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Use of Reservoir and Environment Friendly Bio-Polymers in the Reservoir Drilling Fluid of Upper Assam Basin

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Abstract : Drilling fluid or mud is believed as the most important component of oil and gas well drilling operation. The drilling of the wells from surface to the pay-zones with same conventional drilling fluid may decrease the production and ultimate recovery by damaging the producing interval. Reservoir Drilling Fluid (RDF) is an environmental friendly polymer mud system without having the traditional clay and barite component mostly used in the pay-zone sections of development wells and specifically in horizontal wells to avoid formation damage. In this study some specific biopolymers such as XC-Polymer (XCP), Pregelatinized starch (PGS) and Polyanionic cellulose(PAC) have been used in the laboratory formulation of RDF designed especially for the oilfields of Upper Assam Basin (UAB). The XCP has been basically used as the rheology control agent as a replacement of the clay in the conventional mud due to the non-degradation nature of the clay. The PGS hasbeen basically used as the fluid loss control agent although it has amild effect in controlling the rheology. The PAChas also been used as the fluid loss control agent since it is more resistant to the biodegradation and the degradation due to high temperature than the PGS. A rigorous study has been performed on the mud properties and found their excellent role in respective purposes in the RDF. Also, an attempt has been made to optimize their composition in the RDF for the oilfields of Upper Assam Basin.

Key Words : Reservoir Drilling Fluid; Bio-Polymers; XC-Polymer; PGS; PAC; Reservoir friendly; Environment friendly; Formation Damage; Upper Assam Basin.

1. Introduction

Drilling fluid is the most important element of oil and gas well drilling process. But, the drilling of a well from surface to the target location with conventional drilling fluids may impair the producing interval. In overbalanced drilling, the drilling fluids are kept at a pressure higher than the formation pressure to stop the invasion of formation fluids into the wellbore. This overbalance pressure is considered as the principal cause of inducing damage. Due to this pressure, the mud enters the formation and cause formation damage. Invading particles including drilling fluid's compositional solids, e.g. clay, drilled cuttings, etc. have the tendency to block the formation pores to reduce the rock permeability. Improper control of the mud properties of conventional water based mud (WBM) may leads to wellbore instability, formation damage, differential pressure sticking, borehole washouts, etc. in the drilled formations. The research of Gaurina-Medimurec et al.[1, 2]also demonstrate that the key elements attributed to formation damage due to solids invasion are overbalance pressure, pore size distribution, particle size distribution in the fluid, concentration of mud solids, mud circulation rate and rheology.

According to O'Brien and Chenevert[3],with the conventional WBM, the water of the drilling fluid may adsorbed onto thesurface of the shale while drilling through the problematic shale formation. Subsequently, the water may lead to various consequences depending on the type of shale such as swelling, cuttings dispersion, increase in pore pressure, etc.

The oil based mud (OBM) which is an alternate option for these types of problems is also economically and environmentally not viable.[4,5]In the scenario of current stringent environmental regulations, the industries are compelled to develop environmental friendly biodegradable water based mud.

To reduce the formation damage, the RDF should not use dispersant and non-degradable fine solids such as clay, barite, etc.; should diminish fluid loss; should contain specialized sized materials to bridge all exposed pore openings and should deposit a non-damaging filter cake that is easily and effectively removed.[6]

William et al. [7] reported that use of an inhibited bentonite-free polymer system to drill through the production intervals in some fields of Oklahoma improved drilling performance and lowered both overall drilling cost and drilling fluid cost by increasing penetration rates, while maintaining wellbore stability due to the overall reduction of suspended colloidal solids resulting in lower plastic viscosity and better control of plastic viscosity to yield point ratio.

Antonov et al. [8]also reported that clay free polymer-based drilling fluids with base chemicals polyacrylamide and carboxy methyl cellulose and salts used in the Bashkortostan fields of Russia increased the penetration rates, improved core recovery, minimized formation damage, retained a near-gauge hole, and reduced transportation and preparation costs. Additionally, polymer muds maintain optimal mud cake properties and serve as a tool for bed segregation and selective isolation of water-bearing formations.

The polymer mud incorporates long chain high molecular weight polymers in the system and thereby, able to encapsulate drill solids to prevent dispersion, coat the shale for inhibition, control rheology and fluid loss of the mud, etc. The RDF that the researcher has been trying to design in reference to some oil fields of Upper Assam Basin is a clay and barite free environment friendly water based polymer mud system to be used in the pay-zone sections of development wells to avoid formation damage and to keep the pay-zone or reservoir intact. The major application of this mud will be in the drilling of horizontal wells.

