American Journal of Chemical Engineering
2017; 5(3-1): 21-27
http://www.sciencepublishinggroup.com/j/ajche
doi: 10.11648/j.ajche.s.2017050301.13
ISSN: 2330-8605 (Print); ISSN: 2330-8613 (Online)

Evaluating The Effect of Temperature and Polymer Concentration on Properties of Hydroxyethyl Cellulose Gravel Pack Fluid

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To cite this article:

Anthony Okon John, Ogbonna Joel, Franklin Chukwuma. Evaluating The Effect of Temperature and Polymer Concentration on Properties of Hydroxyethyl Cellulose Gravel Pack Fluid. *American Journal of Chemical Engineering.* Special Issue: Oil Field Chemicals and Petrochemicals. Vol. 5, No. 3-1, 2017, pp. 21-27. doi: 10.11648/j.ajche.s.2017050301.13

Received: March 29, 2017; **Accepted**: March 31, 2017; **Published**: April 15, 2017

Abstract: The commercial success of petroleum wells depends greatly on the type of completion, especially the choice of gravel packing fluid system for wells with gravel pack completions. Currently several polymers are in use to viscosify gravel pack fluids. These polymers are expected to exhibit acceptable properties such as good solubility, viscosity yield, rheology, sand carrying capacity, thermal stability, break profile, low residue content and others, to match the job requirements, in order not to jeopardize the sand control process or cause hydrocarbon production impairment. Hydroxyethyl cellulose (HEC), one of the most commonly used polymers used in formulating gravel pack fluids has so many good qualities, such as very low solid residues and easy clean out. In this paper, gel break time was investigated for 40lbs/1000gal and 60lbs/1000gal HEC polymer concentrations at 140°F, 160°F and 180°F, using Sodium Persulfate as gel breaker at concentrations of 1.0lbs/1000gal, 5.0lbs/1000gal, 10.0lbs/1000gal and 20.0lbs/1000gal. The proppant carrying capacity at different temperatures was also investigated. Test results indicated that gel break is a function of temperature, breaker and polymer concentrations. At higher temperatures and higher breaker concentrations, gel break is faster, but slower for higher polymer concentration.

Keywords: Gel Breaker, Gravel Pack, Hydroxyethyl Cellulose, Proppant, Sodium Persulfate

1. Introduction

1.1. Well Completions

The reason for drilling oil and gas wells is to economically produce hydrocarbons from the reservoir, or in some cases, to inject fluids into the reservoir. Petroleum well construction involves major activities such as exploration, drilling, completions and production. Well completion is the overall process of preparing the well for a controllable and safe hydrocarbon production or fluids injection. This is achieved by providing a conductive flow path from the reservoir to the wellbore and to the surface equipment or vice versa [1].

Generally, wells completions in soft unconsolidated formations, with low compressive strength less than 1000psi, usually produce formation sand [2]. According to [3], sand production is undesirable and could lead to problems such as low production, sand bridging in casings or tubing, erosion or damage of subsurface and downhole equipment, formation or casing collapse, environmental problem associated with sand disposal and high cost of workover.

Some techniques used to manage or minimize sand production include reduced well production rate, selective completion or production from sections of the reservoir with higher compressive strength, sand consolidation with resinous material, use of resin coated gravels, use of stand-alone slotted liners or screens and gravel packing [2]. The right sand control technique is usually selected based on the adopted well completion type.

1.2. Gravel Packing

Gravel packing is the most common and often preferred sand control techniques, which involves filtration of the formation sand or fines through selected graded medium of screen or slotted liner, placed inside the casing/liner or open-hole, with the annulus packed with gravels. A prepacked screen is sometimes used [3].

Alternate-path gravel packing technique, which utilises perforated shunts placed in the annulus and attached to the screen to provide alternate paths for the slurry flow, is very efficient in eliminating sand bridging and ensuring complete packing in highly deviated or horizontal wells [4]. A viscoelastic fluid with low gravel settling rate is recommended for use when adopting the Alternate-path gravel packing method [5].

1.3. Gravel-Carrier Fluids

Gravel packing operations requires a carrier fluid to help transport sand to the required interval in the wellbore. A good gravel-carrier fluid must exhibit good gravel suspension and transport capability, good leak-off or fluid loss property, good stability, controllable viscosity reduction, good break profile and minimal formation damage [6].

