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The Influence of XC-Polymer on Drilling Fluid Filter Cake Properties and Formation Damage

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Abstract

The filter cake characterization is very essential for doing well selection of the drilling fluids that eliminates the drilling problems such as formation damage. A correct knowledge of filter cake properties gives petroleum engineers a tool for efficiently managing hydrocarbon production process of a field.

This study aimed to experimentally investigate the effect of different concentration of XC-Polymer on filter cake properties, filtrate loss and formation damage to select the optimum concentration of the XC-Polymer. High Pressure-High Temperature (HPHT) filter press with ceramic disk device was used to conduct these experiments. Seven samples of water-based drilling were used in this study. The chemical compositions of the filter cake were described by using Scanning Electron Microscopy (SEM).

The results show that the optimum concentration of the XC-Polymer in current study is 1.0 lb/bbl (1 g/ 350 ml); it was observed that 1g XC-Polymer per 350 ml of the drilling fluid is sufficient for appropriate optimum rheological efficiency. However, if more than 2 g. of XC-Polymer is added, the fluid loses its property and becomes almost immobile. Thus, at 1.0 g of the XC-Polymer concentration there is a less reduction in permeability of the ceramic disk. At this concentration, we got less reduction in permeability of ceramic disk and good properties of the filter cake. In addition, this is an indicator of less formation damage at this concentration of XC-Polymer.

Keywords: Drilling fluid; Mud cake; Formation damage; XC-Polymer

Introduction

Drilling fluids are the most critical parameter in the drilling operation and owing to the rapid development in the drilling well industry. It is very important to improve the properties of drilling fluids in order to satisfy the increasing demands. Mud can be described as thixotropicshear-thinning fluids with a yield stress [1]. The drilling fluids are originally designed in order to make sure that rotary drilling of subterranean formations is possible and economical. Furthermore, it is carrying cutting to surface, cooling and cleaning the bit, reducing friction, maintaining wellbore stability and preventing pore fluids from prematurely flowing into the wellbore. In addition, the drilling fluids are essentially designed to build a filter cake, which is basically intended to decrease filtrate loss to the formation, be thin and hold the drilling fluid in the wellbore [2].

One of the most critical functions of drilling fluids is to try to minimize the amount of drilling fluid filtrate entering the hydrocarbon bearing formation. The drilling fluid filtrates can lead to formation damage because of rock wettability changes, fines migration, drilling fluid solids plugging and formation water chemistry incompatibilities [3].

The filtration properties can be describes as one of the very important characteristics of all drilling fluids. The invasion of filtrate into the formation can substantially lead to reduction in the permeability of the near-wellbore region by a group of mechanisms: clay swelling, particles pore plugging, particles migration and water blocking. Moreover, this nature and thickness of the filter cake deposited on the borehole wall will influence the potential for differential pressure sticking to occur [4].

The filtration control additives for water-based drilling fluids can be used to prevent leak-off of water from the drilling fluid to the formation. Organic polymers constitute by far the huge number of filtration-control additives [5].

The control of drilling-fluid filtration is seen as a part of the best drilling practice. Inadequate control of the drilling-fluid property is related to borehole instability, excessive torque and drag, pressure differential sticking, and formation damage. The control of drilling-fluid filtration characteristics does not include only control of the filtrate volume per unit area and unit time but also the quality of the resulting filter cake formed in the wellbore [6].

The selection of the efficient drilling fluids is based, basically, on the features of the filter cake formed near wellbore region. Minimizing filtrate loss into the formation by forming a thin filter cake with low porosity and permeability is very critical in order to manage the formation damage problems [7].

Several previous researchers [8-12] highlighted the microscopic structure and chemical composition of the filter cake

The objectives of this work are to: (1) Measure the main properties of the drilling fluid such as density and rheological at different concentration composition. (2) Study the characterization of filter cake such as thickness, porosity and permeability. (3) Describe the mineralogy and the chemical composition of the filter cake. (4) Compare the laboratory results with the different concentration composition of the drilling fluid.

Experimental Studies

Materials

Water- based drilling fluid was selected for testing in this work. Barite was used as weighting material and bentonite as viscosifier. The

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features of the ceramic disks which were used have 10 μm mean pore size distribution and permeability of 775 md to stimulate the formation for filtration process at an appropriate temperature and pressure. The porosity of ceramic disk was determined by using the saturated method (the difference in weight of the disk in dried and saturated conditions). The weight of dry condition of ceramic disk was 38.4 g and the weight of wet condition of ceramic disk was 45.9 g. The porosity of ceramic disk can be calculated using Equation 1. It was 37 vol%.

$$\phi = \frac{V_p}{V_b} = \frac{pore\ volume}{bulk\ volume} \times 100 \quad (1)$$

$$pore\ volume = \frac{W_s(wet\ condition) - W_d(dry\ condition)}{\rho f(saturating\ fluid\ density)} \quad (2)$$

$$Bulk\ volume = \pi / 4(D_2 L) \quad (3)$$

Where

ϕ= absolute porosity, volume fraction

V_b= the bulk rock volume, cm^3

V_P= pore volume, cm^3

D =core sample diameter (6.35 cm)

L =core sample length (0.635 cm)

ρf= 1.0 g/cm^3

Preparation of the drilling fluids

The compositions of the drilling fluid samples were prepared in a standard 350 ml laboratory barrel. In other words, each 1 g of material is added to 350 ml of fluid and this is equivalent to add 1 pound of material to 1 barrel of fluid. The compositions of the drilling fluids were used in this study contain the followings: distilled water as the base fluid, Bentonite as viscosifier and filtration control material, Barite as weighting material, Caustic Soda as ph control material, Soda Ash as hardness control material, starch as filtration control material and different concentrations of xanthan gum as rheology control material (0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 g) to select the optimum concentration of XC-Polymer. The compositions of the drilling fluids are given in Table 1. Bentonite is usually added in quantities of (10.5 - 31.5 ppg). According to the desired rheological properties of the drilling fluid, we selected 24.5 g/ 350 ml. Barite is universally used as weighting agent. The quantities of barite needed as weighting agent are given in the formula below:

$$Wight\ Barite\ required = \frac{1490(W_2 - W_1)}{35 - W_2} \quad (4)$$

Where

W_1 = initial weght (ppg)

W_2 = desired final weight (ppg)

The amount of barite (52 g) to keep the mud weight as 9.5 ppg. Typical treatment of Soda Ash range from (0.25 to 2 ppg) depended on the calcium level and water chemistry of the drilling fluid, whereas the Typical concentration of Caustic Soda range from (0.20 to 4 ppg) with treatments depended on the calcium level and water chemistry of the drilling fluid.

