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New Spacer Technology for Cleaning and Water Wetting of Casing and Riser

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Abstract

During the course of drilling and completion of oil and gas wells, it is necessary to remove contaminants such as drilling fluids, drilled solids, pipe sealants, lubricants, and other debris from the casing, riser, and/or the drillpipe. One of the more difficult fluids to clean-up is invert emulsion fluid. Failure to clean-up efficiently can result in excessive rig time to filter brine, damaged production zone, and poorly cemented casing. The primary focus in wellbore clean-up is the complete displacement of drilling fluids and their associated residues and contaminants from the wellbore.

The displacement fluids should have high cleaning power, prevent emulsion or sludge formation, and be compatible when in contact with the drilling fluid. For optimized displacement design, a sequence of spacer fluids is required to complete the cleaning of the casing and/or riser.

In order to optimize the cleaning efficiency of the casing and/or riser, a series of tests were used to evaluate fluid performance. This resulted in design of a system to more effectively remove synthetic-based or oil-based mud and to water wet the casing and/or riser. This new spacer system uses an efficient mesophase technology based on surfactants that do not require the use of common organic solvents including terpenes. Additionally, the system requires only two spacer pills; a displacement and cleaning fluid and a water-wetting spacer. The robustness and efficiency of this system provides a tremendous economic benefit and is simple to use.

This paper describes the detailed laboratory procedures used to examine and test the rheology, compatibility, and cleaning ability of the novel mesophase technology comprising a displacement spacer and a cleaning/water-wetting spacer used in clean-up of synthetic and oil-based drilling fluids. The successful use of this new technology in deep water demonstrates the unique and efficient cleaning of the riser, casing, and tools.

Introduction

Efficient displacement and effective removal of drilling or drill-in fluids and associated residues from the wellbore prior to completion of a well to solids-free brine is critical for optimized hydrocarbon recovery. Unsuccessful displacements often result in excessive rig time, brine filtration costs, unnecessary waste generation, and completion complications. Additionally, failure to clean up the wellbore could lead to formation damage, jeopardizing a project's success, and well productivity.

Operators are particularly interested in improved methods for casing clean up after drilling with synthetic or oil-based mud (S/OBM) due to the difficulty in removing these drilling fluids from casing and downhole tools. As drilling fluid formulations and additives are adapted to challenging drilling applications, the difficulty in removing drilling fluids from the cased wellbore and water-wetting the casing or riser with traditional displacement spacer systems becomes arduous. Heath, safety, and environmental restrictions will continue to further limit the use of solvent and solvent/surfactant based displacements, and will continue to drive the industry to greener technologies. This desire for a more robust, environmentally friendly design has led to new technology that has excellent cleaning attributes, reduces brine circulation times and volumes, reduces surge pressures, reduces waste disposal volumes, and renders casing and down hole tools water wet.

Displacement technology that incorporates oil into a fluid mesophase by a solubilization process has been effective in the laboratory and subsequently verified in field applications.[1,2] The mesophase fluids were developed to effectively displace S/OBM and to solubilize the oil while reversing the wettability of the drilling solids and simultaneously cleaning and water wetting the casing and drill pipe. Hydraulics and spacer modeling of the wellbore displacement aided the operation in determining the proper pump pressures, effective circulating density (ECD), required spacer volumes, and contact times to ensure optimal displacement in the field.[3]

Fluid Development

The key component of the novel displacement fluid and water-wetting spacers is the mesophase fluid additive in a concentration between 5 and 10%. The mesophase fluid additive consists of a blend of surfactants and co-surfactants in water. The selection of these additives was made from phase behavior studies in complex systems of water, oil, surfactant and co-surfactant. The selected mesophase blends were the ones that had high oil solubilization in the aqueous phase and that water-wet the solids when in contact with the S/OBM. Two spacer formulations were selected for cleaning riser and casing following drilling operations with S/OBM. One formulation is a viscous displacement spacer that simultaneously pushes the drilling fluid out the wellbore and removes the S/OBM and debris adhered to the casing and risers. The second spacer fluid is a mesophase in brine that cleans and water-wets the metal. The components of each spacer are shown in **Table 1.**

A series of laboratory scale experiments that simulated the displacement conditions (temperature and contact time) were used in the evaluation of spacers. The tests were performed using S/OBM laboratory and field samples to demonstrate the displacement clean-up efficiency and drilling fluid/spacer interface rheology. The drilling fluids tested included S/OBM formulated with various base oils, such as olefin, paraffin, enhanced mineral oil, and diesel. All of the evaluation tests were conducted at temperatures of 40˚F and 150˚F to simulate dynamic riser and downhole temperatures for deepwater wells. The final spacer formulations were evaluated at temperatures up to 180˚F.