The XC-Polymer is a bio-polymer and hence biodegradable. Itis used in the formulation of the RDF to control the rheological properties such as plastic viscosity, yield point and gel strength as a substitute of the clays traditionally used in the conventional drilling fluid. XCP is a premium grade viscosifier and provides non-Newtonian rheology to water base mud and displays very good shear thinning and suspension characteristics.[9]

Two types of biodegradable bio-polymers have been incorporated in the designed RDF basically to decrease the fluid loss.One of them is PGS and another is PAC.PGS is a physico-chemically modified starch that has been simply precooked and drum dried to give products that readily disperse in cold water to form moderately stable suspensions. It is a high-quality non-ionic polysaccharide which controls the filtration loss by sealing the walls of the borehole and by increasing the viscosity due to its long chains of monosaccharide.

Drilling fluids made up with PAC are characterized for the function of reducing fluid loss, good inhibitive capability, high temperature endurance, high resistance for bacterial degradation and high salt endurance. It also provides shale inhibition as a protective colloid and improves the filter-cake quality and stability.[10]PAC has also shale inhibition qualities. It is an anionic polymer and attaches itself to the positively-charged edges of the exposed shale sections and prevents the shalefrom coming in contact with the water.

Although, the biodegradable components, e.g. bio-polymer of drilling fluid may also damage the reservoir and environment slightly during the drilling process, after few days of drilling, the plugs of the polymers and the environment damage will be automatically mended due to the biodegradation nature of the components.

2. Materials And Methods

The general components used for formulating the RDF include a) base fluid: fresh water, b)weighting and bridging materials: calcium carbonate, c) viscosifier: XC-Polymer, d) fluid loss control agent: Pregelatinized starch and Polyanionic cellulose, e) clay/shale inhibitor or stabilizer: Potassium chloride, Choline chloride and Polyol, and f) other additives: Caustic soda for controlling pH, Bactericide to decrease bio-degradation, and Linseed oil and Polyol for lubricity.

To study the role of XCP, PGS and PAC, the RDF was prepared by properly mixing of Fresh Water: 1.5 Litre, XC-Polymer: 0.3% (W/V), PGS: 2.5% (W/V), PAC (LVG): 0.5% (W/V), PAC (RG): 0.4% (W/V), KCl: 5% (W/V) or Choline Chloride: 2.5% (W/V), Polyol: 2.5% (V/V), Biocide: 0.15% (V/V), MCC: 5.1% (W/V), FCC: 3.4% (W/V),NaOH: 0.025% (W/V) and Linseed oil: 0.8% (V/V)[10, 11, 12]

Initially, according to proper measuring manual instructions different muds samples were formulated by varying the composition of rheology control agent XCP and the fluid loss control agents PGS and PAC keeping the other components as constant using the Mettler Electronic Precision Balance to measure the mass of the different component and Hamilton Beach Mixer for proper mixing of the components.

Then the effect of varying composition of XCP, PGS and PAC on mud properties were investigated to understand their role in RDF and to select their optimum composition for the oilfields of Upper Assam Basin. To investigate the effect of varying composition of these three components on the mud properties, the Mud Balance to measure the density of formulated mud, Marsh Funnel Viscometer to measure the Funnel Viscosity of formulated mud, Viscometer to measure Gel_0, Gel_{10}, Apparent Viscosity, Plastic Viscosity, Yield Point, etc., Filter Press for measuring the Fluid Loss and Mud Cake Thickness of formulated mud have been used.[13]

Then, the samples have been kept up to 60 days for XC-Polymer varying samples and up to 45 days for PGS and PAC varying samples in the laboratory basically to examine the durability of the mud samples against the biodegradation. Then, the mud properties have been investigated in a regular routine manner. An optimum concentration of XC-polymer for the study area has been selected. To study the role of PAC in RDF, two numbers of different commercial grades of PAC namely PAC-LVG and PAC-RG have been chosen. Seven numbers of mud samples by varying the composition of PGS, PAC-LVG and PAC-RG by keeping the other components as uniform have been formulated.

Again, to explore the temperature durability of the mud samples, the mud properties have been investigated by increasing the temperature of the mud samples in the laboratory. Then, with a comparative analysis, the best compositions of these two fluid loss control components in RDF have been selected.

For determining the Apparent Viscosity, Plastic Viscosity and Yield Point, the following formulas have used: Apparent Viscosity = ($\theta600/2$) CP; Plastic Viscosity = ($\theta600- \theta300$) CP; Yield Point = ($\theta300-$ PV) $lb/100ft^2$

3. Results and Discussion

Firstly, the effect of varying composition of XCP on mud properties were investigated to understand its role in RDF and to select its optimum composition for the oilfield of Upper Assam Basin.The mud properties were measured after 2-3 hours of proper mixing in the Hamilton Beach mud mixer. Then the measured/estimated mud parameters were tabulated in the Table 01.From the Table 01, it can be observed that the XCP has negligible effect on Specific Gravity, pH and Salinity of mud, and has slight effect on the Mud Cake thickness and the Fluid Loss characteristics of mud. But it has great effect on the rheological properties such as Viscosity, Yield point and Gel Strength of the mud.

