

Influence of Mud Properties by Microbial Contaminates of an Environmentally Friendly Water-Based Mud System

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Abstract

Oil exploration has, by any criterion, changed significantly over the last several decades. The operators' struggle to balance cost with environmental regulations has driven the increasing use of guidelines and products designed to inflict minimal or no harm on the environment. Many of the drilling fluid additives used today are derived from natural sources or are synthetics proven to be biodegradable. While the use of biodegradable products addresses the environmental issues it can stimulate bacterial growth by adding a carbon source to the drilling fluid system. If unmitigated, bacterial growth can cause increased costs and damage to drilling fluid performance and overall well production.

This study examines the fluid properties and microbial load throughout the course of several weeks of samples from an environmentally friendly water-based drilling fluid system (Maxim-100, Conquest Drilling Fluids, Conroe, TX) with and without treatment with biocide. In the study, bacterial load rapidly increased and the drilling fluid was quickly degraded and rendered unacceptable for use unless biocide was present. Although bacterial load in a typical drilling fluid system in the field could be kept to a minimum by jetting and replacing contaminated fluid, the authors recommend using a proactive approach by treatment with biocide. This would prevent any biodegradation of drilling fluid components and thereby minimize the overall cost and maximize the ease of reaching the drilling objective.

Introduction

The physical and chemical reactions that can potentially cause damage to oilfield and gas reservoirs and equipment are very well understood. This is in contrast to the potential effects microorganisms can have on oilfield operations. Microorganisms are by far the most abundant life form on the planet and, through their vast numbers, have the ability to drive biogeochemical reactions on a global scale. Despite this fact, there is relatively little understanding on their potential effects on oilfield operations.

Most of the knowledge on the importance of microorganisms in oilfield operations comes from studies performed on wells after drilling operations have ceased. It is accepted that sulfate reducing bacteria (SRB), acid producing bacteria (APB) as well as some general heterotrophic bacteria

(GHB) can cause complications to producing and injection wells. Sulfate reducing bacteria have the ability to obtain energy from organic molecules or molecular hydrogen while reducing sulfate (SO_4^{-2}) into hydrogen sulfide (H_2S) during anaerobic respiration. Biogenic production of H_2S by SRBs can cause significant problems for production due to corrosion of equipment, plugging of formation and equipment by precipitation of amorphous ferrous sulfide as well as increased risks to health and safety due to the flammable and poisonous nature of H_2S gas (1-3). Under the same conditions that SRBs operate, APB can also begin to oxidize organic molecules releasing acidic short chain fatty acids or other products that can also be highly corrosive. In addition to the complications caused by growth of SRB and APB, general heterotrophic bacteria can result in polymer degradation and production of CO_2 which can further aid the corrosion process (4). Although GHB require oxygen to become active, they can multiply quickly under ideal conditions and cause serious problems with well conductivity. Microorganisms have been shown to penetrate rock formations along with injection water and have resulted in the loss of permeability which can cause a loss of production capacity long before reservoir depletion (5, 6).

The potential for dramatic increases in the cost of oil and gas recovery and processing due to microbial activity has led to research into the source of bacterial contamination. Although some studies have suggested that indigenous bacteria play the major part in biogenic souring and plugging of wells (7), the consensus now is that both native microorganisms and those introduced to the formation by drilling operations, hydraulic fracturing (fracing) and injection wells are important (1, 4, 8). It is imperative to understand more about the populations of microorganisms found associated with oilfield operations in order to mitigate future damages. It is widely accepted that biogenic souring of reservoirs in the North Sea, Saudi Arabia and Barnett Shale has cost hundreds of millions of dollars to date (1, 9, 10). There is evidence to support the supposition that the souring of entire fields of oil and gas wells has occurred by microbial contamination of new wells by reusing fracing and drilling fluid containing high concentrations of microorganisms (1, 10).