Results and Discussion

Vial Tests

Vial tests were conducted in the initial screening to evaluate concentrations and cleaning capacity of each spacer. A series of vial tests that simulated the drilling fluid/spacer interface were carefully prepared with OBM/spacer ratio between 90/10 and 10/90. As can be seen in **Figure 2**, the displacement spacer has sufficient viscoelasticity and density to statically support the OBM. After dynamic mixing, the vials were allowed to static age overnight at the designated test temperature. Further mixing and fluid disposal, followed by light rinsing with water, revealed the cleaning efficacy of the individual spacers at the interface between OBM and spacer as shown in **Figure 2**. The cleanliness of the vials containing 75% and 90% spacer is an indication that the displacement spacer will remove a high percentage of the mud while pushing the drilling fluid out of the hole.

Beaker Tests

A beaker test was performed to simulate oil-wetting properties in casing and riser. Using a pre-weighed beaker, the drilling fluid was applied to the inside of the beaker and re-weighed. Pre-heated or cooled displacement spacer was then added to the beaker, and the beaker was placed into a thermal cup on a Fann 35 and mixed at 100 rpm for 10 minutes. Afterwards, the displacement spacer was poured out and the next spacer (cleaning/water-wetting spacer) was added to the beaker and the process of mixing and weighting the beaker was repeated. Upon completion of the test, the fluids were poured out and the beaker was lightly rinsed with water to remove loosely water-wet solids, dried, and re-weighed. Visual inspection and mass removal of S/OBM provide clear indications of the effectiveness of the spacer train. **Figure 3** shows the results of a beaker test with 12.5 lb/gal OBM. The results show a 99.5% of OBM removal. The cleaning capacity of the spacer train proved to be much more effective than the baseline of conventional technology based on mutual solvents/surfactants. Similar results were obtained with drilling fluids formulated with various base oils over a broad range of densities.

Fluid Compatibility: Rheology of Spacer/Drilling Fluid Blends

Fluid compatibility of S/OBM and spacers is important to accurate modeling of the displacement and aids in determining surge pressures, pump pressures, and ECD. The difficulty in displacing S/OBM to any water-based fluid is the increased pressures observed because of the thick emulsion formed at the interface of the two fluids. Several drilling fluid/spacer mixtures were prepared and the rheology measured at 40 ˚F and 150 ˚F. From the expected rheological profile, one can model the displacement to determine appropriate flow rates, ECD, and pump pressures prior to commencing the field application. **Tables 2 and 3** show the rheological properties of a displacement spacer/OBM and water-wetting spacer/OBM measured with a Fann 35 viscometer. The result showed that no noticeable increase in viscosity was observed when the displacement spacer was mixed with the OBM at various ratios. Evaluation of water-wetting spacer/OBM (**Table 3**) showed that the rheological properties of the OBM dropped about 50% as soon as they contacted the spacer, as shown in the results of the test with 90% OBM and 10% spacer. The results indicate that no viscous emulsion or sludge are formed at the interface between the OBM and these novel mesophase spacers.

Case History

On a recent deepwater application, the new wellbore cleanup spacer system was used to displace synthetic drilling fluid, and to water-wet the 9.625” casing and riser prior to the completion process. The OCS-G 25103 well, located in 1598 ft. of water in Mississippi Canyon, Block 707, Gulf of Mexico, was drilled using 14.7 lb/gal synthetic drilling fluid and required 14.5 lb/gal $CaCl_2/CaBr_2/ZnBr_2$ brine for the completion fluid.

