

‘Drill-In’ Fluids and Drilling Practices Drilling More Productive, Less Costly Geothermal Wells

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ABSTRACT

GRC presentations on drilling fluids and formation damage was presented in 2007 and 2010. This current paper exists as an update, and introduces some of the recent developments in geothermal drilling fluids and drilling practices, with specific emphasis on minimizing formation damage and optimizing well producibility. During the past numerous years since the previous paper presentations, mud additives and drilling operations have evolved, and geothermal drilling fluids programs have typically moved away from the conventional hi-temp claybased systems of the past, in favor of minimally-damaging ‘Drill-In’ fluids. These new fluids use little or no Bentonite and conventional LCM, providing benefits which may include enhanced lubricity, superior wellbore stability and inhibition, reduced potential for formation damage, and reduced stimulation requirements.

Recent Geothermal Drilling Fluids and Drilling Operations Advancements

Non-damaging fluids rheology modifiers (viscosifiers, suspension agents)

Non-damaging sweep additives

Use of inhibitive base fluids (supported with lab/field testing)

Applied Hydraulics

Increased mud pump (circulating) capacity

Brief History of Geothermal Drilling Fluids

As the renewable energy industry ‘gained steam’ and interest during the Arab Oil Embargo of the late ‘70s and early ‘80s, many large O&G companies (Chevron, Unocal, Mobil, Phillips, Occidental, etc) attempted a diversification into the geothermal industry. They brought conventional O&G drilling technologies and drilling fluids, and implemented limited research on high temp drilling fluids systems for this new application. Unocal Research in Brea was one of the most renowned of these, and implemented significant ‘prequalification testing’ of drilling fluids for use at their geothermal leases at the Salton Sea and the Geysers. The typical claybased geothermal drilling fluids systems were costly, prone to high temperature gelation and wallcake buildup, yet generally gave very good hole cleaning and stability characteristics.

The major oil companies (excepting one Major in the international market) left the geothermal industry by the early 1990s, replaced by a number of independent renewable Operators who focused more intensely on field development and cost containment. So, during this period (1990s to early 2000s) there was an emphasis on improved drilling operations, including the use of better SCE (Solids Control Equipment), high temp polymers used in mud systems, the expansion of underbalanced drilling techniques, use of aerated drilling, and other developments.

Since ~2000, many Operators began investigating lower temp (230-300°F) geothermal opportunities, especially in the domestic US; this soon led to marginal projects and concern of wellbore stability and formation damage issues associated with reactive clays and shales. Many other Operators on large scale, high temp projects found that well production appeared to be compromised when damaged by high volumes of conventional claybased muds and LCM (lost circulation materials).

This led to the development of the currently applied, 'low-clay' or 'clay-free' minimally damaging 'Drill-In' fluids, utilizing viscous sweeps and new operational considerations. Some of these operational changes include underbalanced drilling, high volume pumping/circulating to remove drilled fines, the use of non-damaging additives, circulating the reserve pit for settling, the use of inhibitive brines, and other considerations. Although these technical developments have paralleled similar trends in the O&G industry, the nature of geothermal drilling and the resources has required specific fluids technology be developed to provide wellbore protection stability, and inhibition.

Current Geothermal Drilling Operations and Drilling Fluids

Today's geothermal drilling activities generally utilize conventional rotary drilling methods, incorporating state-of-the-art directional and hydraulics technologies and other innovations. Surface hole is drilled to (or near) the top of the target interval, where protective casing is run in anticipation of drilling the production zone. Directional drilling is often used to target specific bottom hole locations, and a typical completed geothermal producer will have 9 5/8" slotted liner or barefoot completion in a final 12 1/4" hole size, or 7" slotted liner or barefoot completion in a final 9 7/8" or 8 3/4" hole size. These upper hole intervals, which are eventually protected by casing, are normally drilled using a simple claybased mud system, using bentonite clay as the base and specialized polymers and/or lignites for control of fluid loss, rheology, and hole cleaning, and temperature stable lubricants and other additives to promote good hole stability. Conventional LCM is utilized to control any whole mud losses to a minimum.

Through the production interval, the goal is to provide good wellbore stability and inhibition while minimizing the possibility of formation damage from the mud additives. Depending upon the actual lithology of the drilled formations, the use of clay/bentonite and other potentially damaging additives may be discontinued, and only temperature-degradable or acid-soluble materials are recommended in the designed 'Drill-In' fluid. In the case where additional formation protection is required, sensitivity tests may be undertaken, to determine the most inhibitive base fluid formulation for any specific formation. CST (Capillary Suction Time) and Sensitivity Test results may indicate that any of the following may be applicable base fluids to inhibit potential swelling of hydratable formations (3-10% KCl, 3-10% CaCl₂, lease/formation water, freshwater with K-Sub Inhibitor, etc).

