

Scavenger Slurries: Recycling Vintage Technology for Improved Zonal Isolation and Economic Optimization

Debby Duckworth, Baker Hughes, Inc.

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Abstract

Development drilling projects operate under more stringent economics. Any operationally sound and HSE compliant technology that yields net savings and improved outcomes should be investigated no matter how vintage. One such opportunity lies in reducing behind pipe losses of oil based mud. When oil prices rise and/or budgets are more constrained, the ability to reclaim and recycle an expensive commodity like oil based mud (OBM) is worth pursuing. Additionally, this technology becomes more attractive if it is easily implemented, economically prudent and has no adverse effect on other phases of the drilling and completion operations. This paper presents the challenges and rewards of designing, implementing and evaluating the success of an OBM recovery program through the use of vintage technology such as scavenger slurries in two development areas, the Pinedale Anticline in Wyoming and the north Texas Barnett Shale. It demonstrates how vintage technology is recycled, refined and successfully applied in today's oil and gas drilling operations (i.e. "everything old is new again".)

Introduction

The use of scavenger slurries was not new technology. Scavengers were used for decades as spacers between the mud and cement to minimize primary cement slurry contamination and to displace the drilling mud from the annulus. The known advantages of scavenger slurries included ready availability of materials, ability to pump "on the fly" and make "real-time" density adjustments, simplicity of design and low cost. In many cases the engineering involved little more than loading extra lead cement slurry and adding water to retard gel strength development, increase the yield and attain the desired density. Not much effort was made to understand the properties of scavengers or to optimize their effectiveness. Often, no post job analysis was performed to determine their effectiveness.

In designing the scavenger systems for these development drilling projects, several key parameters were identified and addressed to insure the end result yielded effective mud displacement, competent zonal isolation, adequate cement bonding to the casing and cost effective recovery of the OBM. These parameters included:

- Determining the scavenger slurry rheologies and properties
- Testing for compatibility with the drilling mud
- Optimizing scavenger slurry volume and pump rates
- Modeling mud displacement efficiency and ECDs

In the Wyoming Pinedale Anticline project the wellbores were S-shaped with $<20^\circ$ inclination. The productive sections were drilled underbalanced through managed pressure drilling (MPD) operations. Care was taken to minimize losses while controlling gas flow. The shale intervals were sensitive to fresh water and subject to sloughing. The advantages of drilling with OBM not only included greater ROPs and reduced washouts but also clay control and maintaining hole stability. The shales were not productive zones but rather lenses between multiple pay zones extending across a vertical section 6,000' – 8,000' in length. Behind pipe losses of OBM averaged 150-200 bbls per well.

In North Texas, the wells were drilled horizontally with $\approx 4,000'$ laterals ($85 - 95^\circ$ inclination). The density of the OBM was low (8.7 – 9.2 ppg) due to weak zones up hole and low pay zone frac gradients. While heavier muds provided better solids removal, the equivalent circulating densities (ECD's) generated by denser fluids during the drilling operations could fracture and damage the productive zones. These same reservoir conditions required the spacer and cement densities to be reduced as well. Loss of returns during cementing compromised the actual cement tops and adversely affected completion operations in the productive shale intervals. Most of the North Texas area operators used inexpensive water based drilling fluids but some discovered that oil based mud could be used to reduce drilling and cementing costs by increasing ROPs and minimizing washouts. Unfortunately these savings were reduced by the higher costs associated with oil based drilling fluids. Behind pipe losses on these wells ranged from 150 – 300 barrels depending on the designed cement tops (TOC's).

In both areas the opportunity existed to reduce overall drilling costs by recovering more OBM and minimizing behind pipe losses. The recovered drilling fluid could be reconditioned and used on future wells.

Designing Effective OBM Scavenger Slurries

There are many excellent spacer systems available for displacing OBM. It is generally not cost effective to pump several hundreds of barrels of these spacers to displace all the drilling mud in the annulus. Often the cement spacers cost more per barrel than the drilling fluids. Scavengers become attractive alternatives for reducing behind pipe losses.