Properties of the drilling fluids

Drilling fluid density: The mud weight or density was conducted by using a mud balance device. The mud weight of each sample was kept as 9.5 lb/gal (ppg).

Drilling fluid rheological properties: The rheological parameters such as shear stress, shear rate, plastic viscosity, yield point, gel strength of all of the drilling fluids were measured and the apparent viscosity was calculated by using Viscometer Model 900. Table 2 summarizes the properties of the drilling fluids used and (Figures 1-7) show the relationship between shear stress, shear rate and effective viscosity of non-Newtonian fluids at different concentration of XC-Polymer(0.0 g,

Product	Function	Per Lab. bbl (350 ml)						
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Water	Based liquid	325.5 ml	325.5 ml	325.5 ml	325.5 ml	325.5 ml	325.5 ml	325.5 ml
Bentonite	Viscosifier & filtration control	24.5 g	24.5 g	24.5 g	24.5 g	24.5 g	24.5 g	24.5 g
Barite	Adjust mud density	52.0 g	52.0 g	52.0 g	52.0 g	52.0 g	52.0 g	52.0 g
Caustic Soda	Ph control	0.20 g	0.20 g	0.20 g	0.20 g	0.20 g	0.20 g	0.20 g
Soda Ash	Hardness control	0.25 g	0.25 g	0.25 g	0.25 g	0.25 g	0.25 g	0.25 g
Poly - SAL	Filtration control	0.40 g	0.40 g	0.40 g	0.40 g	0.40 g	0.40 g	0.40 g
XC-Polymer	Rheogy control	0.0 g	0.50 g	1.0 g	1.50 g	2.0 g	2.50 g	3.0 g

Table 1: Formulation of Drilling Fluids.

Fluid Reference	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
Plastic Viscosity (cp)	29	36	45	47	51	65	70
Apparent Viscosity (cp)	39	51	70.5	79.5	87.5	115	127.5
Yield Point (lb/ 100ft²)	20	30	51	64	73	100	115
Gel Strength @ 10 sec (lb/ 100ft²)	1.6	9	18.5	25	27	46	54
Gel Strength @ 10 min (lb/ 100ft²)	2.6	11.5	22	30	32	63	72
θ_{600}	78	102	141	159	175	230	255
θ_{300}	49	66	96	112	124	165	185
θ_{200}	32	52	80	93	100	135	156
θ_{100}	19	34	56	67	72	104	122
θ_6	2.5	10	21	27	30	55	65
θ_3	1.1	8.5	18	23	25	52	61

Table 2: Rheological Properties.

0.5 g, 1.0, 1.5 g, 2.0 g, 2.5 g and 3.0 g). The following calculations are performed:

Plastic Viscosity (μ_p), cp =ϕ_{600}-ϕ_{300}…….. (5)

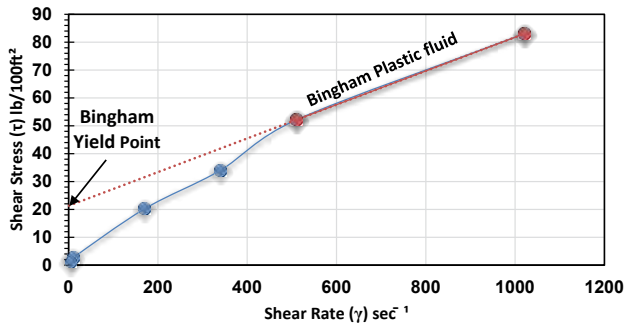

Figure 1: Shear rate vs. Shear Stress (@ 0.0 gm XC-Polymer).

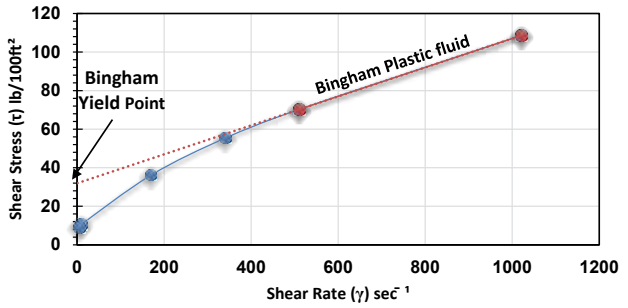

Figure 2: Shear rate vs. Shear Stress (@ 0.5 gm XC-Polymer).

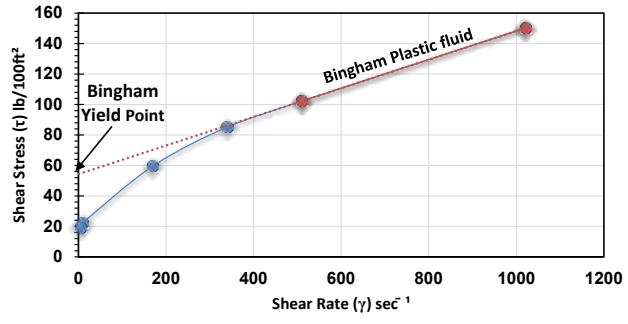

Figure 3: Shear rate vs. Shear Stress (@ 1.0 gm XC-Polymer).

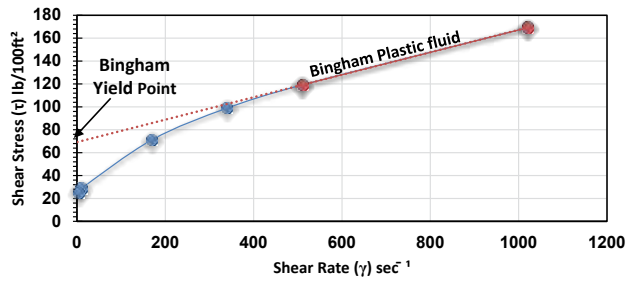

Figure 4: Shear rate vs. Shear Stress (@ 1.5 gm XC-Polymer).