Spacer Fluid Preparation and Operational Sequence

Table 4 shows the properties of the synthetic drilling fluid that was used to drill the well and needed to be displaced and cleaned. In order to perform the wellbore displacement and clean-up, it was decided to use the train of two mesophase spacer pills (displacement spacer and water-wetting spacer) with the compositions described in **Table 5**. The displacement or pilot spacer was mixed in seawater and the required density was reached by the addition of barite. The water-wetting or tail spacer consisted of a 14.5 lb/gal $CaCl_2/CaBr_2/ZnBr_2$ brine blend with 10% mesophase additives. The water-wetting spacer is designed to be a near-Newtonian fluid for ease of achieving turbulent flow; hence the use of brine as the weighting agent. **Figure 4** shows a photograph of the vial test made with the water-wetting spacer and the field mud. An excellent cleaning of the vials with a 90/10 and 75/25 spacer/SBM ratio was obtained, which is an indication of expected good performance in the wellbore.

Prior to initiating the operations, a detailed pre-displacement and cleanup procedure was defined and discussed with the operator. The team involved in the evaluation and qualification process established the key performance metrics, which included the interface volumes, NTU (Nephelometric Turbidity Units) of brine, residual solids, waste volume, and visual inspection of tools. In operation, typical target values of the NTU, which is the measurement of the clarity of the brine, are between 20 and 40 NTU.[3] A key performance indicator (KPI) of less than 30 was established. Another important KPI was the circulated volume of spacer required to achieve the clean return with less than 30 NTU. Common operational practices consider a very good wellbore cleaning if this is achieved with around one hole volume circulated. Considering that the spacer was a heavy brine (14.5 lb/gal) containing $ZnBr_2$, which could make it more difficult to clean the SBM, a 1.5 hole volume of mesophase spacers was established as KPI.

Displacement simulation software was used to simulate pump rates, pressures, volumes, and flow patterns prior to displacement and is a critical part of the planning and execution process. A detailed inspection of the surface pits and flow lines was carried out by the field service representative prior to taking on 14.5 lb/gal $CaCl_2/CaBr_2/ZnBr_2$ brine.

Table 6 and **Figure 5** show the sequence of the displacement fluids and volume of the spacer train required to achieve the plan of 10 minutes or more contact time while circulating.

Once the water-wetting spacer (tail spacer) entered the BOP stack, the riser boost pump was used to displace the choke, kill, and boost lines, as well as boosting the riser at an additional four barrels per minute. A summary of the pump rates and pressure of the displacement operations is shown in **Table 7.**

The interface of the water-wetting spacer/brine during the displacement was easily identified and diverted, resulting in a minimal interface of less than 20 bbls. The properties of samples that were taken during the displacement showed reasonable rheological properties, which is an indication that no viscous emulsions or sludge were formed when the spacer contacted the SBM (see **Tables 8 and 9**).

After all the surface equipment and flow lines were cleaned and flushed, the 14.5 lb/gal $CaCl_2/CaBr_2/ZnBr_2$ brine was filtered. A total of 1,177 bbls of 14.5 lb/gal $CaCl_2/CaBr_2/ZnBr_2$ brine was pumped, and NTU's recorded every five minutes. **Figure 6** shows the NTU's of the brine going into the well and at the flow line. The flow line NTU's dropped dramatically, once the circulation began, only rising slightly to a maximum of 100 NTU's. The results showed that, with less than one full circulation, (85%) the NTU's of the brine had dropped to below < 30.

After pumping 1,177 bbls, the brine had an NTU of 23 going to the hole and 28 into the flow line. The pipe was then tripped and the riser brushes, brush subs, and tool joints were inspected. **Figures 7 and 8** are photographs of the tools used. These pictures show no residual drilling fluid on any of the metal surfaces. All surfaces were successfully cleaned and water-wet. No short trip was required to the liner top to lay down the riser brushes.

Table 9 shows the expected results for the key performance indicators and the actual results obtained after the wellbore displacement with the spacers formulated with mesophase technology.

Conclusions

- A mesophase spacer fluid system without organic solvents was successfully developed for applications to clean the riser and casing prior to completion.
- The displacement spacer (spacer 1) acted as an aqueous piston scraper and effectively cleaned the S/OBM. The water-wetting spacer (spacer 2) exhibited excellent cleaning and water-wetting capacity on surfaces with a high percentage of SBM
- The field trial proved that:
  - The novel mesophase displacement spacer and water-wetting spacer successfully displaced the 14.7 lb/gal synthetic-based drilling fluid from the well and riser in one full circulation, with a minimal interface (approximately 20 bbls).
  - The clean condition of the riser brushes, brush subs, and tool joints indicated that the riser and casing were all successfully cleaned
  - No short trip was required to the liner top to lay down the riser brushes
  - The mesophase technology used in the wellbore cleanup spacer system provided maximum wellbore cleaning efficiency while reducing the cost and risks associated with SBM deepwater displacement and cleanup operations.

