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Maintaining Consistent Rheology of Fluids Containing an Exceedingly High Volume of Low Gravity Drilled Solids for Oil and Gas Drilling

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Abstract

Low gravity drill solids (LGS) build-up from recycling of invert emulsion drilling fluids is a troublesome issue for oil operators as conventional solids control equipment have difficulty removing small size cuttings. At high LGS volumes (>10 %), the fluids exhibit elevated rheology and become untreatable due to increased colloidal content. Dilution of drilling fluid is a typical option but will increase fluid inventories and require additional tank space. A novel wetting additive was developed to treat these challenges at the rig site and mud plants, mitigating the rheology dilemma while preserving emulsion stability.

Invert emulsion drilling fluids were formulated to 12 ppg with 80/20 oil-water ratio using standard additives for land drilling of oil and gas wells. The formulated drilling fluids were loaded to 20% v/v – of simulated drill solids for this study. To replicate the drilling aging process, the muds were periodically hot rolled at 250°F and sheared on laboratory mixers. The muds were treated with typical industry available wetting agents and the performance was compared to the novel wetting additive. Drilling fluid properties of rheology (150°F), electrical stability (150°F) and fluid loss (250°F, 500 psi) were initially evaluated, before treatment and after treatment stages.

The drilling fluid samples treated with standard industry additives exhibited elevated rheology after treatment, though both the fluid loss and emulsion stability were within specifications. However, the fluids treated with the novel wetting additive significantly reduced and maintained a consistent rheology with improved emulsion stability and reduced fluid loss.

Introduction

It is difficult to discern a positive light from the COVID-19 pandemic, which has aggressively challenged every aspect of the global oil and gas industry (Spears & Associates, Inc. 2021). The margin-squeezing pressures caused by the pandemic has forced the industry to focus on efficiency and effectiveness. Though the headlines concentrate on the doom and gloom during these unprecedented times, drilling has made some unprecedented strides in both rate of penetration and total feet drilled with the continued adoption of horizontal directional drilling (HDD) and equipment improvements (Rystad Energy 2021). These record-breaking achievements place extraordinarily high performance demands on oil-based drilling fluids. An inherent advantage of using the non-aqueous type drilling fluids is their endurance to challenging conditions and reusability. However, these muds can also come with environmental hazards that make disposal cost soar (Lal 1988). To aid in sustainability and cost effectiveness, oil-based muds are recycled from rig to rig, reconditioned as needed and sent to the next site. Increasingly more often, recycled muds are returned to service companies laden with drill solids that have been ground by equipment down to colloidal sizes, making removal near impossible and significantly diminishing the performance benefits that allow for the record rates and depths.

Drilled solids contamination by low gravity drilled solids is usually observed first in the rheological parameters. According to Sauki, the commonly used Bingham plastic model of rheology provides a high positive correlation between the plastic viscosity and yield point to the low gravity solids concentration (2020). Plastic viscosity of a drilling mud is often used to describe the physical resistance in the mud while yield point is associated with the chemical resistance caused by interparticle forces; a high YP/PV ratio suggests coagulation and flocculation of the drilled solids in the mud (Chilingarian, et al. 1983). Drilled solids also disrupt the mud stability, consuming the emulsifiers away from the oil-water emulsion, thus lowering the electrical stability and significantly increasing the fluid loss. An emulsion breakdown will ultimately lead to costly issues such as formation damage, surge and swab pressure build up, and stuck pipe (Robinson 2006).

There are four methods to control solids: mechanical treatment, dilution, chemical treatment or disposal (Eritia 2018). Mechanical treatment is the first line of defense operators have to combat drill solids accumulation but are usually limited to particles four microns and higher (Eritia 2018). Those small particles inevitably make their way back through the cycle, ground into finer and finer particle sizes, and ultimately poison the beneficial performance properties (Robinson 2006). Combined with recycling practices, accelerated drilling rates and elongated depths reached in modern drilling, drilled solids accumulation and treatment has become a significant challenge for oil-based muds to overcome. For example, if dilution is chosen to treat solids accumulation, the volume of mud would need to be doubled in order to reduce the solids concentration in half (ASME Shale Shaker Commitee

2005, 22-24; 335). Operators and service companies are then left with a difficult choice. Discard half of the original mud to make room for dilution or increase the total mud volume and store it onsite. Both options have significant costs, environmental hazards and logistical issues associated with them (Lal 1988).

Chemical treatment with surfactants to oil wet the solids into the oil is another option to control solids. Many wetting agents currently available perform initially, but as the mud is recycled and treated with these wetting agents their concentration in the mud increases. Upon reaching a threshold, the standard chemical treatments will have a reverse effect and ultimately thicken the mud more than if they were never used. Since the surfactants are affecting the charges on the surface of the LGS particles, this phenomenon is most easily seen in the yield point increase throughout the mud's lifecycle. Once this threshold is reached, the only option is disposal.

Ingevity developed a novel wetting agent (NWA) to treat the high YP of the OBM at very high concentration of fine drilled solids without the risk of overtreatment in OBM lifecycles as seen in ***Figure 1***. This NWA addresses the challenges operators and service companies face due to market pressures and extreme drilling conditions.

The NWA can successfully deliver:

- Significant decrease in overall mud rheology when highly contaminated with low gravity solids
- Improved emulsion stability
- Low to no overtreatment risk
- Versatility in both diesel and mineral oil-based drilling fluids
- Ability to be used as a reactive or continuous treatment
- Superior wetting agent performance to industry standard chemical treatments
- Prolonged drilling fluid functional life

Materials & Methods

Development of Novel Wetting Agent

Supported by a statistical software tool, the NWA was developed through an extensive design of experiments (DOE) process with key performance indicators (KPI). Using yield point as the main KPI, the DOE also optimized for plastic viscosity, electrical stability, and high-pressure high-temperature (HPHT) fluid loss while supervising the effects on gel strengths and 600 rpm viscometer readings. The performance indicators of the novel wetting agent were compared to industry standard wetting agents. The NWA was optimized as a robust additive that performs in a variety of nonaqueous mud systems.

Evaluated Nonaqueous Fluid Systems

A diesel-based system was designed that would mimic a typical US land-based drilling fluid system to develop the novel wetting agent. The diesel-based, three-stage mud system can be seen in detail in **Table *1*** and contains the following additives:

- Base oil
- Alkalinity control agent
- Organophilic clay
- Commercially available primary and secondary emulsifiers
- Calcium Chloride ($CaCl_2$) for water phase salinity
- FLA
- Weighting agent for density adjustments
- API Standard Base Evaluation Clay as the LGS contamination
- NWA to treat the LGS contamination effects
- IND Industry standard wetting agent

Additionally, the NWA was also tested in a field based mineral oil fluid formulation (**Table *2***) using slightly different additives to validate the findings in the diesel system and ensure the additive could be used in a variety of base oils.

