassium/sodium formate fluid were utilized to measure three samples. Thereby, shale recovery for the potassium formate fluid due to shale preventive property are less than the two samples.

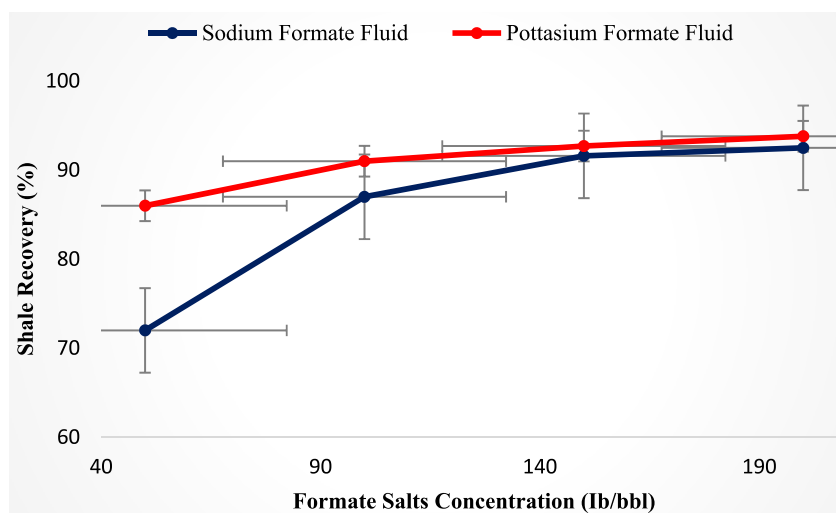


Fig. 8. Effect of potassium/sodium salts concentration on the shale recovery.

Table 2

Rheological properties of different formate fluids.

Rheological property	100 g of potassium formate fluids	100 g of sodium formate fluids	50 g of potassium + 50 g of sodium formate fluids
Apparent viscosity before applying temperature (Talashek and Kelco)	33	21	26
Apparent viscosity after applying temperature (Talashek and Kelco)	29	18	22
Plastic viscosity before applying temperature (Talashek and Kelco)	22	15	17
Plastic viscosity after applying temperature (Talashek and Kelco)	19	13	15
Yield point before applying temperature (lb/100ft ²)	24	15	19
Yield point after applying temperature (lb/100ft ²)	20	12	16
Fluid loss before applying temperature (mm)	12	12	8
Fluid loss after applying temperature (mm)	7	7.5	5
Shale recovery (%)	87.1	91.3	94.8

It was about 87%. Besides, shale recovery for the mixture of potassium/sodium formate fluid with the relative value of 95% is the most shale recovery rather than sodium and potassium formate fluids.

4. Conclusions

Formate fluids are considered as one of the most applied drilling fluids in petroleum industries regarding their high potential to match with the different types of formation rocks. Low ECD (Equivalent Circulation Density) of formate fluids in mud system caused the lower pressure drop. Thereby, the use of formate fluids would lead to the drilling of more wells with higher depth and lower wellbore diameter. Due to the relatively low values of yield point in formate fluids, however, they need lower primary pump pressure to flow the mud through the well.

Moreover, regarding their low viscosities and high densities, better hydraulic efficiency was provided during the drilling operation. Due to the low amount of solid percentage in this fluid, the reservoir will be damaged mechanically less than other fluids. Consequently, it is demonstrated that mixture fluid had good rheological properties, thermal stability and shale recovery instead of sodium and potassium formate fluids. The following conclusions were obtained from this study, which profoundly demonstrated the principal roles of formate fluids in the drilling operational performances rather than other drilling fluids. Potassium and sodium formate fluids could make fluids with a density of 90 PCF. The percent of shale recovery for the potassium formate fluid due to shale preventive property is approximately 87%, which is the least shale recovery percent rather than sodium formate fluid and the mixture of sodium and potassium. The highest percent of shale recovery was related to the mix of sodium and

potassium (about 95%). Due to the presence of poly-thin and poly-drill polymers in the mud sample one, the value of viscosity reduction before and after applying temperature is less than other samples. The presence of PAC-R and PAC-UL in the formate fluids have caused to increase the drilling fluids characteristics such as yield point, apparent viscosity, and plastic viscosity.

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