

Recommendations for Compatibility of Different Types of Polymers with Potassium/Sodium Formate-Based Fluids for Drilling Operations: An Experimental Comparative Analysis

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Abstract

A formate-based fluid has been successfully used in many high pressure High temperature (HPHT) well operations since they were introduced in field practice. The laboratory research was carried out to determine composition of formate-base drilling fluid. It was formulated using sodium and potassium formate salts, Carboxymethyl Cellulose (CMC), Polyanionic Cellulose (PAC) and other types of polymers. In this research, the compatibility of different polymers with fluids, including potassium/sodium formate salts is being studied. Having said this, however, polymers, when taken to high temperatures, lose their properties. Therefore, this experimental procedure has been done at a temperature of 250°F over a period of 16 h. For doing these tests, six types of potassium/sodium formate fluids were made by different polymers. All samples formulation regarding their type and amount of water used in preparing fluids and the volume of salts used are simultaneously kept constant. On the contrary, the only differences were the types of polymers used in the different formulations. Formulation of formate-base fluids gives the best rheological properties in terms of AV/PV, YP and shale recovery than other fluids.

Keywords: CMC; PAC; Formate fluids; Compatibility

Abbreviations: CMC: Carboxymethyl Cellulose; HPHT: High Pressure High Temperature; OBM: Oil Based Mud; PAC: Polyanionic Cellulose; PV: Plastic Viscosity; AV: Apparent Viscosity; WBM: Water Based Mud; YP: Yield Point; API: American Petroleum Institute; PAC-UL: Polyanionic Cellulose-Ultra low Viscosity; PAC-R: Polyanionic Cellulose-Regular Viscosity; HT-PM: High Technology Polymer Materials; PHPA: Partial Hydrolyzed Polyacrylamid; CaCO₃: Calcium Carbonate; Na₂CO₃: Sodium Carbonate

Introduction

To produce hydrocarbons wells need to be drilled. The main objective when drilling a well is to drill a hole as fast as possible without accidents. Drilling is an important part when producing hydrocarbons and drilling fluids represent one fifth (15-18%) of the total cost of well drilling [1]. Therefore it is of interest to develop better solutions for a less costly operation. Better techniques have been made to improve the production, such as horizontal wells, directional drilling and managed pressure drilling. Drilling fluid, sometimes referred to as drilling mud, is used in drilling operations [2]. It is circulated down the drill string, through the bit and back to the surface through the annulus. The particle improves the mechanical strength and reduces the filtrate loss.

The development of deep offshore operations gives new and more technical challenges due to the harsh conditions encountered at these water depths. The extreme conditions that exist require an adaption and a particular design of the drilling and cementing fluids. One of the most challenging problems of deep offshore drilling is the range of temperatures and pressures. The temperature of the drilling fluid when circulating in the well may range from 0°C to 150°C and it is important that the drilling fluid maintain acceptable rheological properties within the whole range. The rheological properties of the mud will strongly depend on the temperature and the pressure variations.

To solve the problems with the mud properties it is often necessary to use several additives either separately or concurrently. The major drawback of the conventional additives is that they are generally unstable at high temperatures normally encountered in deep wells. The

rheological properties of traditional water- and oil-based muds may change, often dramatically, when regions of high temperature and/or pressure are encountered in a deep well. Alternatively, there are several natural and synthetic polymers available which exhibit better resistance to thermal, bacterial and even mechanical degradation. For these reasons the new polymers are increasingly replacing conventional additives as rheology modifiers in the drilling industry [3].

When drilling a well it is very important to know the exact pressure drop for many reasons. Some of the reasons might be [4].

- To optimize the pressure drop on the drilling bit in order to get a maximum impact on the formation, and thereby increase the rate of penetration.
- For optimizing the flow rate in the annulus, the area between the borehole wall and the drill pipe, to get a better transport of drilled cuttings to the surface as well as to maintain a proper hole cleaning.
- To avoid fracture of the formation crossed due to the underestimation of the annular pressure drop.
- To detect any unexpected changes of the standpipe pressure, due to changes in the hydraulic drilling circuit (i.e., washout, plugged nozzles and fluid kick) and make opportune decisions to restore the original conditions.