Performance Testing Procedure

Replicating the rheological challenges faced by drilling fluid companies in the laboratory was achieved by developing a staged mixing, contamination, and treatment procedure separated by dynamic aging as shown in a simplified version in ***Figure 2***. Both the diesel-based and mineral oil-based systems followed the same basic procedures and can be viewed alongside the mud system components in **Table *1*** and **Table *2***, respectively. This three-stage progression through the procedure is intended to mimic the lifecycle of a drilling mud while on the rig site and will hence be referred to as the *Lifecycle Procedure*.

Reactive Treatment Lifecycle Procedure

The total *Lifecycle Procedure* process is typically spread across four days and generally follows the procedures outlined in the Recommended Practice for Laboratory Testing of Drilling Fluids API 13I (2009) and the Recommended Practice for Field Testing of Oil-based Drilling Fluids API 13B-2 (2005). On the first day in the *Initial Stage (I stage)* in ***Figure 2***, four lab barrels of a 12 ppg, diesel-based mud were prepared in a two-liter, conical, stainless steel container on a Silverson L5M-A mixer at 6,000 rpm. Industry standard primary and secondary emulsifiers at low dosages were paired with an alkalinity control agent, organoclay, 25% $CaCl_2$ brine, fluid loss additive, weighting agent, and 3% v/v low LGS contamination simulated by API Standard Base Evaluation Clay. The initial L LGS were added in the *I stage* to simulate the lightly used or fresh seeded mud. After mixing for 40 minutes, the mud was transferred to four pressurized rolling cells and dynamically aged in an OFITE 5-roller oven for 16 hours. On the second day, the muds were allowed to cool and remixed for five minutes on a Hamilton Beach mixer. *I stage* rheology was measured on an OFITE 900 viscometer at 150°F, followed by electrical stability (ES) on a FANN model 23E ES meter. HTHP fluid loss was collected on an OFITE 500 mL HPHT apparatus with a 500 psi pressure differential. The remaining three muds were not tested and instead continued directly to the *Contamination Stage (C stage)*.

To simulate a worst-case scenario, where LGS content exceeds any reasonable amount, an additional 17% v/v LGS were introduced to the post aging *I stage* muds in the *C stage*, bringing the total LGS content to 20% v/v. The residual LGS contamination was mixed with the three *I stage* muds on the Hamilton Beach mixer on high for 15 minutes and transferred to the pressurized aging cell for another dynamic aging event. All three muds were dynamically aged for 16 hours and allowed to cool on the third day of testing. One of the muds was tested for rheology, emulsion stability (ES) and HPHT fluid loss as described in *I stage*, while the other two continued to the *Treatment Stage (T)*.

Finally, the two remaining contaminated muds were treated with the material to be evaluated (either blank – or no treatment, typical IND wetting agents, or the novel wetting agent) on the Hamilton Beach mixer at medium speed for five minutes in the *T stage*. Further, these two muds were mixed for an hour on the Hamilton Beach mixer at high speed to achieve still finer particle sizes. As in the *I* and *C stages*, the two muds were dynamically aged and tested for rheology, ES and HPHT fluid loss.

As the NWA is introduced in the *T stage* in this procedure, after the LGS contamination had caused an unacceptable increase in rheology, we referred to it as a *Reactive* Treatment Procedure. A *Continuous* treatment procedure is also presented where a portion of the NWA is added in the *I stage* and another portion in the *T stage*.

Results and Discussions

Diesel-Based System Results

The following targets were selected as ***T stage*** goals for the KPIs of the NWA in the diesel-based mud system:

- YP between 10.0 – 25.0 lb/100ft^2
- PV ≤ 35 cP or as low as possible
- ES > 400 V
- HPHT fluid loss > 10 mL with no water in filtrate

Blank, IND, and NWA Reactive Treatment Comparison

The detailed mud performance results can be viewed in **Table *3*** in the appendix. The KPI datapoints can be viewed graphically in **Figure *3* – Figure *5***. **Figure *3*** shows the PV and YP reactive treatment comparison of the blank, IND and NWA over the lifecycle procedure. **Figure *4*** and **Figure *5*** compare the blank, IND and NWA reactive treatments ES and HPHT fluid loss results, respectively.

The muds began the lifecycle procedure with acceptable KPI values for PV (17.5 cP), YP (9.8 lb/100ft^2), ES (602 V) and HPHT fluid loss (2.7 mL with no water in filtrate) in the *I stage*. Once the LGS content reached 20% in the *C stage*, all parameters suffered with YP notably at 70 lb/100ft^2, a value so high the mud would be considered difficult to manage and require to be reconditioned. HPHT fluid loss was 25.5 mL of filtrate, including trace water in the filtrate. The blank experiment that was carried through the lifecycle procedure without any additional treatments, did not meet the targeted *T stage* KPIs and especially suffered in electrical stability and HPHT fluid loss.

In the IND treatment *T stage* results with 7 ppb of the IND wetting agents, the emulsion stability significantly improved over the blank as shown by the +880 V increase in ES. Also, the fluid showed an -84% decrease in HPHT fluid loss. However, the rheological parameters, PV and YP were 77.1 cP and 117.1 lb/100ft^2, respectively. This effect was confirmed in our interactions with drilling fluid specialists who observed a similar behavior from the IND chemical treatments in the field.

Comparatively, the reactive treatment with 5 ppb NWA showed considerable overall improvement over both the blank and IND treatment in the *T stage* results. The YP was brought back into control to 23.6 lb/100ft^2, a -80% decrease from IND treatment. Likewise, the PV improved -56% versus the IND treatment to 33.9 cP. ES was also improved up to 461 V, +34% higher than the blank. HPHT fluid loss decreased -83% versus the blank, down to 5.1 mL.

Reactive and Continuous NWA Treatment Comparison

The detailed performance data comparison of the reactive and continuous NWA treatment data can be viewed in **Table *4*** in the appendix and KPI datapoints pertinent to the discussion can be viewed in **Figure *6* – Figure *8***. **Figure *6*** displays the reactive and continuous treatment YP and PV throughout the lifecycle of the mud. **Figure *7*** compares the reactive and continuous ES over the lifecycle while **Figure *8*** evaluates the reactive and continuous HPHT fluid loss over the lifecycle procedure.

In the *I stage*, the continuous treatment of the NWA increased the rheology as compared to the reactive treatment, though not above the targets listed above. The continuous NWA treatment experiment gave a smaller PV increase (+9%) and larger YP increase (+30%) as compared to the reactive treatment. ES was improved by approximately +50% in the continuous treatments compared to the reactive treatment results. HPHT fluid loss did not follow the electrical stability trend and worsened slightly up to 7.6 mL for the continuous treatment.