It is often possible (and desirable) to drill a production interval underbalanced, using water/air/foam as the circulating medium, either in fresh water or an inhibited fluid base. Air is introduced via compressors, either injecting directly into the drill string or through a parasite string set at a predetermined depth. The fluid phase of this operation is treated with PH adjusters and corrosion inhibitors to assist with corrosion protection, as well as with foamers to enhance cuttings removal from the wellbore. Penetration rates are generally significantly increased when using this underbalanced drilling method, when compared to conventional drilling.

Geothermal Formation Damage Mechanisms

Damage mechanisms will vary from area to area, as well as formation to formation within a particular well and at varying temperatures. Specific damage mechanisms may include fracture plugging from poorly removed drill cuttings and drilling mud (clay, LCM, non-degradable additives), cement plugs, significant loss of mud and cuttings into permeable (production/injection) zones, interstitial clay swelling and possible microfracture plugging if using non-inhibitive drilling fluids, commingling of incompatible waters with formation waters and mineralogy, fines migration deep into fracture systems, and others.

Mechanical Damage – Operational changes and new drilling practices will help reduce the occurrence and severity of potential damage from mechanical plugging, including the following innovations: the use of high volume circulating pumps (sometimes as many as three 1,000hp+ pumps in tandem, circulating drilling fluids at rates >1500gpm); avoiding the use of Gel, conventional LCM, and other materials that might leave residual degradation byproducts in the formation; the use of non-damaging sweep materials to provide temporary plugging and effectively remove cuttings; the implementation of large surface volume pits (and reserve pits) to extend cuttings settling time; the use of water/air/foam and other minimally-damaging 'Drill-In' systems; the implementation of superior SCE (Solids Control Equipment) for effective drilled solids removal.

Chemical/Reactivity Damage - Laboratory analysis and testing can be performed to identify specific mineralogy and sensitivity (swelling/hydration) tendencies of various drilling fluids. If core samples and/or representative drill cuttings are available from a project, SEM analysis, Sensitivity tests, CST (capillary suction time) analysis, and other

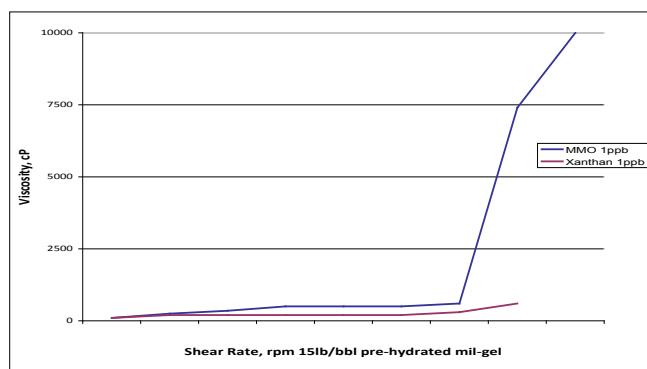
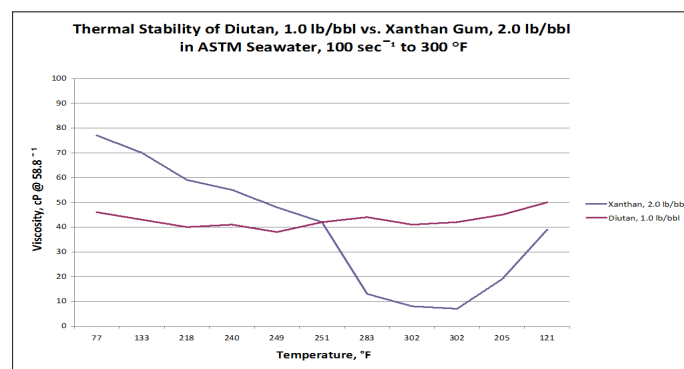
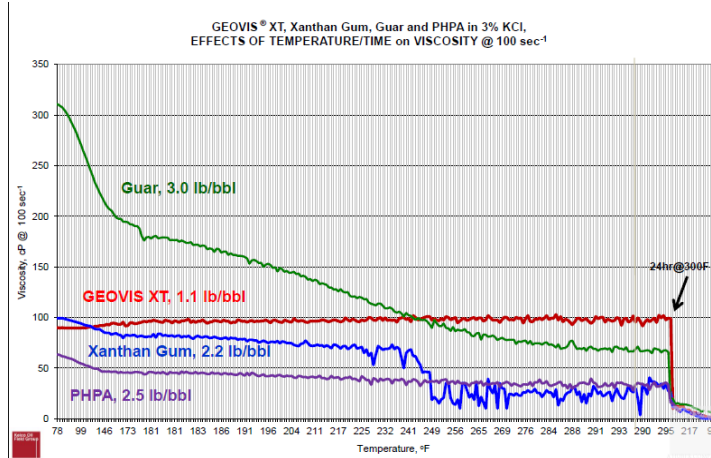
testing can be performed. The type of reactive clays present may also be important, as although K⁺ ion inhibition will stabilize mixed layer clays and illites, K⁺ ions can actually destabilize inactive kaolinite into active, swelling illites. Effectively planned and analyzed tests can provide the Operator with a good indicator as to the type of formation damage that might be expected, a comparison of different mud system types and their respective levels of inhibition for a particular geothermal site and formation, and result in a proper, inhibitive 'Drill-In' fluid selection for the specific project.