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- To better design the mud pumps available on the drilling rig.

In addition to the reasons mentioned above might the drilling of ultra-deep wells with high temperatures and pressures influence the rheological properties of the drilling fluids in several ways [4]. Physically, decreases in temperature and increases in pressure both affect the mobility of the system and lead to an increase of apparent viscosities and viscoelastic relaxation times [5]. The effect of pressures is expected to be greater with oil-based systems due to the oil phase compressibility [6].

Electrochemically, an increase in temperature will increase the ionic activity of electrolytes and the solubility of any partially soluble salt that may be present in the mud. This could change the balance between the inter-particle attractive and repulsive forces and also the degree of dispersion and flocculation in the mud systems. In some occasions this can also affect the emulsion stability of oil-based muds [7]. All these phenomena have a big impact on rheological properties, especially as far as viscoelasticity and thixotropy are concerned.

Chemically, all hydroxides react with clay minerals at temperatures above 90°C and for many kinds of muds this can result in a change in the structure and also a change in the rheological properties [4].

Due to the large number of variables involved, the behavior of the drilling mud at high pressures and temperatures may be very difficult to explain because of the complexity. It can be very difficult to set general guidelines for each group of muds (oil-based muds (OBM), water based muds (WBM), etc.) or even for the same kind of mud as small differences in composition may result in large differences in the rheological behavior [4].

Methodology of Work

Field description

The vertical well to be drilled was an exploration well that could provide information on potential reservoirs and lithological information of the field. No offset data were available on the well and the nearest well information was 80 km away. Geologist forecast from this well required drilling through reactive shales. Table 1 shows the lists the interval parameters for drilling.

The objective was to drill a 8 1/2-in. hole section from 10900 ft, to the casing point at a measured depth (MD) of 12500 ft. A 7-in. casing string was then to be run 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.

Laboratory tests

Material: Initially, optimized base fluid systems are developed at different concentrations as shown in Table 2. Fann V-G meter 35SA model (Fann Instrument Company, Houston, Texas) was used to

Formation Type	Member A compose of shale
Thickness interval depth	400 feet
Interval Hole size	8 1/2 inches
Fluid Type	Formate based mud
Bit type	Mill Tooth bit
Nozzle size	3*16/32 inches
String Rotation speed (rpm)	100-130 rpm
Weight on Bit (WOB)	20-25klb

Table 1: Interval well Parameters.

Material	Sample No	A	B	C	D	E	F
1	Water (sea) (cc)	350	350	350	350	350	350
2	Na ₂ CO ₃ (g)	0.3	0.3	0.3	0.3	0.3	0.3
3	Poly drill (g)	-	-	-	-	-	6
4	Poly thin (g)	-	-	-	-	-	1
5	PAC-UL (mg)	3	-	-	-	-	-
6	PAC-R (mg)	1	-	-	-	-	-
7	HT-PM (g)	-	4	-	-	-	-
8	STARCH (g)	-	-	4	-	-	-
9	CMC(g)	-	-	-	4	-	-
10	Polysal (g)	-	-	-	-	4	-
11	PHPA(PolyPlus) (g)	1	1	1	1	1	1
12	Duo Tec (mg)	1	1	1	1	1	1
13	KCl (g)	21	21	21	21	21	21
14	Formate Na (g)	50	50	50	50	50	50
15	Formate K (g)	50	50	50	50	50	50
16	CaCO ₃ (g)	50	50	50	50	50	50

Table 2: Materials that was used in formulation of formate sample muds for evaluating the compatibility of different polymers.

S/n	Additive(s)	Function(s)
1	Water	Base fluid
2	Polyanionic Cellulose	Filtration Control
3	PHPA	maintaining the rheology of the fluid inside the wellbore
4	CaCO ₃	Weighting agent- bridging material
5	Na ₂ CO ₃	Calcium precipitant and pH reducer in cement contaminated mud

Table 3: Shows the additive and its functions.

measure the dial readings which were further empirically correlated to determine rheological properties like plastic viscosity, apparent viscosity, yield point, fluid loss; and also the initial and 10 min gel strength of the prepared homogenous solutions.

