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ORIGINAL ARTICLE

A visual investigation of different pollutants on the rheological properties of sodium/potassium formate fluids

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Abstract
Nowadays, the adverse effect of drilling operation performances on the environment is considered as one of the major concern of petroleum industries which should be taken into the consideration to virtually eliminate the unnecessary expenses of improving the wasting quality before entering to the environment. Volume and toxicity of discharged materials evaluate surface discharge severity. The ubiquitous utilization of formate fluids has revolutionized the way petroleum industries have conquered the lower drilling inefficiencies. We investigated the profound impact of different pollutants on the potassium/sodium formate fluids using experimental tests. The particular sample for mud pollution test was formate fluid with starch biopolymers. To do this, five samples of formate fluids were made, and each of them was polluted by several pollutants such as cement, lime, acid, alkali and stucco. Consequently, rheological properties and the pH changes and their effect on the formate fluids were evaluated.

Keywords Formate fluids · Rheological properties · Pollutants · Core samples

Introduction

The ubiquitous utilization of numerous types of drilling fluids in petroleum industries is considered as one of the significant principal issues that would revolutionize the way petroleum engineers drill the hydrocarbon formations. The accurate selectivity of proper drilling fluid is always a significant concern for petroleum industries, and they have tried to choose those drilling fluids which have the most adaptation with the reservoir characteristics (Caenn and Chillingar 1996; Cayeux et al. 2014; Javora et al. 2003; Kakoli et al. 2016; Karimi et al. 2015; Lan and Polycarpou 2018). An essential drilling fluid is contained in two main phases, continuous phase and discontinuous phase, which are utterly dependent on the types of selected formation. To achieve the best and optimum results in the drilling operations and completion performances of a well, the proper estimation of formation property to provide the sufficient requirement before commencing the drilling procedures should be taken into consideration. Although the expenditures of providing required material for making the drilling fluid for the proposed drilled well are small enough rather than the whole expenses of drilling, the appropriate selection of drilling fluid retains its specific properties in the urgent situations. The principal function of drilling fluids is to minimize the cutting concentration from the wellbore and around the drill bit, which significantly improves the quality of drilling operations (Lemasson et al. 2015; Li and Luft 2014; Mahto and Sharma 2004; McMillan et al. 2015; Mehrabian et al. 2017; Peng et al. 2018).

Drilling fluids are classified with respect to the basic types of fluids and primary ingredients: the gaseous drilling fluid which contains nitrogen and air; aqueous solution that is included with foam in the presence of gas, polymer, clay and other emulsions; non-aqueous solution that are entailed oil-base mud, invert oil emulsions and all types of synthetic oil mud. Formate drilling fluid is one of the state-of-the-art types of new drilling fluid, which has profoundly influenced the drilling performances, and is considered as the most common drilling fluids that are extracted from salty inorganic materials. There is the ubiquitous and pervasive utilization of formate drilling fluids in shale layers that have the most problematic situations than other conventional formations. Consequently, due to the lower solid particles in the construction of drilling formate fluids, the performed

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damage on the formation reached its minimum point in comparison with other drilling fluids; drilling formate fluid has been used in many drilling operations due to its low expenditures in the total cost of drilling. The advantages of formate fluids that specify it from other drilling fluids are (Patel et al. 2007; Peng et al. 2018; Rabbani et al. 2018; Balavi and Boluk 2018; Rossi et al. 2017) as follows:

- *Phase trapping/blocking f*ormate fluids improve the invading phenomenon and the constant fluid filtration entrapment around the wellbore. Therefore, relative permeability gradually increased regarding higher fluid movement in the pores.
- *Good compatibility of formate fluids with the environment* formate brines contain any surfactants and multivalent ions that cannot cause adverse reactions with formation fluids.
- *Optimize wellbore hydraulic* the produced friction on the drilling bit, and between the walls of formation and rotated drill string, generates a considerable amount of heat. The high rates of circulating formate drilling fluid provide the sufficient energy to transfer the produced heat far from the frictional sites by absorbing it into the liquid phase of the fluid and carrying it away.
- *Surficial absorption of chemical materials and wettability changes* there is a noticeable change in the rate of hydrocarbon wettability and leads to having higher permeability.
- *Substantial particle penetration* good dispersion and suspension of solid particles in the formate drilling fluid prevent reservoir pore blocking in the fluids used for the completion and drilling performances.
- *Minimize the formation of damage* formate drilling fluids have been used to supply a constant change in the value of relative permeability.
- *Increase drilling penetration rate* it improves the mobility of drilling fluid in the formation which leads to increasing the penetration rate (Salas et al. 2015; Santos et al. 2018; Yan et al. 2018; Weems et al. 2016; Yihdego 2017; Zhang et al. 2018).

