



Evaluation and Selection of Drill-In and Completion Fluid Systems for Minimal Damage

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ABSTRACT

Design and use of the correct drilling and completion fluid is a critical aspect of maximizing well productivity. We also now realize the important impact the drill solids in the mud filtercake can have on productivity. This paper will review selected past references that cover various aspects of cake formation, their properties and effective removal, including a review of Session 5: Fluid Evaluation and Selection for Minimal Damage from the 2001 SPE European Formation Damage Symposium. Sections of this paper advocate taking new approaches to the development and selection of drill-in fluid materials, including the development of new invert-emulsion gravel pack carrier fluid. A different approach to the drill-in process to mitigate drill solid effects by using a pullback under-reamer concept, for selected applications, is suggested.

Introduction

Mitigation and minimization of production impairment remains extremely important in all types of completions; but a quote from Jacques Alfenore, SPE Distinguished Lecturer, in the June 2000 JPT provides focus for today's projects: "Delivering a high-productivity well is always a challenge for well-construction teams. The challenge is even greater when it concerns high-permeability sandstone produced through long, horizontal open hole wells. Deepwater prospects are promising in terms of oil production, but development will be economical only if large amounts of oil can be produced by a reduced number of wells. High productivity, with little scope for failures, is the key."

Previous literature (1) has focused on individual and overall aspects of drill-in and completion fluid performance aimed at both robust ability and damage minimization through improved design and components. A comprehensive publication by Hale, et al., (2) stated that an integrated multidisciplinary laboratory testing and field surveillance program is required to help ensure fluids that deliver adequate drilling and completion performance for horizontal wells drilled in the Gulf of

Mexico. From a drilling perspective, the primary issues addressed were drilling performance (rate of penetration, cuttings transport), depleted reservoir zones intermixed with overpressure shales, long shale intervals drilled during the build, resistance to cement contamination, high (>250 deg F) and low (<35 deg F) temperature, environmental compatibility, and unconsolidated high-permeability sands. Meeting all of these criteria would result in an extremely robust drill-in fluid system.

From a completion perspective, the primary issues were (and still are) fluid-loss control, maintenance of hole stability, shale control, prevention of formation damage and prevention of screen plugging.

Critical unresolved issues, when this paper was published, were:

- displacement techniques
- borehole stability (shale and reservoir)
- ability to slide
- development of water-based fluids with densities greater than 15 lb./gal
- synthetic/oil-based fluids with densities greater than 12.5 lb./gal
- effective, non-corrosive clean-up/stimulation chemicals and procedures for long, heterogeneous horizontal intervals
- ability to handle high overbalance for water-based drill-in fluids.

This checklist is still good today for areas where improvements are needed.

Another fundamental aspect that has not changed since stated in a paper by Ezzat (3) is that drill-in and completion fluid design should be based on a detailed study of the reservoir characteristics at the downhole conditions. There is no substitute for having both reservoir rock and fluid samples to conduct fluid sensitivity/compatibility studies.

The greatest enemy of all to damage free completions is the rock itself, i.e., drill solids. Fundamental work by Abrams (4) has been followed by later work to better define the issue (5). Bailey, et al., state that particulate invasion is one of the primary causes of formation damage from drilling fluids. During the initial stages of filter cake growth, particles are forced into the formation, building an internal filtercake that plugs the near-surface pores. Removal of this internal cake can be difficult and can lead to reduced permeability. The importance of minimizing internal filter cake is widely recognized. Most attention has focused on the selection of an appropriately sized agent to bridge across surface pores, thereby helping to minimize spurt loss (6). Better understanding of the properties of both the internal and external cake is needed for improvements in drill-in fluids.

Some selected conclusions from a statistical approach to help optimize drill-in fluid formulation (7) are given here.

- The filtration properties of drill-in fluids are independent of the formation permeability and the solid particle concentration **IF** (emphasis added) the particle size distribution is correct for the formation permeability.
- The type and concentration of the viscosifying polymer (Xanthan and scleroglucan in this case) are the factors that mainly influence the filtration properties and the cake permeability.

Another area of emphasis due to drilling long horizontal producing intervals in relatively unconsolidated formations is the interest in using synthetic oil-based fluids (SOBF) to enhance borehole stability when shale intervals are encountered. Since the industry has less experience using these types of drill-in fluids, their use raises a number of potential issues:

- fluid incompatibility/emulsions if water base completion or gravel pack carrier fluids are used
- possible loss of filtrate control due to low lift-off pressures of SOBF filter cakes under "swab" conditions
- potential to use SOBF as a gravel pack carrier fluid
- and the question of whether filter cake removal is necessary for SOBF

As to the latter question, some say "NO" to other than normal back-flow (8).

