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All Powder-Package Invert Emulsion Drilling Fluid – Because Liquids Freeze, Powders Don't!

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Abstract

The origin of non-aqueous drilling fluids can be traced to the 1920s when crude oil was used as a drilling fluid. In the 1940s, diesel-base drilling fluids were developed that not only tolerated water, but used emulsified it to control and maintain properties. Ever since, the main additives used to create an invert emulsion drilling fluid, such as emulsifiers, wetting agents, rheology modifiers, and thinners, have been liquid products typically packaged in 55-gallon drums. While they are effective and fast-acting, drum-packaged liquid additives are challenging to transport, freeze in cold environments, and generate waste stream and costs associated with drums cleanup/disposal. With the hydrocarbon quest expanding to remote and colder locations, it became obvious that drilling fluids additives packaged in small sacks rather than bulky heavy drums is the way to go.

An all powder-package invert emulsion (APPIE) system composed of exclusively dry products, other than base fluid and brine, provides advantages over current systems in cold weather environments where the pour point of a liquid product is a concern; remote areas with logistical challenges and areas where handling 55-gallon drums or tote tanks pose additional health, safety, and environmental risks. The alternative APPIE system was developed and delivered similar overall properties to those of commonly used invert emulsion fluids at various densities, temperatures, and contamination levels. Performance and stability evaluation of the dry products were carried out in comparison with their liquid equivalents in different formulations.

This paper presents the results of the APPIE drilling fluid development composed of powder wetting agents, rheology modifiers, and thinners for a complete dry-product system that followed the successful field introduction of the 100% active dry emulsifier.

Introduction

Invert emulsion drilling fluids are complex mixtures of immiscible liquids, such as oil (or synthetic), water, and solids. The water is broken up into small droplets and uniformly dispersed in the external non-aqueous phase. These droplets are kept suspended in the oil (or synthetic) phase and prevented from coalescing by surfactants (emulsifiers) that stabilize the mixture by being partially soluble in water and partially soluble in oil. Typical emulsifiers are liquids; long-chain fatty alcohols, fatty acids or amines, and can be anionic, cationic, or non-ionic.

Most solids found in invert emulsion fluids (barite, clays, and drill solids) have a natural preferential water wetting tendency. They must be wetted by the continuous liquid phase of the drilling fluid or, if water-wet, they will aggregate and settle. Wetting agents are used to alter the wettability of the solid-liquid interfaces to allow preferential wetting of solids by the oil or synthetic. As long as the solids are maintained in an oil-wet condition and do not coalesce or fully deplete the required surfactant concentration, they will form a stable suspension. Nitrogen compounds with long hydrocarbon chains, imidazoline, and reacted fatty acids all in liquid state at ambient temperatures are examples of commonly used wetting agents.

Removal of cuttings from the wellbore is crucial for a successful drilling operation. Improper hole cleaning can result in a number of drilling problems, including over-pull on trips, high rotary torque, hole packoffs, and stuck pipe. The common approach to reach optimized rheological properties in a fresh mixed fluid is treatment with rheology modifiers.

The two rheological modifiers most commonly used in drilling fluids are also liquids based on polyamides or fatty acids. The polyamide-type of modifier is used mainly for temporary viscosifying purposes, while the fatty acid rheological modifiers are used to increase the fluid's shear-thinning and thixotropic characteristics with minimum clay-based additions while drilling.

A contrasting scenario is when the fluids build excessive and undesired viscosity. This is typically caused by an excess of colloidal solids that become entrained in the drilling fluid. Often, these fines cannot be removed effectively by the solids control equipment to restore the drilling fluid to its desired rheological properties. In such cases, either dilution with base fluid can be used or treatment with thinners is required. The most common thinners are also liquid imidazoline or polyacid derivatives.

One of the greatest limitations of conventional liquid invert emulsion fluid components is cold temperatures. As the emulsifier/secondary emulsifier/wetting agent/rheology modifier or thinner cools, the product in viscosity increases to a point that it can be impossible to get out of the drum or tote without applying external heating.