Table 01: Properties of the RDF with increasing composition of XC-Polymer at the first day of formulation

Composition of XC-Polymer, gm/100ml	Mud Properties											
	Funnel Viscosity, Seconds	Apparent Viscosity, CP	Plastic Viscosity, CP	Gel Strength, lb/100ft^2		Yield Point, lb/100ft^2	Density of mud, kg/m^3	pH (Hydrogen Ion Concentration)	Salinity, ppm	Fluid Loss, ml	Mud Cake Thickness, mm	Temperature, ^{0}F
				Gel_o	Gel_{10}							
0	35	13	11	1	1.1	4	1079	9.8	38200	6.5	1.5	75.2
0.05	37	16.9	13.2	1.5	1.7	7.3	1075	9.8	38200	7	0.35	77
0.1	40	21.6	15.3	2.3	2.4	12.5	1071	9.7	38200	6.7	0.32	77
0.15	43	26	16.5	4.6	5.5	19	1068	9.7	38200	6.4	0.31	75.2
0.2	47	30.5	18.5	8.2	8.6	24	1064	9.8	38200	6.4	0.3	78.8
0.25	50	33.4	20.2	9.1	11	26.3	1061	9.5	38200	6.3	0.3	75.2
0.3	56	37.6	20.4	11.5	13	34.4	1060	9.4	38200	6.2	0.3	75.2
0.35	61	40.3	21.3	14	15.5	37.9	1058	9.4	38200	6.2	0.3	77
0.4	68	44.1	22.2	15	18.5	43.8	1053	9.7	38200	6.2	0.3	78.8
0.45	73	45.8	22.5	16.5	21	46.5	1052	9.6	38200	5.8	0.3	73.4

[1 **PSU= 1 gm/kg = 1000 ppm (equivalent to per thousand**)]

(**Note:** Although the temperature varies in a small range, i.e. (73.4-78.8 ^{0}F) in each experimental test, the temperatures vary is considered negligible and assumed as constant temperature in each test in making the comparisons of the properties)

It can be observed that the viscosity, yield point and gel strength increases with the increasing composition of XC-polymer due to the increased amount of long-chain high molecular weight polymer. This long-chain high molecular weight polymer offers high resistance to flow to the fluid, and thereby increases the viscosity. Again, due to the presence of this polymer, the internal structure of the fluid builds up strength while at rest, and thereby increases the gel strength and yield point. The funnel viscosity or apparent viscosity or instantaneous viscosity which represents the overall viscosity of the fluid increases at high rate with increasing composition of XC-polymer. But, the plastic viscosity is basically the result of the interaction of solids in the mud, and indicative of the number, type and size of colloidal particles present in the mud. It increases with increasing the composition of XC-polymer at a slower rate than the funnel viscosity or apparent viscosity.

The density of the designed RDF is basically responsible for the presence of the $CaCO_3$, but the volume of the mud increases slightly with the increasing composition of XC-polymer and thereby the density or specific gravity of the RDF decreases slightly. The salinity of the designed RDF is the outcome of the presence of KCl salt in the mud, and therefore the XC-polymer has no role in the salinity. Again, the pH (the negative logarithm of the hydrogen ion concentration) of the designed RDF is basically the outcome of the presence of OH^-anion from the NaOH in the mud, and therefore, being a nonionic polymer, the XC-polymer has no contribution for the pH value of the RDF.

It can be observed that the fluid loss decreases with the increasing composition of XC-polymer by increasing viscosity of the fluid due to its long chains of monosaccharides. Due to the better sealing effect by increasing viscosity and gel strength on the bridging particles, the mud cake thickness decreases with increasing composition of XC-polymer up to certain composition of XC-polymer and after that it becomes constant. The designed range of funnel viscosity, plastic viscosity, yield point, Gel_0 and Gel_{10} for successful drilling in the pay-zone of Upper Assam Basin are 51.1 ± 5 Seconds, 13.8 ± 5 CP, 29.3 ± 10 lb/100ft^2, 9.6 ± 4 lb/100ft^2 and 17.5 ± 5 lb/100ft^2 respectively.[14]

Now, it can be investigated that the range of 0.25 - 0.35 gm/100ml composition of XC-polymer offers all the rheological properties in their designed range for Upper Assam Basin. Within this range of XC-polymer composition, the range of funnel viscosity is about 50 - 60 Seconds; the range of plastic viscosity is about 20 - 21 CP; the range of yield point is about 26 - 38 lb/100ft^2; the range of Gel_0 (gel strength) is about 9 - 13.8 lb/100ft^2; and the range of Gel_{10}(gel strength) is about 10.5 - 15.5 lb/100ft^2.