Despite all of the research being performed on the impact of microorganisms after drilling operations are

finished, the initial source of contamination of the well is by microorganisms in the drilling fluid. Drilling fluids are used during drilling operations to suspend and remove cuttings from the well, cool and lubricate the bit in addition to helping control the integrity of the wellbore. Due to increasing environmental regulations, the use of biodegradable products to perform the vital functions of drilling fluid are becoming more common. These drilling fluid additives include a combination of natural polymers such as starch, guar gum and xanthan gum as well as semi-synthetic polymers such as carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC) and polyacrylates synthesized by chemical modifications of naturally occurring polymers. By their very nature of being biodegradable, these fluid additives can act as a carbon source for microorganisms (8, 11, 12). There are numerous studies identifying the growth of bacteria in live drilling fluids (8, 10, 13) with the results of one study showing on average 4.1×10^6 culturable aerobic heterotrophs per ml of fluid (8). It would be impossible for drilling operations as we currently know them to operate under sterile conditions because of the inherent potential sources of contamination starting from the makeup water and the drilling fluid additives themselves. Other potential sources of contamination include direct contact with the formation, windblown dust and contact with humans. It is estimated that there are as many as 10^6 microorganisms per ml of fresh water, commonly used to make up the drilling fluid, as well as 2.0×10^9 microorganisms per gram of soil (14). Not every microorganism encountered will necessarily grow or thrive in the conditions existing in drilling fluid, but the warm temperatures, nutrient rich components and high oxygen content due to mixing and solids removal equipment generally creates conditions conducive for survival. Many drilling fluid programs ignore the potential of bacterial growth or rely on factors such as high dissolved solids, high pH or high temperatures to control microorganisms which may give a false sense of security. Microorganisms can grow in nearly every environment on Earth no matter how harsh including pH levels from 1 to 14 and temperatures from -20°C to 121°C (15, 16) and studies have identified activity by microorganisms in drilling fluids above pH of 11 (10), 50 lbs/bbl brine (10) and temperatures up to 95°C (13).

In addition to the potential negative effects of microorganisms left behind after drilling activities have ceased, some studies have suggested mechanisms by which biological activity can directly affect the properties of drilling fluids (17). The excretion of metabolic wastes by microorganisms can indirectly influence the properties of drilling fluids. These wastes can include CO_2 , organic acids, short chain fatty acids as well as H_2S which can all have serious negative effects including loss of pH and subsequent changes in viscosity and consistency. Microorganisms can also have direct effects on the drilling fluid by metabolizing drilling fluid components. Nearly every organic molecule known to man can be digested by microorganisms including the drilling fluid additives used to provide viscosity, fluid loss control, and lubricity. As those constituents are consumed the

benefits they provide are also lost. Furthermore, because many of these components consist of long organic chains, breaking them at even a few places can reduce the overall performance characteristic substantially (11). Despite the general agreement that microorganisms can degrade drilling fluids, there are no studies quantifying how quickly or to what extent the characteristics of the fluid can be affected and what actions would be required to restore fluid properties.

Biocides are generally considered the best solution to control microbial growth. A suitable biocide should be effective against a wide variety of microorganisms, be compatible with the chemistry of the drilling fluid and be effective at low dosages allowing it to be economical. Because microbial activity can cause costly damages to drilling fluids as well as permanently contaminate the formation, control of bacteria should take place from the start of drilling operations and throughout the lifetime of the well. With a wide variety of biocides available, in addition to extreme differences in drilling fluid formulations and well conditions, a biocide should be evaluated before implementation into a drilling program.

The objectives of this study then were to:

- Examine to suitability of the CQ Bio-24 biocide for use in the Maxim-100 Mud System.
- Quantify the amount of GHB growing in the drilling fluid over a period of 28 days.
- Optimize the dosage of biocide for the system.
- Quantify the damage to fluid properties caused by microbial activity.

