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Significance of using All-Oil Fluids as a Specialized Water-Free RDF Fluid for Preserving Rock Wettability & Obtaining Native-State Core Samples with Improved Reservoir Protection

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Abstract

Efficient reservoir drilling operations hinge on maximizing reservoir protection. This paper addresses two critical concerns with the potential to compromise reservoir integrity: aqueous phase trapping and plugging of fractures by drill solids and fines (commonly known as fine migration). This paper presents a specially designed all-oil reservoir drilling fluid (AO-RDF system) which minimizes water in the drilling fluid and is formulated to control fines and emulsions that plug small pores and reduce production rates.

All-oil drilling fluids systems are called “all oil” because either there is no additional water added or only a minimal amount of water is added to the oil which serves as the base of the drilling fluid systems. These all-oil systems are used most often for coring operations where the invasion of drilling fluid containing emulsified water or changes in wettability from high concentrations of wetting agents and emulsifiers is undesirable.

To address these challenges, a specialized reservoir drilling fluid has been carefully designed and can be formulated from any base oil using several approaches. This all-oil system is engineered to both prevent and mitigate the specified risks. The paper will provide a comprehensive overview of the design and operation of this carefully chosen RDF, emphasizing its role for reservoir integrity and optimizing drilling performance.

Introduction

From the time the drill bit enters the reservoir until the well ceases production, the formation is exposed to a series of fluids and operations that can severely affect its productivity. Any reduction in well performance is known as “formation damage” and reduces production and recoverable reserves.

There are a number of causes for formation damage. For the purposes of this paper, the focus is on formation damage in the reservoir that can be impacted by reservoir drilling fluid (RDF) and coring fluids. The mechanisms of particular interest are aqueous phase trapping caused by water in the drilling fluid system and narrow pore and throat sizes that can be clogged by drill solids, fines, and emulsions.

Aqueous Phase Trapping

Aqueous phase trapping is a significant issue in tight reservoirs, which exhibit water saturation levels below laboratory predictions. In their virgin state, these reservoirs possess low-water saturation, defying capillary pressure data, suggesting a higher irreducible saturation. Unexpectedly, even though these formations are typically water-wet, they exhibit a remarkable capacity to absorb additional water. The result is an enduring, capillary-driven process that persists as long as an aqueous source is available. In most cases, the drilling fluid serves to transport water into the fragile reservoir environment.

Oil-based and synthetic-based fluids may alter formation wettability, releasing water to be emulsified. In water-based fluids, filtrate compatibility can be tested and adjusted with alternative formulations and non-emulsifiers. Reducing fluid loss from the drill-in fluid also minimizes the depth of potential emulsion damage.

Complicating matters is the fact that these formations have very low permeability and narrow pore throats, necessitating substantial force to displace the aqueous phase. In most cases, the required force exceeds what the reservoir can provide, even with zero sand-face pressure. Moreover, if fluids can be extracted from pore throats, laboratory findings indicate that the saturation typically only returns to around 50%, rather than the original 10%. Therefore, the final cleaned permeability often plummets to values much lower than the virgin rock.

Drill Solids and Fines

Formation pore throats can be plugged by solids contained in a drilling fluid and cause formation damage. These solids can be added materials, such as commercial clays, drilling fluid chemicals, or incorporated drill solids. Compressible and deformable solids, such as hydrated clays, are the most difficult (or impossible) to remove.

The filtrate contains damaging polymers, wetting agents and emulsifiers where it interacts with formation water, reservoir fluids, and clay materials in the pores and formation. Furthermore, the filtrate may be incompatible with formation water adding to the deposited solids which cause formation damage in the near wellbore region. High overbalance or surge/swab pressure during drilling and other operations will further push the damage deeper in the near wellbore region.

"Emulsion blocking" is the term to describe the fine solids in the fluid filtrate combined with asphaltenes in the oil, that reacts to form emulsifiers that are not compatible with the formation/operational fluid. This can cause formation damage and restricting the flow of reservoir fluids during production.

During completion operations, poor displacement may allow residual fluid to remain in the wellbore adding to solids that are carried into the near wellbore vicinity. Dirty brine enters perforations in the pore network carrying these solids deeper into microfractures where it might be incompatible with formation fluids leading to emulsions or additional precipitation of solids, and increased water saturation due to the intrinsic viscosity of the brine.

Fracturing fluid failures or damage may occur due to formation mineral incompatibilities with the stimulation acid and deposit acid sludge. Fines, asphalt/paraffin, or mineral scale may trigger precipitate or bacterial scale.

During production, high production rates may trigger mobilization of fines leading to formation damage. Reservoir features such as fractures, faults, inhomogeneities, or sand content can lead to particle precipitation or sand production.

Conventional drilling and coring fluids usually contain high concentrations of strong oil-wetting surfactants that could cause dramatic alteration to the core sample. Properly engineered invert emulsion fluid filtrate can prevent this alteration.