Moreover, it can be inspected that the fluid loss offering by the XC-polymer composition range of 0.25 - 0.35 gm/100ml is about 6.2 ml, which is within the designed value of fluid loss for Upper Assam Basin (which is 6.3 ± 2 ml[14]).

Again, the smooth or problem free drilling operation also demands optimum mud cake thickness. Low thickness can cause high fluid loss and thereby high formation damage; on the other hand, high thickness results in sloughing or breaking and dropping of the mud cake, which again cause unstable borehole, high fluid loss and formation damage. High quality low permeable thin mud cake is considered as the preeminent mud cake for formation damage and drilling point of view. The mud cake thickness decreases slightly with the increasing composition of XC-polymer and shows its minimum value above 0.2 gm/100ml composition of XC-polymer.

But, as discussed earlier, the XC-polymer is highly bio-degradable. The observations also reveal the same fact. After two to three days of formulation, the mud incorporating XC-polymer starts to degrade. Again, from the field experience, it has been noticed that the average time period required for drilling of the pay-zone in the oilfields of Upper Assam Basin is about10 - 20 days. Offsetting the biodegradable nature of XC-polymer considering the number of days required to drill out the pay-zone sections with present day technologies using RDF in the Upper Assam Basin and the amount of XC-polymer that generally be lost in the field during operation, it can be recommended that the starting composition for XC-polymer in the formulation ofRDF at the rig site should be 0.3 gm/100ml, although the productive range that has been established based on the laboratory results and field experience is 0.25 - 0.35 gm/100ml for successful drilling in the oilfields of Upper Assam Basin.

Table 02: Properties of the RDF with increasing composition of PGS at the first day of formulation
(the temperature vary(84.2-87.8 ^{0}F) is considered negligible and assumed as constant temperature)

Composition of PGS, gm/100ml	Mud Properties											
	Funnel Viscosity, Seconds	Apparent Viscosity, CP	Plastic Viscosity, CP	Gel Strength, lb/100ft^2		Yield Point, lb/100ft^2	Density of mud, kg/m^3	pH (Hydrogen Ion Concentration)	Salinity, ppm	Fluid Loss, ml	Mud Cake Thickness, mm	Temperature, ^{0}F
				Gel_0	Gel_{10}							
0	50	32	17	11.9	17	30	1070	9.5	38200	8.4	1.2	84.2
0.5	55	34.3	18.5	12.8	17.5	31.5	1068	9.46	38200	7.5	0.33	87.8
1	58	37.5	21	13.6	17.9	33	1067	9.43	38200	6.9	0.32	87.8
1.5	66	39	22	13.8	18.2	34	1064	9.4	38200	6.6	0.31	86
2	70	40.5	23	14.9	18.6	35	1061	9.35	38200	6.4	0.3	85.1
2.5	77	42.5	24	15.2	19.3	37	1059	9.31	38200	6.3	0.29	87.8
3	79	46	25	15.5	20.5	42	1058	9.25	38200	6.25	0.29	84.2
3.5	90	52	27	16.5	22	50	1056	9.23	38200	6.2	0.29	86
4	96	55	28	16.7	22	54	1055	9.19	38200	6.2	0.29	86.9
4.5	101	57	29	17.5	23	56	1054	9.19	38200	6.1	0.29	84.2

Then the effects of increasing composition of PGS on mud properties have been investigated and tabulated the parameters against the compositions of PGS as shown in the Table 02. The mud properties were started to measure after 2 - 3 hours of proper mixing in the Hamilton Beach mud mixer.

From the Table 02, it can be observed that the PGS has negligible effect on specific gravity, pH and salinity of mud, and has slight effect on the mud cake thickness and rheological properties such as viscosity, yield point and gel strength of mud. But it has great effect on the fluid loss characteristic of mud. It can be noticed that the viscosity, gel strength and yield point increases with the increasing composition of PGS due to the increased amount of long-chain high molecular weight polymer. Since, the plastic viscosity is basically the outcome of the interaction of solids in the mud, and indicative of the number, type and size of colloidal particles present in the mud, it increases with increasing composition of PGS at a slower rate than the funnel viscosity or apparent viscosity. It can be observed that the fluid loss decreases with the increasing composition of PGS by increasing viscosity of the fluid and by sealing the walls of the borehole due to its long chains of monosaccharides. Due to the better sealing effect by the PGS on the bridging particles, the mud cake thickness decreases with increasing composition of PGS up to certain composition of PGS and after that it becomes constant. Thus, it can be established that the PGS is primarily a very good filtration control agent and secondarily a rheology control agent.

