Sustainable drilling for oil and gas: challenging drilling environments demand new formulations of bentonite based drilling fluids

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ABSTRACT

Demand for multifunctional drilling fluids continuously increases. In the quest for more hydrocarbons, drilling has extended to deep water areas (now in excess of 2.000 m) and to very deep wells (now in excess of 6.000 m). In these extreme conditions, low temperatures, as low as 1-5°C on the sea bed, high temperatures, in excess of 200°C, and high pressures, more than 1.000 bars, in the bottom of the well, are frequently encountered.

In these harsh environments, synthetic oil and oil based drilling fluids are used, but the former are expensive while strict environmental requirements have limited the use of the latter. Thus, drilling industry has turned back to water based drilling fluids which use bentonite as primary viscosifier and as a fluid loss control additive. However, in conditions of high temperatures, bentonite suspensions gel and loose their exceptional low temperatures properties, thus, additives are needed to overcome such problems.

In this article we review these challenging drilling environments and establish the requirements for the multifunctional drilling fluids. Our research indicates that demand for continuing use of bentonite by drilling fluid industry is strong. Furthermore, we bring forward the opportunities for new additive development which can expand the operational ranges of bentonite suspensions.

1. INTRODUCTION

Bentonite is an essential component for the oil-well drilling industry. World production of bentonite remained high, between 12.5 and 17.5 million tons per year (2002 data, Robinson et al., 2004; Agnello, 2005) with USA producing 44% while exporting 22%. Greece runs a close third from China, with 1.26 million tons per year, contributing ~ 7.5% to world production (Robinson et al., 2004). Of the many uses of bentonite, the use in oil well drilling fluids accounts for about 25% in USA (USGS, 2005) and about 5% in South Africa (Robinson et al., 2004), countries for which data were publicly available. In Figure 1, the apparent use of bentonite over the past seven years in USA is shown together with the consumption of bentonite by drilling fluid industry.

Drilling fluids are essential elements for the successful drilling of oil, gas, and geothermal wells. Drilling fluids are used to: (1) cool and lubricate the bit, (2) transfer the cuttings from the bit face to the surface, (3) apply hydrostatic pressure to keep formation fluids from entering the wellbore, and (4) maintain stability of the borehole. The drilling environment is changing to more hostile conditions because deeper and
more horizontal wells are drilled encountering, harder rock and abrasive formations, and higher pressures and temperatures. Drilling fluid research has resulted in a range of drilling fluids with many additives that are capable of performing these formidable tasks in difficult environments. Among the properties that drilling fluid must possess are appropriate viscosity and fluid loss values. Additives together with bentonite are used to formulate drilling fluids for difficult drilling conditions.

Bentonite, with montmorillonite as the principal component, when mixed with water forms non-Newtonian suspensions. Bentonite suspensions have the unique ability to gel when left undisturbed and it is this property that makes bentonite valuable to drilling industry because the suspension can support and transfer rock cuttings from the bottom of the hole to the surface. Furthermore, bentonite forms a filter cake of low permeability on the walls of the borehole thus isolating the well from the producing formations. These exceptional characteristics are observed in fresh water systems and room temperatures. In conditions of high salinity and high temperatures bentonite particles flocculate and lose their filtration and rheological characteristics (Rossi et al., 1999; Kelessidis et al., 2007a, b, c).

Demand for more oil and gas production will be on the rise at an average rate of 1.5% per year for the years to come (Energy Information Administration, 2006). By 2010, half of the oil and gas daily volumes needed to meet projected worldwide demand is not on production today, and the estimated costs of finding the needed oil are around US$ 100 billion, substantially more than the industry spending in 2002 (Longwell, 2002). Petroleum exploration and production industry, however, is one of the highest-tech industries in the world and will meet these challenges relying on technological advances, as it has done for the past 150 years, since the first oil discovery by Col. Drake in Pennsylvania, in 1859. This will be achieved by focusing on offshore oil and gas production and more specifically in deep waters, despite earlier strong pessimism, as for e.g. thirty years ago, presented in a well respected scientific journal, where it was stated that ‘hydrocarbon potential is not considered adequate to give any optimism for the deeper waters providing substantial additions to the reserves of exploitable hydrocarbons’ (Wharman, 1978). Developments in the past ten years have proven these views wrong and uncovered the strong potential of subsurface ocean waters, with about 550% increase in oil and gas production from water depths greater than 305 m in the Gulf of Mexico (Mineral Management Services, 2004), as depicted in Figure 2.