In the *C stage*, rheology was better maintained in the continuous treatments. An approximately -35% PV reduction and -60% YP reduction was observed in the continuous treatment compared to the reactive treatment. This suggests the NWA has a protection effect on rheology when dosed to the *I stage*. The same protection effect was perceived in the ES for the continuous experiment, yielding 466 V. HPHT fluid loss differences between the two experiments were unremarkable, and no HPHT fluid loss benefit was observed in the *C stage* by dosing the NWA in the *I stage*.

In the *T stage*, rheology parameters for the continuous NWA treatment was not as significant as the reactive treatment. The PVs and YPs did not go as high as the blank or IND treatment experiments as seen in **Figure *3***, but did not surpass the reactive NWA treatment PV and YP drop. The continuous NWA treatment ended the lifecycle just above the targets identified for PV and YP. Conversely, ES improved in the continuous treatment, giving +279 V over the reactive NWA treatment. The continuous treatment gave HPHT fluid loss relatively lower than the reactive treatment.

Mineral oil-Based System Results

Yield point was the only target for the mineral oil-based system as dictated by the field requirements. The NWA had to meet a strict YP criteria in the *T stage* to be technically approved for the customer.

- YP brought back to between 8.0 – 12.0 lb/100ft^2

Blank and NWA Reactive Treatment Comparison

The detailed mud performance results can be viewed in **Table *5*** in the appendix and KPI datapoints pertinent to the discussion can be viewed graphically in **Figure *9*** which shows the PV and YP reactive treatment comparison of the blank and NWA over the lifecycle procedure in the mineral oil-based system.

The mineral oil system was notably more solids tolerant than the diesel system and provided lower overall rheology parameters than the diesel system. In the *I stage* with 3% LGS contamination, YP began around 8.2 lb/100ft^2 near the low end of the targeted range. Once the LGS contamination was increased to 20%, *C stage* YP increased +73% to 14.2 lb/100 ft^2, over the targeted maximum YP goal. Following into *T stage*, the blank experiment YP was maintained at the *C stage* YP level. Comparatively, a 2 ppb NWA reactive treatment brought the YP down -27% versus the blank to 10.4 lb/100ft^2.

Conclusions

1. The NWA provided superior solids wetting performance to consistently control YP within the KPI targets for both the diesel and mineral based fluid systems of this study.
2. In the diesel fluid systems, both the reactive and the continuous treatment procedures substantially lower the YP in the *T stage* to within or near the KPI targets.
3. The NWA significantly improves emulsion stability and filtrate loss – as described by ES and HPHT fluid loss results – within the target KPI specifications for the diesel fluid system

Results collected from this research support the NWA as a superior chemical treatment alternative to industry standards that will prolong functional life in non-aqueous drilling fluids. While solids equipment should always be used to remove as much of the drilled solids as possible up front, the NWA will assist operators and service companies in chemically treating the LGS that will inevitably escape and accumulate in the system. By avoiding large dilutions and delaying disposal, the NWA is offered as a new tool to aid in the cost-effectiveness and sustainability of a drilling rig.

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Nomenclature

10m Gel = *10 Minute Gel Strength*
10s Gel = *10 Second Gel Strength*
API = *American Petroleum Institute*
cP = *Centipoise*
C stage = *Contamination Stage*
°F = *Degree Fahrenheit*
DOE = *Design of Experiments*
ES = *Electrical Stability in V*
FLA = *Fluid Loss Additive*
ft = *Foot*
g = *Grams*
HDD = *Horizontal Directional Drilling*
HPHT = *High Pressure, High Temperature*
h = *Hour*
I stage = *Initial Stage*
IND = *Industry Standard*
KPI = *Key Performance Indicator*
LGS = *Low Gravity Solids*
mL = *Milliliter*
min = *Minute*
NWA = *Novel Wetting Agent*
OWR = *Oil to Water Ratio*
% = *Percent*
PV = *Plastic Viscosity in Bingham Plastic Model in cP*
ppb = *Pound per Barrel*
ppg = *Pound per Gallon*
psi = *Pound per Square Inch*
rpm = *Revolutions per Minute*
SG = *Specific Gravity*
SS = *Shear Stress (Dial Reading)*
T stage = *Treatment Stage*
US = *United States of America*
V = *Volts*
v/v = *Volume to Volume ratio percentage*
WA = *Wetting Agent*
YP = *Yield Point in Bingham Plastic Model in* $lb/100ft^2$

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Tables

Table 1: Diesel-Based System with Reactive and Continuous Treatment Procedures

Stage	**Mud Additive**	**SG**	**Lab Barrel Mass** (g)		**Mixing** (min)
			REACTIVE	**CONTINUOUS**	
I stage (Silverson L5M-A, 6,000 RPM)	Diesel	0.84	190.7	190.7	5
	Alkalinity Agent	2.24	5.0	5.0	
	Organophilic Clay-1	1.60	6.5	6.5	5
	PE-1	1.00	2.0	2.0	5
	SE-1	0.94	2.0	2.0	
	NWA	1.00	-	3.0	
	25% $CaCl_2$ Brine	1.24	68.0	68.0	10
	Gilsonite FLA	1.20	3.5	3.5	5
	Weighting Agent	4.20	228.5	228.5	5
	LGS Contamination (+3% v/v)	2.35	24.8	24.8	5
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Initial Properties***				
C stage (Hamilton Beach, high)	LGS Contamination (+17% v/v)	2.35	140.3	140.3	15
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Contamination Properties***				
T stage (Hamilton Beach, medium)	IND	0.91	0.0, 7.0	-	5
	NWA	1.00	0.0, 5.0	2.0	
	Mix on Hamilton Beach on High				60
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Treatment Properties***				

Mud Weight:	12.0 ppg → 13.1 ppg	**O/W Ratio:**	80/20
Aging Temperature/Pressure:	250°F/150 psi	**Rheology Temperature:**	150°F
HPHT Fluid Loss Temperature/Pressure:	250°F/500 psi differential	**ES Temperature:**	150°F

Table 2: Mineral Oil-Based System with Reactive Treatment Procedures

Stage	**Mud Additive**	**SG**	**Lab Barrel Mass** (g)	**Mixing** (min)
			REACTIVE	
I stage (Silverson L5M-A, 6,000 RPM)	Mineral Oil	0.79	163.8	5
	Alkalinity Agent	2.24	7.5	
	Organophilic Clay-2	1.70	6.0	5
	PE-2	0.98	2.0	5
	SE-2	0.96	8.0	
	WA	0.86	1.0	
	25% $CaCl_2$ Brine	1.24	103.0	10
	Asphaltic FLA	1.20	4.0	5
	Weighting Agent	4.20	230.0	5
	LGS Contamination (+3% v/v)	2.35	26.2	5
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Initial Properties***			
C stage (Hamilton Beach, high)	LGS Contamination (+17% v/v)	2.35	148.6	15
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Contamination Properties***			
T stage (Hamilton Beach, medium)	NWA	1.00	0.0-2.0	5
	Mix on Hamilton Beach on High			60
	HOT ROLL *(16 hr)*, ***REMIX*** *(5 min, Hamilton Beach - high)*, ***TEST Treatment Properties***			