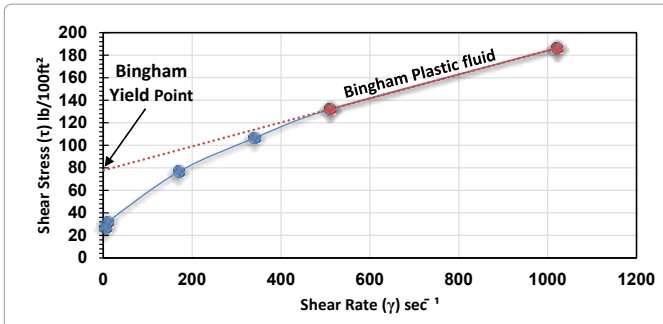

Figure 5: Shear rate vs. Shear Stress (@ 2.0 gm XC-Polymer).

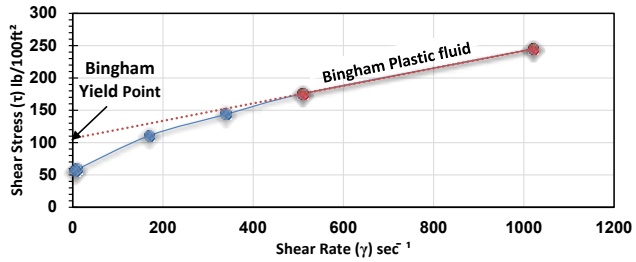

Figure 6: Shear rate vs. Shear Stress (@ 2.5 gm XC-Polymer).

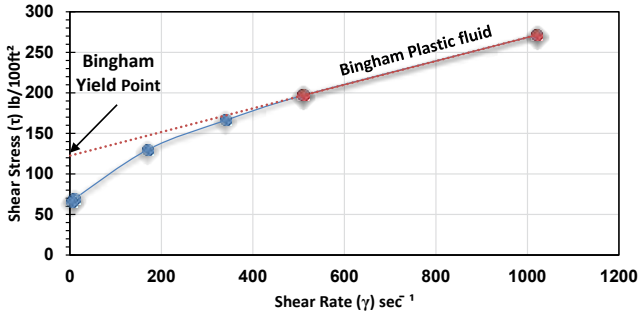

Figure 7: Shear rate vs. Shear Stress (@ 3.0 gm XC-Polymer).

Apparent viscosity (μ_a), cp = $\frac{\phi_{600}}{2}$ …….. (6)

Yield point (Y_p), (Ib/100 ft²) = $\phi_{300} - \mu_p$ ……. (7)

Effective viscosity (μ_a), cp= $\frac{300\times\phi}{\omega}$ …….. (8)

Shear rate (γ), sec^{-1} =1.7023 × ω …….. (9)

Shear Stress (τ), Ib/100ft² = 1.065 × ϕ…….. (10)

Where

ϕ = the dial reading, lb/100ft²

ω = the rotor speed, rpm

It was observed that shear stress increases as the XC-Polymer concentration increases, its maximum value at 3 g/350 ml. On the other hand, the bubbling and flocculation of the fluid with this concentration does not allow using this higher value. However, if more than 2 g of XC-Polymer is added, the fluid loses its property and becomes almost immobile. Experimentally, it was observed that 1g XC-Polymer per 350 ml of the drilling fluid is sufficient for appropriate optimum rheological efficiency. Gel strength is very important property of the drilling

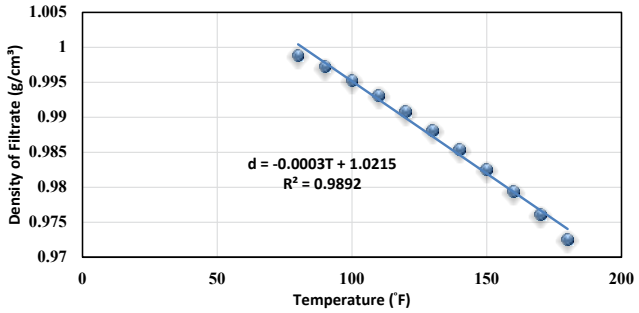

Figure 8: Change of filtrate fluid density with temperature (0.0 gm XC – Polymer).

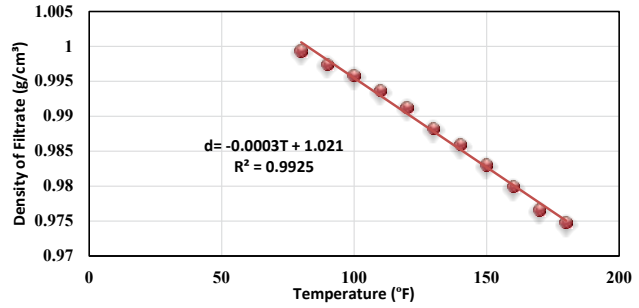

Figure 9: Change of filtrate fluid density with temperature (0.5 gm XC – Polymer).

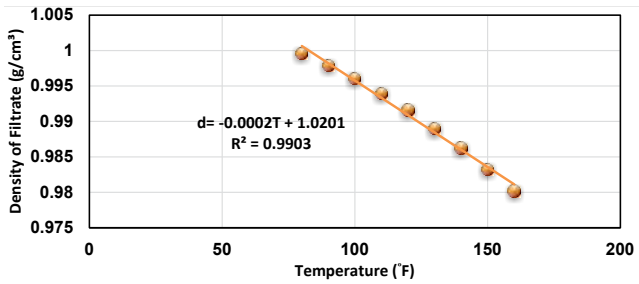

Figure 10: Change of filtrate fluid density with temperature (1.0 gm XC – Polymer).