Drilling fluid design: Materials that was used in formulation of formate sample muds for evaluating the compatibility of different polymers. Component of each formate sample are illustrated more in Table 2.

The materials used for this study are:

- ✓ Shale sample
- ✓ Fresh water
- ✓ Hamilton Beach Mixer
- ✓ Mud balance API filter press
- ✓ Variable speed rheometer
- ✓ Marsh funnel
- ✓ Fann V-G meter
- ✓ PH meter.

Table 3 shows the additive and its functions.

Fann V-G meter: The V-G meter is a rotational type viscometer in which the fluid is contained between coaxial cylinders. The outer cylinder rotates at a constant speed and the viscous drag of the fluid on the inner cylinder or bob exerts a torque that is indicated on a calibrated dial. The torque is proportional to shear stress and the rotational speed is proportional to shear rate. The indicated dial reading times 1.067 is equivalent to shear stress in lb/100 sq. ft. And the rotational speed in rpm times 1.703 is equivalent to shear rate in reciprocal seconds.

Two models of the V-G meter in common use are the Fann 35 and 34. The Model 35 is a six-speed model (600, 300, 200, 100, 6, and 3 rpm) and the Model 34 is a two-speed model (600 and 300 rpm). These instruments provide measurements of the actual flow parameters of shear rate and shear stress and also provide a means of making gel strength measurements. With this information we are better equipped to diagnose flow behavior and prescribe mud treatment than with the funnel viscosity. After the shear stress/shear rate data are collected, they can be handled and reported in a number of ways. Traditionally, these data have been used to calculate plastic viscosity and yield point in the Bingham plastic rheological model, and these parameters have been reported on the mud check sheet. The difference in the V-G Meter dial readings at 600 and 300 rpm is the plastic viscosity, and the plastic viscosity subtracted from the 300 rpm reading is the yield point.

Since the Bingham plastic model does not truly represent the shear rate/shear stress behavior of most muds, the calculated yield point is not equivalent to the true yield stress and the plastic viscosity is not a true viscosity. However, the wealth of experience we have acquired in the use of these parameters make them quite useful in predicting mud performance and diagnosing mud problems.

Rheological properties measured with a rotational viscometer are commonly used to indicate solids buildups flocculation or deflocculation of solids, lifting and suspension capabilities, and to calculate hydraulics of a drilling fluid.

A rotational viscometer is used to measure shear rate/shear stress of a drilling fluid - from which the Bingham Plastic parameters, PV and YP, are calculated directly. Other rheological models can be applied using the same data. The instrument is also used to measure thixotropic properties, gel strengths. The following procedure applies to a Fann Model 35, 6-speed VG Meter.

Plastic Viscosity (PV) and Yield Point (YP): There are following steps:

1. Obtain a sample of the mud to be tested. Record place of sampling. Measurements should be made with minimum delay.
2. Fill thermal cup approximately 2/3 full with mud sample. Place thermal cup on viscometer stand. Raise cup and stand until rotary sleeve is immersed to scribe line on sleeve. Lock into place by turning locking mechanism (Figure 1).
3. Place thermometer in thermal cup containing sample. Heat or cool sample to desired test temperature of $115^{\circ} \pm 2^{\circ}\text{F}$.

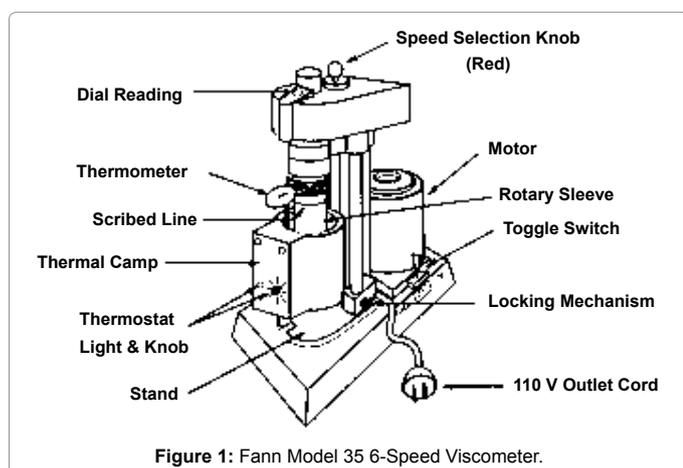


Figure 1: Fann Model 35 6-Speed Viscometer.