Mud Weight:	11.8 ppg → 13.1 ppg	**O/W Ratio:**	73/27
Aging Temperature/Pressure:	250°F/150 psi	**Rheology Temperature:**	150°F
HPHT Fluid Loss Temperature/Pressure:	250°F/500 psi differential	**ES Temperature:**	150°F

Figures

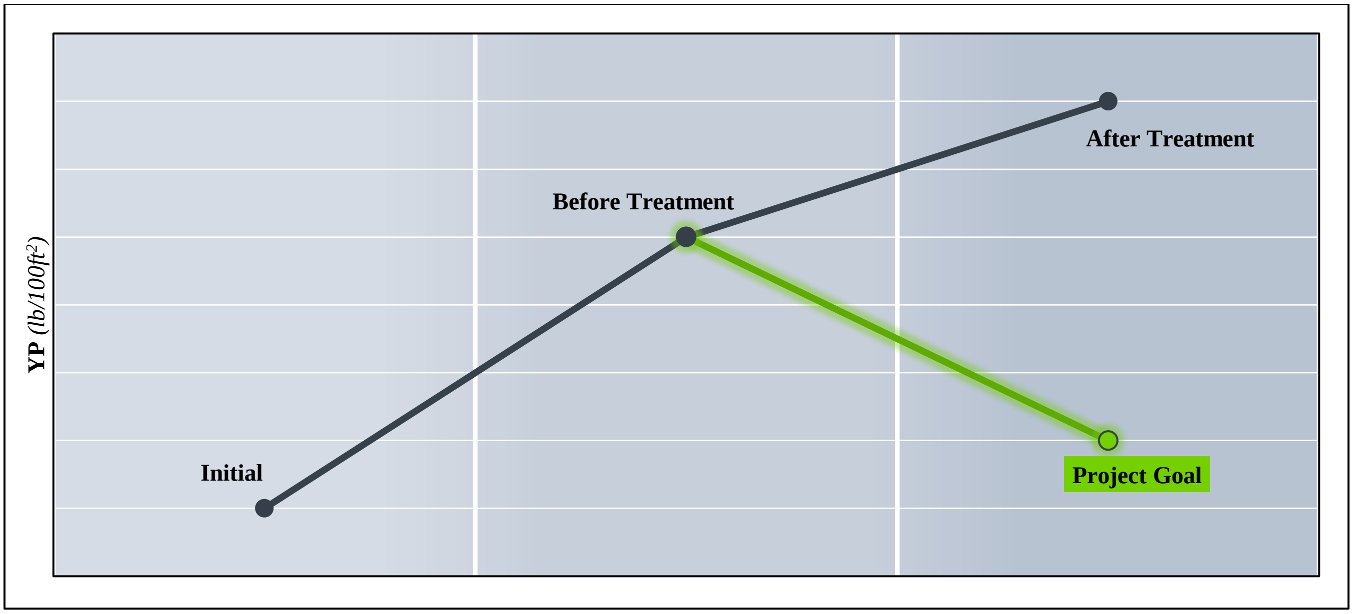

Figure 1: Yield Point Lifecycle of Mud

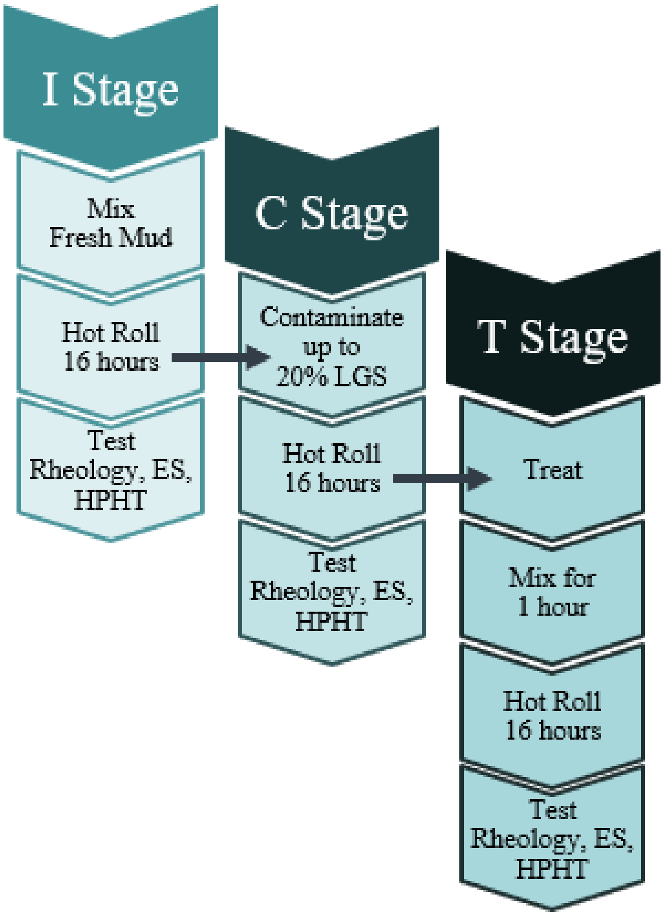

Figure 2: Simplified Lifecycle Testing Procedure