Historically, many fluids have been used for gravel packing and this includes brine, diesel, crude oil, foams, viscoelastic surfactant, crosslinked and viscous linear gels [2]. Polymers that are used to yield the high viscosity for viscous fluids include random-coil and the helical polymers. The random-coil polymers, which include guar, hydroxypropyl guar (HPG) and hydroxyethyl cellulose (HEC), are susceptible to severe viscosity loss at high temperatures; while helical polymers, which include xanthan, welan gum, diutan, and scleroglucan, are thermally stable [7]. The three most common used carrier fluids for gravel packing are Hydroxyethyl cellulose, Xanthan and Viscoelastic surfactant [8], [9].

HEC is the least damaging of all polymers as it leaves behind the least amount of residues when broken [9]. Shearing and filtration processes introduced into the process of preparing HEC has helped in eliminating fish eyes and micro-fish eyes usually formed as a result of incomplete polymer hydration [10], [11]. However, HEC system has no gel strength to aid gravel transport in situations such as highly deviated wells or in long intervals [12].

Other additives commonly used in formulating gravel-carrier fluids include salts, biocides, surfactants, iron chelating agent, acids, bases, breakers and others [13]. Salts function as clay stabilizers and also are used to increase the weight of the mix water for well control purposes. Biocides are used to preserve the polymer from bacteria effects. Iron chelating agents prevents iron precipitation and crosslinking of the gel. Surfactants lower the surface tension of the fluid system and prevent formation of stable emulsion with the formation fluid. Acids and basic buffers are used to adjust the pH of the fluid system to aid polymer dissolution, hydration, stability and break.

Gel breakers are usually added at the surface to the gravel packing fluids systems to reduce the viscosity downhole and facilitate good wellbore clean up [14], [15]. The gravel carrier fluid must not break too fast, to cause premature sand out and jeopardize the process, but must allow complete packing of the entire interval and break at the right time with little or no damaging effect on the permeability of the packed zone or formation. The known available breakers include oxidizers, acids and enzymes [16], [17]. The gel breaker reaction depends on temperature, type and concentration of breakers, type and concentration of polymer and pH [18], [19].

Selection of the right additives to prepare competent fluid systems is very vital to the successful execution of the gravel packing process. In this study, some properties, such as rheology, sand suspension capacity and break time, of HEC based gravel-carrier fluid system required for optimum gravel placement at different temperatures were investigated through laboratory experiments, to serve as a guide in determining the optimum concentration of additives required for a particular well condition.

2. Materials and Methods

2.1. Fluid Formulation and Preparation

The HEC based gravel-carrier fluid system recipe used for the experiment is shown in Table 1. The amount of the additives required to mix 1000cc of the fluid system was determined. 2% by weight of water (bwow) potassium chloride (KCl) brine was used as base fluid for the experiment. 40lbs/1000gal (40ppt) and 60lbs/1000gal (60ppt) HEC polymer loadings were investigated, with varying concentration Sodium Persulfate (SP) oxidizer breaker.

Table 1. *HEC Fluid Recipe.*

S/N	Materials	Concentration (per 1000gal)
1	Fresh water	1000 gal
2	KCl	2% bwow
3	Biocide 1	0.15 lbs.
4	Biocide 2	0.15 lbs
5	Iron chelating agent	10 lbs
6	Surfactant	0.5 gal
7	HEC	a) 40 lbs b) 60 lbs
8	Sodium carbonate	Amount required to obtain pH = 8 to 9
9	SP breaker	0; 1; 5; 10; 20 lbs

The HEC gravel pack fluid was mixed using a waring blender and the additives were added according to the order listed in Table 1. The HEC polymer was slowly added and as soon as all the powder HEC has gone into solution the pH of the mixture was increased with a base to between 8 and 9. The mixture was then mixed for 30 minutes to ensure full gel hydration. The final pH, temperature and apparent viscosity of the gel were measured using pH meter, digital thermometer and viscometer model 35 equipped with F1 spring, B1 bob and R1 rotor, respectively. The viscosity was measured at 300rpm, corresponding to 511 s^{-1} shear rate.

2.2. Rheology

The rheological readings of the 40ppt and 60ppt HEC fluid systems were determined, using Fann model 35 viscometer at different temperatures of 80°F, 120°F, 140°F, 160°F and 180°F, after conditioning in a water bath, pre-set to the desired temperature.

2.3. Proppant Suspension Test

The capability of the 40ppt and 60ppt HEC fluid systems to suspend proppant was determined by mixing the hydrated gel with the required amount of mesh 20/40 resin coated proppant to form a 10ppa slurry, which was poured into a 100cc glass measuring cylinder, placed in a preheated water bath at the test temperature and the volume of clear free fluid formed at the top of the slurry bed was measured at 0, 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 25 and 30 minutes time intervals.