4. Flip VG meter toggle switch, located on right rear side of VG meter, to high position by pulling forward.
5. 6/94 3-2
6. Position red knob on top of VG meter to the 600-rpm speed. When the red knob is in the bottom position and the toggle switch is in the forward (high) position -this is the 600-rpm speed.
7. With the sleeve rotating at 600-rpm, wait for dial reading in the top window of VG meter to stabilize (minimum 10 seconds). Record 600-rpm dial reading.
8. With red knob in bottom position, flip the VG meter toggle switch to low position by pushing the toggle switch away from you. Wait for dial reading to stabilize (minimum 10 seconds). Records 300-rpm dial reading.
9. The Plastic Viscosity and Yield Point are calculated from the 600-rpm and 300-rpm dial readings (Figure 2).

Gel Strength (10-sec/10-min): There are following steps to be followed:

1. With red knob in bottom position, flip toggle switch to 600-rpm position (forward position). Stir mud sample for 10 seconds.
2. Position red knob to the 3-rpm speed. When the red knob is in the middle position and the toggle switch is in low (rear) position - this is the 3-rpm speed. Flip toggle switch to off position. Allow mud to stand undisturbed for 10 seconds.
3. After 10 seconds, flip toggle switch to low (rear) position and note the maximum dial reading. This maximum dial deflection is the 10-second (initial) gel strength in lb/100 ft². Record on the mud check sheet.
4. Pull toggle switch to high and position red knob to 600-rpm speed. Stir mud for 10 seconds.
5. After 10 seconds, and while mud is still stirring, position red knob to the 3-rpm speed. Flip toggle switch to off position and allow mud to stand undisturbed for 10 min.
6. After 10 min, flip toggle switch to low (rear) position and note the maximum dial reading. This maximum dial deflection is the 10-min gel strength in lb/100 ft². Record on the mud check control of filtration properties of a drilling fluid can be useful in reducing tight hole conditions.

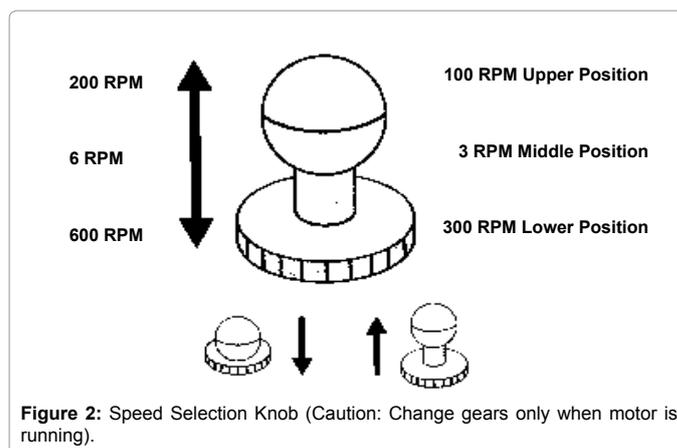


Figure 2: Speed Selection Knob (Caution: Change gears only when motor is running).

Marsh funnel for measuring apparent viscosity: The Marsh funnel is a crude method for measuring the consistency of a fluid. Although listed on the mud check sheet as viscosity, the Funnel viscosity is not in the true sense a viscosity at all. The test consists of filling the funnel to the bottom of the screen with mud (1500 ml) and timing how long it takes for one quart to flow out of the funnel. The time in seconds is reported as the funnel viscosity. Fresh water at 70°F will have a funnel viscosity of 26 seconds. This test has the advantage of being quick, simple, and requiring very little equipment. It is useful in showing gross changes in the overall “viscosity” of a fluid, but it does not measure specific flow parameters. It can be changed by changes in plastic viscosity, yield point, gel strength, or density. For this reason it should be used only to monitor a mud and not to diagnose problems or to prescribe treatment (Figure 3).

