International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

A Study on the role of Polyanionic Cellulose (PAC) in the NDDF for the oilfields of Upper Assam Basin

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***Abstract*: One of the most common ways of damaging a formation during the drilling process is the filtration loss. Due to the overbalance pressure, the mud invades the formation and can cause formation damage. Starches are environment-friendly water-base drilling mud additives used to control the filtration loss. The Pre-Gelatinized Starch (PGS), a non-ionic polysaccharide which controls the filtration loss by sealing the walls of the borehole due to its long chains of monosaccharide, has been using as the filtration control component in the NDDF. This paper reports the effect Polyanionic Cellulose (PAC) in compare to PGS as a high temperature and biodegradation resisting component in the NDDF. In this work, an attempt also has been made to study the effect of varying composition of PAC on the different mud properties of laboratory formulated NDDF and to choose its optimum composition based on the required mud parameters for the Oilfields of Upper Assam Basin.**

Keywords: NDDF; PAC; Mud Rheology; Filtration Loss; Formation Damage; Upper Assam Basin

1. Introduction

A conventional water-based mud (WBM) may cause wellbore instability, formation damage, torque & drag, stuck pipe, logging and primary cementation failures, borehole washouts etc. in water sensitive clays and shale formations. The alternate option of oil-based mud (OBM) is also economically & environmentally unviable. [5]

According to Mandal et al [6], to counter the formation damage, an optimally designed drilling fluid should not use dispersant and non-degradable fine solids like- Clay, Barite, etc. in the mud; should reduce fluid loss; should minimize drilled fine solids in the mud; should produce inhibitive saline filtrate which would not swell the clay envelops in the formation particles and should not react with the formation fluid to generate insoluble precipitate; should contain specialized sized materials to bridge all exposed pore openings; should deposit a thin and tough non - damaging filter cake that can be easily and effectively removed by acid jobs; must hold all the relevant drilling fluid characteristics; should lower overall well costs and most importantly must optimize the production without neglecting HSE regulations.
Non Damaging Drilling Fluid (NDDF) is a clay and barite free environmental friendly polymer mud system mostly used in the pay zone sections of development wells and specifically in horizontal drilling to avoid formation damage. It incorporates long-chain, high molecular weight polymers in the systems either to encapsulate drill solids to prevent dispersion or to coat the shale for inhibition as well as to increase Viscosity, Yield Point and Gel Strength and to reduce Fluid and fine solids invasion and Mud Cake thickness. An extensive range of particle sizes is used which, on de-hydration, fit together into a strongly compacted very low permeable high quality Mud Cake on the surface of the rocks to quickly seals off the permeable paths of the pay-zone.

The drilling fluids are kept at a pressure higher than the formation pressure to stop the invasion of formation fluid into the wellbore. This overbalance pressure is considered as the major cause of inducing formation damage by the invasion of fluid and suspended solid into the formation. These solids (drilling fluid's compositional solids, drilled cuttings and polymers' particles) have a tendency to block the pores to reduce the rock permeability. Mud filtrate can interact with formation minerals to cause mobilization and subsequent re-deposition of in-situ fines, to swell the pay-zone clay, to alteration of reservoir rock wettability, to development of emulsions, and may generate scales due to chemical reaction with formation fluid leading to a decrease in formation permeability. Thus, this invasion can cause irreversible formation damage.

According to Pang and Sharma [8], almost every operation in the petroleum reservoir can cause formation damage and thereby decreases the productivity or injectivity of the formation. To avoid this risk and high cost involved in recovering the damaged formation, it is necessary to minimize it.

Starches [$(C_6H_{10}O_5)$ n] consist of about 27% linear polymers (amylose) and about 73% branched polymer (amylopectin). The two polymers are intertwined within starch granules and are insoluble in cold water. PGS ($C_{27}H_{48}O_{20}$) is a physicochemically 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 non-ionic polysaccharides which reduce the fluid loss by increasing the viscosity of the drilling fluids and by sealing the walls of the borehole due to its long chains of monosaccharide.

Polyanionic Cellulose (PAC) is a cellulose derivative similar in structure, properties and usage in drilling fluids to Carboxymethyl Cellulose. It is considered to be a premium product because it typically has a higher degree of Carboxymethyl substitution and contains less residual NaCl than technical grade Carboxymethyl Cellulose. Drilling fluids made up with PAC are characterized by good function of reducing fluid loss, good inhibitive capability, high temperature endurance and high salt endurance. It also has good stability and good high temperature resistance (150℃). It has the strongest salt tolerance and works especially well in deep high temperature wells. PAC can effectively lower the filtration loss of fresh water mud and saturated salt water mud.

It reduces and controls the API filtration rate while stabilizing the rheology of the mud without substantially increasing the viscosity regime of the fluid system. It also provides shale inhibition as a protective colloid and improves the filter-cake quality and stability between the wellbore and the formation.

In the Upper Assam basin, following horizons have been identified (top to bottom): a) Tipam Sand, b) Barail Sand, c) Kopili, d) Sylhet, e) Basal Sandstone, and f) Basement as the producing formation. In most of the fields, the main producing horizons are Tipam and Barail main sand. In addition, few wells are producing from the Barail coal-shale unit. The geological age of the Barail main sand and Barail coal-shale is Oligocene and that of Tipam is Miocene.

In this work, the effect of Polyanionic Cellulose in compare to PGS as a high temperature and biodegradation resisting component in the NDDF is studied. Moreover, an attempt has been made to study the effect of varying composition of PAC (RG) and PAC (LVG) on the different mud properties of laboratory formulated NDDF and to choose their optimum composition based on the required mud parameters for the Oilfields of Upper Assam Basin.