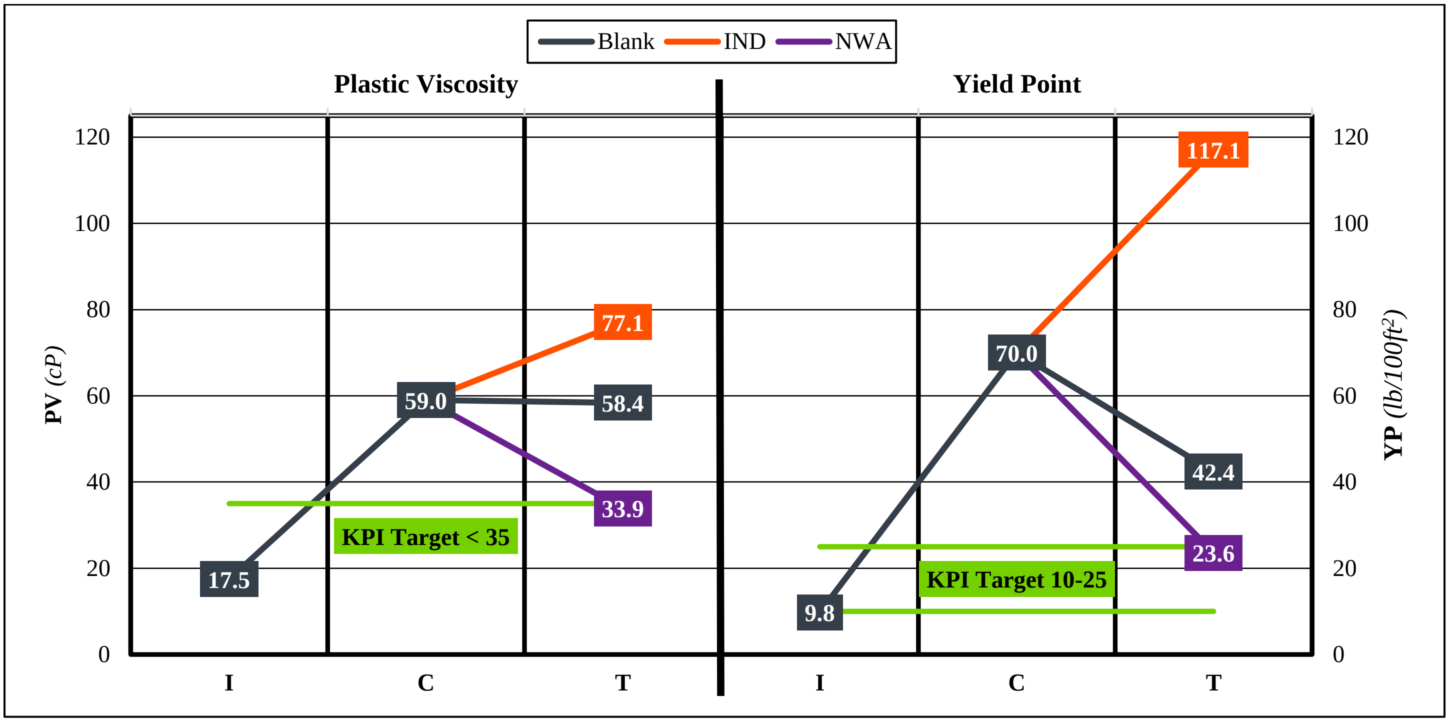

Figure 3: PV/YP Lifecycle Comparison of Blank (No Treatment), IND (7 ppb in *T stage*), and NWA (5 ppb in *T stage*) Reactive Treatment in Diesel-Based System

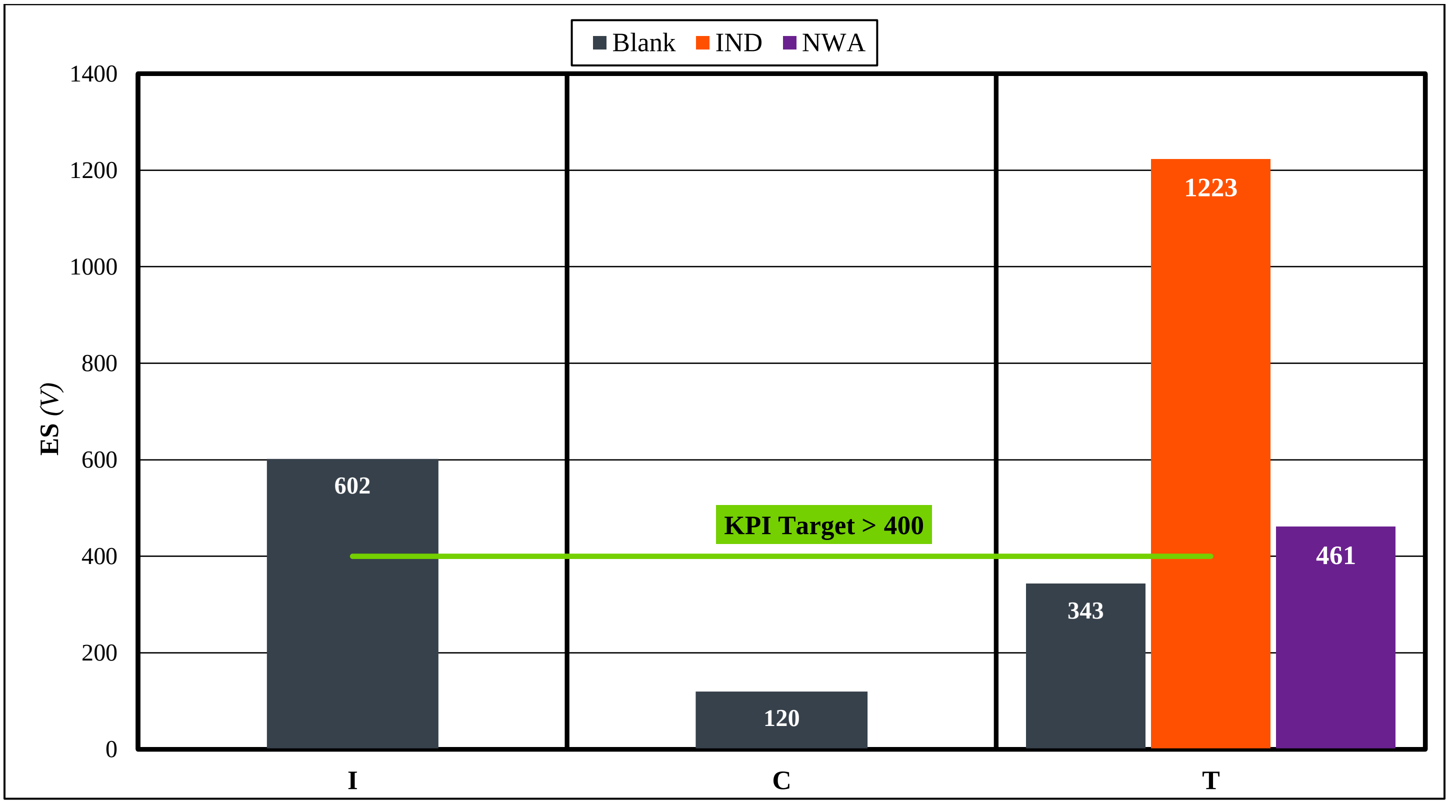

Figure 4: ES Lifecycle Comparison of Blank (No Treatment), IND (7 ppb in *T stage*), and NWA (5 ppb in *T stage*) Reactive Treatment in Diesel-Based System