It can be investigated that even about 0.5 gm/100ml composition of PGS offers all the rheological properties in their designed range for Upper Assam Basin. Again, it can be observed that the fluid loss offering by the PGS composition of 0.5 gm/100ml is about 7.5 ml, which is within the designed value of fluid loss for Upper Assam Basin (The designed value of API Fluid Loss for the oilfields of Upper Assam Basin is 6.3 ± 2 ml [14]). But the fluid loss is almost constant above the PGS composition of 2.5 gm/100ml. And, the composition of PGS against the mean fluid loss for the oilfields of Upper Assam Basin, 6.43 ml [14]is about 2 gm/100 ml.Again, the smooth or problem free drilling operation also demands optimum mud cake thickness as discussed earlier. In this study, the mud cake thickness decreases with the increasing composition of PGS and shows its minimum value above 2.5 gm/100ml composition of PGS. Moreover, the PGS is highly bio-degradable. The observation of the Figure 01 and 03 also reveals the same fact. It can be perceived that the fluid loss rapidly increases with the increasing time due to highly biodegradable nature of PGS. After 10 - 15 days from formulation the fluid loss increases almost 30%. Again, from the field experience, it has been noticed that the average time period required for drilling of the pay-zone in the oilfields of Upper Assam Basin is about 10 - 20 days.

Thus, counterbalancing the biodegradable nature of PGS considering the number of days required to drill out the pay-zone sections with present day technologies using RDF in the Upper Assam Basin and the amount of PGS that generally be lost in the rig during operations, it can be suggested that the starting composition for PGS in the formulation of RDF at the rig site should be about 2.5 gm/100ml, although it start to provide the designed mud properties for successful drilling in the oilfields of Upper Assam Basin even from 0.5 gm/100ml composition in the mixture. Higher compositions of PGS can further decrease the fluid loss slightly, but which may have the detrimental effect on viscosity, gel strength, yield point, density and pH.

To study the role of PAC as the fluid loss control agent in RDF, an investigation on the properties of RDF by varying the composition of PAC has been conducted. In view of that, seven numbers of different RDF samples have been formulated by varying the composition of PGS, PAC-LVG and PAC-RG infresh water volume of 1.5 liter, keeping the other components uniform as XC-Polymer:0.3% (W/V), KCl: 5% (W/V), Polyol: 3% (V/V), Biocide: 0.1% (V/V), MCC:5.1% (W/V), FCC (Limestone): 3.4% (W/V), NaOH: 0.025% (W/V) and Linseedoil: 1% (V/V).The compositions of PGS, PAC-LVG and PAC-RG in the samples are as follows:

Sample 01: PGS: 0% + PAC-LVG: 0% + PAC-RG: 0%,
Sample 02: PGS: 3.5%,
Sample 03: PGS: 3% + PAC-LVG: 0.5% + PAC-RG: 0%,
Sample 04: PGS: 3% + PAC-LVG: 0% + PAC-RG: 0.5%,
Sample 05: PGS: 2.5% + PAC-LVG: 0.5% + PAC-RG: 0.5%,
Sample 06: PGS: 4%,
Sample 07: PGS: 3% + PAC-LVG: 0.5% + PAC-RG: 0.5%.

Then, as discussed earlier, the samples have been kept for 45 days in the laboratory and investigated the mud properties in a regular routine manner basically to investigate the durability of the mud samples against the biodegradation with increasing time from formulation.

To explore the temperature durability of the mud samples,basically the Grace M3600 Viscometer for increasing the temperature of the mud samples and measuring their rheological properties has been used. The mud properties have been investigated by increasing the temperature of the mud samples from 85 ^{0}F to 205 ^{0}F in the laboratory in a regular routine manner with a temperature gap of 10 ^{0}F.

Then, the effects of duration and temperature on the mud properties of the seven formulatedRDF samples have been investigated. From the investigations, it can be perceived that all the - rheological properties and fluid loss properties degrades with increasing time and temperature due to the degradation of the components of RDF. But, the amount of the mixture of (PGS + PAC-LVG + PAC-RG) can build up better rheological and fluid loss properties than the same amount of PGS alone or mixture of (PGS + PAC-LVG) and (PGS + PAC-RG).