This issue is commonly resolved (to a certain extent) by formulating these additives using a combination of pour point depressant, co-solvents, and low viscosity solvents to ensure that the product will remain in a pourable condition at the required operating temperatures. Formulation of fluid additives in this way, however, imposes some undesirable properties:

- The active component of the emulsifier in a drum is necessarily reduced, resulting in additional product cost and additional logistics as more product is required for performance
- Many of the most effective pour point depressants and low viscosity solvents have poor health and safety properties, resulting in a product that is more hazardous to handle and transport
- A number of effective pour point depressants have a detrimental effect on the stability and on the rheology of invert emulsion fluids
- Elevated concentrations of a number of effective pour point depressants can actually reduce the stability of an invert emulsion system
- Many of the most effective pour point depressants and low viscosity solvents have a detrimental effect on the environmental acceptability of both the product and of the invert emulsion fluid.

Dry products are beneficial in numerous ways when compared against their liquid alternatives. By converting a liquid to a dry additive, the pour point and pour point depressant issues can be eliminated. This allows implementation of dry versions of these additives to be more consistent across various climates and lead to greater reliability.

The other benefits to using dry products are related to storage and transportation. With dry products, materials can be stored in sacks as opposed to the standard drums. This benefit provides value, especially in remote areas since sacks disposal is much less of a burden than drum cleanout and disposal.

With the benefits of dry products in mind, it was determined that building a fluid system composed of exclusively dry products other than base oil and brine would add significant logistical, healthy, safety, and environment (HSE), and technical advantages.

The areas where dry OBM additives would provide advantages over current systems were identified to be:

- Cold weather environments where the pour point of a liquid product is a concern
- Remote areas with logistical challenges
- Areas where handling 55-gallon drums pose additional HSE risks.

The system to be focused on was a land-based diesel system. The first goal was to identify dry versions of materials that would fit the drilling fluid additive needs: wetting agent, rheology modifier, and thinning material. These materials would be initially screened in formulations with established liquid additives at different densities and temperatures. The last step was combining all the dry additives together in a formulation and compare the all powder-package invert emulsion (APPIE) fluid to established systems.

The following requirements for the individual additives and the overall system were set:

- Meet environmental regulations and safe to handle with minimal HSE risks
- Free-flowing powder across the temperature range of -20F to 150F and do not cake under prolonged storage at the same temperatures
- Readily dispersed into base fluids with minimal shear at temperatures of 0°F to 120°F
- Deliver stable fluid properties under expected downhole conditions
- Able to perform at density between 9 and 18lb/gal
- Withstand temperatures as high as 400°F
- Tolerant for drilling solids, sea water, and cement contamination
- Be flexible and easy to engineer.

The fluid properties for the APPIE fluid to be developed were required to be comparable to current land-based fluid with diesel as base oil.

Dry Product Testing

Wetting Agent

The primary purpose of the wetting agent in an invert fluid is coating the solids and maintaining them in an oil-wet state rather than the natural water-wet tendency. When the system does not provide enough oil-wetting capacity, the water-wetted solids will clump and fall out of solution. An example of this is shown below in **Figure 1**. In order to perform a proper screen, a fluid formulation was developed, where, if no wetting agent is added, the solids would become water-wet and the system would lock up.

Dry wetting agents were tested into this formulation and visual observations were made on the fluid performance. The best wetting agent was selected based on several criteria with the most important being the amount of solids tolerated with no wetting issues. Table 1 also displays the treated fluid that remains smooth with no solids falling out of solution.

Rheology Modifier

To increase the viscosity/modify the rheology profile of a fluid in circumstances where the fluid becomes too thin, a dry viscosifier was developed. Fluid rheology profile is important for various aspects of drilling fluid performance, such as wellbore stability, sag control, cuttings transportation and efficient cuttings removal.