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Nomenclature

SBM = *Synthetic-Based Mud*
OBM = *Oil-Based Mud*
$CaBr_2$ = *calcium bromide*
$CaCl_2$ = *calcium chloride*
$ZnBr_2$ = *zinc bromide*
Bpm = *barrels per minute*
PV = *plastic viscosity*
YP = *yield point*
cP = *centipoise*
Lb/bbl = *pounds per barrel*
Lb/gal = *pounds per gallon*

Lbf/100 ft^2 = *pounds per 100 square feet*
°F = *temperature in Fahrenheit*
Ft = *feet*
Bbl = *oilfield barrel, 42 gallons*
NTU = *Nephelometric Turbidity Units*
PSI = *pressure*

References

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Tables

Table 1 Additives of spacer formulations

Displacement spacer	Cleaning & water-wetting spacer
Seawater	Brine
Xanthan gum	Mesophase additive 2
Mesophase additive 1	
Barite	

Table 2 Rheology of displacement spacer/SBM blends at 40ºF and 150 ºF

SBM, %	0	10	40	70	90	100
Displacement spacer, %	100	90	60	30	10	0
	Rheology at 40ºF					
PV, cP	29	30	40	54	57	52
YP., lbf/100 ft^2	50	57	24	17	27	15
10-sec gel, lbf/100 ft^2	21	17	11	8	19	4
3-rpm reading	22	16	8	6	11	3
	Rheology at 150ºF					
PV, cP	12	12	13	18	23	15
YP., lbf/100 ft^2	40	48	24	9	16	7
10-sec gel, lbf/100 ft^2	18	17	8	5	18	5
3-rpm reading	17	13	5	4	15	3

Table 3 Rheology of water-wetting spacer/SBM blends at 40ºF and 150 ºF

SBM, %	0	10	40	70	90	100
Displacement spacer, %	100	90	60	30	10	0
	Rheology at 40ºF					
PV, cP	10	10	9	41	24	52
YP., lbf/100 ft^2	0	0	5	4	3	15
10-sec gel, lbf/100 ft^2	1	0	1	3	1	4
3-rpm reading	0	0	1	2	1	3
	Rheology at 150ºF					
PV, cP	1	2	4	6	9	15
YP., lbf/100 ft^2	1	1	3	4	7	7
10-sec gel, lbf/100 ft^2	1	1	1	2	3	5
3-rpm reading	1	1	1	1	2	3

Table 4. Synthetic drilling fluid used in field trial

Drilling fluid properties	
Mud	SBM
Mud weight, lb/gal	14.7
PV, cP (at 150 ºF)	35
YP, lbf/100 ft^2 (at 150 ºF)	12
Max MLT, ºF	47
Max BHT, ºF	187

Table 5 Formulation of spacers used in field trial

Displacement spacer	Volume
Seawater, bbl	0.67
Xanthan gum, lb/bbl	1.34
Mesophase additive 1, %	10
Barite	343
Water-wetting spacer	**Volume**
$CaCl_2$/$CaBr_2$/$ZnBr_2$ brine, bbl	0.90
Mesophase additive 2, %	10

Table 6 Sequence of fluids displaced

Sequence of displacement	Fluids	Density, lb/gal	Volume, bbl
1	synthetic base oil	6.06	25
2	displacement spacer	15.5	180
3	water- wetting spacer	14.5	180*
4	viscous brine	14.5	50
5	brine	14.5	1400

*: An extra 30 bbls of water-wetting spacer was built to displace the kill, booster and choke lines in the riser.