2.4. Break Test

Gel break test was performed for the 40ppt and 60ppt HEC fluid systems at different temperatures of 140°F, 160°F and 180°F, varying the concentration of SP Breaker at 1ppt, 5ppt, 10ppt, and 20ppt.

The required amount of breaker was measured and added to 200cc gel, while mixing. The mixture was thoroughly agitated, poured in an 8oz glass bottle, placed in a preheated water bath at the test temperature and rheological reading periodically determine as specified above. The acceptable break time is fluid apparent viscosity of ≤ 10cP at 511 s^{-1} shear rate.

3. Results and Discussion

The gel hydration test result is summarized in Table 2. It showed that the 60ppt HEC fluid has about twice the apparent viscosity of the 40ppt HEC fluid at 511s^{-1} shear rate. Increasing the polymer concentration increases the viscosity and the rheological dial readings as evident in Table 3. The rheological reading for both polymer concentrations decreases with temperature, similar to the study as explained by [7]. During the preparation of the polymer fluid, the powder HEC was added to the mix fluid while agitating to encourage the process polymer hydration. The pH was lowered to about 2 before the addition of the polymer HEC to facilitate good dispersion of the powder and minimize formation of “fish eyes” as noted by [13].

Table 2. *Gel hydration test.*

Test	40ppt HEC	60ppt HEC
pH of mix brine	5.85	5.85
pH after adding iron chelating agent	1.96	1.71
Final pH of hydrated gel	8.1	8.03
Temperature (°F)	81	81
Apparent viscosity @ 511s^{-1} (cP)	43	98

Table 3. *Rheology test.*

Gel Loading	Temp.	Dial Speed (rpm)						PV	YP	n'	K'
(ppt)	(°F)	600	300	200	100	6	3				
		Shear Rate (s^{-1})						(cP)	(lbf/100ft^2)		(lbf.s/ft^2)
		1021	511	340	170	10	5.1				
		Dial Reading									
40	80	56	42	34	23	4	3	29	13.5	0.41	0.00088
40	120	43	31	25	17	3	2	21	10	0.47	0.00065
40	140	39	27	21	15	3	2	18	9	0.53	0.00056
40	160	33	23	18	13	2	2	15	8	0.52	0.00048
40	180	28	19	16	11	2	2	12	7	0.56	0.0004
60	80	115	93	75	56	13	2	56	37.5	0.31	0.00194
60	120	90	69	52	34	7	2	53	16.5	0.38	0.00144
60	140	72	58	48	31	6	2	41	17.5	0.31	0.00121
60	160	66	50	40	28	4	2	33	17	0.4	0.00104
60	180	56	42	33	21	4	2	32	10.5	0.41	0.00088

PV – Plastic Viscosity; YP – Yield Point; n’ – Flow behavior index; K’ – Consistency index.

For the same temperature, the flow behaviour index, n’, is higher for 40ppt HEC than for 60ppt HEC. n’ increases with temperature at constant polymer concentration as shown in Table 3. The lower the value of n’, the closer the flow regime of the fluid to plug flow as explained by [20]. Therefore, 40ppt HEC will be easier to be subjected to turbulence than 60ppt HEC and the higher the temperature the easier to achieve turbulence.

More so, Consistency index, K’, which describes the pumpability of the fluid, is higher for 60ppt HEC than for 40ppt HEC at the same temperature and the values decreases with increasing temperature. Therefore, 40ppt HEC will be easier to pump and will generate lower frictional pressure and consequently will require lower treatment pressure than 60ppt HEC.

As seen in Figures 1 to 3, the apparent viscosity decreases with increasing shear rate for 40ppt and 60ppt HEC polymer fluids, showing that the fluids are shear thinning, similar to rheology result in the test conducted by [13]. HEC polymer fluid is a non-Newtonian fluid and the apparent viscosity varies with the shear rate. More so, as explained by [18] [19], at the same shear rate the apparent viscosity decreases with increasing temperature for both gel loadings. Ideally, a highly shear thinning fluid is desired, having high apparent viscosity at low shear rates, making it to have a nearly perfect sand suspension when static and low viscosity at high shear rates, thereby reducing the frictional force and overall required treatment or pumping pressure.