These technological achievements come of course at a price. Costs for deep (greater than 305 m) or ultra deep (greater than 1500 m) water depth wells are in the range of US$ 10 to 50 million. Similarly, deep well drilling costs for directional exploration wells for gas production may range from US$ 3 million for an on-shore 17,500 ft well (5,333 m) to nearly US$ 9 million for a 19,000 ft (5.790 m) off-shore Gulf of Mexico well (Schlumberger, 2005). Drilling costs

Figure 2: Production in Gulf of Mexico, from deep water wells (>305 m) and total production (MMS, 2004).
accounted for about 50% of these expenses with costs for drilling fluids being the second largest contributor, accounting for 9.5% of the drilling costs, after the costs for tubulars (Schlumberger, 2005). However, a significant portion of non-drilling costs is related to overcoming significant drilling problems which were drilling fluid related.

The continuous demand for better performing drilling fluids coupled with their significant costs drives research and development of drilling fluid industry for formulating drilling fluids with optimal properties. This paper addresses the challenges put forward to drilling fluid industry in today’s but also future difficult drilling environments and aims to establish the requirements for multifunctional water based drilling fluids and to point out the opportunities that may exist for bentonite industry.

2. DRILLING FLUIDS

Drilling fluids can be divided in water and oil based fluids. Water based fluids or muds (WBMs) consist of fresh or sea water, with a weighting agent (usually barite), bentonite clay (priced at US$ 35-110/ton; Murray, 2002) and several water soluble polymers like polysaccharites, natural and synthetic polymers (Jones and Hughes, 1996). Lignites, tannins and lignosulfonates have been used to enhance thermal stability of water-bentonite suspensions (Gray and Darley, 1980; Rabaioli et al., 1993). Use of synthetic sulfonated polymers has also been reported for temperatures up to 200°C (Plank and Hamberger, 1988). Oil based drilling fluids (OBMs) were formulated for high temperature environments and were originally using crude or diesel oil, but later have been replaced by refined mineral oils with less than 0.25% wt aromatic content. The oil is normally stabilized with emulsifiers, of which organophillic clays are the components mostly used, priced at US$ 1500-4000/ton (Murray, 2002). These are bentonite (or hectorite) clays saturated with an organic cation, more commonly a quarternary amine cation to provide viscosity and filtration properties (Jones and Hughes, 1996).

Stricter environmental regulations, however, together with the continued increase in exploration depths have necessitated the formulation of Synthetic Base Muds (SBMs) which do not contain any aromatics thus reducing toxicity of the base fluids significantly. These compounds contain usually carbon chains between C_{14} to C_{22} and can be esters, ethers, poly-α-olefins, detergent alkylates, linear-α-olefins and isomerized-olefins (Growcock and Frederick, 1996). In general, SBMs are the most expensive, with price tags at around US$ 165 per bbl (US$ 825 per ton) followed by OBMs with the WBMs being the least costly (Urstadt, 2006). Economics, therefore, push the research for expanding the operating window of WBMs to higher and lower temperatures.

Annual worldwide expenditure for drilling fluids is hard to find. Reports have put the price tag around US$ 3.8-4.5 billion for 1990 (Jones and Hughes, 1996) with average cost for drilling fluid per well in deep water in the range of US$ 500.000 (Urstadt, 2006). However, in very difficult environments costs can be substantially higher and cases have been reported where better formulated drilling fluids have saved operators over US$ 1.0 million (Cameron, 2005).