Figure 4 shows apparent viscosity for formate fluids in presence of different polymers. As it can be seen in the Figure 4, the amount of apparent viscosity for fluids including CMC and PAC polymers are more than the other samples. Apparent viscosity for other fluids are approximately remains constant (25 centipoises). Furthermore, viscosity loss after applying temperature are extremely low and it has the minimum amount within formate fluids contained starch.

Figure 5 shows plastic viscosity for different fluids. In the comparison with Figure 4, the amount of plastic viscosity for fluids including CMC and PAC polymers is far high is high. Hence, it isn't appropriate for drilling operations. The amount of plastic viscosity for other samples is in the proper limited and optimum value for drilling operations. As it can be seen in Figure 5, the plastic viscosity loss after applying temperature to the fluids considered be negligible that consequently cause of increasing thermal stability of polymers by formate salts. The amount of plastic viscosity loss for CMC and starch are minimum than others.

Figure 6 shows Yield point for potassium/sodium formate fluids in combining of different polymers. In the same vein, to other Figure 7, fluids that included CMC and PAC polymers have higher yield point than the other samples. The amount of yield point for other samples was relatively remained unchanged and this value could be properly limited for drilling operations and mud pumps required less initial pressure for flowing the fluid.

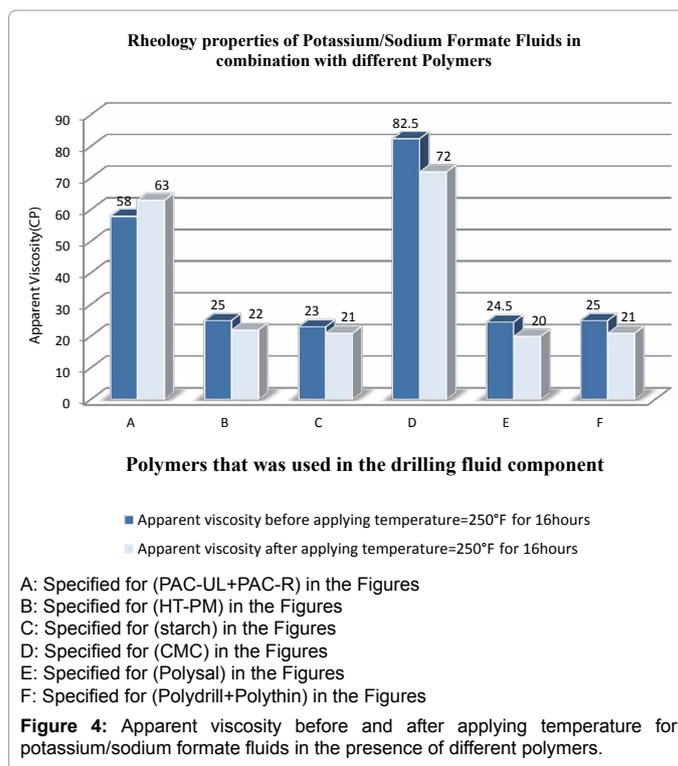
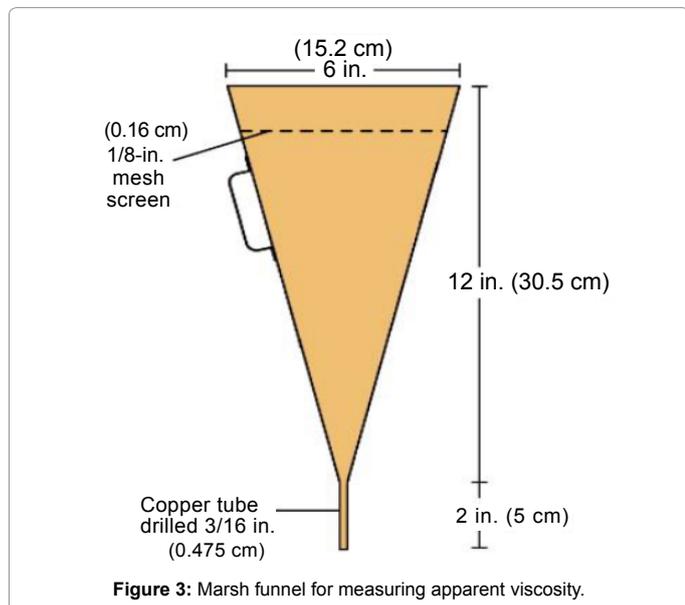
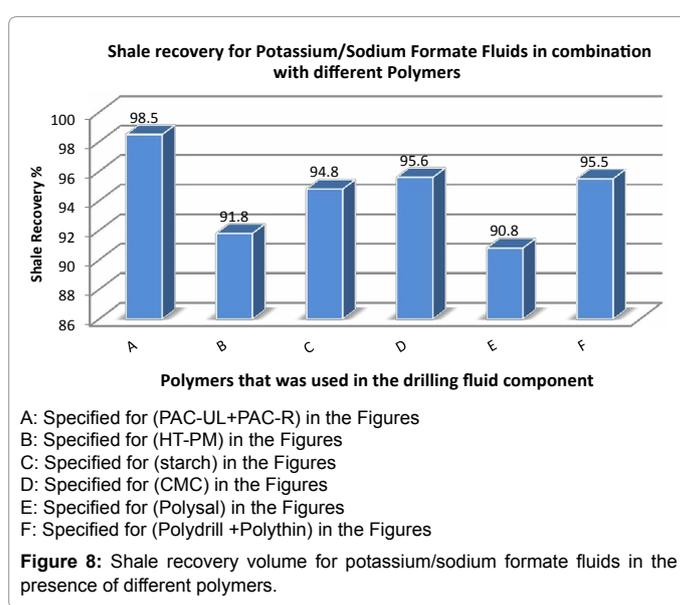
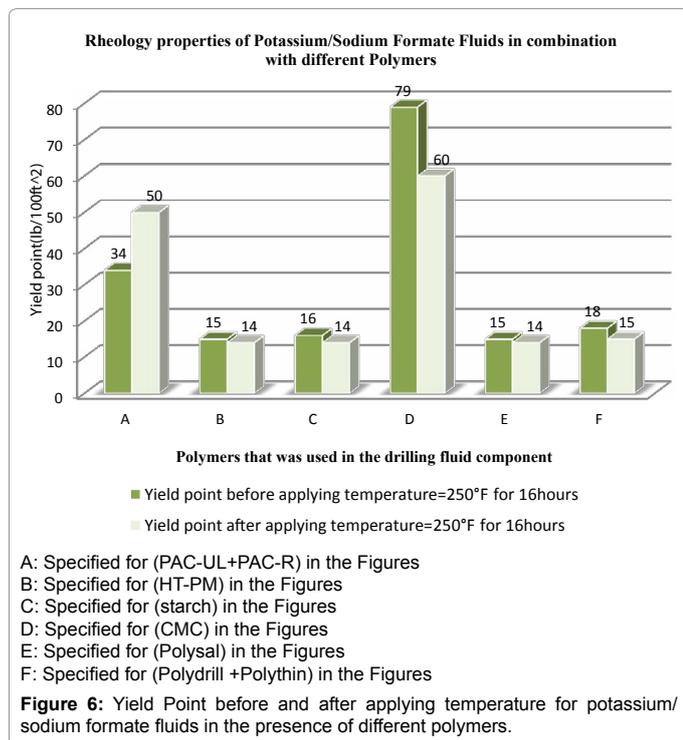
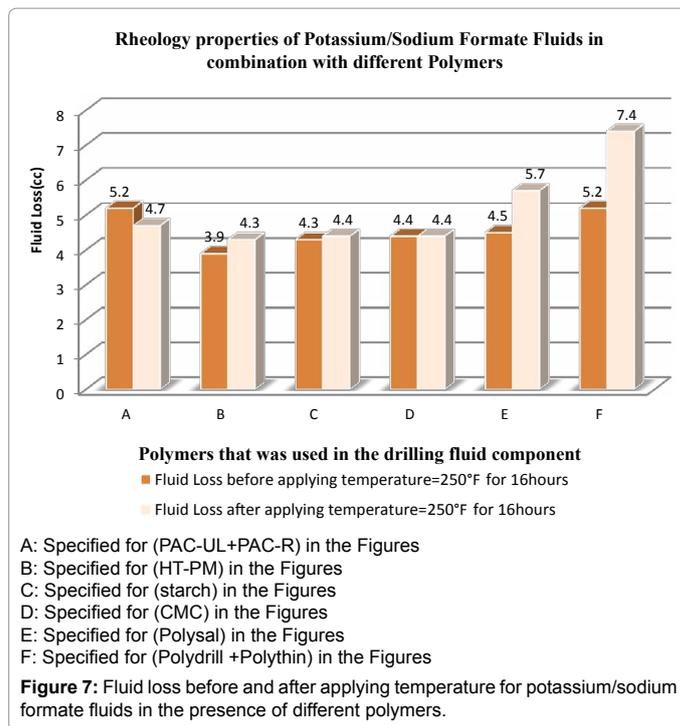
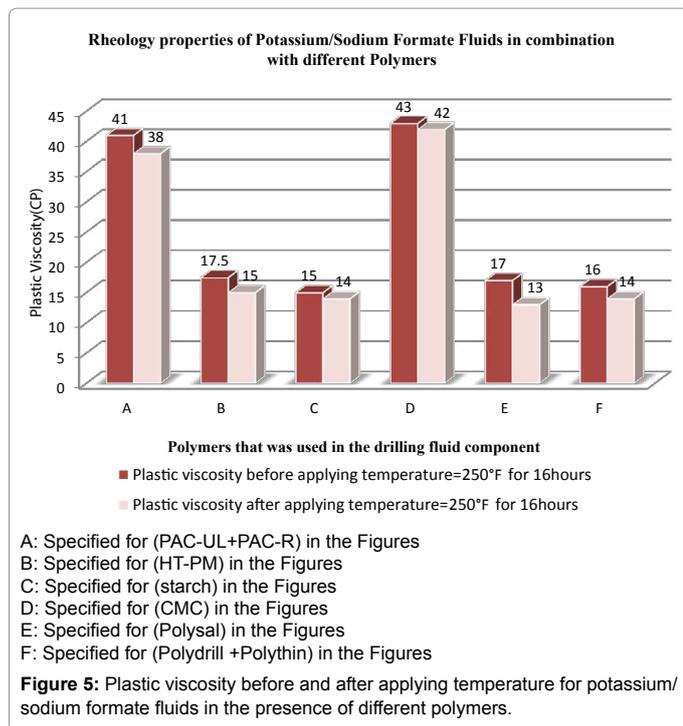