Table 7. Pump rate and pressure of the displacements

Fluid Pumped	Rate, bpm	Pressure, psi	Rotate, rpm/torque	Recip. (Y/N)
Base Oil	6	N/A	NO	NO
Displacement spacer	5-6	2000	NO	NO
Water wetting spacer	6	1450	NO	NO
Viscous brine	6	1090	NO	NO
14.5 lb/gal brine	6-8	1600	40/3000	YES

Table 8. Samples of fluids collected after pump the displacement spacer

Rheology at 150 ºF	SBM	Spacer	Sample 1	Sample 2	Sample 3
Density, lb/gal			15.9	15.5	15.3
PV, cP	35	89	47	32	22
YP, lbs/100 sq ft	12	77	68	16	13
3 rpm reading	5	14	6	5	1
10-sec gel, lbs/100ft^2	9	17	10	6	2
Oil, % by vol.	--	--	21.5	5	5
Solids, % by vol.	--	--	29.5	27	27.5
Water, % by vol.	--	--	49	68	67.5

Table 9. Samples of fluids collected after pump the water-wetting spacer

	Sample 4	Sample 5	Sample 6
Density, lb/gal	15.7	14.4	14.4
PV, cP	28	17	--
YP, lbs/100 sq ft	27	2	--
3 rpm reading	6	0	--
10-sec gel, lbs/100ft^2	8	1	--
Oil, % by vol.	5.5	6	1
Solids, % by vol.	28	26	25
Water, % by vol.	66.5	68	74

Table 10. Key Performance Indicators

Reference Indicator	How to Measure	Target	Achieved
Brine filtration	NTU measurement	NTU < 30 in pits	In 23, Out 28 NTU's
Clean returns	Measure return volumes	< 150% of hole volume	85% of hole volume
Interface volumes	Measure interface volumes	< 20 bbls	< 20 bbls
Brushes & tool joints	Photos/visual inspection,	Free from mud residue	All metal surfaces clean
Residual solids	Inspection of debris from tools, etc.	Debris recovered	Small amount found in riser brushes
Waste volumes	Volume of disposal waste	Minimize volume	< 20 bbls