Materials and methods

Field description

The studied field is one of the Persian Gulf fields in the south of Iran that is vertically drilled to provide the necessary information for the experimental investigation. The objective was to drill a 8 1/2-in. hole section from 10,900 ft. to the casing point at a measured depth (MD) of 12,500 ft. A 7-in. casing string was then to be drilled and cemented. The FBM optimized for member (A) was expected to provide maximum shale stabilization and inhibition to achieve maximum ROP without any incidents such as tight hole, pipe stuck and hole filling.

Measurement of mud rheology

The appropriate measurements of rheological properties were one of the major issues which should be adequately addressed to obtain the best results. The rheological properties of drilling fluid investigated in this experiment are apparent viscosity, yield point, plastic viscosity and gel strength. To obtain these parameters, a viscometer as it is schematically depicted in Fig. 1 is used after it is calibrated to acquire the accurate results in the average format.

Measurement of mud filtrate loss

Fluid loss is the measurement of filtrate passing from the drilling fluid into a porous permeable formation. Low fluid loss is a characteristic of good drilling fluids and the key to borehole integrity. The goal of a good drilling fluid is to create a thin filter cake on the sides of the borehole to prevent the excessive loss of fluids in the formation. The filtration test is measured using the instrument shown in Fig. 2.

Fig. 1 Viscosity measuring instrument

Fig. 2 Measurement of mud fluid loss

Results and discussion (experimental tests)

Considerable influence of pollutants on the rheological properties

Figure 3 demonstrates the fluid rheological properties such as apparent viscosity, plastic viscosity and yield point for polluted fluid and formate base fluids. As shown in Fig. 3, changes in mud rheology properties of fluid polluted by several pollutants were not significant, and exposing the formate fluid to several pollutants approximately maintains its properties, and it does not have a steep rise or remarkable decrease in the rheological properties. Furthermore, those drilling fluids which are polluted by hydrochloric acid, cement and stucco have more impact on the apparent viscosity, plastic viscosity and yield point than the other fluids; accordingly, rheological properties of this material, which was added to the drilling fluid, are lower than other fluids. It seems that these pollutants have influenced more on the reduction in rheological properties of drilling fluids.