Understanding the impact of aqueous phase trapping and the role drill solids/fines/emulsions plays in formation damage, the goal was to develop a reservoir drilling fluid that minimizes damage, minimizes water in the drilling fluid, and controls solids/fines/emulsions. The plan was to develop a flexible fluid that could be used for coring and drilling in the reservoir section.

AO-RDF System Design

An all-oil fluid was chosen for the base fluid of the AO-RDF system. The system uses minimum products to avoid adding any additional water to system which could result in aqueous phase trapping. Also, the selection of products was designed to minimize fluid loss, carefully balancing the choice of emulsifier and amount to provide fluid stability without creating unwanted emulsions that could block the formation pores. A comparison of the AO-RDF System formulation to the conventional oil-based RDF system is given in Table 1. Note that no water is added in the formulation (i.e., 100% all-oil for the base fluid). Table 2 provides the general AO-RDF System formulation discussed in the case histories.

Components within the AO-RDF System:

- As no water is contained within the formulation, a decreased concentration of the strong primary emulsifier is required to maintain emulsion stability if water contamination occurs.

Table 1: Comparison of Products in Conventional OBM RDF and AO-RDF System

Conventional OBM RDF	AO RDF System
Base Oil	Base Oil
Organophilic Clay	Organophilic Clay
	Polar Activator
HTHP Filtration Control	Gilsonite/Amine Lignite/ Polymer
Emulsifiers and wetting agent	Emulsifier
$CaCO_3$	$CaCO_3$
Lime	Lime
Salt /NaCl	
Water	**100% water free*

Table 2: AO-RDF System Formulation

Product	Concentration
Base Oil (mL)	850
Organophilic Clay (kg/m^3)	17.1
Polar Activator (kg/m^3)	10%
Gilsonite/Amine Lignite/ Polymer (kg/m^3)	8.55
Emulsifier (kg/m^3)	2.85
$CaCO_3$ (g)	20

- The organophilic clay is the viscosifier and gelling agent used to provide carrying capacity and suspension properties and improve cuttings removal. This product will also aid in filtercake formation and filtration control. Additionally the organophilic clay concentration can be adjusted to provide increased yield point and gel strengths with minimal plastic viscosity and will improve the shear thinning and thixotropic characteristics of the AO-RDF System.
- High levels of alkalinity are not required within the AO-RDF System; however only a minimal concentration of lime (calcium hydroxide) is required to ensure no acidic environment occurs (e.g., sour gas).
- A Gilsonite/Amine Lignite/ Polymer was designed to provide reductions in HTHP fluid loss and can be used in a normal treatment range up to 16 lb/bbl.
- Calcium carbonate is the acid-soluble weighting and bridging agent to bridge permeable formations limiting fluid invasion and lost circulation. Density increases to within the range of approximately 11.0 lb/gal are possible within the AO-RDF System using this product.

The formulations provided in Table 2 have been tested in the laboratory. Each formulation was prepared, and heat aged in the roller oven for a period of 16 hours at 220°F, before the testing procedure was initiated. Results of the rheological tests are reported in Table 3 and reached the specifications recorded within the tender documents for the case histories reported in this paper.

Table 3: AO-RDF System Properties	
Density (s.g.)	0.91
600-rpm Reading	25
300-rpm Reading	15
200-rpm Reading	13
100-rpm Reading	9
6-rpm Reading	4
3-rpm Reading	4
PV (cP)	9
YP (lb/100 ft^2)	7
OWR (%)	100/0
HTHP (mL)	4

Table 4 shows the return permeability in 3 wells. An average return permeability of 84% was achieved. Typically anything greater than 70% is considered good. With a return permeability of 60%, the well produces at about 88% of its potential.

Table 4: AO-RDF System Return Permeability Test Results

Sample #	Well #	Φ (%)	K_i (mD)	K_f (mD)	Return Perm (%)
18	1	8.29	18.2	15.5	85.17
3	2	9.39	5.3	4.5	84.9
6	3	7.87	1.1	0.9	81.82

Case History #1

The operational goal for Case History # 1 was to increase field productivity in a very depleted field by drilling a 600-meter horizontal drain that would be used as a water injector. The target was to penetrate the section with minimum possible damage to ensure the maximum water injection was achieved to maximize the field production. Because the field was very depleted, the proposed fluid should have a density around 0.9 sg to avoid any possible formation losses.

Using the AO-RDF System the production rates were more than triple expectation. The extremely good production rates helped the operator change the plans from maximum injection to maximum production.

Case History #2

The operator wanted to use a low-invasion coring fluid for a technical reservoir project. The key success of the project was to achieve a near native-state core. A concern was that the invading filtrate would alter the rock wettability and the in-situ oil saturation. The three design criteria for the RDF were 1) provide a core sample with a non-invaded center, 2) the drilling fluid filtrate would not change the rock wettability and alter the water saturation, and 3) the drilling fluid would have adequate properties for rheology, electrical stability (ES), and fluid loss.