Materials and Methods

Testing procedures were performed on the Maxim-100 polymer mud system (Conquest Drilling Fluids, Conroe, TX). Maxim 100 is a biodegradable, water based conventional polymer drilling fluid utilizing several biodegradable additives including ViChem C-300 (ViChem Specialty Chemicals LLC, Conroe, TX) polyacrylate polymer and ViChem L-10 Lubricant, an organic based vegetable oil.

CQ Bio-24 biocide (Conquest Drilling Fluids) was selected because of its broad kill spectrum, acting on both aerobic and anaerobic bacteria including SRB, APB and GHB as well as fungi and bacteria known to form biofilms. CQ Bio 24 also has long term effectiveness and performs under high temperatures and pressures while not significantly affecting the properties of the drilling fluid.

The drilling fluid was assembled and allowed to fully hydrate before proceeding. The prepared drilling fluid was then separated into five aliquots including a control (no biocide), and four treatments containing 200 ppm, 500 ppm, 1000 ppm, and 2000 ppm biocide. All samples were then allowed to incubate in pre-sterilized containers at 37°C for 28 days.

Samples were taken from the control and each of the treatments before incubation (day 0) and at days 1, 2, 3, 7, 10, 14, 21 and 28. Drilling fluid properties (lubricity, API filtrate, pH and yield point) were obtained for the control and each of

the treatments at each sampling event (18). An aliquot of each sample was also serially diluted and subjected to a standard plate count using LB agar plates (Teknova, Hollister, CA) incubated at 37°C for a minimum of 24 hours to determine the number of GHB colony forming units (CFU).

After determining the fluid properties of samples taken from the control at days 1, 2, 3, 7, 14 and 28, the fluid was treated with additional product to approximate the original condition of the drilling fluid. The drilling fluid's lubricity, API filtrate and yield point (YP) were treated with ViChem L-10 Lubricant, ViChem C-300 and DESCO respectively. Additional drilling fluid components were added stepwise and the properties retested until the value obtained before incubation (day 0) was obtained. The approximate cost of treating a 1000 bbl system was calculated using the cost of products and assuming one gram in a 350 ml sample is equivalent to one pound per barrel.

Results and Discussion

The number of colony forming units present in the drilling fluid directly after preparation (day 0) was 2.7×10^4 CFU/ml (**Fig. 1**). This number is comparable to numbers observed during a previous study which determined the concentration of microorganisms in freshly prepared lab mud to be 1,000 GAB/ml as well as 100 SRB/ml (10). Because neither the individual drilling fluid components nor the makeup water are sterile, these numbers reflect the concentration of microorganisms entering into the system through those routes. Because drilling operations are open systems and exposed to contamination from the formation and human contact, sterility of fluid would be impossible. The goal then of a biocidal treatment program is rather to control the growth of microorganisms.

Previous studies have established that drilling fluid can be a good source of carbon and other nutrients and therefore encourage growth by microorganisms (8, 10, 13). Our study corroborated these findings with the number of CFU/ml in the control quickly increasing to a maximum of 1.9×10^7 CFU/ml in 48 hours. These results support the notion that this green drilling fluid did produce an environment conducive to growth by microorganisms. Our results are supported by several previous analyses of operational drilling fluids detecting populations of culturable aerobic microorganisms as high as 10^8 organisms per ml (8, 10). In our study, the number of culturable organisms in the untreated control remained over 10^6 /ml for over a week before steadily declining. The decline in number of organisms is a symptom of the closed system design of the experiment. The carbon sources utilized by the heterotrophic microorganisms are consumed and the resultant changes in pH and oxygen availability eventually makes the fluid less suitable for growth.

Results indicated that CQ Bio-24 was effective at quickly reducing the number of culturable microorganisms as well as keeping the concentration at acceptable levels for up to 28 days (**Fig. 1**). At the lowest recommended dosage (200 ppm) the biocide initially reduced the number of culturable organisms to 100 CFU/ml. A similar result was obtained at

the 500 ppm and 1000 ppm concentrations with microorganisms detected at 300 and 100 CFU/ml respectively. No culturable organisms were detected during the initial sampling of the highest biocide treatment (2000 ppm).