Like all OBM spacers, the scavenger slurry spacers need to be designed not only for cost effectiveness but to remove the drilling fluid with minimal formation damage and leave the casing water wet to insure the cement adequately adheres to the casing surface. Establishing a water wet surface behind the OBM can be difficult. Testing is required to determine the best mixture of surfactants and solvents to be added to the spacers and scavenger slurries. The design of effective scavenger slurries involves understanding mud displacement mechanics and chemistry. These are addressed in industry standards commonly referred to as "Cementing Best Practices".

A Review of Mud Displacement "Best Practices"

Good mud removal and hole conditioning are keys to successful cementing. Choosing the correct spacers and scavenger slurries to pump ahead of the cement is critical. The "correct spacer/scavenger slurry" should be designed within the guidelines of industry recommended "Cementing Best Practices". Adhering to these guidelines is especially critical when designing spacers and scavengers to displace oil based drilling fluids. The following are recommended steps for designing spacers (and scavenger slurries).

- Spacers should be compatible with the preceding fluid as determined by lab testing with actual drilling fluid samples prior to the cementing operations
- Spacers should leave the casing water wet ahead of the cement slurry
- Spacers should be densified (on average 10% heavier or 1 ppg greater than the preceding fluid) as well control and reservoir conditions allow.
- Spacers should be designed to establish a friction pressure hierarchy (exerting 20% greater friction pressure than the preceding fluid)
- Spacers should be capable of breaking the gel strength of the preceding fluid throughout the annulus
- Spacers should be modeled to determine optimal flow regimes
- Spacers should be of sufficient volume to allow for the greater of 10 minutes of annular contact time or 2,000' of linear fill.

Designing OBM Scavengers for the Wyoming Development Wells

In 2007-2009 Wyoming the operators drilled the production string intervals with OBM that averaged \$135/bbl. By leaving 200 bbls of drilling mud behind pipe they were "throwing away" \$27,000.00 of reusable materials per well. The cost savings from recovering and recycling the mud offset

about half of the production string cementing costs. The total savings for the annual 80 well drilling program generated enough money to pay for the drilling and completion of an entire well (Table 1). With this in mind the cementing service company was challenged to come up with a cost effective method of reducing the OBM losses. Scavenger slurries were suggested as a possible solution.

The production string intervals were drilled with 12.5 – 14.0 ppg mud. There were doubts about the ability to design a scavenger slurry that was heavy enough to displace the mud and remain fluid. The operator questioned if the scavenger slurry would develop early gel strength or set-up if mixed at the densities required for effective displacement when subjected to downhole pressures and temperatures. Another concern was potential incompatibility between the scavenger slurry and OBM. Incompatibility could reduce mud displacement efficiency and result in poor zonal isolation.

Testing commenced to determine the most effective scavenger slurry chemistry. To avoid issues with high gel strength and cementation the scavenger was designed using 100% flyash and water with a dispersant added to thin the slurry and reduce the ECDs. Retarder was added to inhibit any cementation properties the slurry exhibited. Surfactants and gelling agents helped maintain slurry stability and left the casing water wet while fiber and particulate material controlled losses (LCM).

Compatibility testing was conducted with the mud after the slurry was designed. The mud and scavenger slurry were incompatible and created a viscous mixture. The solution was to design a dual spacer/scavenger system. The cementing operations initiated with 20 bbls of the conventional OBM spacer successfully used in offset wells. This was followed by the scavenger slurry. The fluids were mixed at the same density (1 ppg greater than the drilling mud). The viscosity was sufficient to break the gel strength of the mud ahead and the total contact time exceeded 30 minutes.

The final step was to model the displacement efficiencies and determine the pump rates which maximized the mud removal without creating high ECDs that would fracture the pay zones and result in losses. The modeling showed the scavengers could not be pumped in turbulent flow without creating excessive ECDs in the annulus. The plug flow rates were impractical so the fluids were designed to be pumped in laminar flow. The casing was sufficiently centralized so effective laminar flow was achieved on both the "wide" and "narrow" side of the annulus.

Designing Scavengers for the North Texas Development Wells

The operators drilling with oil based drilling fluids in the north Texas Barnett Shale wells were equally cost conscious and actively sought technology to reduce costs without compromising job quality. Recovering behind pipe losses was a possible solution. The challenge to design an effective displacement fluid was more daunting due to the lateral extensions, the low density drilling fluids and the low frac gradients of the producing shales.