3. EXPANDING THE FRONTIERS

3.1 Deep water and deep gas drilling

In the quest for more hydrocarbons and with the availability of appropriate technology, the industry has turned to deep and ultra deep waters, particularly in the Gulf of Mexico, offshore Brazil, Angola, Nigeria and even in Mediterranean. In Figure 3 the locations of semi-submersibles and drill ships from a major drilling company around the world are shown. Significant finds in the recent past has proved that deep water drilling, although risky endeavor, is worth taking. These successes enabled more and more countries, for e.g. Angola, Brazil, China, Egypt, Libya and very recently Cyprus, among

Figure 3: Transocean drilling rigs in ultra deep waters (>1400 m) (from Transocean, 2004).
many others, to open or re-open large areas for international exploration and production in deep waters. Drilling in ultra deep waters in Mediterranean, for e.g. Egypt, has resulted in significant finds for natural gas, in 2,700 to 3,000 m water depths, while there are indications for oil at even deeper wells (Osman and Sabry, 2003).

Drilling in ever increasing water depths and record breaking well depths results in encountering pressures exceeding 1,000 bar and temperatures in excess of 200°C (high temperature high pressure wells, HPHT). In Figure 4 temperatures and pressures from some of the known wells are shown (Brownlee et al., 2005). Thus, deep water drilling poses significant challenges to drilling operators with many of them related to drilling fluid formulations such as high equivalent circulating densities, gelation both at high (bottom hole) and low (close to sea bed) temperatures and provision of protection against formation of gas hydrates (Cameron, 2005).

Land drilling in great depths for gas is also ever expanding in US (Drilling Contractor, 2005). Great challenges have been reported for HPHT drilling fluids. In gas deep drilling, wells from 18,000 up to 20,500 ft (5,485 to 6,250 m) have been reported in Wyoming and Louisiana, while in Oklahoma the average depth was 5,360 m with average well costs of US$ 2.65 million (Snead, 2005). In these environments, pushing the operating window for WBM for deep wells pays dividends by enhancing environmental protection and minimizing disposal costs. Newly formulated thickeners for high temperatures for WBMs are in continuous demand, with reports, for e.g. for drilling at 5,500 m and temperatures of 204°C, use of new thickeners enabled the operator to achieve well objectives (Drilling Contractor, 2005).

3.2 Challenges for bentonite industry

The difficult well environments require holistic approach to drilling fluid design. Industry is researching for flexible drilling fluids with adjustable parameters, which require development of additives to obtain the required performance (Dearing et al., 2004; Smalling et al., 2006). Propriety blends of additives for WBMs have been reported with excellent results (Hayes and Beasly, 2004). Different formulations are required at different depth intervals. Some examples have been recorded from numerous SPE and AADE papers and are reported below. In South China Sea, in the intermediate casings, the drilling fluid was a high temperature glycol water based mud containing 0.8% bentonite, 1.5% resin/lignite blend, 4.0% glycol for temperatures in excess of 200°C and 1000 bar, at depths of 4,700 m (Oakley et al., 2000). Offshore Louisiana (Dearing et al., 2004) polyols and sulphonated asphalts have been used in WBMs to enhance shale stability. Oxidized sub-bituminous coal has also been used to deflocculate clays providing very good performance of the drilling fluid in conditions of high salinity, the necessary conditions to combat gas hydrate formation. Similarly, non-chrome zirconium compound has been used to combat gelation at high temperatures (Dearing et al., 2004).

WBMs have been preferred over OBMs and SBMs even in shallow waters offshore Louisiana, but in very difficult environments in terms of shale stability, because they demand minimal storage and deck space. Components used included 10 lb/bbl bentonite, 5 lb/bbl humalite, 0.5 lb/bbl xantan gum with additives for shale stability including methyl-glucoside (1-5%) and a complex ester (1-5%) for added lubricity (Smalling et al., 2006). Even in well killing operations, requiring long waiting times, bentonite has been used in combination with low molecular weight co-polymer for enhanced stabilization providing resistance to 260°C (Spooner et al., 2003).