The concentration of CFU for the 200 ppm treatment remained above the detectable limit but below 1000 CFU/ml during the samplings on days 1 and 2. Cultures of samples taken from each of the other treatments (200-2000 ppm) during the 24 hour sampling were negative for growth during day 1. In each case, however, organisms were detected in subsequent sampling dates (day 2 for 500 ppm, day 3 for 1000 ppm, and day 10 for 2000 ppm). Aliquots were aseptically removed from each of the treatments during sampling events implying the only source of microbial contaminants came from the original fluid constituents. The observation of culturable organisms appearing in the fluid after negative results were obtained suggests that microorganisms in samples taken from the 500-2000 ppm treatments during negative samplings were actually inhibited from growth rather than actually eradicated. Many biocides inhibit the growth of bacteria more efficiently than they kill especially in complex matrixes like drilling fluid and our results, along with other authors recommending control of microbial growth (9), support this supposition.

The microbial load for each of the treated samples seemed to follow the trend of remaining relatively low for a period of time followed by rapid increase in numbers with the exception of the 2000 ppm treatment which remained negative or less than 1000 CFU/ml for the entirety of the study. The concentration of culturable organisms in the 200 ppm treatment increased to over 10^6 CFU/ml during day 10 and reached the maximum of 6.6×10^6 CFU/ml at 14 days. Although the 200 ppm treatment remained above the 10^6 CFU/ml concentration for a longer period of time than the control (18 vs. 9 days), the maximum number of organisms detected in the 200 ppm treatment (6.6×10^6 vs. 1.9×10^7 CFU/ml) was lower. The 500 ppm and 1000 ppm treatments each reached over 10^6 CFU/ml at the 14 and 21 day samplings respectively and the concentration of culturable organisms for both treatments were trending upward at the end of the experiment, so the final values of 1.4×10^7 and 7.3×10^6 CFU/ml for the 500 ppm and 1000 ppm treatments may not represent the maximum obtainable concentrations. The 2000 ppm treatment tested negative at all samplings until day 10 and remained below 1000 CFU/ml for the remainder of the experiment.

It is widely accepted that microorganisms affect the properties of drilling fluids (17). Although adverse effects of microbial activity such as odor, API filtrate control problems, difficulty maintaining pH, fluctuations in consistency and viscosity of fluid, corrosion and generation of H₂S are often acknowledged, there has been no attempt to quantify these deleterious microbially induced processes. Results of this study included monitoring of lubricity, API filtrate, pH and the PV/YP of all of the treatments during each sampling event (**Fig. 2**). The lubricant used for this system is an organic based vegetable oil which provides an excellent source of

carbon for microorganisms. The coefficient of lubricity for the drilling fluid at the initiation of the experiment was 0.025 and was equal for each of the treatments. The lubricity of the control climbed to over 0.10 by the three day mark followed by the 200 ppm treatment on day 7, 500 ppm treatment on day 10 and the 1000 ppm treatment on day 28. The 2000 ppm treatment held most of the lubricity throughout the experiment with the coefficient of lubricity on day 28 still 0.067.

The initial API filtrate for the fluid system as measured ranged from 5.5 ml to 5.3 ml and was not related to the amount of biocide used. Dramatic increases in water loss (up to 11.8 ml – 12.8 ml) was noted in the control and each of the treatments except for the 2000 ppm treatment which actually improved from 5.4 ml at the start of the experiment to 5.1 ml at day 28.