After discussing the success of the Wyoming project with these operators, the cementing service company was asked to provide a solution. The same three step process was used: design the slurry, test for compatibility and model displacement efficiency. This scavenger slurry design was more challenging because the choice of suitable additives was more limited and slurry settling in the lateral sections was a concern. The low density scavenger slurry contained few solids but high water volumes. The solids settled rapidly which was problematic in the lateral and build sections. The solution was to use flyash and gel as the base resulting in a reduction of the mix water requirement and settling tendencies. (Lightweight beads also lowered the density by replacing some of the water content but the beads were cost prohibitive.) Surfactants and solvents were added to water wet the casing ahead of the cement. LCM was added as needed based on recorded losses encountered during drilling operations.

With the slurry design completed, compatibility testing was conducted with the mud (Table 2). Once again the mud and scavenger slurry were incompatible and created a viscous mixture. The solution was to replace the current lightweight water preflushes with the conventional OBM spacers pumped ahead of the scavengers in Wyoming. The OBM spacer and scavenger slurry were weighted between 9.5 – 9.8 ppg. Due to the low frac gradients and a narrow ECD window, the spacers and scavengers were only 0.5 ppg heavier than the mud. To compensate for the diminished density and friction pressure hierarchies the pump rates were lowered to increase the contact time. The viscosities and rheologies of the spacer and scavenger slurry were lower (Table 3) but still sufficient to break the gel strength of the mud ahead as long as the mud was sufficiently conditioned prior to the cement job.

The modeling predicted hole cleaning efficiency and effective displacement of the drilling fluid. It also showed pump rates in excess of plug flow would breakdown the well towards the end of the job (Graphs 1, 2 and 3). This had been a common problem in the offset wells and the result was low cement tops with potential loss of pay. The jobs were designed to be pumped at 5 bpm or less. After determining the maximum pump rates, the scavenger was again tested to confirm stability for longer periods of time at lower rates. Adjustments were made as needed.

Results

Post job analysis indicated engineering and operational successes. In Wyoming there was a 1:1 recovery ratio as every barrel of spacer and scavenger pumped displaced a barrel of OBM. The north Texas operators experienced full recovery of the OBM, improved bonding, a reduction in losses and higher cement tops.

Tables

1. Calculated Cost Savings (Wyoming Wells)

OBM (\$/bbl)	Scavenger (\$/bbl)	Scavenger Volume (bbls)	OBM Recovered (bbls)	Net Savings \$/well
\$135	\$50	200	200	\$17,000

Total Annual Savings \$1,360,000.00
(80 well program)

2. Example of Compatibility Testing (North Texas Wells)

BHCT = 132° F

RPM	100 Mud	75:25 Mud Spacer	50:50 Mud Spacer	25:75 Mud Spacer	100 Spacer
300	23	45	84	107	66
200	19	34	67	95	56
100	12	21	47	79	43
60	9	16	38	72	37
30	7	11	29	64	30
6	4.2	6.9	18.3	42.9	19.7
3	3.6	4.8	13.3	29.3	15.1

3. Fluid Rheologies (North Texas Wells)

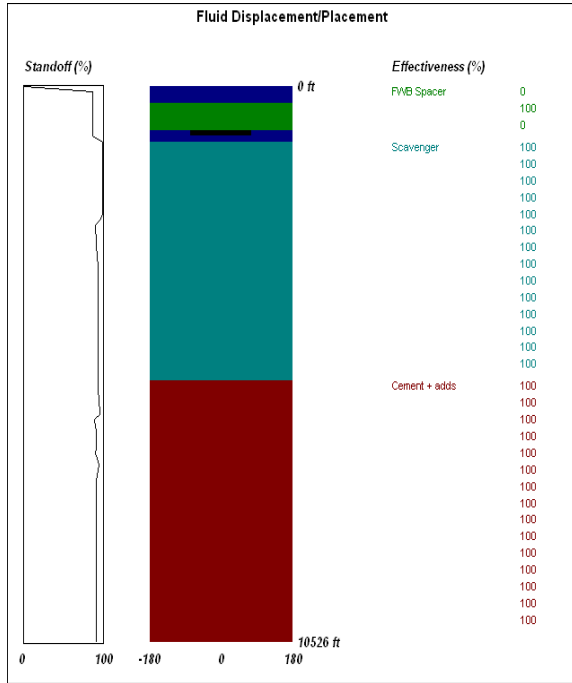
BHCT = 132° F

Fluid System	Viscosity @ 60 rpm	μ_{app} @ 65 sec^{-1}	μ_{app} @ 82 sec^{-1}
OBM	60	76	68
Spacer	90	97	89
Scavenger	90	144	121
Cement	105	191	165