2. MATERIALS AND METHODS

Materials:

The general components used for formulation of NDDF were:

1. Base fluid - fresh water
2. Viscosifier- XCP
3. Fluid loss control agent - Starch e.g. PGS (Pre Gelatinized Starch), PAC (LVG) & PAC (RG)
4. Lubricity- Linseed oil
5. Formation clay/shale inhibitor-Potassium Chloride
6. Weighing and bridging materials: Medium Coarse $CaCo_3$ and Micronized $CaCo_3$
7. Other additives- Caustic Soda, Bactericide (Formaldehyde)

To study the role of PAC, the NDDF was prepared by properly mixing of Fresh Water: 1.5 Litre, XC-Polymer: 0.3%, PGS: 3%, MCC: 4.5 %, MCCC: 3%, Biocide: 0.1%, NaOH: 0.025%, KCl: 5% and varies the composition of PAC (LVG) & PAC (RG) in gm /100ml basis. [1][2][3][4]

The drilling fluids are designed based upon the formation characteristics. Therefore, to study the detail characteristics of the study area, some data about the reservoir as well as some mud policy & well cards for NDDF of drilled wells, mud chemicals, etc. are collected from different operating companies working in this basin.

Table-01 : Reservoir Temperature of ten (10) major oilfields of Upper Assam Basin

Oilfield	Sand	Temperature (℃)
XYZ-G	Gurujan Clay	-----------
	TS	70-80
	BCS	90-92
	BMS	98-105
	KSU	100-108
XYZ-R	TS	-----------
	BCS	-----------
	BMS	-----------
XYZ-L	TS	74-92.8
XYZ-N	Tipam	66-74
	Barail	70-93
	LK+TH	98-112
XYZ-H	Tipam	60-70
	Barail	68-75
	LK+TH	103-116
XYZ-M	Barail	80-99
XYZ-D	LK+TH	103-105
XYZ-J	Tipam	65-84
	Barail	85-88
XYZ-S	Barail	70-90
XYZ- C	Eocene (LK+TH and Langpar)	98-106

(OIL and ONGC, unpublished report)

Methods:

Firstly, a reservoir temperature study of the major oilfields of Upper Assam Basin was done from the data collected from OIL and ONGCL, India.

Secondly, according to proper measuring manual instructions different muds samples were formulated by varying the composition of Fluid Loss control agent: PGS & PAC; keeping the other components as constant using the following equipments:

a. Mettler Electronic Precision balance to measure the mass of different chemicals for proper composition.
b. 1000 ml measurable stainless steel cup for measuring the water volume.
c. Hamilton Beach Mixer for proper stirring/mixing water and the mud component for generation of proper mud properties.
d. 15 ml pipette to measure small liquid volume.

Then, the effect of varying temperature on mud properties of the different formulated muds samples were investigated to select the best components for NDDF at high temperature environment.

To investigate the effect of varying temperature on the various mud properties, the following equipments have used:

a. OFITE 4 scale plastic model Mud Balance to measure the density of formulated mud.
b. Grace M-3600 Viscometer to measure/determine Gel_0, Gel_{10}, Apparent Viscosity, Plastic Viscosity, Yield Point of formulated mud at different temperature.
c. OFITE plastic Marsh Funnel Viscometer to measure the Funnel Viscosity of formulated mud. (Gas burner, Steel Bowl and Thermometer also used to measure the Funnel Viscosity with increasing temperatures.)
d. Filter Press for measuring the Fluid Loss and Mud Cake Thickness of formulated mud.
e. pH Meter for measuring the pH of water used for formulating mud and the formulated mud.

For determining the Apparent Viscosity, Plastic Viscosity and Yield Point, the following formulas have used:

Apparent Viscosity = $(\theta 600/2)$ CP

Plastic Viscosity = $(\theta 600 - \theta 300)$ CP

Yield Point = $(\theta 300 - PV)$ $lb/100ft^2$

Thirdly, again some different NDDF samples were formulated by varying the composition of Fluid Loss control agent: PGS & PAC; keeping the other components as constant using the above mentioned equipments. Then, the effect of duration on mud properties of the different formulated muds samples were investigated to analyse the biodegradation nature of PGS and PAC and then, select the best components for NDDF at the biodegradable environment using the above mentioned equipments.

Fourthly, the Mean and Median of the different NDDF parameters of successfully drilled wells in the producing formations of UAB were calculated from the well-cards of the completed wells collected from different operating companies of this basin to design the optimum mud parameters for successful wells in this basin.

Finally, again some different muds samples were formulated by varying the composition of Fluid Loss control agent: PGS & PAC; keeping the other components as constant. Then the effect of varying composition of PGS & PAC on the mud properties were investigated to see the role of PAC in NDDF and to select optimum composition of PAC which gives suitable parameters of NDDF for the Upper Assam Basin (UAB). The suitable parameters of NDDF for the UAB have been selected from the well cards collected from different operating companies working in this basin and optimum composition of PAC was selected by interpreting the parameters with the generated table and graphs.

3. RESULTS AND DISCUSSION

A reservoir temperature study of the major oilfields of Upper Assam Basin was done from the data collected from OIL and ONGCL, India (Table-01). The Median reservoir temperature of the major oilfields of UAB is 86.5 ºC (187.7 ºF). So, a suitable NDDF should retain its mud parameter required to perform the mud functions properly for the UAB in and around the temperature of 86.5 ºC.

Then, according to proper measuring manual instructions five numbers of NDDF samples were formulated by varying the composition of Fluid Loss control agent: PGS & PAC as follows; keeping the other components constant as Fresh Water: 1.5 Litre, XC-Polymer: 0.3%, MCC: 4.5 %, MCCC: 3%, Biocide: 0.1%, NaOH: 0.025%, and KCl: 5% in gm /100ml basis.