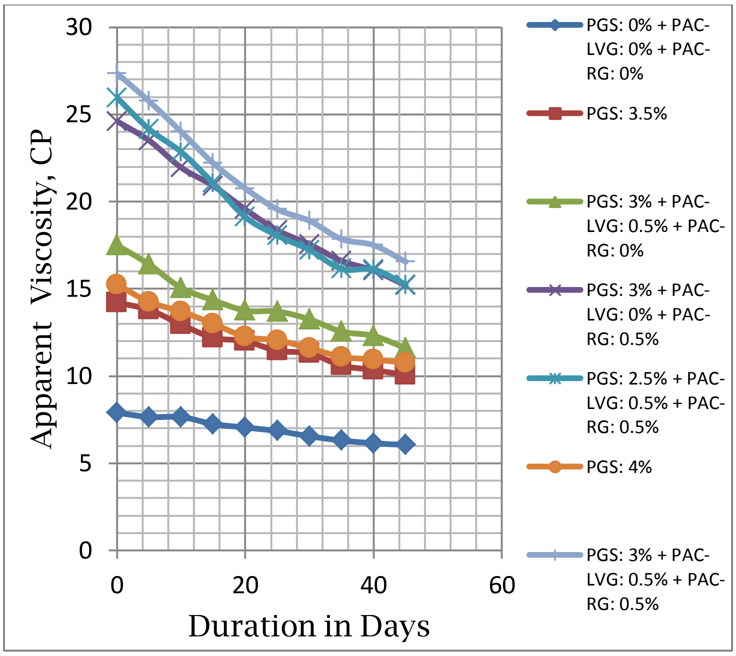

Figure 01: Effect of Duration on Apparent Viscosity

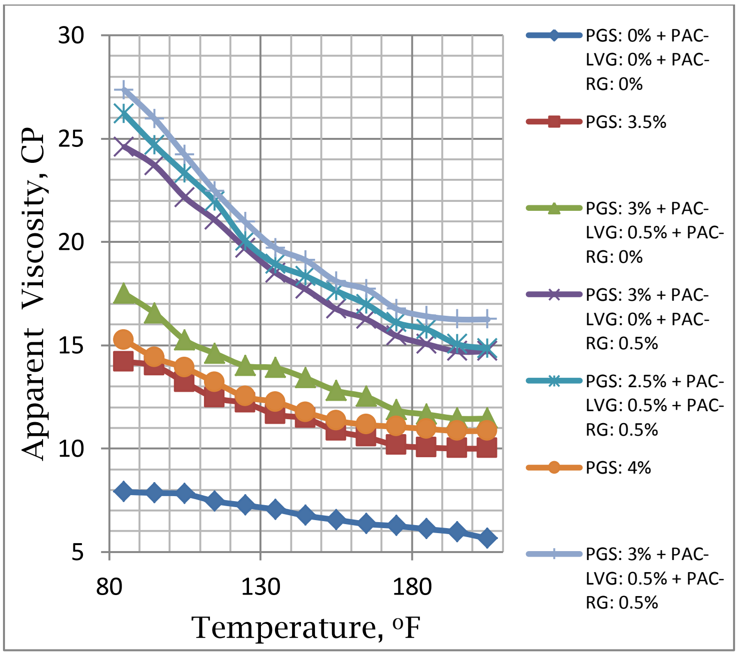

Figure 02: Effect of Temperature on Apparent Viscosity

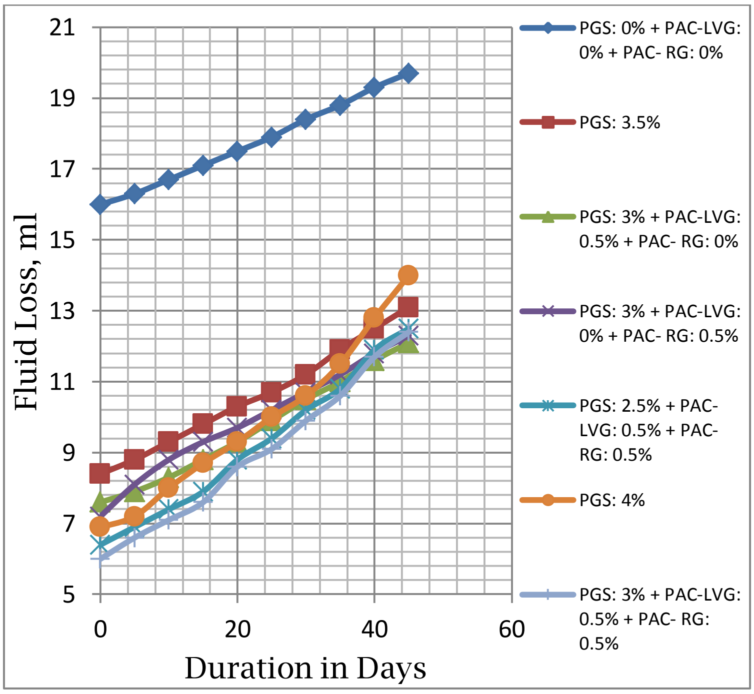

Figure 03: Effect of Duration on Fluid Loss

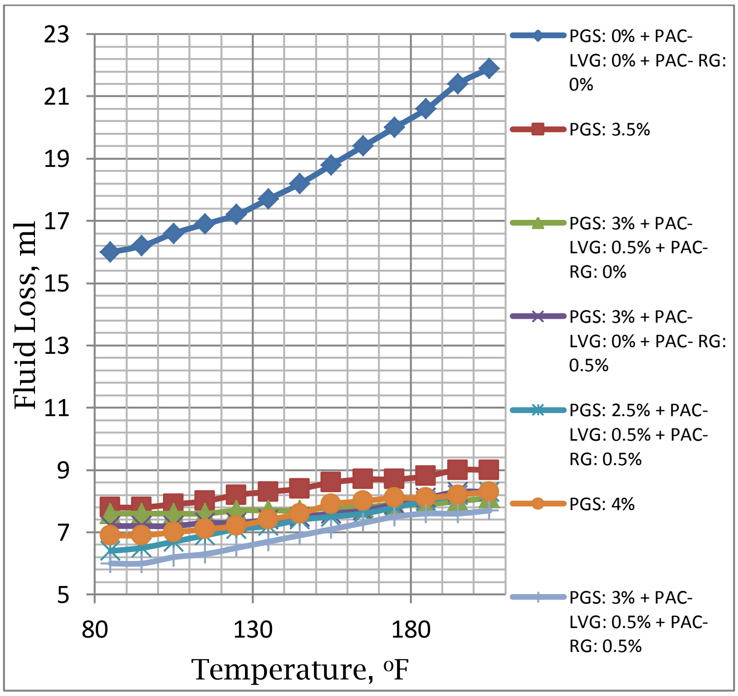

Figure 04: Effect of Temperature on Fluid Loss

Considering the rheological properties such as apparent viscosity in the Figure 01 and 02, the Sample 05 of the total 3.5% fluid loss control component and Sample 07 of the total 4% fluid loss control components are showing their maximum values and Sample 01 is showing the minimum value. The compositions of sample 02, 03, 04 and 06 will not be proper for a long span of drilling and at very high temperature using this RDF. The compositions of Sample 05 and 07 are giving enough rheology even at the long duration of drilling and elevated temperature. So, it is more preferable to apply the composition of Sample 05 and 07, i.e. the mixture of (PGS + PAC-LVG + PAC- RG).

Considering the fluid loss property from Figure 03 and 04, the Sample 01 is giving the maximum fluid loss and all the other samples are giving approximately equal values. But, for Sample 05 and 07, the fluid loss increasing rate with the increasing time and temperature is slower than the other sample 02, 03, 04 and 06. So, it is always preferable to use the composition of Sample 05 and 07, i.e. the mixture of (PGS + PAC-LVG + PAC-RG). The PGS alone or the mixtures of (PGS + PAC-LVG) or (PGS + PAC-RG) are giving higher fluid loss than the mixture of (PGS + PAC-LVG + PAC- RG) after few days of drilling and at or around the median reservoir temperature (187.7 ^{0}F)[14] of the oilfields of Upper Assam Basin. Thus, from this study, it can be recommended that the mixture of (PGS + PAC-LVG + PAC- RG) is the best composition as fluid loss and rheology control agents in RDF for resisting to high temperature degradation and biodegradation.