A 13ppg diesel oil-base mud (DOBM) formulation with 80/20 oil:water ratio (OWR) was used as the base for development of the rheology modifier. A blank reference was also used for comparison. For the dry rheology modifier to be considered effective, it was determined that the fluid should exhibit at least a 20% increase of the rheological properties when compared to the reference with treatments of between 0.5 and 3 lb/bbl. The primary properties affected should be the low shear (3 and 6 rpm) readings and the Yield Point, with higher shear readings being increased to a lesser degree.

Table 1 shows the properties of a 13.2 lb/gal DOBM without and with dry rheology modifier treatment. Comparing the data, it is clear that the rheology modifier treatment resulted in a dramatic increase in fluid rheology initially after shearing the product into the system. The improved rheological profile was sustained through the process of hot rolling at 250°F for 16 hours. These results indicated the material was a suitable rheology modifier in the diesel based drilling fluid.

Thinner

To counter the effects of a fluid's excessive viscosity, such as excessive pump pressure and reduced rate of penetration, either a dilution with base fluid or a thinner can be used.

A 13 lb/gal synthetic based fluid with 70/30 SWR was used as the base for the thinner development, and results were evaluated against a blank reference sample. For the dry thinner to be considered of acceptable performance, the fluid would need to exhibit at least a 20% decrease in rheology when compared with the reference with treatments of between 0.5 and 2 lb/bbl.

A 13 lb/gal synthetic-base fluid with 70/30 SWR was used for evaluation against a blank reference sample. For the dry thinner to be considered passing, the fluid would need to exhibit at least a 20% decrease in rheology when compared with the reference.

The data in **Table 2** depict a direct comparison between the fluids without and with dry thinning material in the system. The dry thinner displayed a dramatic decrease in fluid rheology after shearing the product into the system. The decreased rheology was also sustained through the process of hot rolling at 150°F for 16 hours. These results indicated the product is a very powerful thinner in this formulation and its usage should be at a lower concentration.

APPIE Drilling Fluid System

After the development and thorough testing of individual components, an entire package was developed incorporating the individual components into one complete system. This new system design was such that all the components were in a dry powder form other than the base oil and brine. After compatibility testing with various formulations and materials, a complete system was finalized. The laboratory developed system was designed and tested at densities from 9 lb/gal to 18 lb/gal, at oil water ratios from 70:30 to 85:15, and at heat aging temperatures from 150°F up to 400°F. A summary of system properties across these ranges are shown in **Table 3**.

Another important aspect built into the design of this system was the ability to manipulate the rheology of the fluid if necessary. In **Figure 2**, viscosity curves are shown as an illustration of the rheology control that can be achieved by first treating the drilling fluid with dry rheology modifier then subsequently decreasing the rheological properties with dry thinner treatment. This ability to readily adjust the rheology demonstrated the control of the drilling fluid properties that was desirable when using this fluid in the field.

As part of the system design validation requirements, the fluid system was subjected to various contaminations including two levels of drill solids, sea water at 10% by volume, and class H cement at 10 lb/bbl. The contamination results are summarized in **Table 4** indicating an acceptable level of resiliency from the fluid. Although there are noticeable changes in the fluid properties, none of the different contaminations resulted in a fluid failure. This information is critical for system confidence when implemented in the field.

Conclusions

Combining the new developed products (dry wetting agent, dry rheology modifier, and dry thinner) together with the previously established dry emulsifier allowed for an APPIE fluid that:

- Can be used at densities between 9 and 18 lb/gal
- Withstand temperatures up to 400°F
- Allows flexible engineering
- Tolerates well various contaminants.

When compared to more conventional invert emulsion fluid designs, the development work for the APPIE system yielded a fluid that provides:

- Reduced cost of HSE incident by decreasing the risk of personnel injury while handling drums
- Reduced cost of waste disposal by replacing chemicals packaged in drums with those package in sacks
- Reduced cost of chemicals by increasing the effectiveness of emulsifiers
- Improved logistics by eliminating additives with mixing pour point concerns requiring heated storage.