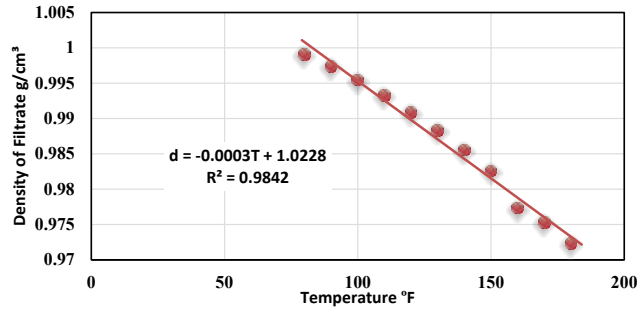

Figure 11: Change of filtrate fluid density with temperature (1.5gm XC – Polymer).

fluids as it measures the ability of the drilling fluid to hold solids in suspension. The results showed that there is an increase in the rheology properties of drilling fluid as XC-Polymer increased.

Static HPHT filtration test

To evaluate the filtration properties of the drilling fluid at high pressure and temperature, a standard High Pressure-High Temperature (HPHT) filter press devicewas usedin this work. The fluid put in the HPHT cell and placed in the heating jacket at desirable temperature (212 °F). The applied pressure was 200 psi as differential pressure. The volume of filtrate was measured in a 30minute period. The density of filtrate was measured by using high temperature density meter (DMA 4500), at different temperature as shown in (Figures 8-14).The filtrate viscosity was measured by using a Brookfield viscometer, at different temperatures as shown in Figure 15.

Results and Discussion

Filter cake thickness

The thickness of filter cake formed on the ceramic disk was measured after completing the HPHT filtration test (T = 212 °F & P =

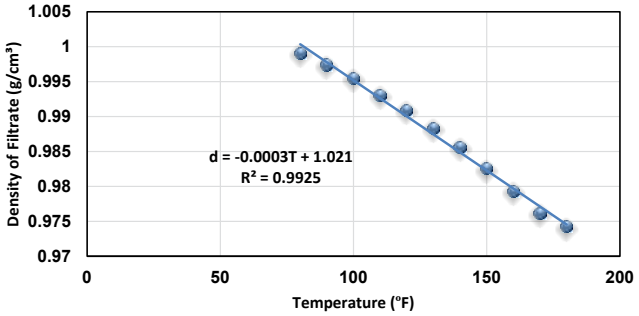

Figure 12: Change of filtrate fluid density with temperature (2.0gm XC – Polymer).

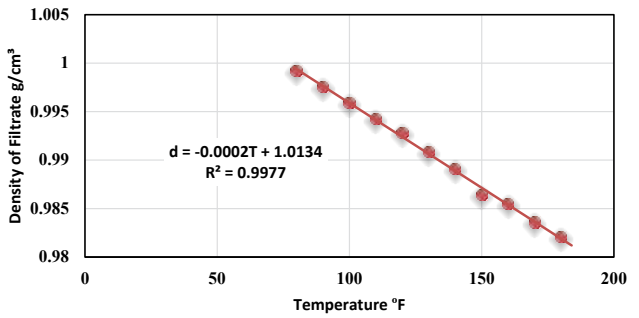

Figure 13: Change of filtrate fluid density with temperature (2.5gm XC – Polymer).

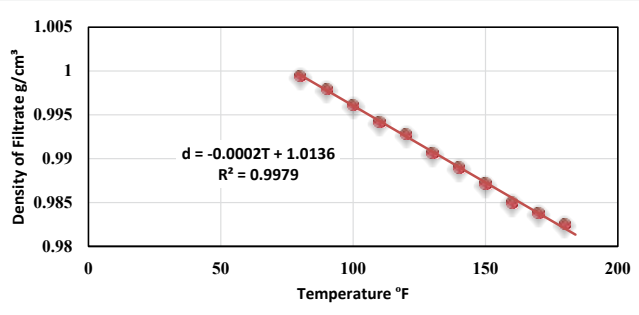

Figure 14: Change of filtrate fluid density with temperature (3.0gm XC – Polymer).

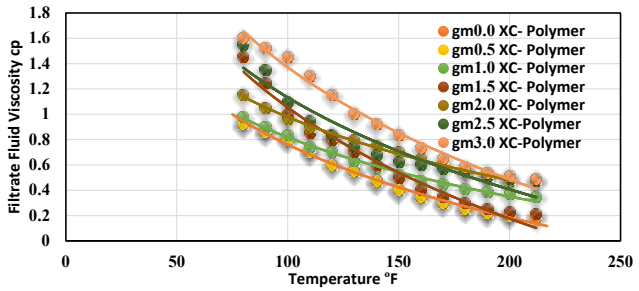

Figure 15: Change in filtrate viscosity with temperature.

Fluid Reference	Thickness of ceramic disk mm	Thickness of ceramic disk + mud cake mm	Thickness of filter cake mm	Thickness of filter cake 1/32 *in*
Sample 1	6.35	11.075	4.725	3.75
Sample 2	6.35	10.150	3.800	3.02
Sample 3	6.35	9.480	3.130	2.49
Sample 4	6.35	9.470	3.120	2.48
Sample 5	6.35	9.450	3.100	2.46
Sample 6	6.35	9.38	3.03	2.41
Sample 7	6.35	8.95	2.60	2.06

Table 3: thickness of Filter Cake h_c (different concentration of XC-Polymer).

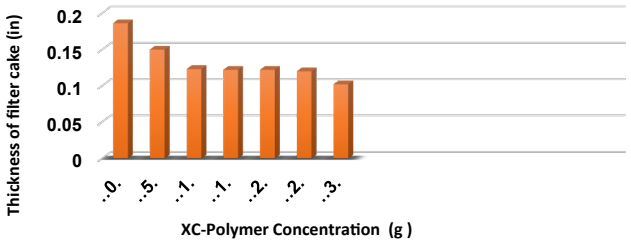

Figure 16: Effect the concentration of XC-Polymer on the thickness of filter cake.

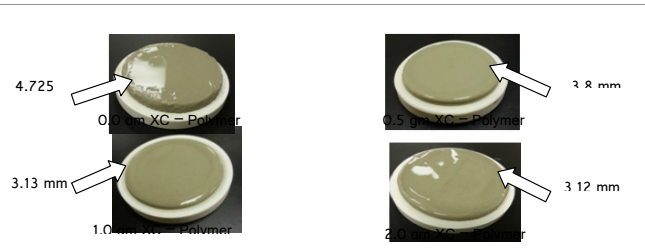

Figure 17: The filter cake samples obtained from filtration loss tests.