The optimum composition of PGS in the RDF for the oilfields of Upper Assam Basin is about 2.5 % in gm /100ml basis. To choose the optimum composition of PAC-LVG and PAC-RG, again some different RDF samples were formulated by changing the composition of PAC-LVG and PAC-RG; keeping the other components as fixed. Then the effect of changing composition of PAC-LVG (Table 03) and PAC-RG (Table 04) on the mud properties were studied to understand their role in RDF and to choose their optimum composition which will offer appropriate parameters of RDF for the Upper Assam Basin. Although the temperature varies slightly in each experimental test for different mud samples, the temperature vary is considered negligible and assumed as constant temperature in each test in making the comparisons of the properties. It can be investigated from the Table 03 and 04that the rheological properties increases and fluid loss decreases with the increasing composition of PAC-LVG and PAC-RG.

Table 03: Properties of the RDF with changing composition of PAC-LVG keeping the other component as constant

Fluid Loss control agents	Funnel Viscosity, Seconds	Apparent Viscosity, CP	Plastic Viscosity, CP	Yield Point, lb/ 100 ft^2	Gel$_0$, lb/ 100 ft^2	Gel$_{10}$, lb/ 100 ft^2	Specific Gravity	Fluid Loss, ml	Mud Cake Thickness, mm
PGS: 0% + PAC-LVG: 0% + PAC- RG: 0%	30	7.9	5.7	4.4	5	6	1.081	16	0.4
PGS: 3% + PAC-LVG: 0% + PAC- RG: 0.4%	52	23.9	15.6	16.6	8	10	1.068	10.4	0.29
PGS: 3% + PAC-LVG: 0.1% + PAC- RG: 0.4%	52	24.15	15.7	16.9	8	10	1.066	8.2	0.29
PGS: 3% + PAC-LVG: 0.2% + PAC- RG: 0.4%	53	24.45	15.9	17.1	8	10	1.067	7.7	0.29
PGS: 3% + PAC-LVG: 0.3% + PAC- RG: 0.4%	54	24.85	16	17.7	8	11	1.069	7.4	0.29
PGS: 3% + PAC-LVG: 0.4% + PAC- RG: 0.4%	55	25.7	16.2	19	9	12	1.068	7.3	0.29
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.4%	57	27.2	16.9	20.6	9	12	1.071	7.3	0.29
PGS: 3% + PAC-LVG: 0.6% + PAC- RG: 0.4%	59	27.4	17.8	19.2	9	12	1.07	7.2	0.3
PGS: 3% + PAC-LVG: 0.7% + PAC- RG: 0.4%	61	28.6	18.8	19.6	9	13	1.075	7.2	0.3
PGS: 3% + PAC-LVG: 0.8% + PAC- RG: 0.4%	63	29.95	20.1	19.7	9	13	1.073	7.2	0.3