SBMs have many advantages over WBMs in terms of performance for rheology, filtration control and maintaining borehole stability. In these great depths, however, pore pressures are very high thus requiring high mud weights while overbalance pressure margin is very small. Hence, mud losses through fractured
formations are very common (Oakley et al., 2000) and due to the higher costs of SBM fluids, optimal formulations of WBMs to withstand these harsh environments can reduce overall costs of drilling fluids.

Better formulation of a synthetic based drilling fluid in deep waters helped saved as much as US$ 1.0 million in a single well while in another well saved US$ 250,000, by reducing significantly mud losses downhole (Cameron, 2005) thus providing great incentives for the development of fluid additives to stabilize bentonite suspensions.

Several studies exist reporting the combined use of bentonites with polymers and/or lignites to extend water based fluid suspension stability at higher temperatures (Rossi et al., 1999; Wu et al., 2002) while recent work (Kelessidis et al., 2007a, b, d) has shown that Greek lignites could be excellent drilling fluid additives for high temperature wells. Addition of organic additives to clay suspensions modifies their colloidal and rheological properties. The additive layers are thought to adsorb onto the clay surfaces leading to dispersion, stabilization or deflocculation (Rossi et al., 1999). The polymers used could be anionic, cationic or nonionic and various modes of interaction have been proposed, as depicted in Figures 5 and 6 (Alemdar et al., 2000; Benchabane and Bekkour, 2006). These, and many additional works, point out the way to the bentonite industry for future research and development work in order to develop appropriate additives to expand the operating ranges of bentonite suspensions capturing thus not only an existing, but also an ever expanding niche market with products of considerable value.

4. CONCLUSIONS

Demand for hydrocarbons will be on the rise for the years to come. The oil and gas industry has responded by exploring deep horizons (>6,000 m) and deep (>305 m) and ultra deep (>1,500 m) waters in various places around the world. Hostile conditions are encountered, however, with temperatures in excess of 200°C, close to freezing and pressures exceeding 1,000 bar. Drilling operations rely strongly on the excellent performance of drilling fluids. A multitude of formulations has been developed in the past and the search is for flexible drilling fluids and newer additives which could expand the operating ranges of water based fluids. These demands present unique challenges to bentonite industry to work together with drilling fluid industry and academia so that newly formulated additives, using lignites and polymers, are developed, capitalizing on knowledge of the requirements for such fluids and on the capabilities that technological advances offer.

REFERENCES


Murray, H., 2002. Industrial clays case study, Mining, Minerals and Sustainable Development, No. 64, IIEC.

Mineral Management Services (MMS), 2004. Deep water drilling fluid helps to drill high pressure wells offshore Louisiana, paper AADE-06-DH-33 presented at the AADE 2006 Fluids Conference, Houston, TX, April 11-12.

Drilling Contractor, 2005, pg.28.


Mineral Management Services (MMS), 2004. Deep water drilling fluid helps to drill high pressure wells offshore Louisiana, paper AADE-06-DH-33 presented at the AADE 2006 Fluids Conference, Houston, TX, April 11-12.

Drilling Contractor, 2005, pg.28.


Smalling, D., M. Reid and M. Deshotels, 2006. Flexible drilling fluid helps to drill high pressure wells offshore Louisiana, paper AADE-06-DH-33 presented at the AADE 2006 Fluids Conference, Houston, TX, April 11-12.

Snead, M.C., 2005. The economics of deep drilling in Oklahoma, www.economy.okstate.edu


Ursstadt, B., 2006. Don't expect the scarcity of fossil fuels to drive us toward alternative energy sources anytime soon: we're getting smarter about finding and extracting oil, The Oil Frontier, July 18.


3rd International Conference on Sustainable Development Indicators in the Minerals Industry, June 2007, Milos island, Greece