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%

In sample-01, we have not used any fluid loss control agent. In all the other four samples the total Fluid Loss control agent is 3.5%. In sample-02, out of total 3.5%, PGS is 3.5%, PAC-LVG is 0% and PAC-RG is 0%. In sample-03, out of total 3.5%, PGS is 3%, PAC-LVG is 0.5% and PAC-RG is 0%. In sample-04, out of total 3.5%, PGS is 3%, PAC-LVG is 0% and PAC-RG is 0.5%. In sample-05, out of total 3.5%, PGS is 2.5%, PAC-LVG is 0.5% and PAC-RG is 0.5%.

Then, the effects of varying temperature on mud properties of the different formulated muds samples were investigated. All the change in values of the mud parameters with different temperature were tabulated and drawn the graphs of the parameters against the temperature as shown in the Fig. 01-08.

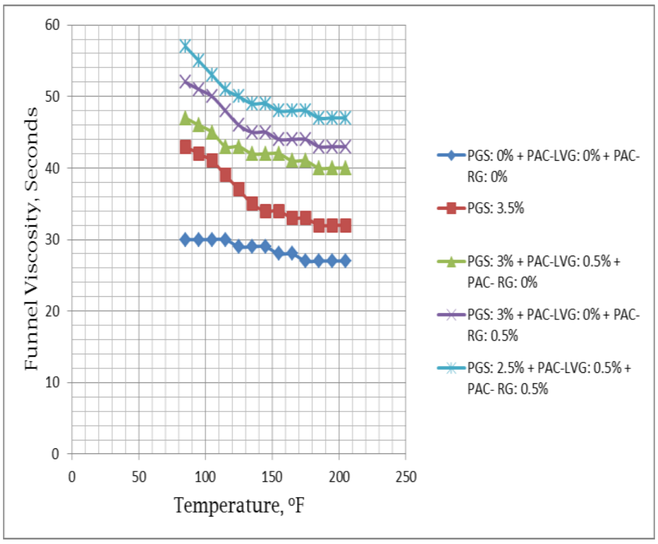

Fig. 01: Funnel Viscosity vs. Temperature

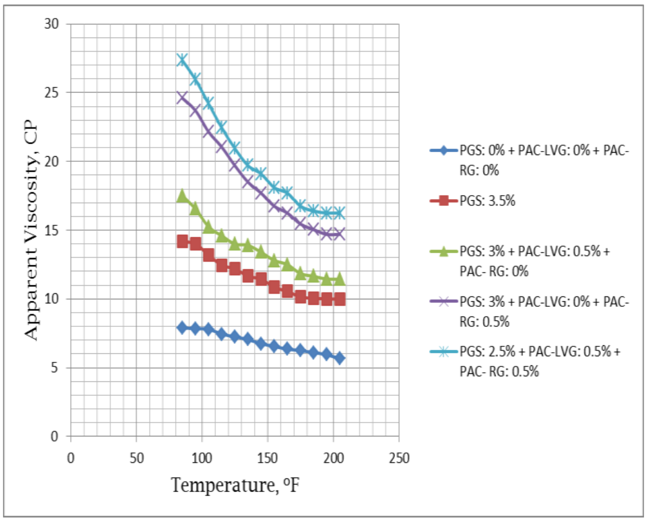

Fig. 02: Apparent Viscosity vs. Temperature

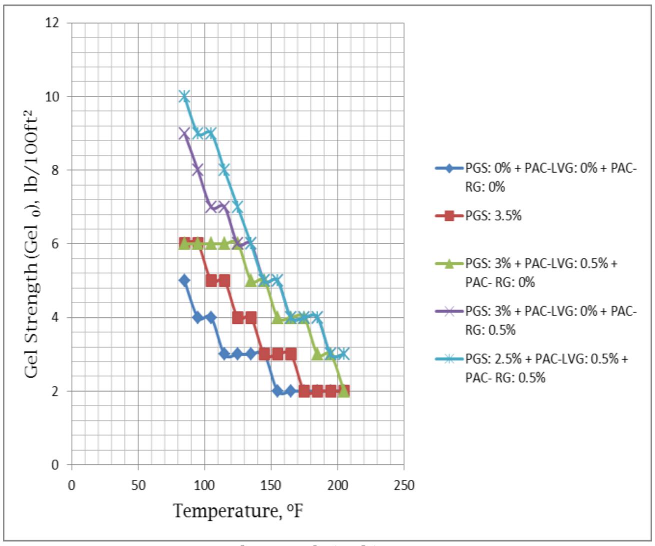

Fig. 05: Gel Strength (Gel_0) vs. Temperature

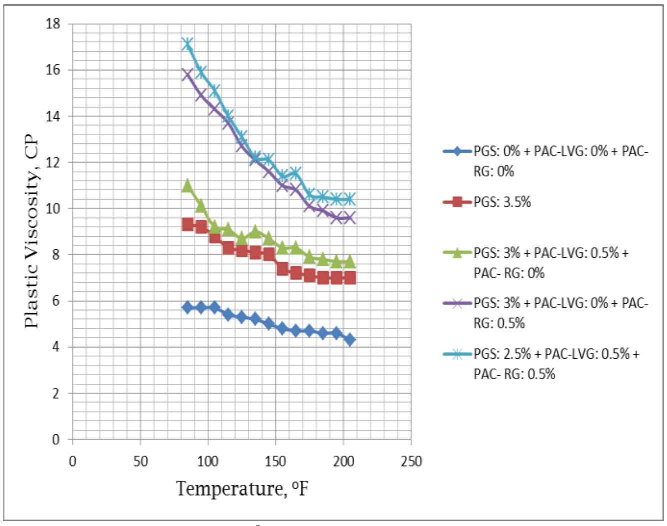

Fig. 03: Plastic Viscosity vs. Temperature

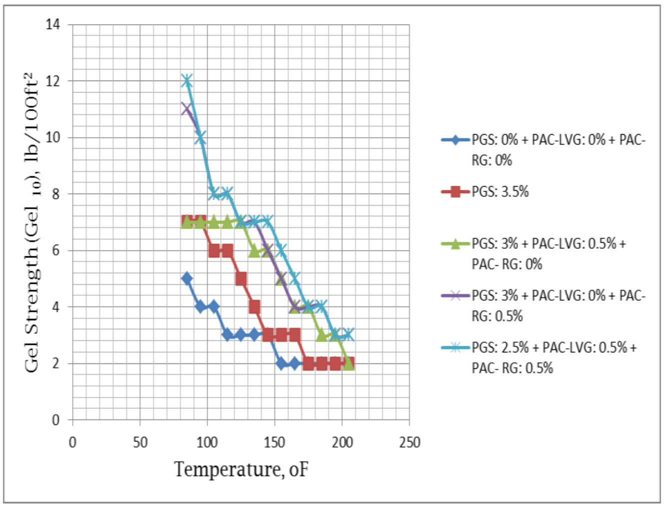