In the Table 03, it can be observed that the designed ranges of the properties are starting from the composition of PAC-LVG of 0.4%. But, offsetting the biodegradable nature of PAC-LVG and the amount of PAC-LVG that generally be lost in the field during operation, it can be recommended that the starting composition for PAC-LVG in the formulation of RDF at the rig site should be just above the 0.4% of PAC-LVG, i.e. from the Table 03, the 0.5% of PAC-LVG can be taken as the starting composition of PAC-LVG in the final RDF mixture to provide the designed RDF properties for successful drilling in the oilfields of Upper Assam Basin.

In the Table 04, it can be observed that the designed ranges of the properties are starting from the composition of PAC-RG of 0.3%. But, offsetting the biodegradable and high temperature degradable nature of PAC-RG and the amount of PAC-RG that generally be lost in the field during operation, it can be recommended that the starting composition for PAC-RG in the formulation of RDF at the rig site should be just above the 0.3% of PAC-RG, i.e. from the Table 04, the 0.4% of PAC-RG can be taken as the starting composition of PAC-RG in the final RDF mixture. Higher compositions of PAC-LVG and PAC-RG can further decrease the fluid loss slightly, but they may have the detrimental effect on viscosity, gel strength and yield point.

Table 04: Properties of the RDF with changing composition of PAC-RG keeping the other component as constant

Fluid Loss control agents	**Funnel Viscosity, Seconds**	**Apparent Viscosity, CP**	**Plastic Viscosity, CP**	**Yield Point, lb/ 100 ft^2**	**Gel$_0$, lb/ 100 ft^2**	**Gel$_{10}$, lb/ 100 ft^2**	**Specific Gravity**	**Fluid Loss, ml**	**Mud Cake Thickness, mm**
PGS: 0% + PAC-LVG: 0% + PAC- RG: 0%	30	7.9	5.7	4.4	5	6	1.081	16	0.4
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0%	47	17.5	11	13	6	7	1.061	8.6	0.28
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.1%	48	20.5	13.1	14.8	7	8	1.066	7.5	0.28
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.2%	51	22	13.7	16.6	9	11	1.065	7.4	0.29
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.3%	53	24.25	14.7	19.1	9	12	1.068	7.3	0.29
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.4%	57	27.2	16.9	20.6	9	12	1.071	7.3	0.29
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.5%	63	31.75	19.7	24.1	10	13	1.07	7.2	0.29
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.6%	70	37	23	28	11	13	1.069	7.1	0.3
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.7%	78	42.5	27	31	12	14	1.07	7	0.3
PGS: 3% + PAC-LVG: 0.5% + PAC- RG: 0.8%	93	49	32.1	33.8	12	15	1.069	7	0.3

4. Conclusion

XC-Polymer, Pregelatinized starch and Polyanionic cellulose work efficiently in reservoir drilling fluid as the rheology and fluid loss control agent.They are biodegradable and high temperature degradable. Therefore, the reservoir damage due to plugging by these polymers and the environment damage by the disposal of the mud will be automatically mended or cleaned out due to this biodegradable nature. Although these polymers degrade at high temperature, the formulated mud using these polymers is still providing suitable properties necessary for the successful reservoir drilling at the median reservoir temperature of 187.7 ^{0}F in the Upper Assam Basin. The mixture of (PGS + PAC-LVG + PAC- RG) is the best composition as fluid loss control agent in RDF which gives very good resistance towards the degradation due to high temperature and biodegradation. From this study including the laboratory experiments and field experience, it can be recommend that the starting composition of XC-Polymer is 0.3gm/100 ml in the formulation of RDF in the drilling rig and may be increased up to 0.35 gm/100 ml with the requirements during the drilling. Again, the starting composition of 2.5 gm/100 ml for PGS in the formulation of RDF can be recommend and may be increased its value upto 3.5 gm/100 ml with proper investigation during the drilling. The starting composition of PAC-LVG and PAC-RG should be 0.5gm/100 mland 0.4gm/100 ml respectively and may be increased slightly by the requirements during drilling.

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