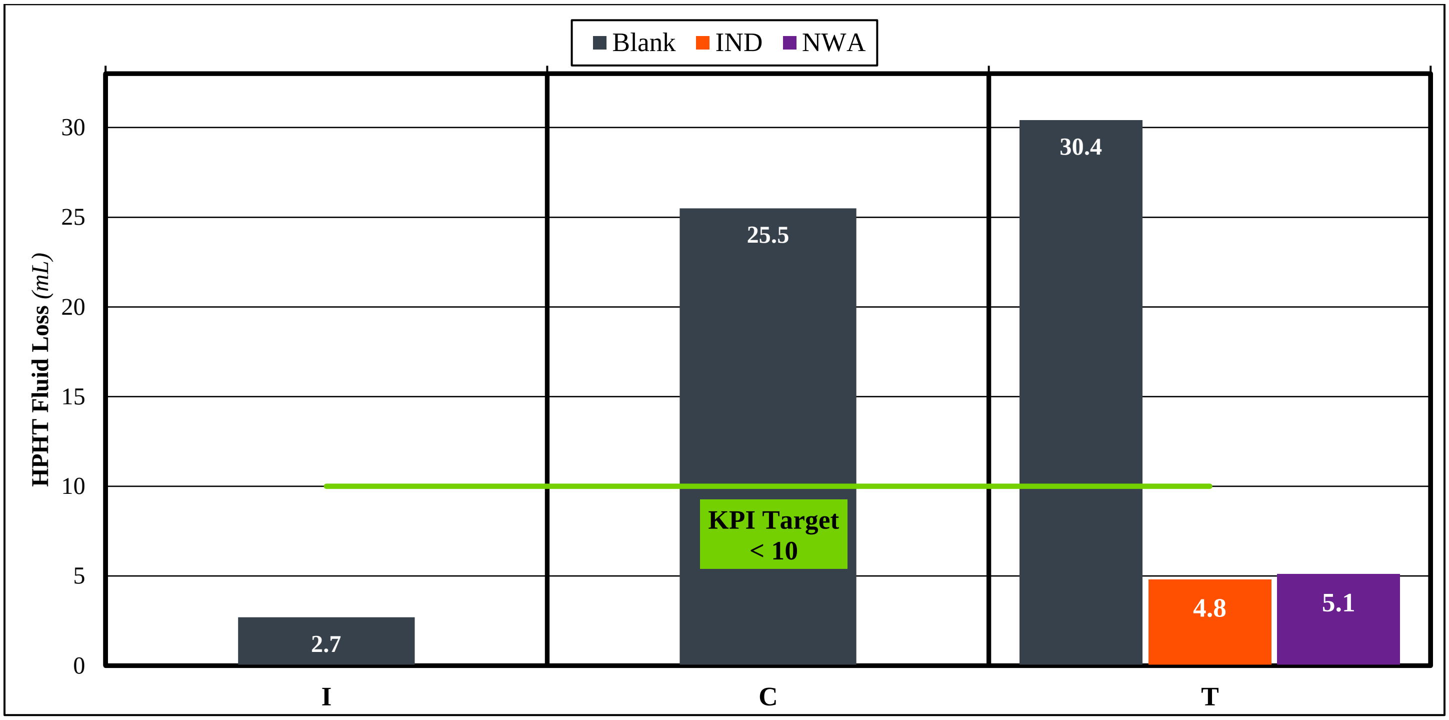

Figure 5: HPHT Fluid Loss Lifecycle Comparison of Blank (No Treatment), IND (7 ppb in *T stage*), and NWA (5 ppb in *T stage*) Reactive Treatment in Diesel-Based System

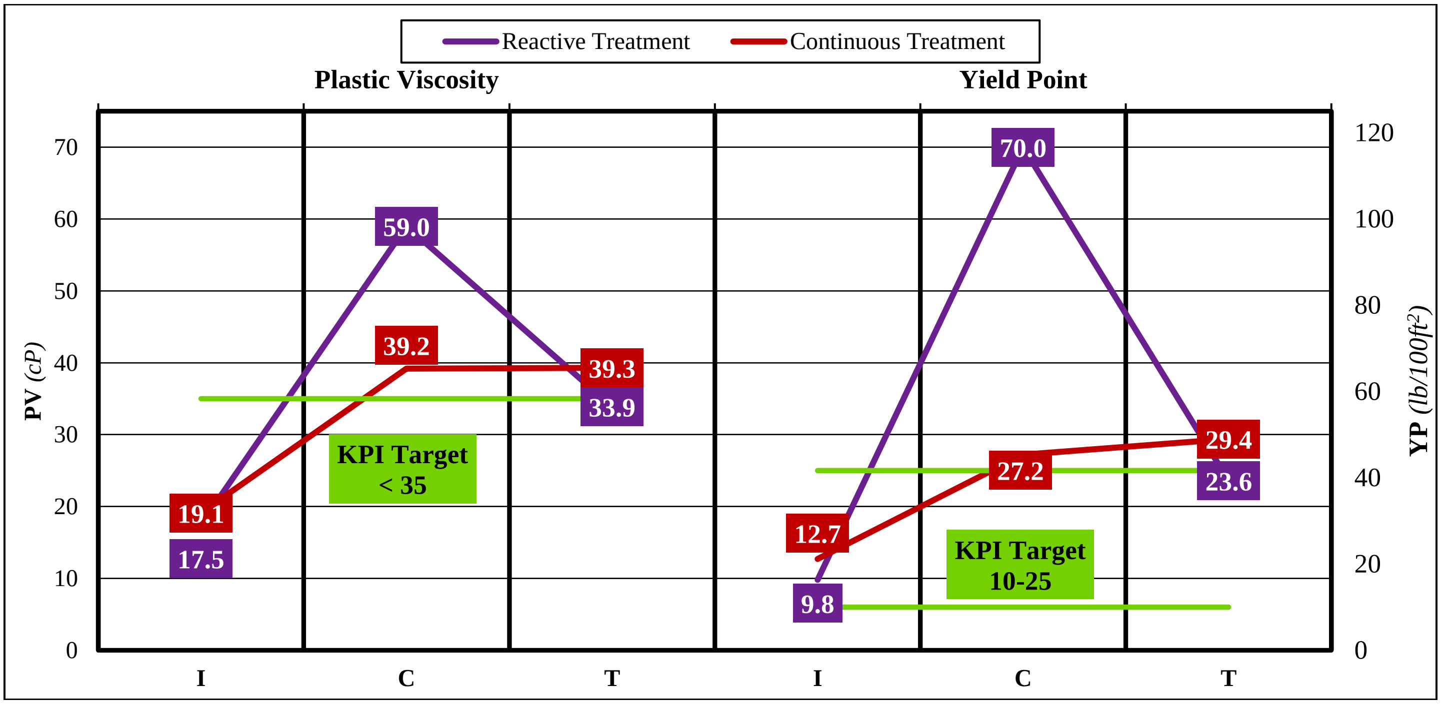

Figure 6: PV & YP Lifecycle Comparison of NWA Reactive Treatment (5 ppb in *T stage*) and Continuous Treatment (2 ppb in I, 3 ppb in T) in Diesel-Based System