200 psi). The tabular results of the thickness of filter cake of the drilling fluid can be seen in Table 3. The results show that there are differences in the thickness of the filter cake of the drilling fluid due to differences in the concentration of XC-Polymer. The thickness was measured where it ranged from 0.102 to 0.186 in. It was observed that there is a decrease in the thickness of the filter cake of the drilling fluid as XC-Polymer increased as shows in Figure 16. The drilling fluid, which has 3.0 g concentration of XC-Polymer, has a small value of thickness. However, at this concentration the mud drilling loses its property and becomes almost immobile and very thick. Figure 17 shows the thickness of the filter cake of drilling fluid sample was obtained from filtration loss test. The filter cake was measured by using Laser and Dial Gauge devices [13].

Scanning Electron Microscopy (SEM) analysis

Scanning Electron Microscopy (SEM) was used to study the structure and the morphology of the filter cake. This technique was used in this work to examine static filter cake formed for water-based drilling fluid. The SEM allows the examination of the filter cake structure and it investigates the effect of the different mud additives in the filter cake [14]. Plank et al. [5] used SEM to study filter cakes containing fluid-loss polymers. The Filter cakes were photographed first to obtain a general overview of the broken surface, which provides information on the cake texture. The Scanning Electron Microscope (SEM) analyses of filter cake of the drilling fluid and the average quantitative chemical compositions of the filter cake were showed in Figures 18-25. Scanning Electron Microscopy (SEM) provides high-resolution and long-depth-of-field images of the sample surface and near-surface.SEM is one of the most widely used analytical tools due to the extremely detailed images it can quickly provide.

Based on the SEM analysis of the filter cake created with water-based drilling fluid, it indicates that filter cake contain five main elements. These elements are Sodium (Na), Aluminum (Al), Silicon (Si), Molybdenum (Mo) and Barium (Ba). The results showed that the percentage of Ba in the filter cake is (11-28 %), because the weighting

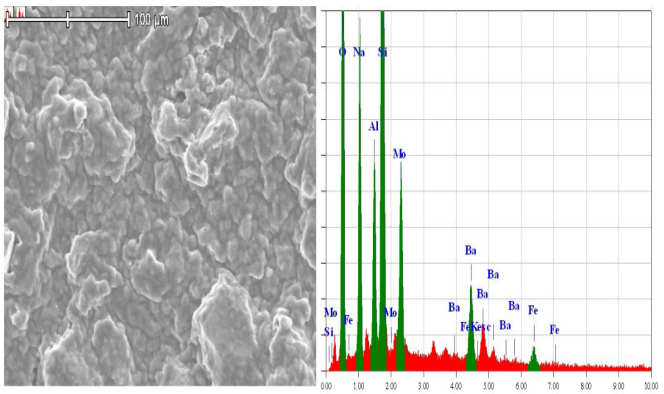

Figure 18: SEM analysis of filter cake, sample 1 (0.0 gm XC – Polymer).

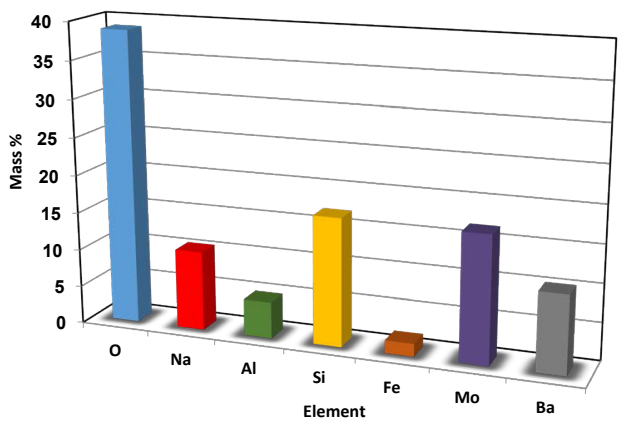

Figure 19: Chemical Composition of the filter cake Using SEM, sample 1 (0.0 gm XC – Polymer).

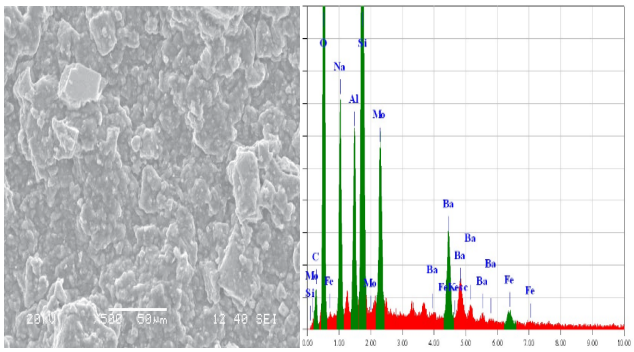

Figure 20: SEM analysis of filter cake, sample 2 (0.5 gm XC – Polymer).

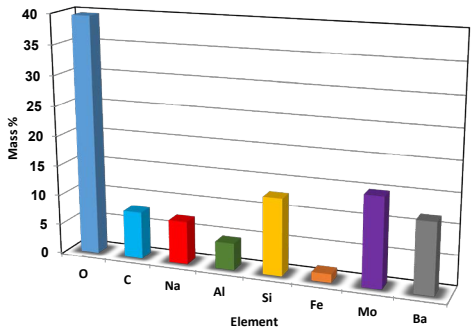

Figure 21: Chemical Composition of the filter cake Using SEM, sample 2 (0.5gm XC – Polymer).