Fig. 06: Gel Strength (Gel_{10}) vs. Temperature

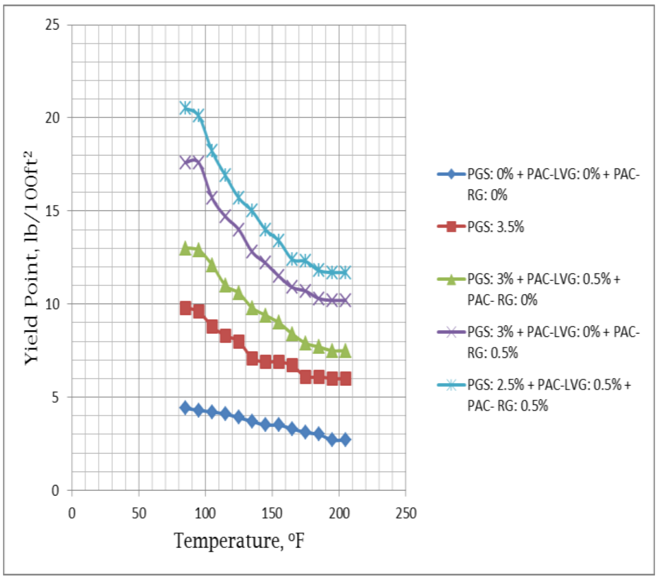

Fig. 04: Yield Point vs. Temperature

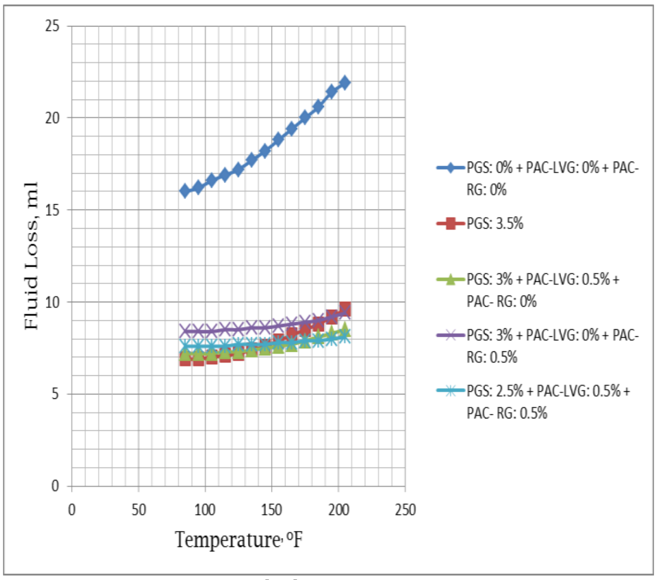

Fig. 07: Fluid Loss vs. Temperature

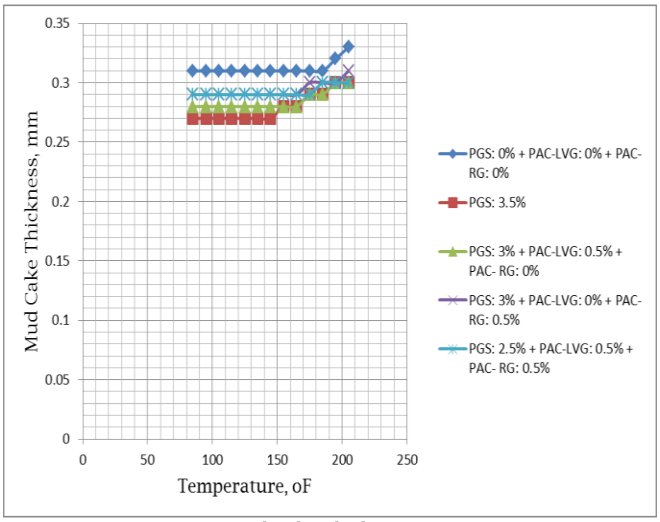

Fig. 08: Mud Cake Thickness vs. Temperature

From Fig. 01-08, we can investigate that all the rheological properties, Fluid Loss properties and Mud Cake Thickness are degraded with increasing temperature. But, the degrading rate of the mixture of PGS and PAC is slightly slower than the degrading rate of PGS alone. If we consider the rheological properties (Funnel Viscosity, Apparent Viscosity, Plastic Viscosity, Yield Point and Gel Strength) in Fig. 01-06, the sample- 05 is showing the maximum values and sample-01 is showing the minimum values. The compositions of sample 02-04 will not be suitable for elevated temperatures. The compositions of sample-05 are giving very good properties even at the elevated temperatures of about the Median reservoir temperature of 86.5 ºC (187.7 ºF). So, we will prefer the composition of sample-05 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 not giving the enough rheology at and around the Median reservoir temperature.