Drill-In Fluid Viscosity, Rheology

Polymer Rheology Modifiers - Viscosity control in geothermal 'Drill-In' fluids includes the concept of increasing and decreasing viscosity and yield point, apparent viscosity, and control of high temperature gelation. High annular velocities and fluid/sweep viscosity are crucial characteristics of geothermal drilling fluids to promote good hole cleaning and reduce potential problems such as surge and swab pressures, excessive buildup of wallcake, differential sticking tendencies, lost circulation, and other potential problems.

Current polymer technology for viscous sweeps in Geothermal fluids includes the use of Xanthan Gum, Guar Gum, Diutan Polymer (Xanthan Gum on steroids), MMO/MMH, and PHPA. These polymer-based additives are especially useful as (regularly circulated) high viscosity sweeps, to enhance existing drilling fluids' carrying capacity and Yield Point, and for use in creating low solids non-damaging geothermal drilling and workover fluids. In the case of Xanthan Gum, Diutan, and MMO/MMH, these are all considered LSRV (low shear rate viscosity) polymers, therefore they extend superior suspension properties at low flow rates. All of the above polymers show virtually total degradation over extended time at 300°F, reducing the potential for formation damage from polymer residue.

Mechanical Rheology Modifiers/Hole Sweeps – Various mechanical sweep materials have been used in the past to assist with the polymer sweeps (Sawdust, Micro-C, Calcium Carbonate, MagmaFiber, etc). However, most either must



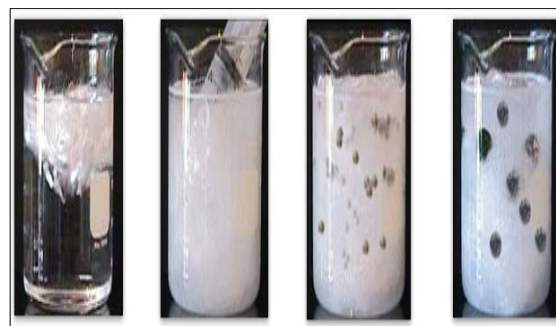
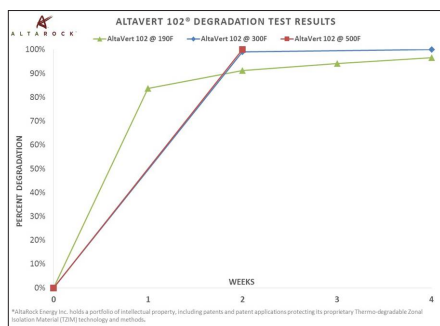
be acidized for full removal, or presumed to be degradable over time by temperature.

AltaVert 102®, a new generation fibrous sweep additive, provides excellent mechanical carrying capacity and hole cleaning in low concentrations, and is compatible with water, brine, aerated and inhibited systems. A secondary benefit is that it performs well as a *temporary* bridging agent/LCM, allowing drilling to proceed through loss/production intervals; then, the product degrades totally in around 2-4 weeks at BHT >190°F, thus returning the affected zone to near original permeability levels.

Optimized Hydraulics

'Significant reductions in drilling time and well costs can be realized by implementing an effective hydraulics program'

Effective drilling hydraulics include the consideration of jet nozzle selection to maximize HHP at the bit, proper bit and jet configuration to ensure the bit is being swept clean by the jetting action, proper drilling fluids rheology (water and/or LSRV fluids with regular sweeps to clean cuttings from the bit area), proper use of fluid aeration, and optimizing mud



pumps. Since most producing geothermal wells are completed in 12 1/4" hole size (barefoot or 9 5/8" liner completion), a combination of three 1,000 hp triplex pumps may be required to adequately clean the hole (washouts are not generally a major problem in geothermal operations through the production interval, as washouts create additional downhole surface area for heat transfer). Pre-planning of the rig circulating pumps and hydraulics can provide significant enhancement of the drilling operation, including improved hole cleaning and ROP.