This "inconclusion" may be well suited to bring us to the "conclusion" that there is ample room for new data to advance our knowledge in how best to provide the most

productive well-bore possible. Design and use of the correct drilling and completion fluid is a critical aspect of maximizing well productivity. At the 2001 SPE European Formation Damage Conference, Session 5: Fluid Evaluation and Selection for Minimal Damage (Appendix 1) examined some mechanisms of formation damage by fluids and discussed effective fluid design.

DISCUSSION

Drill-In Fluid Selection: Simple or Complex

There is a temptation to wonder whether we are making drill-in fluid selection too complicated or too simple. When we do not put too robust a requirement on the drilling capability, the water base fluids are relatively simple - containing viscosifying and fluid loss polymers, acid or water soluble bridging/weight materials, water soluble salts and possibly a pH buffer. Filter cakes from these fluids can be easily "broken" **WHEN** we can contact them with appropriate solvents, oxidizers and/or enzymes. We can control fluid loss well **WHEN** we know the formation pore sizes and include properly sized bridging particles in the formulation. But How often do we drill homogeneous formations?

Unfortunately, all this can change **WHEN** drill-solids are present and **WHEN** our particle size distributions change, both due to drill-solids addition and size attrition of commercial-solids during drilling. To help overcome spurt loss our "internal filter cake" includes drill solids. Internal filter cakes are difficult to prevent and difficult to treat. In addition, high operating costs for offshore deep-water makes it even less desirable to do remedial treatments after the fact. So, it is recommended to put everything needed to break the filter cake in the drill-in and/or completion (including gravel pack carrier) fluids. However, we have to do this with the caveat that we need a controlled/delayed break of the filter cake to maintain fluid loss control during the completion (9). In addition, it is desirable to have non-corrosive remediation systems that will not damage our sand control screens.

And - what about using SOBF systems? **NOW** everything is more complicated, and we still have done nothing specific to mitigate the internal filter cake.

Mitigating Solids in the Filter Cake

With a conventional drilling approach little can be done to mitigate the build up of solids in the drill-in fluid other than dilution and attention to detail on the solids control equipment. The continual flow of the drill solids laden fluid past the drilled borehole will continue to build solids content in the filter cake.

Allen Gault, Conoco Inc., has proposed an approach, and tested it once in the field that may be a solution in many instances. It is to use a "pull-back under-reamer" and open a pilot hole from the "bottom-up". This approach is a completion technique that has application in open hole gravel packs or in horizontal wells to remove a cuttings bed. This operation involves enlarging a pilot hole from the bottom up. It requires that the drilling/completion rig have a top drive system. When opening the hole from the bottom-up, drilled solids are circulated away from the newly opened hole. Cuttings transport is made easier because they are transported in a narrow annulus. Thus, the newly deposited filter cake only contains those agents used in preparing the "drill in fluid". Without the incorporation of drilled solids in the filter cake, the breaking of the filter cake is more likely to be successful.

Pull Back Under-Reamer Application

In 1995, a team composed of Allen Gault, Bob Burton and Steve Bolt, Conoco Inc. Technology, developed a method to improve well production at Milne Point, Alaska. A unique process for recompletion was undertaken with excellent results. The basis of the process was to use a non-damaging, particulate-free completion fluid. This fluid was used in combination with a hole-opening process that did not introduce fines into the productive interval. In short, fines were not mixed with the gravel pack. The non-damaging fluid was clear, clean, produced brine from the field. The fact that the oil in the reservoir was low gravity and the fact that the drilling fluid was relatively cold lead to effective fluid loss control. Since Alaska is normally cold, surface cooling was used.

The means of reducing the introduction of fines was accomplished as follows:

- Pulling the existing completion
- Milling a window and low siding the well
- Drilling a 6-in. pilot hole with drilling mud, thus laying a filtercake
- Pulling out of the hole and installing a section mill (fishing tool)
- Running back to bottom, displacing the mud with brine
- Dropping the ball to activate the section mill
- Enlarging the hole from 6-in. to 12-in. using clear, cold brine

This procedure accomplished the objective of not introducing fines into the enlarged face of the formation .

The cuttings were transported from the section mill upward into the smaller annulus; thus, high velocity was maintained to transport the sand. Fines were not continuously circulated past any of the formation that was to be gravel packed. Also, by pulling on the pipe, the danger of side tracking was completely eliminated.

The process was simple and executed without any significant trouble other than that one of the blades of the section mill being lost. However, the well was completed with a screen and gravel packed without any problems. This well became one of the best producers in the field. A need for a true drilling tool is needed and elimination of an extra trip is highly desirable. Halliburton's Security DBS product service line now has a tool that can be adapted such that the pull back under reaming can be done in a one step process - drilling and under-reaming in a single stage.