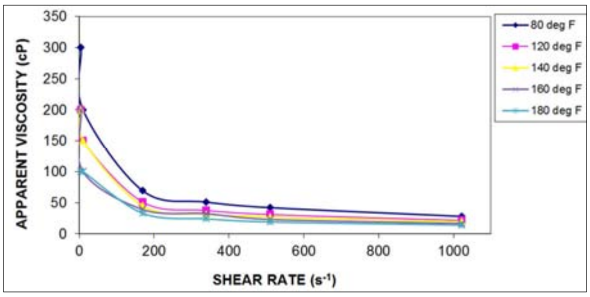

Figure 1. *Apparent viscosity vs shear rate at different temperatures for 40ppt HEC.*

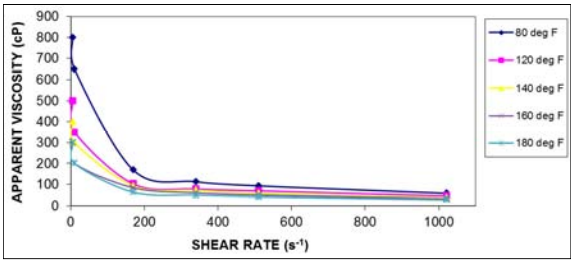

Figure 2. *Apparent viscosity vs shear rate at different temperatures for 60ppt HEC.*

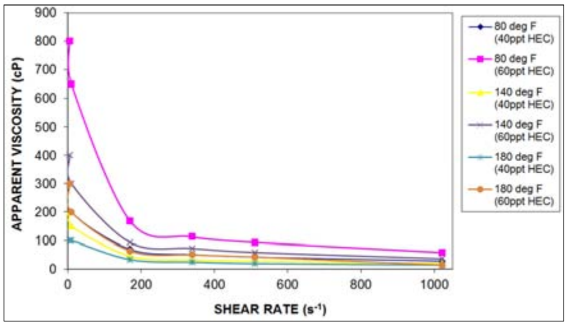

Figure 3. *Apparent viscosity vs Shear rate comparison at different temperatures for 40ppt and 60ppt HEC.*

The proppant suspension property of HEC is a function of temperature and polymer concentration as shown in Table 4. The gravel settling for 40ppt HEC begins almost immediately and intensifies with increasing temperature for both 40ppt and 60ppt HEC, confirming the notion that HEC is thermally unstable as mentioned by [7]. Increasing the concentration of the polymer from 40ppt to 60ppt improves the sand suspension property and thermal stability of the fluid system. More so, the higher values of Yield Point, YP, for 60ppt HEC as compared to 40ppt HEC suggests better particle suspension capability.

Table 4. *Proppant suspension test.*

	Gel Loading (ppt)							
	40	40	40	40	60	60	60	60
Time	**Temperature (°F)**							
(min)	80	140	160	180	80	140	160	180
	Volume of clear fluid above slurry (cc)							
0	0	0	0	0	0	0	0	0
1	10	20	23	24	3	3	5	6
2	15	24	25	25	5	9	10	12
3	20	24	26	26	6	10	15	18
4	25	25	26	26	8	14	19	22
5	26	25	26	27	9	19	21	23
8	27	25	26	27	12	20	22	23
10	27	25	26	27	15	22	22	23
15	27	25	26	27	19	23	22	23
20	27	25	27	27	23	23	22	23
25	27	25	27	27	23	23	22	23
30	27	25	27	27	24	23	23	23

Table 5. *Break Test for 40ppt HEC.*

Time (min)	**Temperature (°F)**											
	180	180	180	180	160	160	160	160	140	140	140	140
	SP Breaker Concentration (ppt)											
	20	10	5	1	20	10	5	1	20	10	5	1
	Viscosity at 511 s^{-1} (cP)											
0	43	43	43	43	43	43	43	43	43	43	43	43
10	10	18	21	24	20	22	23	26	27	28	28	29
20	7	8	10	18	10	15	17	20	22	23	26	26
30	6	6	7	13	9	10	13	15	19	19	20	21
60				10		7	10	14	13	15	19	20

Time (min)	Temperature (°F)											
	180	180	180	180	160	160	160	160	140	140	140	140
	SP Breaker Concentration (ppt)											
	20	10	5	1	20	10	5	1	20	10	5	1
	Viscosity at 511 s^{-1} (cP)											
90				7			7	12	10	12	14	17
120								10		10	13	17
150								7			12	16
180											11	15
210											10	14
240												13
300												12
330												10

The break time for 40ppt and 60ppt HEC decreases with increasing concentration of SP breaker from 1ppt to 20ppt at the same temperature as shown in Tables 5 and 6, with the 60ppt gel far slower in breaking, similar to the result obtained by [13]. Break time for the HEC fluid is also affected by temperature. Tables 5 and 6 and Figures 6 and 7 show a rapid decrease in break time as temperature is increased from 140°F to 180°F for both the 40ppt and 60ppt HEC for the same breaker concentration. The effect of temperature on break time is more pronounced at higher breaker concentrations than at lower concentrations.