SCE, Drilled Solids Removal

Removing contaminating drilled solids is an important consideration in maintaining good drilling fluid properties and minimizing formation plugging. Solids control/removal equipment (SCE) will generally consist of dual or triple high G-force linear shakers, followed by a hydrocyclone desilter/mud cleaner, and complemented with a high volume centrifuge to remove ultrafines from the drilling fluid. A mud 'cooler' is often included in the configuration, which can reduce the circulating temperature of the recirculated drilling fluid significantly. Where possible, it is often standard procedure to circulate returns from the well through a large volume reserve pit, thereby allowing significantly more time for settling of fines and for mud cooling. In addition, an appropriate total flocculent may be used in the reserve pit, to enhance settling (and avoid recirculation) of low gravity fine drill solids.

Deep migration of ultrafines create significant issues in O&G and Waterwell drilling operations, and it can be assumed that this mechanical damage is also present in the highly permeable geothermal zones.



Corrosion

Considerations of corrosion rates and treatment must also be an important factor in geothermal drilling fluids selection, as the low- to mid-salinity 'drill-in' systems and formation water are generally highly corrosive to drilling tubulars and tooling, especially in the presence of high temperature and aeration. Corrosion coupons should be run regularly and analyzed both quantitatively and qualitatively, and a prescribed corrosion control treatment implemented to maintain corrosion rates less than ~4 #/sqft/yr. A water/mud pH of 9.5-10.0 is generally recommended to assist with corrosion protection, and higher pH may be required if H₂S is present.

Various corrosion additives, including oxygen scavengers, general polyphosphonate inhibitors, film-forming amine compounds and others are highly effective in controlling corrosion to acceptable levels, IF treatment rates are determined and adjusted based on field observations and rig-site corrosion coupon analysis. Treatment rates can vary widely based on actual conditions and operational considerations.

The use of the freshwater 'Drill-In' system with an appropriate (K-Sub) inhibitor will provide formation protection while also performing a secondary function as a high temp corrosion inhibitor, thereby minimizing corrosion treatment costs.

Drilling Fluids Lubricity - Lubricity is a significant issue affecting geothermal wells, especially during the implementation of directional drilling or redrilling programs, or during workover operations in existing holes. This is very important when drilling with water; very few lubricity additives have been time-proven (with sufficient laboratory and field success) to provide reliable lubricity in high temperature drilling operations.

TORKease^[5] is an environmentally friendly, non-hydrocarbon and non-damaging lubricant that has been in use in the geothermal industry since the mid-1970s. A modified potassium (K+) based lubricant, TORKease exhibits excellent temperature stability (>650°F, 343°C), is non-damaging, and has proven itself in geothermal drilling and workover operations worldwide.

Biodiesel/B-99 vegetable oil is also an accepted lubricant for geothermal operations, occasionally used as a spotting fluid and then incorporated into the active mud system. An effective concentration of .5-1.5% by volume is generally maintained in severe conditions, and B-99 generally provides very good metal/metal lubricity.

Methods for Correcting/Reversing Geothermal Formation Damage

Various techniques have been offered for reversing geothermal formation damage, and/or for increasing permeability in geothermal fracture systems. Included among these are EGS (hydro-shearing/displacement of inherent and nearby fracture systems), Deflagration (use of a wireline conveyed proppant charge to create auxiliary permeability and extend existing fracture systems), conventional acidizing, long-term injection of high volumes of water, and others. The success of these 'damage reversal' mechanisms, as expected, varies significantly from field to field.

Conclusions

The recent focus on minimizing induced formation damage in geothermal wells (while drilling) has led the geothermal industry to new drilling technologies and the design of clay-free 'Drill-In' systems. The implementation of a well-designed drilling program, utilizing current state-of-the-art technologies, optimized hydraulics, underbalanced drilling where possible, non-damaging polymers and bridging/sweep agents, and a lab-tested inhibitive 'Drill-In' fluids system, should provide more productive wells, in addition to a significant reduction in drilling times and trouble costs, and significant direct cost savings.

The focus of applying this new technology is to MINIMIZE drilling-related formation damage, so that the resulting wells can provide maximum productivity.

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