Figures

Figure 1. Initial step of vial test: SBM poured on top of spacer

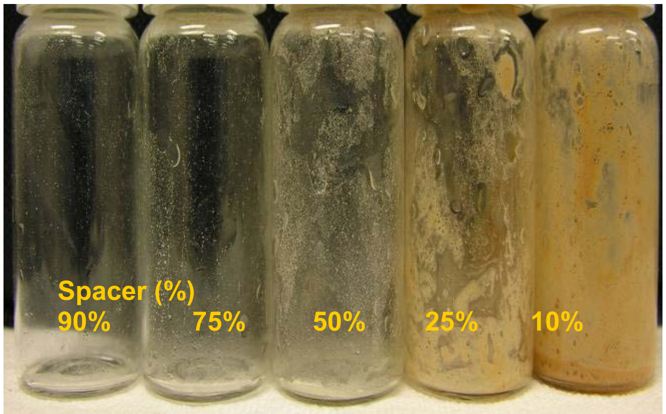

Figure 2. Final step of vial test: rinse with water

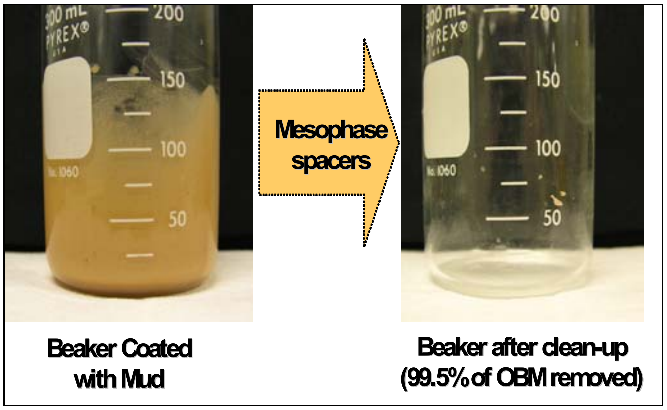

Figure 3. Cleaning test in a beaker

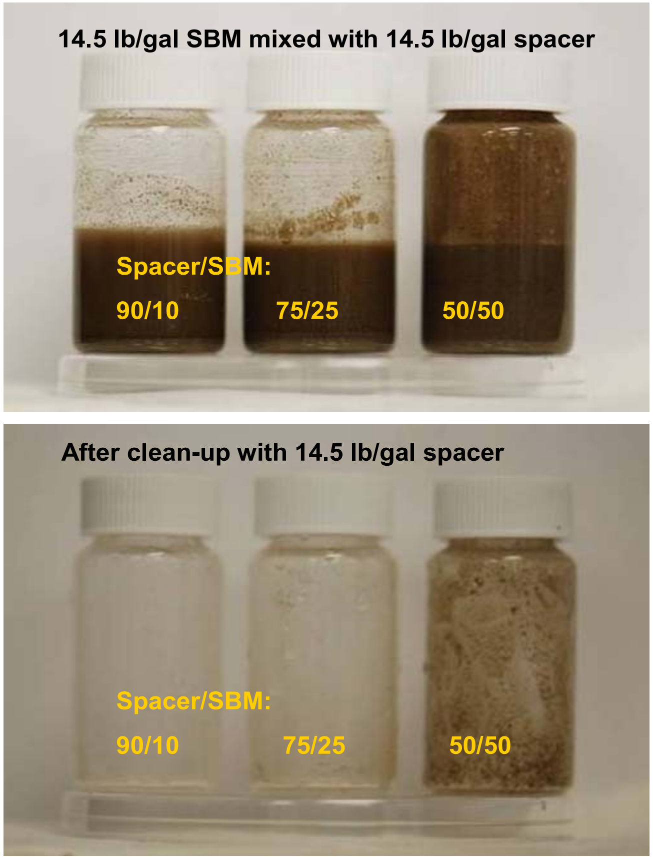

Figure 4. Clean-up test of SBM from OCS-G 25103 well with water-wetting spacer

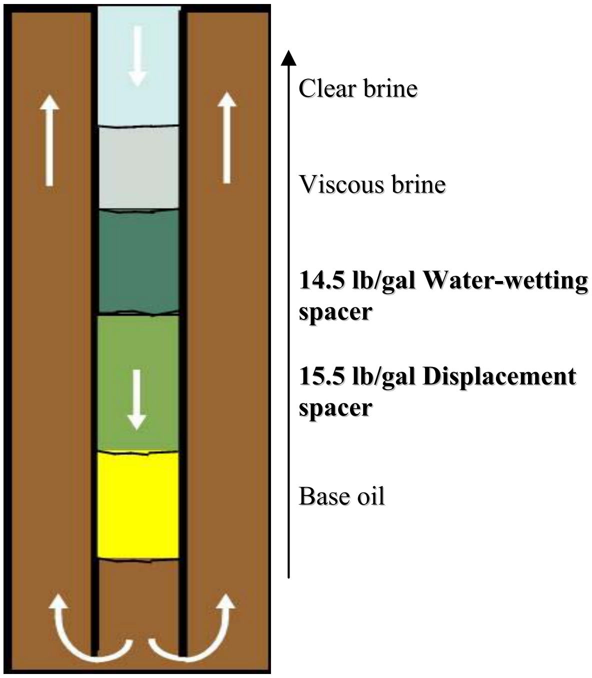

Figure 5. Sequence of fluids displacements

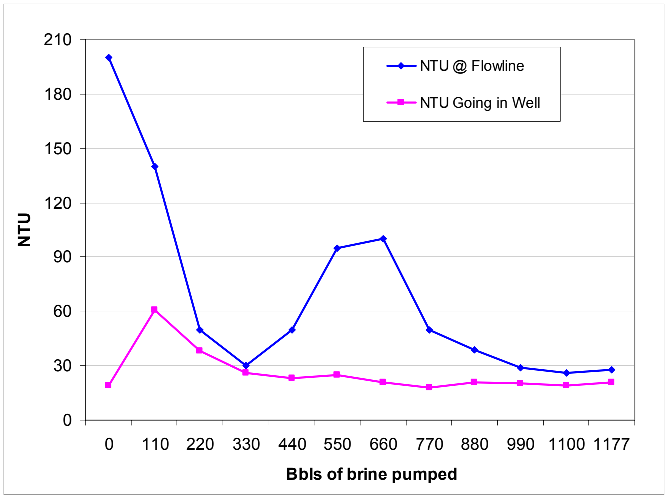

Figure 6. NTU of brine used in OCS-G 25103 well

Figure 7. Photograph of clean drill pipe and tool joints after displacement

Figure 8. Photograph of casing brush after displacement