The 40ppt HEC broke at about half of the time of the 60ppt HEC at the same temperature for the same concentration of breaker as seen in Figures 8 and 9. The rate of breaking is enhanced by temperature, confirming the results of the study by [18], [19].

Table 6. *Break Test for 60ppt HEC.*

Time (min)	Temperature (°F)											
	180	**180**	**180**	**180**	**160**	**160**	**160**	**160**	**140**	**140**	**140**	**140**
	SP Breaker Concentration (ppt)											
	20	**10**	**5**	**1**	**20**	**10**	**5**	**1**	**20**	**10**	**5**	**1**
	Viscosity at 511 s^{-1} (cP)											
0	98	98	98	98	98	98	98	98	98	98	98	98
10	23	24	29	62	68	70	71	71	72	73	74	92
20	8	10	18	46	28	44	58	65	65	67	72	90
30	6	7	9	37	16	28	44	55	57	62	70	88
60	4	4	6	25	9	15	34	51	50	58	63	77
90				21		10	25	44	42	54	59	67
120				19			18	38	31	47	55	65
150				18			14	35	25	40	51	63
180				18			12	33	20	36	47	58
210				17			10	28	15	33	43	51
240				17				27	13	30	38	49
300				16				26	11	26	34	48
330				16				22	10	22	30	47
360				15				21	8	19	28	46
390				15				20	8	16	26	45
420				14				19	7	12	24	44
450				14				18		10	23	42
480				13				17			22	40
510				13				16			21	39
540				12				16			19	38
570				12				16			17	36
600				11				16			15	34
630				11				16			13	32
660				11				15			12	30
690				10				15			11	28
720								14			10	26
1080								14				21
1440								14				17
1800												13
2160												10

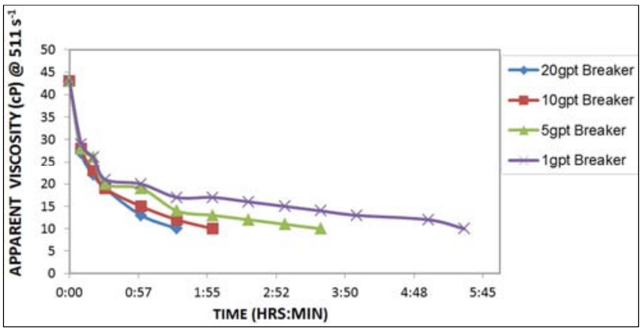

Figure 4. *Effect of breaker concentration on break time for 40ppt HEC at 140°F.*

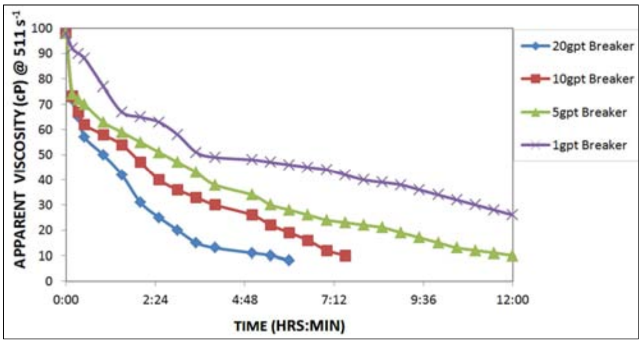

Figure 5. *Effect of breaker concentration on break time for 60ppt HEC at 140°F.*

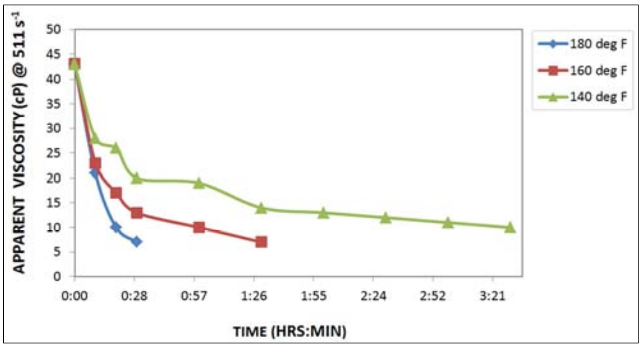

Figure 6. *Effect of Temperature on break time for 40ppt HEC with 5ppt SP breaker.*