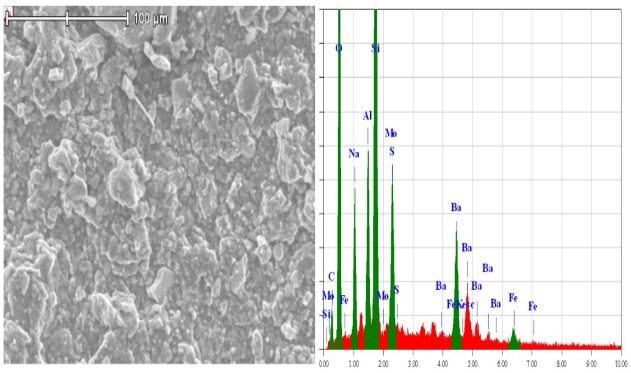

Figure 22: SEM analysis of filter cake, sample 3 (1.0 gm XC – Polymer).

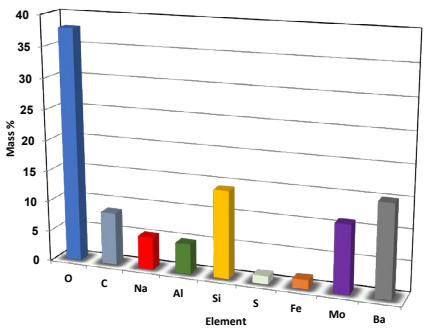

Figure 23: Chemical Composition of the filter cake Using SEM, sample 3 (1.0gm XC – Polymer).

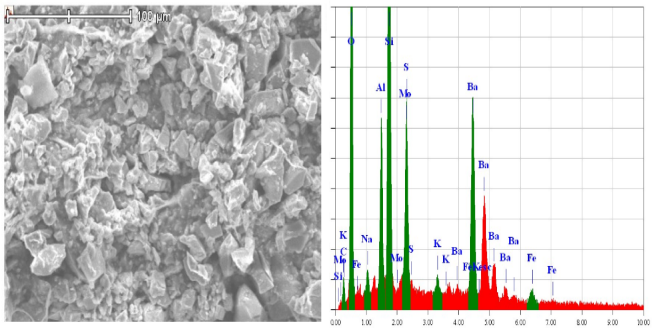

Figure 24: SEM analysis of filter cake, sample 5 (2.0gm XC – Polymer).

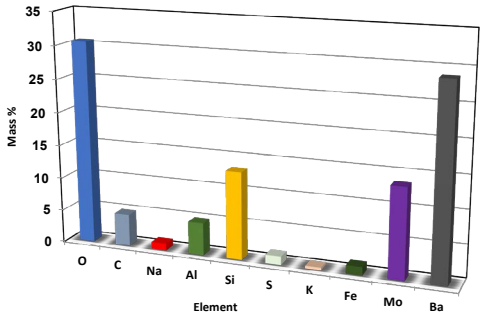

Figure 25: Chemical Composition of the filter cake Using SEM, sample 5 (2.0gm XC – Polymer).

material of the drilling fluid is Barite ($BaSO_4$) which has a high percentage component in the drilling fluid. Further, it illustrate the distribution of these elements in conjunction with oxygen to form the main phase of the filter cake

Porosity determination

Filter cake porosity: The porosity of the filter cake of the drilling fluid was measured. Table 4 summarizes the porosity of the filter cake of the drilling fluid with different concentrations of xanthan gum (0.0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 g). Chenevert et al. [15] presented a method that was used to measure the filter cake porosity. The results show that the porosity of the filler cake of the mud drilling ranged to be from 0.866 – 0.813. It was observed that there is a slight decrease in porosity of the filter cake as XC-Polymer concentration increase.

Procedure for filter cake porosity determination: To determine the filter cake porosity the following procedures were applied:

1. By using highly sensitive balance of 0.01 g resolution balance, the dry and wet weight of the ceramic disk was measured.
2. After completing the test of the fluid loss, the filter cake is directly removed from the cell.
3. The wet weight of the ceramic disk and filter cake combination (as 100 % saturated with filtrate) was measured.
4. The weight of wet ceramic disk was subtracted to get the net wet weight of the filter cake.
5. The cake is dried at 200 °F (93 °C) for 24 hour to drive off all water.
6. The dry weight of the ceramic disk and filter cake combination was measured.

Porosity of filter cake								
Fluid Reference	**Weight of dry ceramic disk *g***	**Weight of wet ceramic disk *g***	**Wet weight of CD & MC *g***	**Net wet wt. of MC *g***	**Dry weight of CD & MC *g***	**Net dry wt. of MC *g***	**Average grain density ρg pg *g/cc***	**Porosity ϕ_c**
Sample 1	40.369	47.133	63.300	16.167	45.614	5.245	2.09	0.866
Sample 2	39.537	46.387	59.290	12.903	43.281	3.744	2.50	0.859
Sample 3	38.516	45.156	57.190	12.034	41.999	3.483	2.37	0.853
Sample 4	39.01	45.822	57.570	11.748	42.594	3.584	2.12	0.828
Sample 5	39.876	46.508	56.634	10.126	43.027	3.151	2.14	0.826
Sample 6	39.306	46.050	55.945	9.895	42.362	3.056	2.01	0.818
Sample 7	40.694	47.215	56.452	9.237	43.456	2.762	1.85	0.813

Table 4: Porosity of Filter Cake ϕ_c (different concentration of XC-Polymer).

Fluid Reference	Weight of dry sample W_d.	Weight of saturated sample W_s.	pore volume (V_p)	Final porosity %
Sample 1	40.474	46.990	6.516	32
Sample 2	39.688	46.398	6.7100	33
Sample 3	38.662	45.536	6.874	34
Sample 4	39.146	45.710	6.564	32.64
Sample 5	39.994	46.655	6.661	33
Sample 6	39.726	46.358	6.632	32.97
Sample 7	40.889	47.542	6.653	33

Table 5: change in porosity of ceramic disk.

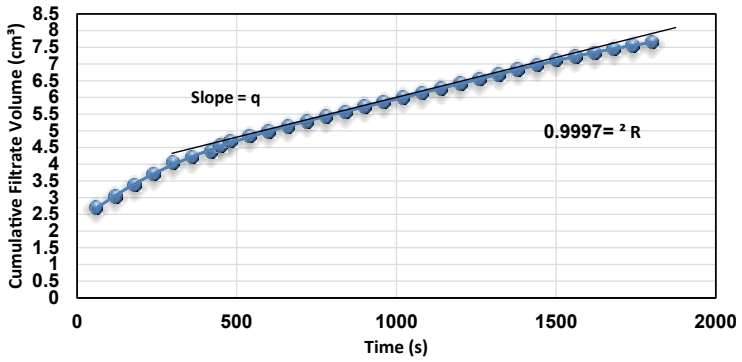

Figure 26: The permeability of the filter cake using Li et al. [16] method, (0.0 gm XC – Polymer).