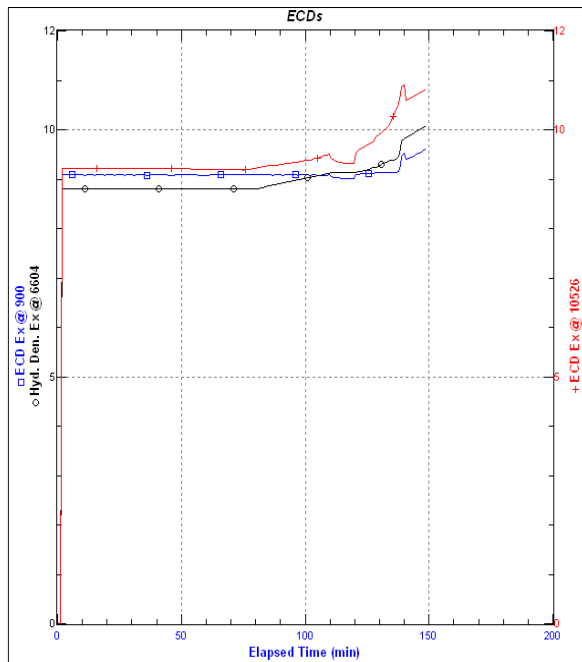
Graphics

The graphics below illustrate the modeling of the scavenger slurry pumped in the north Texas wells.

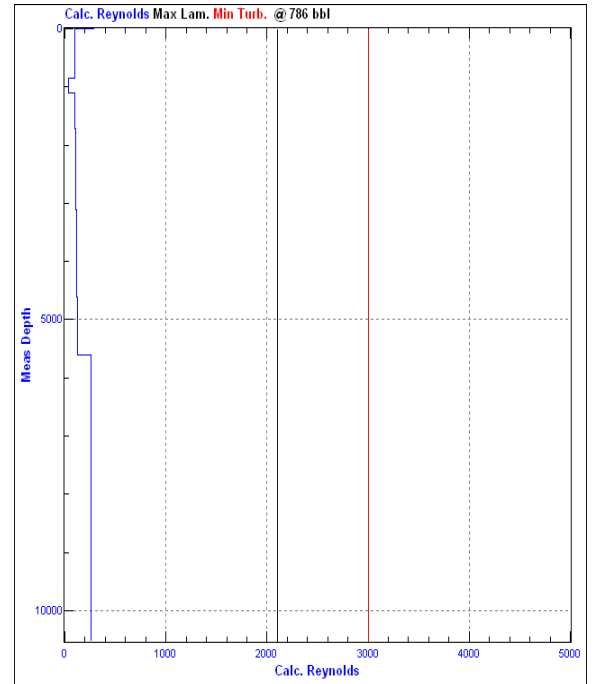
1. Modeling Output – Displacement Efficiency



2. Modeling Output – ECD's



3. Modeling Output – Flow Regimes



Conclusions

Operators can look for answers to drilling and completion challenges in yesterday's technology. Scavenger slurries are one example of recycling and improving upon vintage technology. These systems are still relevant if they are designed and implemented for success. The process doesn't have to be complicated but it should be engineered than just adding water to the lead slurry. Success arises from adherence to industry "Cementing Best Practices" for spacer design, modeling to optimize displacement efficiency and creating a dynamic plan that easily adapts to the changes in the well as drilling progresses.

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Nomenclature

- HSE = Health, Safety Environment
- OBM = Oil Based Mud, bbls
- ROP = Rate of Penetration, feet per hour or minute
- ECD = Equivalent Circulating Density, ppg
- MPD = Managed Pressure Drilling
- TOC = Top Of Cement, ft
- BPM = Barrels Per Minute
- LCM = Lost Circulation Material

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