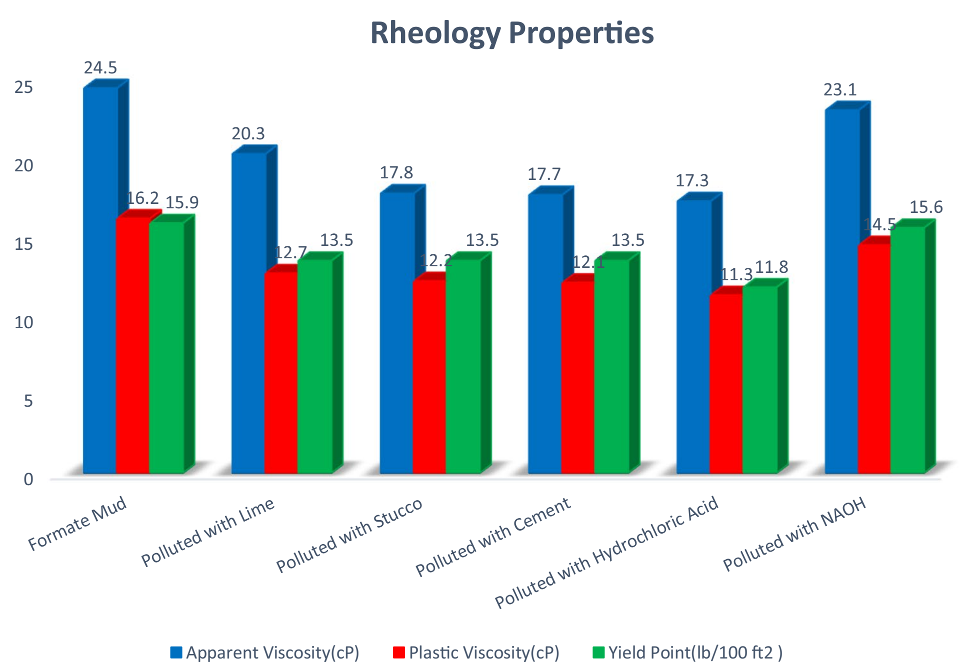
Fluid loss measurements

Figure 4 illustrates the fluid loss of formate fluids in comparison with several pollutants; as shown in Fig. 4, fluid loss of fluid polluted with several pollutants does not have a noticeable increase. Moreover, the fluid loss increased 1 mm when the mud is polluted with cement and NaOH. Moreover, drilling fluids polluted with cement and NAOH have the maximum amount of fluid loss changes than the other fluids, 5.1 and 5, respectively. That is to say that these pollutants play a significant role in the increase in fluid loss and it considers as a negative point for drilling operations.

pH measurement

Figure 5 illustrates the amount of pH for formate fluids in comparison with several pollutants. The amount of pH for formate fluid is approximately 9. Even though, as shown in Fig. 5, the amount of pH of the fluid polluted with lime decreased minimally (nearly 8.3) and with stucco decreased

Fig. 3 Mud rheological properties changes in the presence of several pollutants



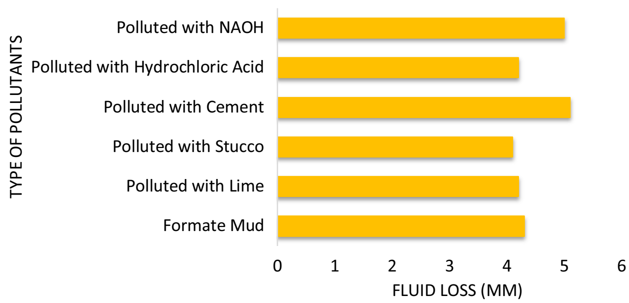
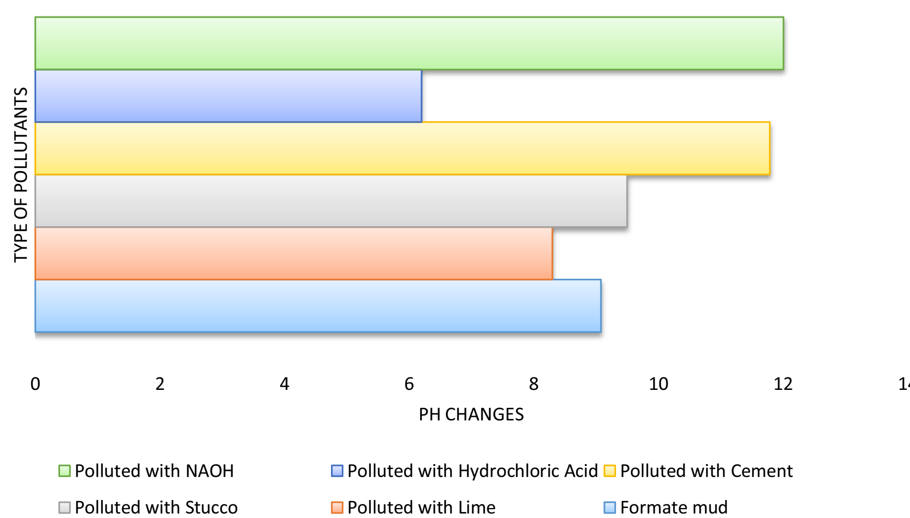


Fig. 4 Fluid loss changes in the presence of several pollutants

gradually (about 9.5). The highest increase in pH of formate fluid polluted by NaOH (relatively 12) is obtained and the second highest increase is related to the fluid polluted by cement (nearly 11.8). By adding a significant amount of hydrochloric acid (35 cc hydrochloric acid 37%), the amount of pH decreased suddenly to 6. Also, those drilling fluids which are polluted with hydrochloric acid regarding its acid property have the minimum amount of PH changes than the other fluids. It seems that hydrochloric acid severely affects

Fig. 5 pH changes in the presence of several pollutants



the properties of drilling fluid and changes it too acidic fluid than other fluids.