The pH of each of the samples was set at 9.0 at the beginning of the experiment and drifted down to a minimum of 5.7 – 5.2, which generally coincided with the first sampling date exponential growth of microorganisms was observed on the control as well as 200 ppm, 500 ppm and 1000 ppm samples. The pH of the control and 200 ppm sample began to drift back up to a 6.2 and 6.4 respectively as the number of CFU/ml detected decreased. Because the concentration of CFU in the 500 ppm and 1000 ppm treatments reached their maximum at the end of the experiment, the pH did not drift back up as noticed in the samples with a lower dose of biocide. The pH of the 2000 ppm treatment remained relatively stable throughout the experiment and only drifted down to an 8.0 which is likely due to the lack of any significant microbial growth in the sample.

The yield point (YP) of the drilling fluid after hydration was 7 and behaved similarly but opposite to the pH. Yield point generally increased to a maximum of 32 – 36 on samples and corresponded with the day of the maximum observed CFU/ml. Because the concentration of CFU in the control and 200 ppm treatment reached a maximum and then had time to decrease, the YP also began to decrease following the trend. The YP of the 500 ppm and 1000 ppm samples increased through day 28 along with the concentration of CFU. The YP of the 2000 ppm treatment slowly increased from 6 at the start to 11 at day 28. Using all of this data, we determined that 10^6 CFU/ml is the maximum load of microorganisms this drilling fluid system can maintain before serious deleterious effects are observed.

After the concentration of microorganisms and fluid properties during each sampling date were determined for the control, drilling fluid reagents were then added to restore the contaminated fluid to its original condition. For sampling days 1, 2, 3, 7, 21 and 28, known amounts of L-20 lubricant, C-300 water loss reagent and DESCO were added and the total cost of treatment for 1000 barrels was calculated assuming 1 g per 350 ml is equivalent to 1 lb per barrel (**Table 1**). The cost to remediate the damage to fluid properties caused by microbial activity in 1000 barrels of this drilling fluid after allowing microorganisms to grow unmitigated for 24 hours was estimated to be over \$3,000. Because of the exponential growth of microorganisms in ideal conditions

created in this fluid system, the money required to remediate damages quickly increases to about \$11,000 within 48 hours and \$23,000 on the third day. Conditions in the drilling fluid deteriorate after day three to the point where microbial growth is no longer strongly supported, so the increase in estimated cost does not rise as quickly after that point. However, even though there is not a significant difference in the estimated costs to treat the drilling fluid samples in this experiment from day 3 to day 7, the lack of increase in damage does not represent the true situation. The sample of untreated drilling fluid in this laboratory experiment as early as day 3 was not appropriate for use during live drilling operations.

Although deterioration of the quality of drilling fluid properties over time is not completely dependent on microbial activity, results from this study strongly suggest the influence of microbial activity on lubricity, API filtrate, pH and YP on this drilling fluid system. A typical oil or gas well drilled with this fluid system requires, on average, approximately 28 days to complete so the maximum dose of 2000 ppm biocide is recommended for use in this system. A suite of factors can influence the required dosage of biocide for use during drilling operations and previous authors have also suggested the importance of optimizing the biocidal treatment program for each application (1, 3, 9).

Prevention of the buildup of microorganisms by the initiation of an effective micro-biocidal treatment program will avert the biodegradation of drilling fluids. Limiting the deleterious effects of microbial activity minimizes the overall cost and maximizes the ease of reaching the drilling objective. An effective microbiological control program will also prevent contamination of the well with potentially deleterious organisms which can cause serious post-drilling complications reaching across all phases of production operations for the life of the well.

Conclusions

1. The growth of microorganisms was confirmed in an environmentally friendly drilling fluid with a maximum of 1.9×10^7 organisms detected (a $1000 \times$ increase) after only 48 hours.
2. Although biocide did not completely kill all organisms at any dose it is still the most effective way to control their growth.
3. The type of biocide and concentration of use should be optimized for the type of drilling fluid and conditions expected during drilling operations.
4. Microbial growth caused deleterious effects to drilling fluid properties including decrease in pH and detrimental effects to lubricity, API filtrate and rheologies.
5. It was estimated that damage to drilling fluid due to unmitigated microbial growth could cost as much as \$3,000 per day and as much as \$23,000 over three days in a 1000 bbl system if left untreated.