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Nomenclature

APPIE = All powder-package invert emulsion
AHR = After hot rolling
BHR = Before hot rolling
DOBM = Diesel oil-base mud
HPHT = High pressure, high temperature
OWR = Oil water ratio
OBM = Oil-base mud
PV = Plastic viscosity, cP
YP = Yield point, $lb_f/100\ ft^2$
lb/gal = pounds/gallon
lb/bbl = pounds/barrel

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Figure 1. Side-by-side comparison of a fluid designed to display water-wet solids without a wetting agent.

Blank	**Dry Wetting Agent**
	

Table 1. Fluid properties for a 13.2ppg, 80/20 OWR formulation hot rolled at 250°F and treated with dry rheology modifier compared to the baseline without modifier.

	Blank		**Dry Rheology Modifier Treatment**			
Rheology at 150°F	BHR	AHR	BHR	AHR	% Increase against Blank BHR	% Increase against Blank AHR
600	72	59	111	80	54	36
300	51	41	78	55	53	34
200	42	43	66	46	57	7
100	32	25	50	35	56	40
6	16	12	37	20	131	67
3	15	11	36	19	140	73
PV (cP)	21	18	33	25		
YP (lb/100ft^2)	30	23	45	30		
10" Gel (lb/100ft^2)	14	11	46	27		
10' Gel (lb/100ft^2)	15	12	46	32		

Table 2. Properties of a 13.4ppg, 70/30 OWR fluid formulation hot rolled at 150°F with dry thinner compared against baseline.

	Baseline					Dry Thinner Treatment					% decrease against base @ 150F
	BHR		AHR			BHR		AHR			
Rheology at:	70°F	150°F	40°F	100°F	150°F	70°F	150°F	40°F	100°F	150°F	
600	141	69	212	87	75	68	27	160	64	35	53
300	85	44	129	52	50	35	14	84	32	19	62
200	63	35	97	40	40	25	10	57	21	12	70
100	39	24	62	27	30	13	6	29	11	6	80
6	12	12	20	12	17	1	1	2	1	1	94
3	11	11	18	11	16	1	1	1	1	1	94
PV (cP)	56	25	83	35	25	33	13	76	32	16	36
YP ($lb/100ft^2$)	29	19	46	17	25	2	1	8	0	3	88
10" Gel ($lb/100ft^2$)	20	17	24	18	23	1	1	2	1	1	96
10' Gel ($lb/100ft^2$)	27	25	34	23	31	1	1	2	1	1	97

Table 3. Fluid formulations ranging from 9 lb/gal to 16 lb/gal hot rolled at various temperatures.

	9 lb/gal formulation with OWR of 70:30 hot rolled at 150°F		13 lb/gal formulation with OWR of 80:20 hot rolled at 250°F		16 lb/gal formulation with OWR of 85:15 hot rolled at 300°F		16 lb/gal formulation with OWR of 85:15 hot rolled at 350°F		18 lb/gal formulation with OWR of 85:15 hot rolled at 400°F	
Rheology at 150°F	BHR	AHR	BHR	AHR	BHR	AHR	BHR	AHR	BHR	AHR
600	40	53	44	54	79	75	89	74	183	107
300	25	36	28	35	49	43	55	40	121	56
200	18	29	20	27	37	31	41	24	98	38
100	13	21	13	19	26	19	28	17	71	21
6	7	13	6	10	13	7	14	5	42	4
3	6	12	5	9	11	7	14	4	41	3
PV (cP)	15	17	16	19	30	32	34	34	62	51
YP ($lb/100ft^2$)	10	19	12	16	19	11	21	6	59	5
10" Gel ($lb/100ft^2$)	9	13	7	13	18	16	27	16	51	10
10' Gel ($lb/100ft^2$)	11	15	12	20	25	28	32	32	50	24
ES@150F (Volts)	190	265	737	989	534	842	1189	1040	1018	833
HPHT FL @ 250°F (ml/30 min) at		2.6		4.4		2		4.4		4

Figure 2. Manipulation of 13ppg fluid viscosity by rheology modifier and thinner sequential treatments.