Statistical evaluation for each parameter

The *t* test assesses whether the means of two groups are statistically different from each other. This analysis is appropriate whenever the means of two groups are compared. The top part of the ratio is just the difference between the two means or averages. The bottom part is a measure of the variability or dispersion of the scores. This formula is mostly another example of the signal-to-noise metaphor in research: The difference between the means is the signal that, in this case, we think our program or treatment introduced into the data; the bottom part of the formula is a measure of variability, that is, mostly noise that may make it harder to see the group difference. Figure 6 shows the formula for the *t* test and how the numerator and denominator are related to the distributions. The result of *t* test is obtained from Eqs. 1 and 2

$$\mathrm{SE}\left(\bar{X}_T - \bar{X}_C\right) = \sqrt{\frac{\mathrm{var}_T}{n_T} + \frac{\mathrm{var}_C}{n_C}}, \tag{1}$$

$$t = \frac{\bar{X}_T - \bar{X}_C}{\sqrt{\frac{\mathrm{var}_T}{n_T} + \frac{\mathrm{var}_C}{n_C}}}. \tag{2}$$

From Eq. 2, it is calculated that:

$$t = \frac{\bar{X}_A - \bar{X}_B - \bar{X}_C}{\sqrt{\frac{\mathrm{VAR}_{TA}}{n_A} + \frac{\mathrm{VAR}_{TB}}{n_B} + \frac{\mathrm{VAR}_{TC}}{n_C}}}, \tag{3}$$
$$t = -14.236.$$

The *t* value from Table 1 will be positive if the first mean is larger than the second and negative if it is smaller. Once you compute the *t* value, you have to look it up in a table of significance to test whether the ratio is large enough to say that the difference between the groups is not likely to have a chance finding. To test the significance, you need to set a risk level. As it can be seen, the amount of t is calculated −14.236 and it shows that the effect of pollutants on the formate fluids is less significance.

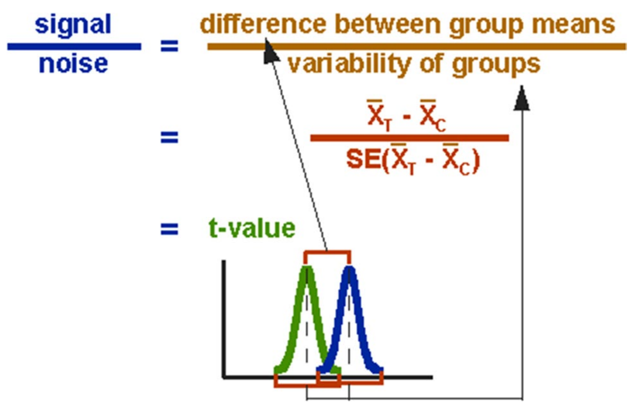


Fig. 6 Formula for the *t* test

Conclusions

In this comprehensive paper, experimental laboratory tests indicate the comparison of influential effects of several pollutants on the formate drilling fluids; accordingly, however, pollutants lime, stucco, cement and acids change mud rheological properties; in some cases, it would be diminished the effect of these parameters on the formate drilling fluid. Furthermore, sodium/potassium formate fluids maintain their properties properly, and it does not have a significant increase or decrease in the mud rheological properties. The amount of pH for sodium/potassium formate fluids in the presence of several pollutants does not have a noticeable change. In comparison with hydrochloric acid, it can be observed that formate fluids have a considerable resistivity. Moreover, by adding a large amount of hydrochloric acid (35 cc hydrochloric acid 37%) the amount of pH decreased suddenly to 6.2. Buffering properties of these fluids are the cause of this reduction regarding addition of carbonate and bicarbonates. Consequently, it can be considered that formate fluids have a small reduction in the amount of pH.

Table 1 Statistical evaluation for each parameter

	Apparent viscosity (*A*)	Plastic viscosity (*B*)	Yield point (*C*)
	16	15	23
	13	13	19.5
	13	12	18.5
	13	12	18.5
	12	11	17
	16	14	22
$\bar{X}$	13.8333333	12.83333	19.75
VAR_T	2.96666667	2.166667	5.275

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