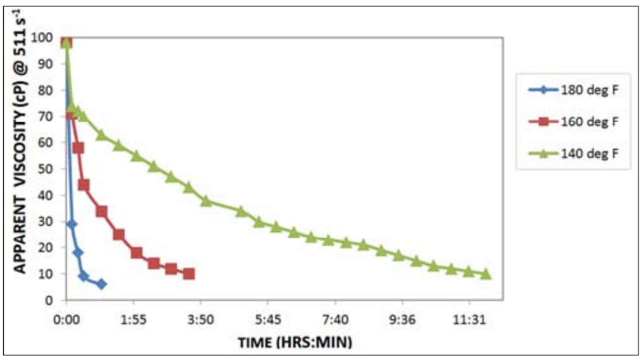

Figure 7. *Effect of Temperature on break time for 60ppt HEC with 5ppt SP breaker.*

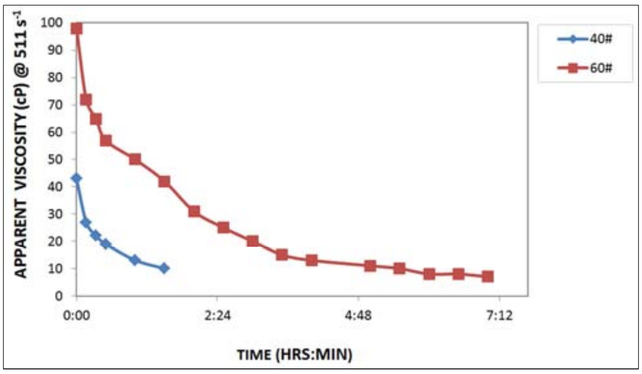

Figure 8. *Effects of gel loading on break time with 20ppt SP breaker at 140°F.*

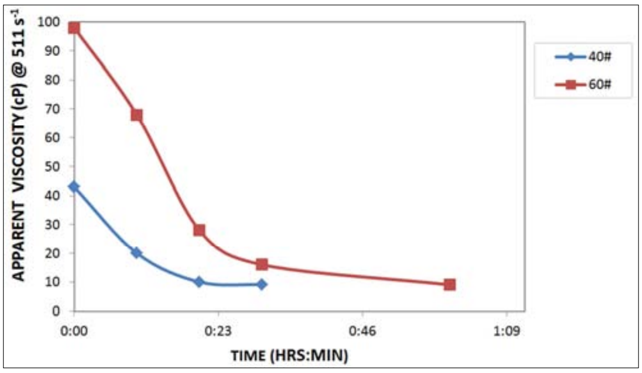

Figure 9. *Effects of gel loading on break time with 20ppt SP breaker at 160°F.*

4. Conclusion

HEC has a shear thinning property, which is very important for sand suspension and transport as the fluids moves into region of low shear rates in the wellbore. However, HEC is thermally unstable. Increase in polymer concentration improves the thermal stability.

Gravel settling begins immediately in HEC fluids; the gravel suspension improves with increase in polymer concentration but becomes poorer as temperature increases.

The HEC polymer fluid tends to break faster with increase in temperature and increase in concentration of breaker. The break time of HEC polymer increases with increase in polymer concentration. The effect of temperature on the rate of HEC polymer degradation is more pronounced at higher breaker concentrations.

n' and K' are very important parameters used in predicting the flow behaviour of fluids in tubing or pipeline and therefore used for engineering simulation and fluid properties optimization.

The fluid mixing and laboratory quality assurance processes are very important in formulating and optimizing the fluid design in order to deplore competent gravel pack fluid system. The success of the fluid engineering design, field job execution and the commercial performance of the well greatly depends on the fluid formulation and effectiveness of the quality assurance processes.

Acknowledgements

The authors which to thank the World Bank and the staff and management of World Bank Africa Centre of Excellence in Oilfield Chemical Research for all the support during this project.

Nomenclature

Bwow	by weight of water
cc	cubic centimeter
cP	centipoise
K'	Consistency Index
n'	Flow behaviour index
ppa	pounds of proppant additive per thousand gallons
ppt	pounds per thousand gallons
PV	Plastic Viscosity
rpm	revolution per minute
YP	Yield Point

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