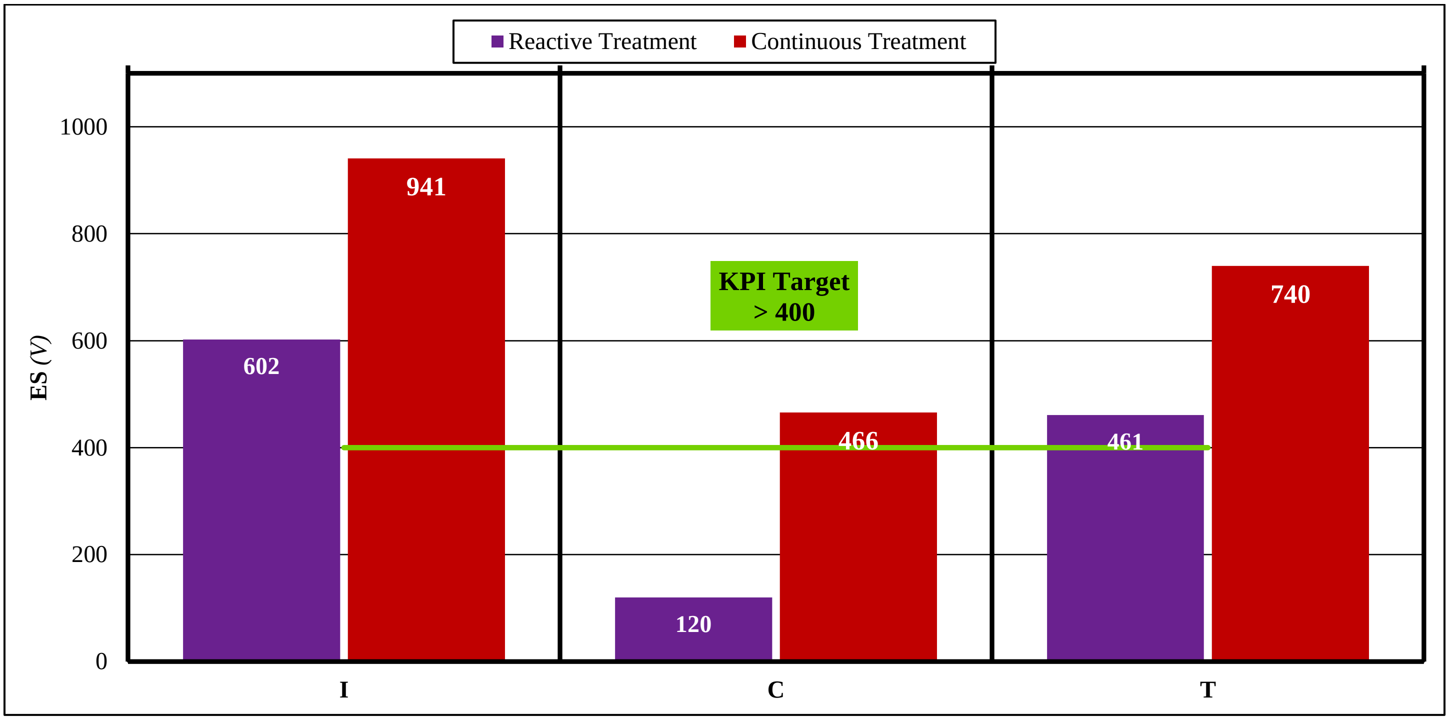

Figure 7: ES Lifecycle Comparison of NWA Reactive Treatment (5 ppb in *T stage*) and Continuous Treatment (2 ppb in *I stage*, 3 ppb in *T stage*) in Diesel-Based System

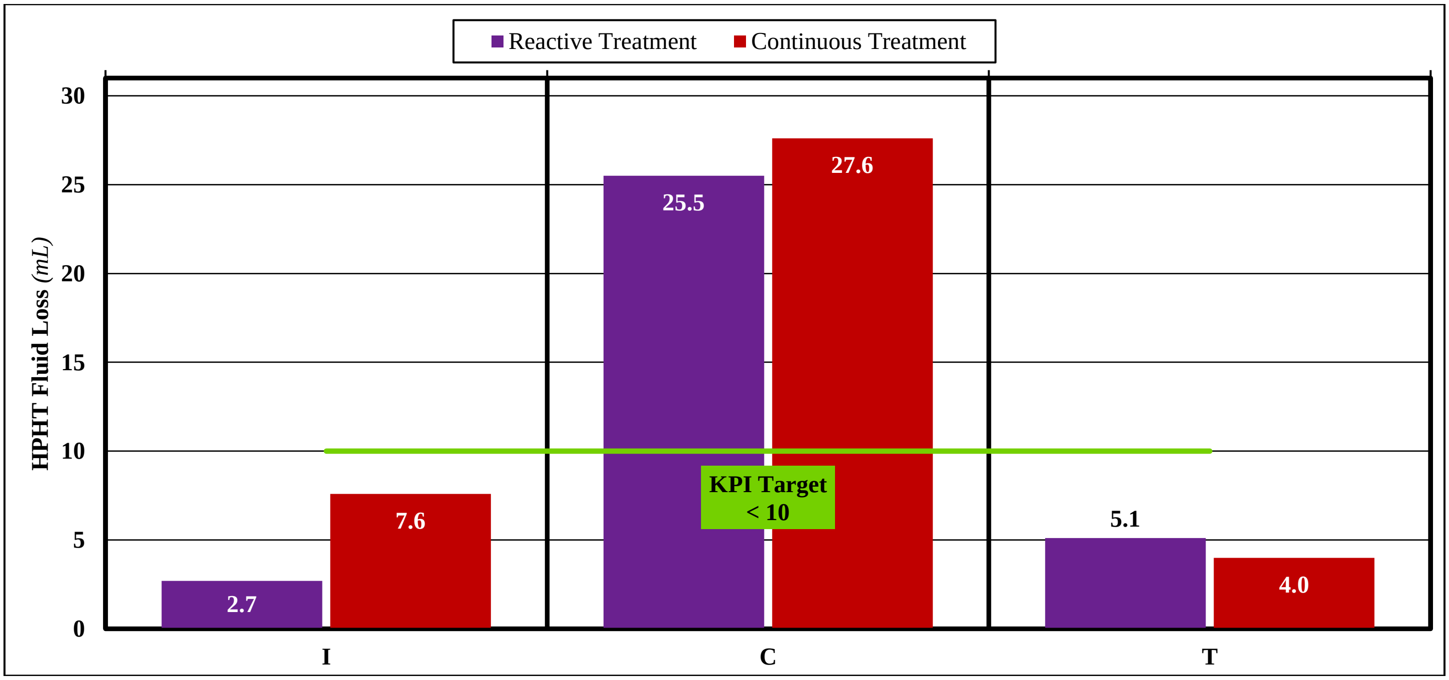

Figure 8: HPHT Fluid Loss Lifecycle Comparison of NWA Reactive Treatment (5 ppb in *T stage*) and Continuous Treatment (2 ppb in *I stage*, 3 ppb in *T stage*) in Diesel-Based System