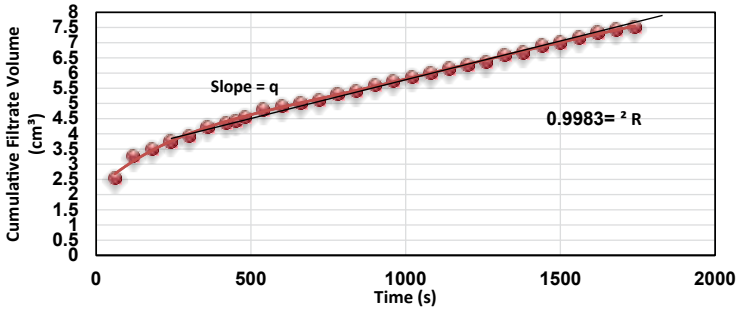

Figure 27: The permeability of the filter cake using Li et al. [16] method, (0.5 gm XC – Polymer).

7. The weight of dry filter cake was subtracted to get a net dry weight of the filter cake.

Denoting the fluid and grain densities by ρ_f and ρ_g respectively, the porosity of the cake ϕ_c can be calculated as:

$$\phi_c = \frac{V_p}{V_b}$$

Where

$$Pore\ volume, V_{p(cc)} = \frac{(net\ wet - net\ dry)\ weight\ of\ the\ cake}{\rho f}$$

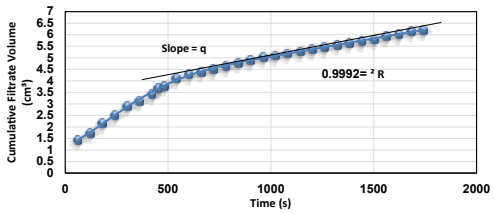

Figure 28: The permeability of the filter cake using Li et al. [16] method, (1.0 gm XC – Polymer).

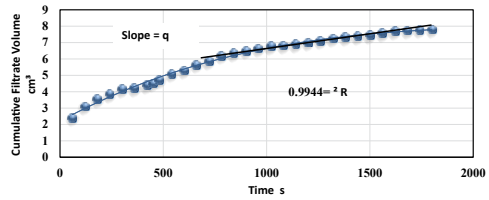

Figure 29: The permeability of the filter cake using Li et al. [16] method, (1.5 gm XC – Polymer).

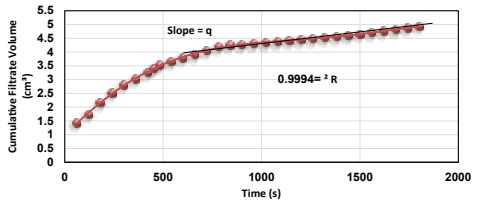

Figure 30: The permeability of the filter cake using Li et al. [16] method, (2.0 gm XC – Polymer).

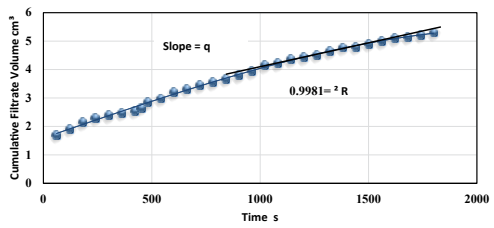

Figure 31: The permeability of the filter cake using Li et al. [16] method, (2.5 gm XC – Polymer).

$$Bulk\ volume, V_{p(cc)} = \frac{net\ dry\ weight\ of\ the\ cake}{\rho_g}$$

Then rearranging the above equations to get the filter cake porosity as:

$$\phi_c = \frac{\alpha}{\alpha + \frac{\rho f}{\rho g}} \quad (14)$$

Where

$$\alpha = \frac{net\ wet\ weight}{net\ dry\ weight} - 1$$

Filter disk porosity: At end of the filtration test (T = 212 °F & P = 200 psi), the final porosity of ceramic disk was measured by the difference in weight of disk in dried and saturated condition. Table 5 summarizes the calculation of final porosity of the ceramic disk. The results show the change in porosity of ceramic disk. It was measured and ranged from 32 to 34 %. The fluid drilling @ 1.0 g XC-Polymer concentration) has higher porosity than other fluids drilling.

Permeability determination

Filter cake permeability: The permeability of filter cake was measured by using Li et al. [16] method based on Darcy's Law for liquid flow through an already formed cake and a filter media resistance was included. This method depends on the relationship between the cumulative filtrate volume and time where the slope is equal to flow rate as shown in Figure 26. The flow rate can be obtained from the slope of the straight line region of the filtrate volume vs. time curve, divided by total filtration area. (q/A = filtrate rate, $m^3/m^2.s$)

To determine the filter cake permeability the following techniques were applied:

1. Media resistance K_m can be determined by a separate clean water flow through filter media only test.
2. Cake thickness L_c and media thickness L_m can be measured.
3. With known K_m, L_m and q, pressure drop across filter media Δp_m can be calculated based on equation (16).
4. From equation (17) we can be obtained pressure drop across cake Δp_c with known total pressure Δp_t and pressure drop across filter media Δp_m.
5. Finally, with known q, Δp_c, μ and L_c, permeability of cake can be then determined from equation (18).