If we consider the fluid loss from Fig. 07, the sample-01 is giving the maximum Fluid Loss and all the other samples are giving approximately equal values. But, for sample-05, the fluid loss increasing rate with the increasing temperature is slower than the other sample- 02, -03 and -04. So, we will always prefer the composition of sample-05 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) at or around the Median reservoir temperature.

If we consider the mud cake thickness from Fig. 08, the sample-01 is giving the maximum Mud Cake Thickness and all the other samples are giving approximately equal values. Thus, the PGS alone or the mixtures of PGS + PAC-LVG or PGS + PAC-RG or PGS + PAC-LVG + PAC-RG are giving almost equal mud cake thickness even around the Median reservoir temperature.

Then, according to proper measuring manual instructions again five numbers of other NDDF samples were formulated by varying the composition of Fluid Loss control agent: PGS & PAC as follows ; keeping the other components constant as Fresh Water: 1.5 Litre, XC-Polymer: 0.3%, MCC: 4.5 %, MCCC: 3%, Biocide: 0.1%, NaOH: 0.025%, and KCl: 5% in gm /100ml basis.

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%

Then, the effects of duration on the mud properties of the different formulated NDDF samples were investigated. All the change in values of the mud parameters with duration were tabulated and drawn graphs of the parameters against the time as shown in the Fig. 09-16.

From Fig. 09-16, we can investigate that all the rheological properties, Fluid Loss properties and Mud Cake Thickness are degraded with increasing time due to the biodegradation of the components of NDDF. But, same amount of the mixture of PGS + PAC-LVG +PAC-RG can build up more rheology than the same amount of PGS alone or same amount of mixture of PGS + PAC-LVG and PGS +PAC-RG. The degrading rate of the mixture of PGS + PAC is also slightly slower than the degrading rate of PGS alone.