The AO-RDF System was proposed to achieve a very low invasion depth of less than 1.5 inches. The AO-RDF System would be used as a coring fluid and then for drilling 100 meters to TD after finishing the coring job.

The AO-RDF System was used for both the coring and drilling the final 100 meters to TD. The quantity of both the emulsifier and wetting agent was minimized for maximum core protection. Calcium carbonate effectively bridged the pore throats and there were no losses to the formation. The job was accomplished without any operational or HSE incidents either in the coring or drilling operations.

Case History #3

The operator proposed drilling the 6-in. section from 10,151 to 10,479 ft utilizing a special application of the AO-RDF System to minimize changes to the wettability of the formation. The AO-RDF system would be formulated with a combination of the asphaltic material, organophilic clay, and the liquid rheological modifier. The emulsifier would be used in a very low concentration and no added water. Calcium carbonate was used for bridging and non-damaging characteristics in the AO-RDF system. The rheology was controlled in the specified range (Table 5) to provide optimum hole cleaning by using the appropriate organophilic clay and rheology modifiers.

Table 5: AO-RDF System Requirements	
Density (lb/gal)	8.7
PV (cP)	As low as possible
YP (lb/100 ft^2)	15-20
Initial Gel (lb/100 ft^2)	5-10
6-rpm Reading	10-15
HTHP Fluid Loss (mL/30 min	<5
HTHP Filtercake (1/32-in.)	1
Pom (mL/0.1 H_2SO_4)	1-2
ES (v)	>2,000
Drill Solids (%)	<2

Key issues of concern were dealing with lost circulation and water contamination. Water contamination was of concern in both formulation and in operational elements from mixing to displacement procedures.

As a precautionary measure to avoid skin damage, use of conventional LCM was not advised should lost circulation or seepage be encountered as the conventional LCM could permanently plug the pore throat. Therefore, the recommended procedure would be to spot a pill with effective bridging and sealing characteristics that would be acid soluble and less damaging to the formation.

Avoiding substantial volumes of water is an important criteria of the AO-RDF System. Although the AO-RDF System is promoted as "water-free", it will pick up water from the pits during displacement. The actual water content may be within the range of 0.5 to 1%/vol. The recommended operational guidelines with regard to water contamination are very similar to those employed during the use of conventional oil-based drilling fluids – inspect the water sources prior to the progression of the mixing process as any sizable water contamination will adversely and drastically impact the AO-RDF System properties. In some cases, the design criteria will have to take these changes into consideration.

It is further recommended that the entire mixing system be flushed with base oil prior to the start of the mixing. This includes the pits, mixing hoppers, and associated lines, thus limiting the amount of water that can be picked up during the mixing process.

The pumping of a 30-bbl oil-based spacer viscosified with invert emulsion gelling agent during displacement will act as a cushion and limit the increase in density that normally occurs when displacing a heavyweight fluid with a lightweight fluid. This will also help the conversion to an oil-wet condition for the entire cased wellbore and provide an interface separating the two fluids. A constant pump rate should be maintained during displacement according to the optimum flow rate derived by the calculation on the differential pressure. This should be the highest pump rate to provide turbulent flow, if possible. Rotate and reciprocate the drillpipe during the displacement procedure to minimize channeling. At the end of the displacement, when the high-viscosity pill reaches surface, it will be recovered or separated if possible, and will be incorporated into the total volume returned to storage. At this point, the trough should be cleaned with base oil and all the hatches sealed to avoid spills into the reserve pits.

Conclusions

The case histories presented illustrate the advantages of an all-oil RDF. These advantages include significant improvement in production, low-invasion fluid for coring, if a non-damaging RDF is required, or problems are encountered with shale stability, torque and drag, or a low ROP with a water-based drilling fluid.

Case History #1 showed a greater than triple improvement in production rates.

Case History #2 showed a very low invasion depth of less than 1.5 inches and the flexibility to serve as both a coring and drilling fluid.

Case History #3 showed the ability to minimize changes in formation wettability and control the added water that an all-oil drilling fluid picks up from the pits.

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Nomenclature

AO = *All Oil*
ES = *Electrical Stability*
HTHP = *High-Temperature, High-Pressure*
K_f = *Final Permeability*
K_i = *Initial Permeability*
LCM = *Lost Circulation Material*
OBM = *Oil-Based Drilling Fluids*
OWR = *Oil/Water Ratio*
Pom = *Alkalinity level of oil-based mud*
PV = *Plastic Viscosity*
RDF = *Reservoir Drilling Fluids*
TD = *Total Depth*
YP = *Yield Point*
Φ = *Porosity*