A DIFFERENT APPROACH

Our conventional approach in the past has been to adapt available materials to a new application - then improve as we gain experience. Have we gained enough experience with drill-in fluids that we should be looking for entirely new materials? Conceptually, we would design fit-for-purpose materials for which we already had a means to break, or remove, the filter cake once the completion is in place. This approach contrasts with the more conventional approach of designing a remediation job for the available materials.

As an example, we can examine the use of calcium carbonate as our bridging and weight material. It is acid soluble, so we have a means to remove it from the filter cake. On the other hand, its specific gravity of 2.6 limits our ability to use a centrifuge to remove drill solids since their specific gravity is also a nominal 2.6. Non-acid solvents such as EDTA can also be used to remove calcium carbonate from the filter cake - but a considerable amount of EDTA is required due to its high molecular weight.

Zinc oxide and magnesium oxide are examples of materials that are soluble in non-acid, ammonium chloride and have specific gravities (SG) different from the drill solids. Environmental concerns may rule out zinc oxide - but magnesium oxide or other similar minerals may have potential to provide a bridging or weight material with better qualities for application to drill-in fluids.

Some of the desirable properties we would look for in desirable particles would be:

- hardness - maintain particle size distribution

- density - differentiate from sand/shale (2.6 sg)
- low sg for bridging
- high sg for weight
- minimized clean-up chemical requirement
- solubility - non-mineral acids or chelating solutions.

Attributes of a "clean-up" material would be:

- non-corrosive to screens
- delayed reaction (typically 6-24 hours)
- low molecular weight
- delivered with the fluid system
- reasonably easy to handle.

Other Aspects of the Completion System

Invert-Emulsion Gravel Pack Carrier Fluid

Until recently, horizontal wells drilled with an invert-emulsion fluid were still gravel packed with completion brine as the carrier. The industry's perception is that displacing from an invert-emulsion system to completion brine can impact productivity adversely because of one of the following factors:

- incompatibility of drilling fluid with completion fluid
- formation incompatibilities
- formation of precipitates
- potential for creating a sludge/emulsion.

While this adverse impact may be avoided by using good displacement techniques and protocols, an associated risk still exists. Insufficient data could cause the wrong completion brine selection, which could lead to excessive hole enlargement or hole collapse, ultimately compromising the gravel-pack. A compromised gravel-pack could lead to the failure of the gravel-pack screen, requiring recompletion or redrilling the well.

Halliburton's Baroid product service line has recently developed a new invert-emulsion gravel pack carrier fluid (IGPF) that can overcome the challenges listed above. Operators now have an option other than water base brines for completing wells after they have been drilled with invert-emulsion drilling fluids. With the IGPF system, operators can displace their invert-emulsion drilling fluid system to an invert-emulsion completion

fluid, which is then used for gravel-packing the well. According to our tests, this fluid is expected to be compatible with both the displaced drilling fluid and with the zone being completed. The invert-emulsion system is an integral part of the drilling and completion package, which can provide better productivity results.

Design work was conducted by Halliburton to help validate the new system. The test program consisted of evaluating regained permeability and filter cake erodability, and testing -- on a gravel-pack simulator loop -- to help determine the effectiveness of the fluid as a gravel carrier. SPE 71669 describes the testing protocol and fluid design (9). This paper also describes fluid properties of the new fluid as a gravel-carrier fluid compared to the properties of conventional brines used as gravel carrier fluids.

The primary challenge was to design an invert-emulsion system with high density but without adding typical weighting agents/solids. Additionally, for horizontal wells, the system needed to have low rheological properties to generate the required alpha/beta waves for gravel packing. Several of the primary developmental goals were:

- high density invert-emulsion without solids
- stable emulsion with minimal emulsifier
- passive emulsifier, minimizing wettability concerns
- filterability of the invert-emulsion while gravel packing
- low rheological properties for the generation of the alpha/beta wave
- compatible with invert-emulsion drilling fluids
- compatible with reservoir fluids.

As noted previously, the system was designed for low rheology. If required, the rheology can be increased by modifying the product mix or by adding polymers that are compatible with the system.

REFERENCES

1: No comprehensive attempt was made to survey all literature in this area. These are selected/example papers.

2: Hale, Arthur H., et al. "Selection and Qualification of Drill-In Fluids for Horizontal Wells in Unconsolidated Sands," SPE 37077, 1998 International Conference on Horizontal Well Technology held in Calgary, 18 Nov 1996.

3ⁱ Ezzat, A. M., "Completion Fluids Design Criteria and Current Technology Weaknesses," SPE 19434 presented at the SPE Formation Damage Control Symposium in Lafayette, LA, 22-23 Feb 1990.

4ⁱ Abrams, A., "Mud Design to Minimize Rock Impairment Due to Particle Invasion," JPT, PP 586-592, May 1977.