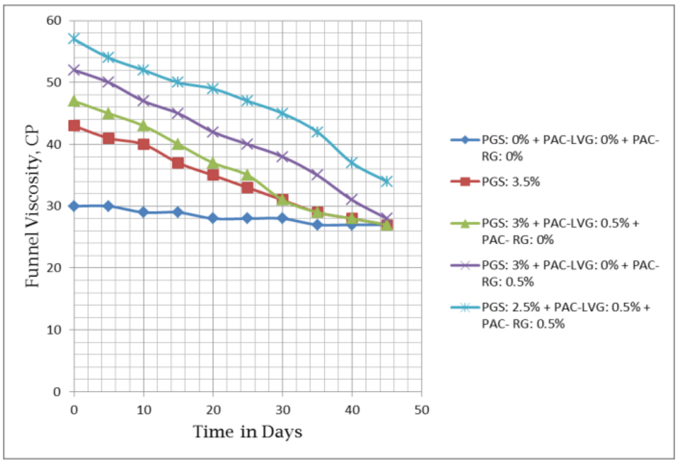

Fig. 09: Funnel Viscosity vs. Duration

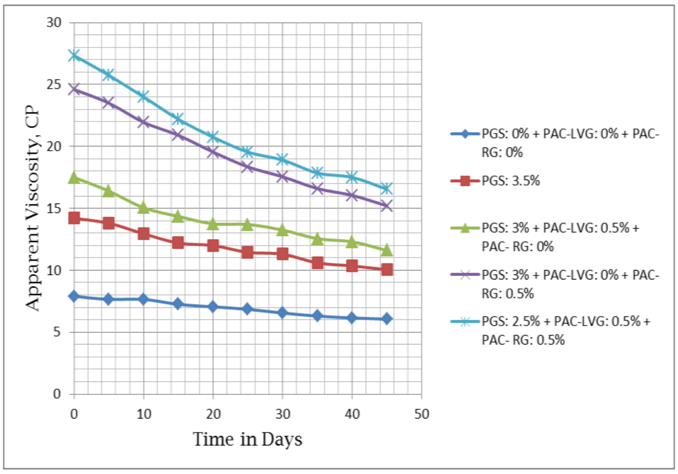

Fig. 10: Apparent Viscosity vs. Duration

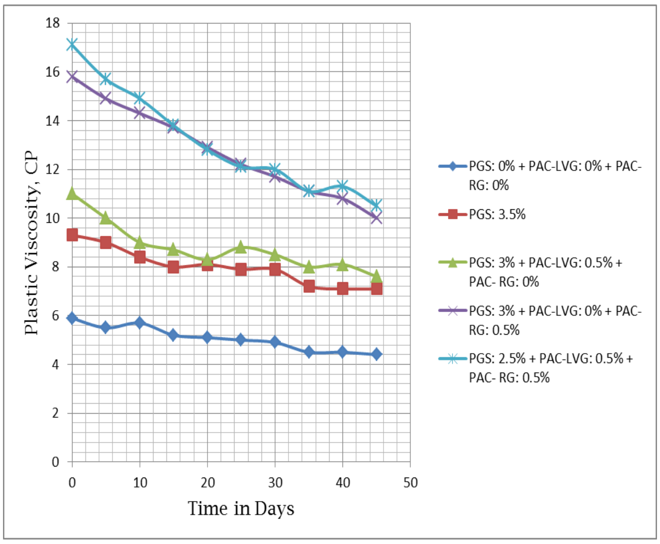

Fig. 11: Plastic Viscosity vs. Duration

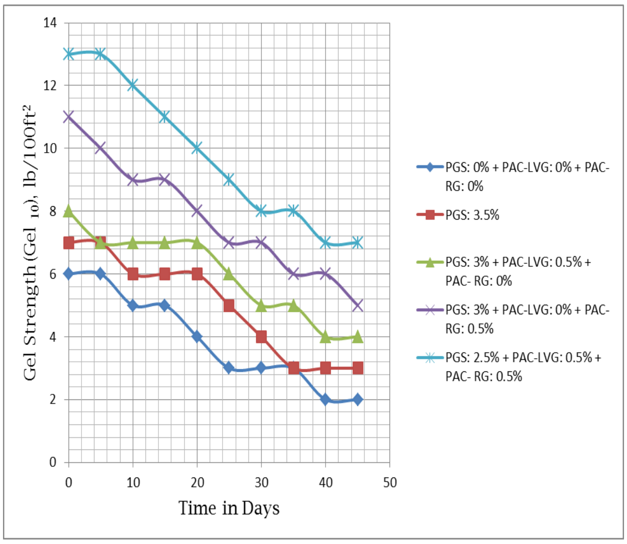

Fig. 14: Gel Strength (Gel_{10}) vs. Duration

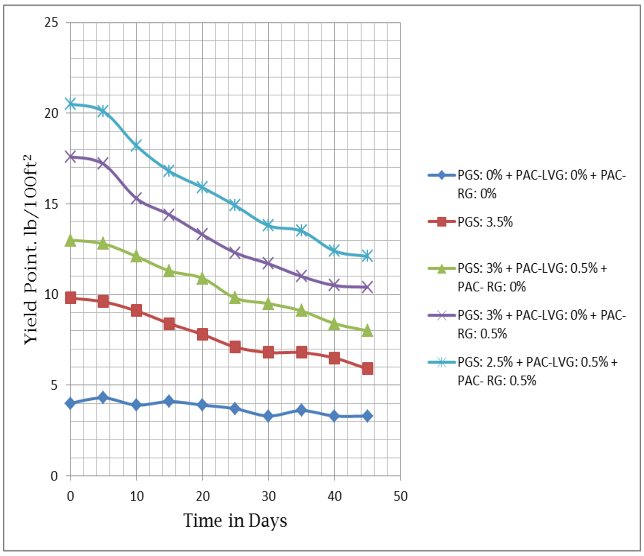

Fig. 12: Yield Point vs. Duration

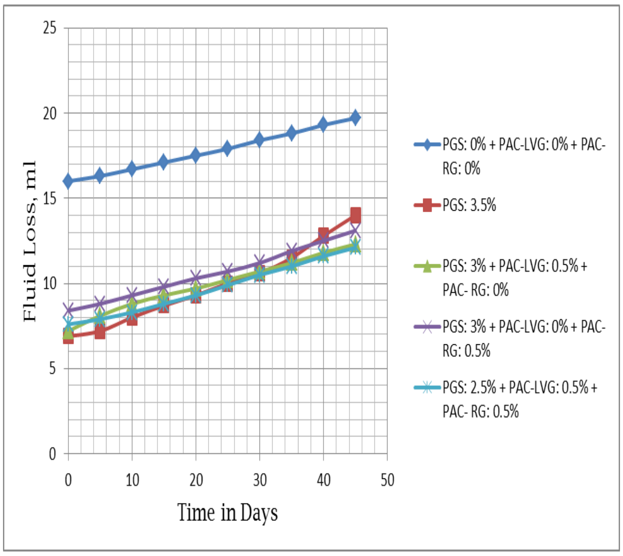

Fig. 15: Fluid Loss vs. Duration

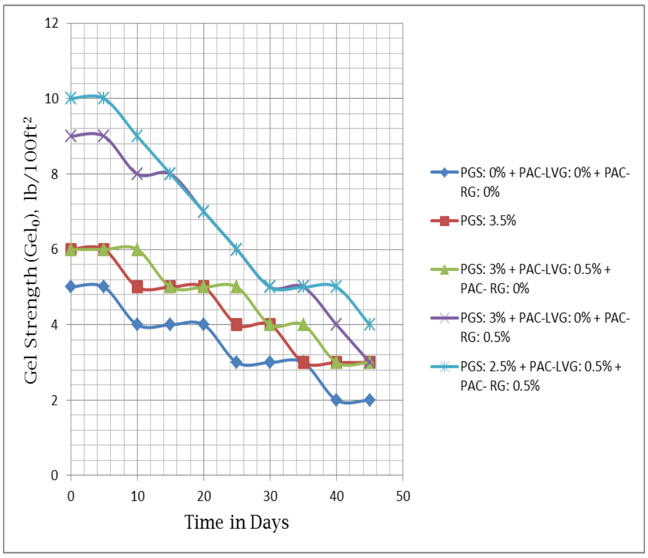

Fig. 13: Gel Strength (Gel_0) vs. Duration

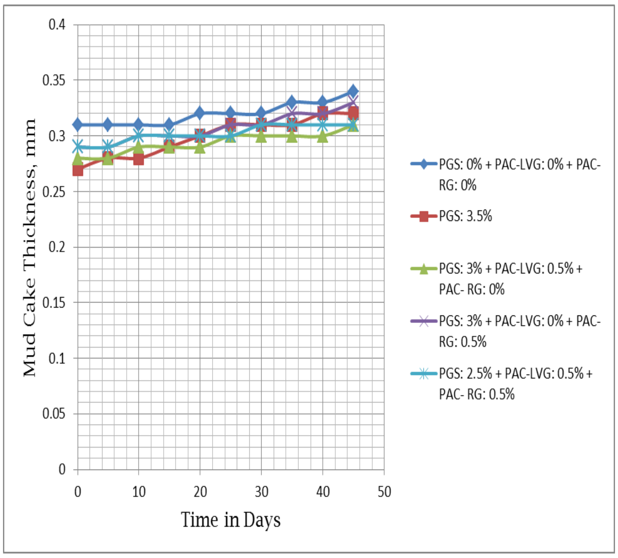

Fig. 16: Mud Cake Thickness vs. Duration

Table-02 : NDDF parameters of Sixteen successfully drilled wells in producing formations of Upper Assam Basin