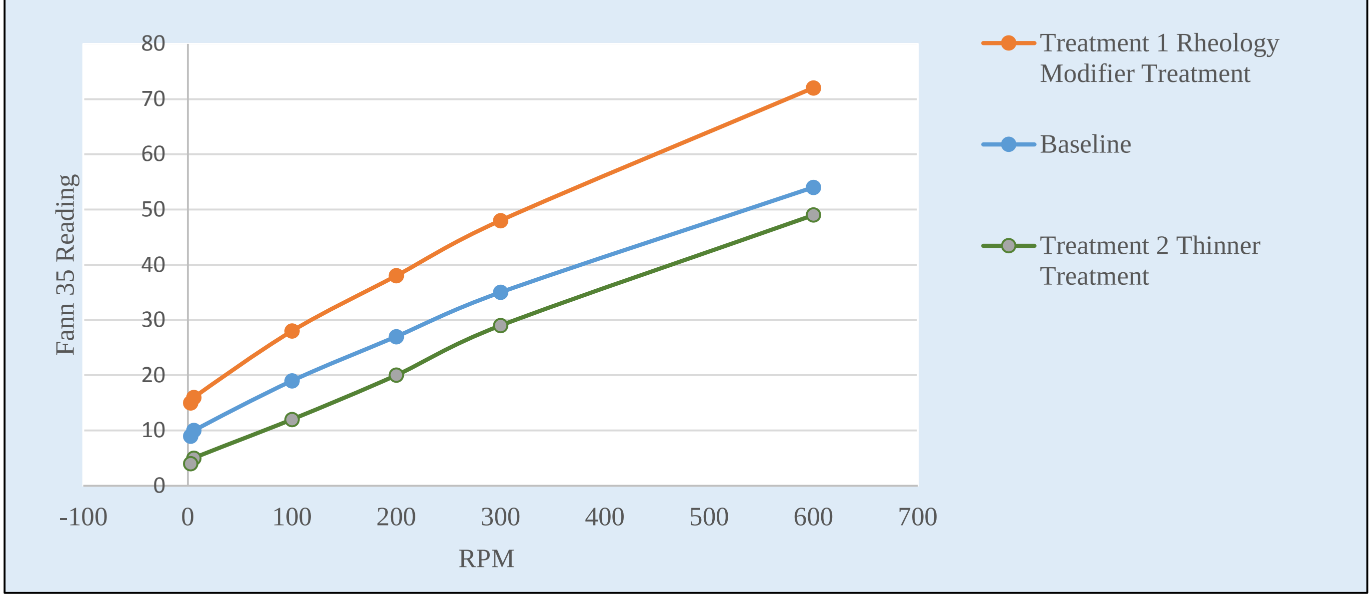

Table 4. Formulation at 16 lb/gal with OWR of 85:15 hot rolled at 350°F with various standard contaminations.

	Base	**OCMA Clay 30 lb/bbl**	**OCMA Clay 60 lb/bbl**	**Class H Cement 10 lb/bbl**	**Seawater 10%/ vol/vol**
Rheology at 150°F	**AHR**	**AHR**	**AHR**	**AHR**	**AHR**
600	54	56	58	52	56
300	35	32	35	34	34
200	28	24	2	27	25
100	20	15	617	20	16
6	11	7	7	10	7
3	10	6	6	9	6
PV (cP)	19	24	23	18	22
YP (lb/100ft^2)	16	8	12	16	12
10" Gel (lb/100ft^2)	13	12	14	12	11
10' Gel (lb/100ft^2)	20	20	23	20	20
ES@150F (Volts)	954	437	266	790	529
HTHP FL @ 250°F (ml/30 min) at	4.4	9.6	13.6	5.4	3.4