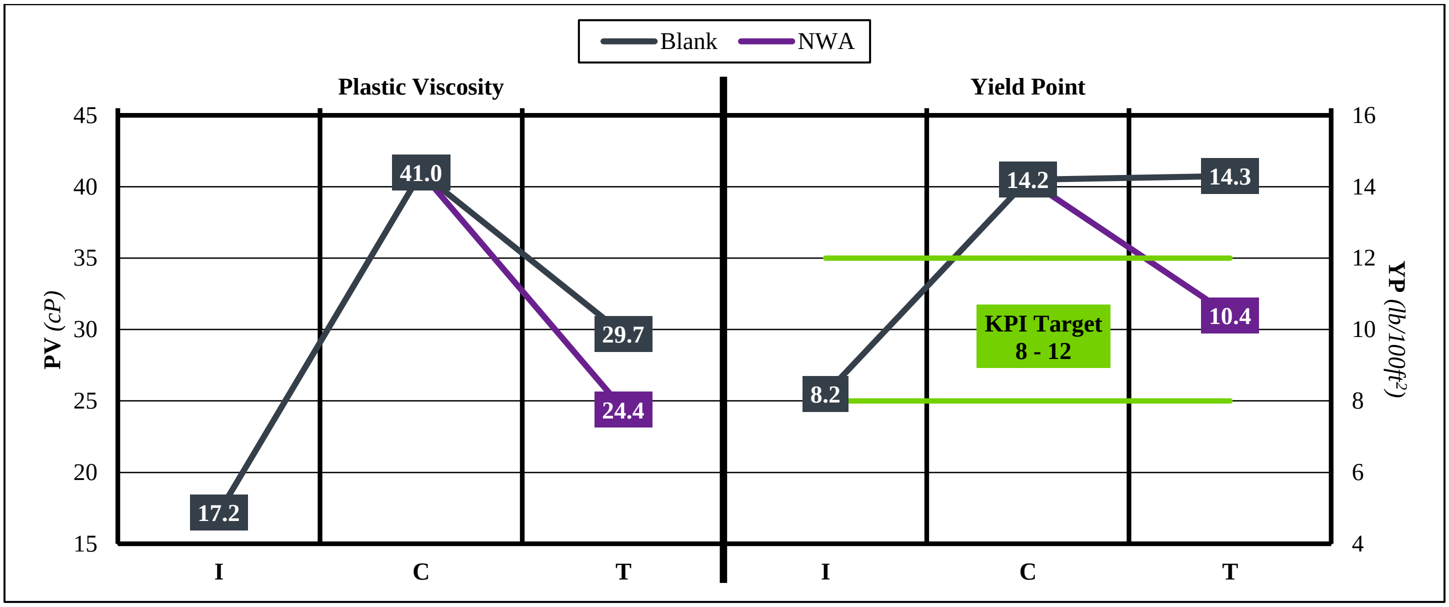

Figure 9: PV & YP Lifecycle Comparison of Blank (No Treatment) and NWA Treatment (2 ppb in *T stage*) in Synthetic-Based System

Appendix

Table 3: Diesel-Based System Reactive Blank, IND Treatment, and NWA Treatment Comparison

Stage	***I stage***	***C stage***	***T stage***		
LGS Content	3%	20%	20%	20%	20%
Treatment Type			*Blank*	*IND*	*NWA*
Treatment Dosage				*7 ppb*	*5 ppb*
600 rpm *(SS)*	44.8	188.0	159.1	271.3	91.4
300 rpm *(SS)*	27.3	129.0	100.8	194.2	57.5
200 rpm *(SS)*	19.5	100.0	79.8	165.0	45.8
100 rpm *(SS)*	13.0	65.3	56.7	129.6	33.4
6 rpm *(SS)*	5.5	23.3	27.7	79.0	17.2
3 rpm *(SS)*	5.2	20.8	25.7	76.2	16.1
PV *(cP)*	17.5	59.0	58.4	77.1	33.9
YP *(lb/100ft^2)*	9.8	70.0	42.4	117.1	23.6
10s Gel *(SS)*	5.0	20.5	31.5	70.0	16.3
10m Gel *(SS)*	7.5	23.5	42.0	78.0	22.0
ES *(V)*	602	120	343	1223	461
HPHT Fluid Loss *(mL)*	2.7	25.5	30.4	4.8	5.1
HPHT Filtrate Water *(mL)*	0	0.6	0	0	0

Table 4: Diesel-Based System Reactive and Continuous NWA Treatment Comparison

Experiment	**Reactive Treatment**			**Continuous Treatment**		
Stage	***I stage***	***C stage***	***T stage***	***I stage***	***C stage***	***T stage***
LGS Content	3%	20%	20%	3%	20%	20%
NWA Addition			5 ppb	2 ppb		3 ppb
600 rpm *(SS)*	44.8	188.0	91.4	50.9	105.6	108.0
300 rpm *(SS)*	27.3	129.0	57.5	31.8	66.4	68.7
200 rpm *(SS)*	19.5	100.0	45.8	23.7	52.7	55.5
100 rpm *(SS)*	13.0	65.3	33.4	16.4	37.2	41.2
6 rpm *(SS)*	5.5	23.3	17.2	7.5	17.8	22.5
3 rpm *(SS)*	5.2	20.8	16.1	6.8	16.8	21.4
PV *(cP)*	17.5	59.0	33.9	19.1	39.2	39.3
YP *(lb/100ft^2)*	9.8	70.0	23.6	12.7	27.2	29.4
10s Gel *(SS)*	5.0	20.5	16.3	7.0	17.0	22.0
10m Gel *(SS)*	7.5	23.5	22.0	8.0	20.0	27.0
ES *(V)*	602	120	461	941	466	740
HPHT Fluid Loss *(mL)*	2.7	25.5	5.1	7.6	27.6	4.0
HPHT Filtrate Water *(mL)*	0	0.6	0	0	0	0

Table 5: Mineral Oil-Based System Blank and NWA Treatment Reactive Dosage Study

Stage	***I stage***	***C stage***	***T stage***	
LGS Content	3%	20%	20%	20%
NWA Addition			Blank	2 ppb
600 rpm (*SS*)	42.6	96.2	73.7	59.2
300 rpm *(SS)*	25.4	55.2	44.0	34.8
200 rpm *(SS)*	18.1	41.3	34.2	26.5
100 rpm *(SS)*	12.2	26.9	24.3	17.8
6 rpm *(SS)*	4.8	10.6	12.0	7.1
3 rpm *(SS)*	4.3	9.5	11.3	6.5
PV *(cP)*	17.2	41.0	29.7	24.4
YP *(lb/100ft^2)*	8.2	14.2	14.3	10.4
10s Gel *(SS)*	5.0	11.0	13.0	8.0
10m Gel *(SS)*	6.0	13.0	19.0	12.0
ES *(V)*	420	416	338	385