5ⁱ Bailey, L., et al., "Particulate Invasion from Drilling Fluids," SPE 54762 presented at the SPE European Damage Conference, The Hague, 31 May-1 June 1999. (Later published as SPE 67853, SPEJ, Dec 2000.)

6ⁱ Dick, M. A., et al., "Optimizing the Selection of Bridging Particles for Reservoir Drilling Fluids," SPE 58793, SPE International Symposium on Formation Damage, Lafayette, LA, 23-24 Feb 2000.

7ⁱ Cobianco, S., "How to Manage Drill-In Composition to Minimize Fluid Losses During Drilling Operations," SPE/IADC 57581, SPE/IADC Middle East Drilling Technology Conference, Abu Dhabi, 8-10 Nov 1999.

8ⁱ Davison, J. M., "Oil-based Muds for Reservoir Drilling: Their Performance and Clean-up Characteristics," SPE 58798, International Symposium on Formation Damage, Lafayette, LA, Feb 2000.

9ⁱ Todd, B and Powell, R., "Delayed Breakers for Horizontal Well Cleanup", AADE 2001 National Drilling Conference, Houston, TX, 27-29 March.

10ⁱ Donaldson, A., et al., "Invert Gravel Pack Carrier Fluid", SPE 71669, 2001 SPE Annual Technical Conference and Exhibition, New Orleans, LA, 30 Sept-3 Oct 2001.

Appendix 1

2001 SPE European Formation Damage Conference Session 5: Fluid Evaluation and Selection for Minimal Damage

There were five papers and eight posters in this session that covered wide ranges of topics that include:

- planning
- laboratory evaluation
- new systems
- applications
- basic understanding

Papers

SPE 68957

E-Methodology for Selection of Wellbore Cleanup Techniques in Open-Hole Horizontal Completions, S. Mason, et al., Schlumberger.

How to take a systematic approach to clean-up method selection.

SPE 68958

Addressing the Issue of Mud Cake Cleanup Open Hole Gravel Packed Sea Water Injection Wells, S. Cooper, et al., bp.

Lab data conclude both a chemical stimulation package with the gravel pack and backflow is required for injector wells.

SPE 68959

Use of Oil Based Reservoir Drilling Fluids in Open Hole Horizontal Gravel Packed Completions: Damage Mechanisms and How to Avoid Them, H. K. J. Ladva, et al., Schlumberger.

Recommendations on how to avoid damage in wells drilled with an oil-based drill-in fluid.

SPE 68960

Development and Application of Surfactant Based Systems for Treatment of Wells Drilled with OBM, C. Giard-Blanchard, et al., Institut Francais du Petrole.

How to treat wells drilled with an oil-based drill-in fluid with an oil-based surfactant system to mitigate production impairment.

SPE 68962

In-depth Permeability Damage by Particle Deposition at

High Flow Rates, J. Veerapen, et al., Institut Francais du Petrole.

A theoretical study provides practical conclusions to prevent injectivity damage in non-fractured reservoirs.

Posters

SPE 68963

A Novel Approach for Evaluation of Calcium Carbonate Scale Formation and Inhibition, N. Kohler, et al., Institut Francais du Petrole.

How to determine minimum concentrations of calcium carbonate scale inhibitors.

SPE 68964

Strategies for Sizing Particles in Drill-In and Completion Fluids, A. Suri, et al., U. of Texas at Austin.

Polymers and drill solids are the problem for production impairment; How to size solids to minimize secondary invasion.

SPE 68965

Development of New Biopolymer-Free, Low Solids, High Density Reservoir Drilling Fluid, R. Horton, et al., M-I.

New bio-polymer free and minimum solids containing water-based drill-in fluid.

SPE 68966

Filtrate Invasion, Barite "Sag" and Grain Crushing by Cutter Impact Experimental Wellbore Damage, R. Crossley, et al., Robertson Research International.

Full Scale "laboratory" coring study provide implications for field applications.

SPE 68968

Laboratory Device for Testing of Delayed Breaker Solutions on Horizontal Wellbore Filtercakes, B. Todd, et al., Halliburton Energy Services.

Modified equipment aids how to evaluate delayed filter cake breakers.

SPE 68969

Optimising Gravel Pack Performance in a High Rate Gas Development, R. Watson, et al., Corex (UK).

Laboratory study investigates design phases of open hole gravel pack completion.

SPE 70757

Field Test of Novel Drill-In Fluid Clean-Up Technique, R. C. Burton, et al., Conoco.

Enzyme/EDTA/free radical generator provides controlled/long term filter cake degradation.

SPE 68970

Integration of Reservoir Engineering and Production Chemistry for Optimization of Scale Inhibitor Squeeze Design, E. J. Mackay, Heriot Watt University.

Integrated full field reservoir with simple near-well squeeze simulation minimizes scale control risk.