Figure 7 shows the fluid loss for different types of polymers. As it can be seen, the amount of fluid loss before and after applying temperature for fluids contain HT-PM, CMC and starch are nearly similar and the rise of fluid loss after applying pressure could be ignored. The maximum amount of fluid loss after and before applying temperature are the fluids than contain poly-drill and poly-thin. Samples produced mud cakes are thin and flexible.

Figure 8 shows shale recovery for formate fluids in presence of different polymers. The amount of shale recovery are being measured by and experimental test according to API-13I. This test didn't propose the accurate amount of shale recovery. Besides, the accuracy of steps of test procedure and specially washing shale grains by saturated salty water has noticeable effect on the experimental results. The result of this test is also extremely affected by fluid viscosity. As a result, by increasing fluid viscosity, shale grains washing might be more difficult and mud with high viscosity are separated from shaly grains strictly. Thereby, in this occasion some amount of mud didn't separate from shaly grains. Subsequently shaly grains weight after applying temperature are more than the real amount. So, the amounts of shale recovery are being shown more than the real amount. In this experiment, as it can be seen in Figure 8 the amount of shale recovery for fluids contain CMC and PAC polymers is more than the other samples. In addition, these fluids have more viscosity than the others. Therefore, cause of increasing in the amount shale recovery depended directly to the high viscosity. As a consequence, overall in most cases combination of formate fluids with several polymers, show noticeable shale recovery.