Well Name	Well's Brief Description	NDDF Parameters						
		Specific Gravity	Funnel Viscosity, Seconds	Fluid Loss, ml	Plastic Viscosity, CP	Yield Point, lb/100ft^2	Gel Strength (Gel_0), lb/100ft^2	Gel Strength (Gel_{10}), lb/100ft^2
GKGR	Development well, Inclined (L) profile, Tipam Pay-zone, 2617 m TVD	1.07-1.08	55-59	5-8	11-16	30-36	8-10	16-18
GKHV	Development well, Inclined (L) profile, Tipam Pay-zone, 2880 m TVD	1.06-1.07	42-55	7-8.5	11-14	16-24	6-8	11-16
GKGW	Development well, Inclined (L) profile, Tipam Pay-zone, 2900 m TVD	1.08-1.11	53-60	5.5-6.2	14-19	25-35	6-7	10-13
GKGU	Development well, Inclined (L) profile, Tipam Pay-zone, 2900 m TVD	1.08-1.12	47-57	4.2-7	10-17	35-38	8-12	15-18
G#129A	Development well, Inclined (L) profile, Tipam Pay-zone, 3051 m MD	1.08-1.12	43-50	3.4-7.6	9-18	22-37	8-12	10-17
GKHL	Development well, Inclined (L) profile, Tipam Pay-zone, 3010 m TVD	1.08-1.12	45-50	4.5-6.5	12-20	23-36	7-12	14-22
GKHG	Development well, Inclined (S) profile, Tipam Pay-zone, 3150 m TVD	1.09-1.11	45-49	5.5-6.0	11-18	20-28	7-11	14-16
GKFS	Development well, Horizontal profile, Tipam Pay-zone, 3258 m TVD	1.04-1.06	54-60	8-10	7-14	26-40	10-15	27-48
GKHU	Development well, Inclined (L) profile, Tipam Pay-zone, 3569 m TVD	1.12-1.18	42-47	5.7-6.5	10-17	19-25	5-7	11-17
GKFU	Development well, Inclined (L) profile, Tipam Pay-zone, 3600 m TVD	1.08-1.09	53-58	6-8	10-12	32-42	10-13	17-20
DGDB	Development well, Inclined (L) profile, Barail Pay-zone, 3850 m TVD	1.14-1.20	50-55	4.6-5.8	14-19	24-43	9-12	15-19
RSED_H	Development well, Horizontal profile, Barail Pay-zone, 3085 m TVD	1.05-1.07	45-50	4-6	13-16	23-28	7-9	13-15
CHDC	Development well, S-profile, Tipam and Barail Pay-zone, 3500m TVD	1.06-1.15	45-52	5.5-9	10-16	18-37	8-9	12-18
LKFO_H	Development well, Horizontal profile, Tipam Pay-zone, 2477 m TVD	1.10-1.14	48-52	5-7	11-18	24-28	9-12	24-30
GKGJ	Development well, Inclined (L) profile, Barail Pay-zone, 4250 m TVD	1.08-1.18	44-65	4.6-8.6	12-18	14-39	8-18	15-51
RSDP_H	Development well, Horizontal profile, Barail Pay-zone, 3073.5 m TVD	1.04-1.06	51-57	8-8.5	13-15	29-36	10-12	16-18
Mean		1.09	51.16	6.43	13.91	29.13	9.53	18.63
Median		1.10	51	6.05	13.75	29.5	9.75	16.75
Designed Value		1.09 ± 0.05	51.1 ± 5	6.3 ± 2	13.8 ± 5	29.3 ± 10	9.6 ± 4	17.5 ± 5

(Prepared from Well-Cards collected from different operating companies of Upper Assam Basin)

If we consider the rheological properties (Funnel Viscosity, Apparent Viscosity, Plastic Viscosity, Yield Point, and Gel Strength) in Fig. 09-14, the sample- 05 is showing the maximum values and sample-01 is showing the minimum values. The compositions of sample 02-04 will not be suitable for a long span of drilling using this NDDF. The compositions of sample-05 are giving enough rheology even at the long duration of drilling. So, we will prefer the composition of sample-05 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 not giving the enough rheology after a few days of drilling.

Table-03: Properties of the NDDF with changing the 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	API Fluid Loss	Mud Cake Thickness
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

Table-04: Properties of the NDDF with changing the 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	API Fluid Loss	Mud Cake Thickness
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

If we consider the Fluid Loss property from Fig. 15, the sample-01 is giving the maximum Fluid Loss and all the other samples are giving approximately equal values. But, for sample-05, the Fluid Loss increasing rate with the increasing time is slower than the other sample 02, 03 and 04. So, we will always prefer the composition of sample-05 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.

If we consider the Mud Cake Thickness from Fig. 16, the sample-01 is giving the maximum Mud Cake Thickness and all the other samples are giving approximately equal values. Thus, the PGS alone or the mixtures of PGS + PAC-LVG or PGS + PAC-RG or PGS + PAC-LVG + PAC-RG are giving almost equal Mud Cake Thickness with the increased drilling time also.

Then, the Mean and Median of the different NDDF parameters of successfully drilled wells using NDDF in the pay-zone sections of the producing formations of UAB were calculated (Table-02) from the well-cards of the completed wells collected from different operating companies of this basin to design the optimum mud parameters for successful wells in this basin.