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Nomenclature

| | |
|------------|----------------------------------|
| <i>SRB</i> | = Sulfate reducing bacteria |
| <i>APB</i> | = Acid producing bacteria |
| <i>GHB</i> | = General heterotrophic bacteria |
| <i>lbs</i> | = pounds |
| <i>bbl</i> | = barrels |
| <i>C</i> | = Celsius |
| <i>ml</i> | = milliliters |
| <i>CFU</i> | = colony forming units |
| <i>ppm</i> | = parts per million |

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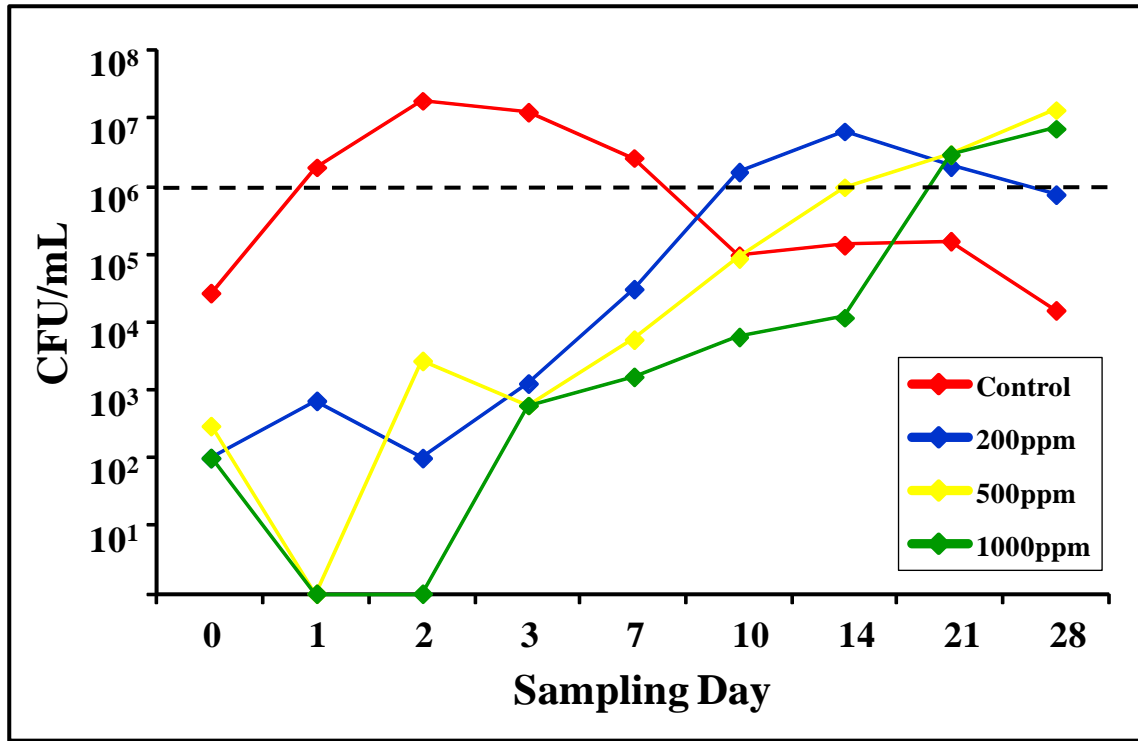


Figure 1: Number of colony forming units of general aerobic bacteria detected per ml (CFU/ml) of base drilling fluid and treatments containing between 200 ppm and 1000 ppm biocide during sampling days 1 – 28. A treatment containing 2000 ppm biocide (not shown) remained negative until day 10 and remained less than 1000 CFU/ml throughout.

