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HORIZONTAL WELL DRILL-IN FLUIDS

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Main objective of horizontal driling is to place a drain-hole for a long distance within the pay zone to enhance productivity or injectivity. In drilling horizontal wells, more serious problems appear than in drilling vertical wells. These problems are: poor hole cleaning, excessive torque and drag, hole filling, pipe stucking, wellbore instability, loss of circulation, formation damage, poor cement job, and difficulties at logging jobs. From that reason, successful drilling and production of horizontal well depends largely on the fluid used during drilling and completion phases.

Several new fluids, that fulfill some or all of required properties (hole cleaning, cutting suspension, good lubrication, and relative low formation damage), are presented in this paper.

Ključne riječi: Horizontalne bušotine, Bušenje, Fluidi

Glavna svrha horizontalnog bušenja je izrada kanala bušotine, unutar proizvodne zone radi povećanja njene proizvodnosti ili injektivnosti. Pri izradi horizontalnih bušotina javljaju se ozbiljniji problemi, nego pri izradi vertikalnih bušotina. Ti problemi su slijedeći: loše čišćenje kanala bušotine, prekomjerna torzija i nateg, ispunjavanje kanala bušotine, gubitak cirkulacije, oštećenje stijene, nekvalitetna cementacija i poteškoća pri mjerenjima u kanalu bušotine. Zbog toga, uspješna izrada kanala horizontalne bušotine i njezina proizvodnost u velikoj mjeri ovise o fluidu koji se primijenjuje tijekom bušenja i opremanja bušotine.

U radu je opisano nekoliko novih tipova fluida koji uglavnom imaju svojstva potrebna tijekom izrade horizontalnih bušotina (djelotvorno čišćenje kanala bušotine, zadržavanja krhotina u suspenziji, dobro podmazivanje i relativno malo oštećenje proizvodnih stijena).

Introduction

Many of today's smaller and more marginal hydrocarbon accumulations can only be developed economically by horizontal wells. Under these delicate and stringent conditions attention must be focused on maximizing production from spudding of the first well. Formation damage mimimization and skin awareness are now concepts familiar to all those present on a drilling rig and selection of drilling fluids is beginning to play a critical role in these processes (Byrd and Zamora, 1988; Ezzat, 1993; Dearing and Ali, 1996). High angle and horizontal hole drilling are difficult to achieve, but the present state-of-the-art technology is sufficiently well developed that they can now be performed with a satisfactory degree of confidence. Selected drilling fluids for horizontal drilling should satisfy the same basic function which are common to all drilling muds and they have to provide excellent reservoir protection.

Major drilling problems such as poor hole cleaning, excessive torque or drag, wellbore instability, stuck of drill string, loss of circulation, subsurface pressure control, poor cementing jobs, difficulties associated with running electric logs and formation damage can result if the drilling fluid is poorly designed or executed (Byrd and Zamora, 1988). The reason for the growing importance of drill-in fluids is the expanding number of horizontal wells being drilled. In these wells, producing formations have a greater tendency to be damaged by the drilling process than those in vertical wells (Dearing and Ali, 1996).

Geological criteria relevant to the reservoir section is now the main driver for the selection of the drill-in fluid. As the number of horizontal, and now multi-lateral, wells continues to grow, so the use of drill-in fluids is growing as well. The way by which we consider drilling of boreholes is changing. The drilling phase of a well can be finished just above the reservoir and any penetration of potential hydrocarbon zones can be considered as part of the completion process. Traditional drilling fluids are designed from a safety and efficiency point of view, primarily with the overburden lithologies in mind. These fluids often are not best suited to maximizing productivity and minimizing damage in the reservoirlithologies.

A new generation of fluids, collectively known as drill-in fluids, has been developed to overcome these limitations (Jachnik, 1995; Dearing and Ali, 1996).

Horizontal drilling problems

A combination of a very high angle well path and a poor quality of reservoir may require a more complex drilling fluid specification compared to that used when drilling a conventional directional well, not only because of the increase in angle, but above all because poor quality reservoirs do not tolerate any further degradation and in order to avoid expensive and/or problematic stimulating treatments. Thus before considering hole-cleaning technique it should be pointed out that as we expect more from horizontal wells than from vertical wells, additional precautions have to be taken to (Byrd and Zamora, 1998; Ezzat, 1993; Dearing and Ali, 1996):

- ensure bore hole stability (in inconsolidated formations),
- hole cleaning,
- avoid damage to reservoir characteristics,
- avoid incompatibility between reservoir formation and fluid used,
- provide lubricity to decrease torque and drag, and hence, the possibility of sticking of drill string and casing.

Wellbore stability

Maintaining a stable borehole is one of major problems encountered in horizontal drilling. Caving is especially ready to occur if water-sensitive shales are located in high-angle well section or if there is a high content of active clay in the formation.