Figure 9 shows the Effect of Xanthan polymer concentration on the formate fluid yield point with mud weight of 78 PCF. Figure 10 shows the Effect of Xanthan polymer concentration on the formate fluid Gel strength with mud weight of 78 PCF.



Results and Conclusions

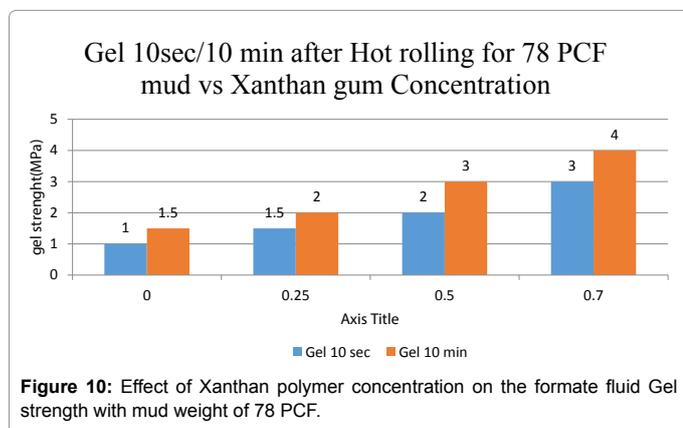
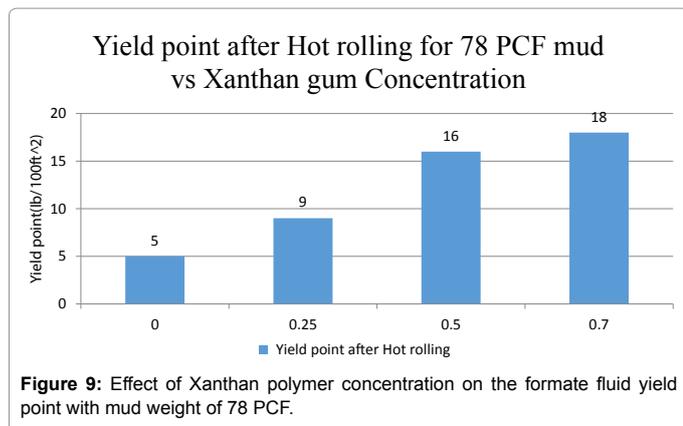
Results

Regarding to the polymers and several bio-polymers compatibility tests with potassium/sodium formate fluids, it can be observed that formate fluids with all used polymers and bio-polymers showed proper and reasonable compatibility.

Rheological properties (AV, PV and Yp) for formate fluids in

combination of PAC and CMC polymers are more than other used polymers. Reduction in rheological properties for different polymers through the formate fluids are extremely low. As for, formate salt have impacts on increasing thermal stability of polymers and bio-polymers. Thereby, the amount of fluid loss before and after applying temperature has no differential effects and the fluid loss for different polymers such as HT-PM polymer, CMC bio-polymers and starch are minimum and it is in the optimum level for drilling operations of a reservoir.

The amount of shale recovery in combination with several polymers is optimum and the amount of shale recovery for all samples is more than 90%. It should be noted that shaly sample that was used for shale recovery tests including high percent of clay materials is in type of montmorillonite that has high water absorption and will easily rescued.



Conclusions

The results of the comparison of several fluid tests compared to each other, such as silicate, glycol and potassium chloride fluids with formate fluids illustrated that formate fluids maintain rheological properties and fluid loss after applying temperature better than other fluids. Moreover, these muds have higher thermal stability in 250°F during 16 h rather than silicate, glycol and potassium chloride fluids. The amount of shale recovery in these muds is always more than silicate, glycol and potassium chloride fluids.

Experimental tests of mud pollution with several pollutants illustrated that mud rheological properties changes after it is polluted by several pollutants like cement and acids didn't have a large volume. Potassium/sodium formate fluids maintained their properties properly and did not cause a strict reduction in mud rheological properties.

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