Figure 26: Li et al. [16] atypical volume of filtrate against time curve

$$q = K_m \frac{\Delta P_m}{\mu L_m}$$

$$\Delta p_t = \Delta p_c + \Delta p_m$$

$$q = K_c \frac{\Delta P_c}{\mu L_c}$$

Where

R_t = Total resistance

R_m = Resistance of cake

R_c = Resistance of filter media

q = filtrate rate, m^3/m^2-s

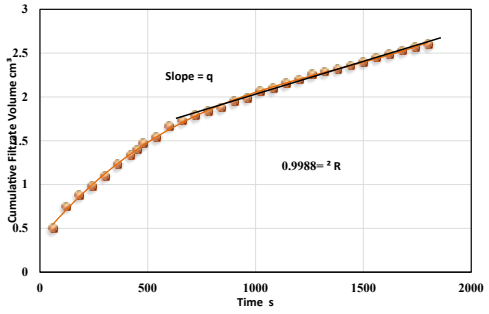

Figure 32: The permeability of the filter cake using Li et al. [16] method, (3.0 gm XC – Polymer).

K_m = filter medium permeability, m^2

K_c = filter cake permeability, m^2

L_m = thickness of filter medium, m

L_c = thickness of filter cake, m

μ = filtrated fluid viscosity, Pa.s

Δp_m = pressure drop across the filter medium, Pa

Δp_c = pressure drop across the filter cake, Pa

Δp_t = total pressure drop, Pa

Figures 27-32 show the relationship between the cumulative filtrate volume and time.

Table 6 shows the average permeability of the filter cake. The permeability of the filter cake was calculated. It ranged from 0.258 to 0.571μd. The results show that the permeability of filter cake decrease as XC-Polymer increase. It was observed that the average permeability of the filter cake was decreased as the concentration of XC-Polymer increased

Filter disk permeability and reduction in permeability: The change in permeability of the ceramic disk can be obtained from Equation 19, which developed by [17,18]

$$K_{final} = K_{initial}\left(\frac{\phi_{final}}{\phi_{initial}}\right)^3$$

Where

$K_{initial}$= initial permeability of ceramic disk, md

K_{final} = permeability of ceramic disk after filtration process, md

$\phi_{\square i}$ = initial porosity of ceramic disk, volume fraction

ϕ_f = final porosity of ceramic disk after filtration process, volume fraction

Therefore, the damage ratio was determined by taking the ratio of the final permeability of the ceramic disk (k_f) to the initial permeability of the ceramic disk (k_i). Mathematically, the damage ratio, in percentage, is shown in the following equation:

$$DR = \left(\frac{K_f}{K_i}\right)\times 100$$

Table 7 summarizes the calculation of final permeability of ceramic disk and the reduction in permeability. The results show that the concentration of XC-Polymer was changed from 0.0 to 3.0 g as shown in Figure 33. This plotted was constructed to obtain the optimum concentration of XC-Polymer for less damage. The reduction in permeability was 35% at 0.0 g of XC-Polymer concentration. It decreased to 29% from 0.0 to 0.5 g, also decreased to 22.5% from 0.5 to 1.0 g, and then increased to 31.35% from 1.0 to 1.5gm. The analysis of the results shows that at above 2.0 lb/bbl concentration of the XC-Polymer, the effect of XC-Polymer on formation damage is stabilized at constant value. Thus, the concentration of XC-Polymer, which has a less reduction in permeability, is 1.0 g.

Conclusions

In this study, we prepared and examined seven samples of water-based drilling fluid, which contained the same composition with different concentrations of XC-Polymer additives to select the optimum concentration of XC-Polymer and evaluate the filter cake characteristics. Based on the results obtained, the following conclusions may be drawn:

1. There is an increase in the rheology properties of drilling fluid as XC-Polymer increased.
2. SEM analysis provided a good method to study the structure and morphology of the filter cake. Further, it allowed knowing the average quantitative chemical compositions of the filter cake.
3. The thickness of the filter cake of the drilling fluid is decrease as XC-Polymer increased.
4. There is a slight decrease in porosity and permeability of the filter cake as XC-Polymer concentration increase.

Permeability of filter Cake K_c						
Fluid Reference	**Filtrate rate ($m^3/m^2.s$)**	**ΔP_m (Pa)**	**μ (Pa.s)**	**ΔP_c (Pa)**	**Average CakePermeability y (m^2)**	**Average CakePermeability (μd)**
Sample 1	9.14 X 10-7	1.3656	0.18 X 10-3	1378998.634	5.64E-19	0.571
Sample 2	9.37 X 10-7	1.5555	0.20 X 10-3	1378998.455	5.16E-19	0.523
Sample 3	6.31 X 10-7	1.8332	0.35 X 10-3	1378998.167	5.01E-19	0.506
Sample 4	6.078 X 10 -7	1.0595	0.21 X 10 -3	1378998.941	2.96E-19	0.299
Sample 5	2.90 X 10-7	1.0832	0.45 X 10-3	1378998.917	2.93E-19	0.297
Sample 6	2.80 X 10 -7	1.0923	0.47 X 10 -3	1378998.908	2.89E-19	0.293
Sample 7	2.76 X 10 -7	1.1226	0.49 X 10 -3	1378998.877	2.55E-19	0.258

Table 6: Average filter cake permeability.

Fluid Reference	K final, (md)	Damage Ratio (DR), %	Reduction in Permeability, %
Sample 1	501	65	35
Sample 2	550	71	29
Sample 3	601	77.5	22.5
Sample 4	532	68.65	31.35
Sample 5	550	71	29
Sample 6	548	70.71	29.29
Sample 7	550	70.97	29.03

Table 7: change in permeability and reduction in permeability of ceramic disk.

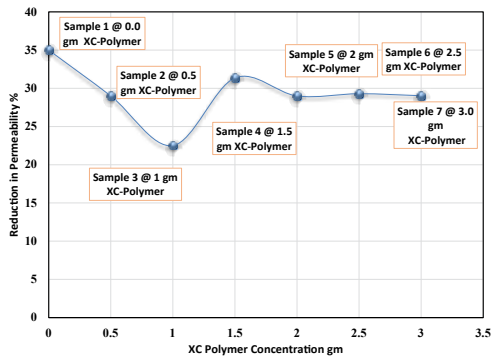

Figure 33: Effect of XC - Polymer concentrations on Reduction in Permeability.

The analysis of the results shows that at above 2.0 lb/bbl concentration of the XC-Polymer, the effect of XC-Polymer on formation damage is stabilized at constant value. Therefore, the concentration of XC-Polymer, which has a less reduction in permeability, is 1.0 g.

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