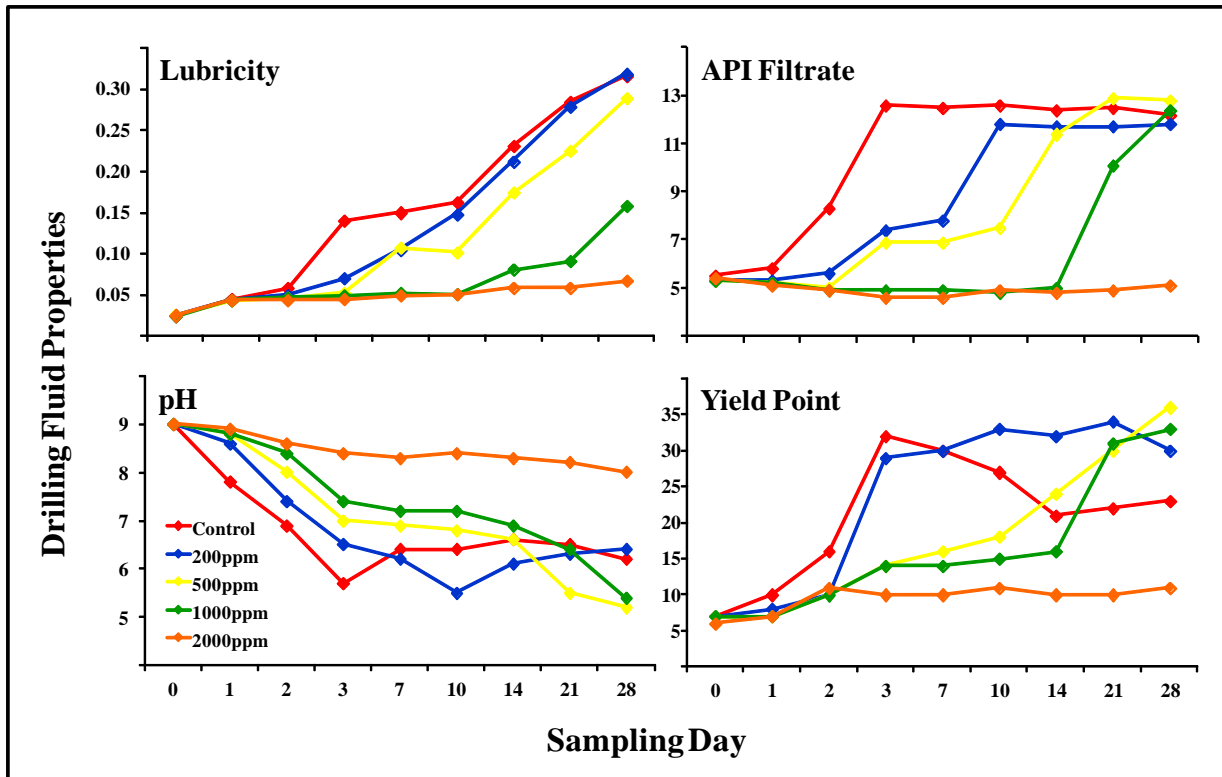


Figure 2: Values of drilling fluid properties measured during sampling of base drilling fluid plus treatments containing 200 ppm to 2000 ppm biocide before incubation (day 0) and after 1 – 28 days of incubation at 37°C.

Table 1: Estimated Value of Degraded Product

| | Day 1 | Day 2 | Day 3 | Day 7 | Day 21 | Day 28 |
|--------------|--------------|--------------|--------------|--------------|---------------|---------------|
| L-20 | \$1,222 | \$1,833 | \$5,498 | \$6,109 | \$12,218 | \$14,662 |
| C-300 | \$500 | \$5,000 | \$11,500 | \$11,000 | \$10,000 | \$9,750 |
| DESCO | \$1,280 | \$4,000 | \$6,400 | \$6,720 | \$8,000 | \$11,200 |
| Total | \$3,002 | \$10,833 | \$23,398 | \$23,829 | \$30,218 | \$35,612 |