From the above study, it has been confirmed that mixture of (PGS + PAC-LVG + PAC- RG) is the best composition as Fluid Loss and Rheology control agent in NDDF which can be used for resisting to high temperature and biodegradation. The optimum composition of PGS in the NDDF for the oilfields of UAB is the 3% in gm /100ml basis. [1] Now to choose the optimum composition of PAC-LVG and PAC-RG, again different NDDF samples were formulated by varying the composition of PAC-LVG and PAC-RG; keeping the other components as constant mentioned as above. Then the effect of varying composition of PAC-LVG (Table-03) and PAC-RG (Table-04) on the mud properties were investigated to see their role in NDDF and to select their optimum compositions which will give suitable parameters of NDDF for the Upper Assam Basin. The suitable parameters of NDDF for the UAB have been selected from the well cards collected from different operating companies working in this basin and optimum composition of PAC-LVG and PAC-RG were selected by interpreting the parameters with the generated tables.

From the Table-02, the designed value of Funnel Viscosity, Fluid Loss, Plastic Viscosity, Yield Point, Gel $_0$, and Gel $_{10}$ respectively are 51.1 ± 5, 6.3 ± 2, 13.8 ± 5, 29.3 ± 10, 9.6 ± 4, and 17.5 ± 5 for the NDDF to successfully drill the wells using NDDF in the pay-zone sections of the producing formations of UAB.

In the Table-03, we can see that the designed ranges of the properties are starting from the composition of PAC-LVG of 0.4%. If we take the composition of PAC-LVG of about 0.4 %, then the build-up mud properties are:

Funnel Viscosity: 55 Seconds
Apparent Viscosity: 25.7 CP
Plastic Viscosity: 16.2 CP
Yield Point: 19 lb/100ft^2
Gel Strength (Gel$_0$):9 lb/100ft^2
Gel Strength (Gel$_{10}$):12 lb/100ft^2
Specific Gravity: 1.68
Fluid Loss, ml: 7.3 ml
Mud Cake Thickness, mm: 0.29 mm

All of these properties are within the designed range for the study areas.

Therefore, we can recommend the starting composition of PAC-LVG as 0.4% and may be increased slightly with the requirements during the drilling with proper investigation of the mud parameters.

In the Table-04, we can see that the designed ranges of the properties are starting from the composition of PAC-RG of 0.3%. If we take the composition of PAC-LVG of about 0.3 %, then the build-up mud properties are:

Funnel Viscosity: 53 Seconds
Apparent Viscosity: 24.25 CP
Plastic Viscosity: 14.7 CP
Yield Point: 19.1 lb/100ft^2
Gel Strength (Gel$_0$):9 lb/100ft^2
Gel Strength (Gel$_{10}$):12 lb/100ft^2
Specific Gravity: 1.068
Fluid Loss, ml: 7.3 ml
Mud Cake Thickness, mm: 0.29 mm

All of these properties are within the designed range for the study areas.

Therefore, we can recommend the starting composition of PAC-RG as 0.3% and may be increased slightly with the requirements during the drilling with proper investigation of the mud parameters.

From the above study, we can investigate that the PAC has negligible effect on Specific Gravity, pH and Salinity of mud, and has minor effect on the Mud Cake thickness, but it has great effect on the rheological properties of mud, e.g. Viscosity, Yield point and Gel Strength. All these mud parameters must be optimum for smooth successful drilling without any complications. A low value of Viscosity and Yield Point can results in low cuttings carrying capacity of mud; high values can results in high pumping pressure which may results in formation fracture, lost circulation, may demands high capacity rig, etc. A low value of Gel strength and Yield Point may results in low capacity to suspend the solids of mud at rest; high values can results in high pumping pressure.

From Table-03 and Table-04, we can explore that if the composition of PAC-LVG and PAC-RG are less than the recommended composition i.e. 0.4% and 0.3% respectively, the Yield Point will not develop to our designed range. Moreover, if their compositions are higher, then it may be detrimental for us regarding the technical standpoint as discussed above as well as economic perspective.

4. CONCLUSION

From the above study, the following conclusions are drawn:

- The Median reservoir temperature of the major oilfields of UAB is 86.5 ºC. The NDDF can be made to remain stable / favourable at and around this temperature by adding the PAC.

- The PAC makes the NDDF to be stable upto atleast 20 days without much biodegradation. The designed NDDF parameters for the UAB within this range of time can be obtained by adding the designed composition of PAC.

- PAC works excellently as the rheology and Fluid Loss control agent in NDDF which also has a moderate role in controlling the Mud Cake Thickness. So, it can be effectively used in drilling fluid where formation protection, solids suspension and improved borehole cleaning are the primary concerns. But, the drawback of PAC is that it is biodegradable. After some days of formulation it starts degrading and adversely affects the mud properties. Therefore, the drilling time using NDDF should be as low as possible or the drilling rate in the pay zone should be as high as possible. The Bactericide must be added to decrease the degradation rate.

- The mixture of (PGS + PAC-LVG + PAC- RG) is the best composition as Fluid Loss and Rheology control agent in NDDF which gives resistance towards high temperature and biodegradation.

- All the reservoirs in the world are heterogeneous. The properties and characteristics are different in different location in the reservoir. Therefore, the composition of any component or the value of any properties of NDDF to serve any function will not be fixed. In this study, from the laboratory experiments and field experience, we can recommend the starting composition of PAC-LVG and PAC-RG as 0.4% and 0.3% respectively and may be increased slightly by the requirements during the drilling with proper investigation of the mud parameters.

- The best wells are often the ones where we expose the formation to the mud system for the least amount of time, no matter what kind of fluid is being used.

ACKNOWLEDGMENT

The authors gratefully acknowledge the ED-Asset Manager, Assam Asset, ONGCL, India for conveying the permission to pursue the research work in the existing facilities of ONGC and collecting information for research purpose. The authors are thankful to the authorities of OIL, India for providing the the permission for collecting reservoir temperature data from the G & R department, OIL for research purpose.

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