The prime cause of wellbore instability can be hydration of montmorillonite, and it is most important to make efforts to control it (prevent hydration and dispersion – use strongly inhibitive mud system, reduce the filtration rate, improve the quality of mud cake).

In order to ensure the wellbore stability further, mechanical aspects of causing instability should also be taken into consideration. The mud density should be adequate (Tan and Willoughby, 1993).

Hole cleaning

Once all other parameters have been studied and defined (mud weight, filtrate, salinity, solid content, etc.), it is necessary to adapt the rheology to provide a sufficient carrying capacity of the mud along the annulus varying in inclination and size.

As opposed to what happens is conventional wells (increasing thixotropy improves cutting transport), in highly deviated wells and even more so in horizontal wells, the drilled cuttings have to come up through variously inclined sections from 90 to 0° where the optimum parameters required for hole cleaning may vary greatly from one section to the other. Cutting transport is not only a problem in horizontal conditions but hole angles of 25° to 65° can be even more critical when parameters such as mud rheological properties and velocities are not optimized (Zamora and Hanson, 1991; Zamora et al., 1993). Transport of cuttings by mud is more difficult in a highly deviated or horizontal hole than that in a vertical one because cuttings trend to settle at the bottom of the hole and the mud trends to pass above. High fluid velocities and turbulent flow are benefits to hole cleaning, but that can be restricted by a tendency of washout of the wall of the borehole and also by the physical capacity of the mud pump to provide flow. To promote turbulent flow, it is desirable to keep a low fluid viscosity. However, a high viscosity is necessary to restrict the settling of cuttings when the flow is stopped. These conflicting requirements can be accommodated by making the mud a non-Newtonian plastic fluid with a high ratio of yield point to plastic viscosity. Both experimental results and field performance should be verified, so that selected mud can be used effectively.

The main procedure to improve the transport of cuttings includes a rational adjustment of rheological parameters in the highly deviated sections and the forming of turbulent flow in the horizontal section. The turbulent flow is considered to improve the transport of cuttings because the flatter profile eliminates the turning moment.

Prevention of formation damage

In horizontal wells, fluid is typically in contact with the reservoir for a much longer period than in vertical or lower angle wells. Formation damage tends to be more significant in horizontal well for a number of reasons (Dearing and Ali, 1996). Among the reasons are:

- drilling fluid is in much longer contact with the payzone,
- most horizontal wells are completed open hole without casing and perforation, (shallow fluid invasion may result in skin damage which can reduce production),
- long, exposed payzones can result in difficulty obtaining uniform drawdowns to clean up damage,
- flow mechanics in horizontal wells differ from those in vertical wells, as do the horizontal and vertical permeabilities of most formations (these differences result in greater productivity inpairments in horizontal wells exposed to equivalent damage).

A more important issue is to find approaches to minimize invasive damage in horizontal wells (perhaps: so called »temporary blocking technique«, use bridging agent and fluid loss additive). If high penetration rates are there in the horizontal section and during a successful operation in cementing, the relatively short contact time of fluids to the formation and less invasion depth can be obtained.

Lubricity

In the horizontal and highly deviated sections of a horizontal well, the torque and drag are usually large enough to cause an unacceptable loss of power, and differential sticking was particularly liable to occur (Byrd and Zamora, 1988; Hemphill and Larsen, 1993). To solve this problem crude oil or certain lubricating agents should be used. The selected mud should be good enough to avoid sticking of the drilling string effectively in the horizontal well drilling.

Choice of drill-in fluid type

In order to design the best suitable drill-in fluids for horizontal wells, drilling problems generally encountered in each field should be studied and laboratory tests planned and conducted.

Laboratory tests include:

- study the reservoir rock and fluids characteristics,
- select the most suitable and economical fluid formulations,
- examine the effective pore size distribution and morphology of each reservoir rock,
- run flow tests on core samples taken from each reservoir to determine the residual damage caused by several candidate fluids,
- geological testing of reservoir samples in the drilling fluids (SEM, X-ray diffraction, petrography and mineralogy, and physical and chemical compatibility testing).

Standard tests such as fluid density, rheology, filtration, solid analysis and chemistry should be also performed because the drill-in fluid must act as a drilling fluid, often in quite demanding conditions in long horizontal wells.

Drill-in fluids are specialized systems designed to minimize formation damage or be used as packer fluids after completion operations. The impact of these systems to the productive formation must be capable of being reversed with remedial treatments such as acidizing and oxidation or through completion techniques and production operations. Systems consist of fluids which range from clear brines to polymer fluids (weighted with sized salt or calcium carbonate) to highly treated mud (packer) fluids.

Polymer-based systems

Polymer fluids incorporating generally long-chain, high-molecular-weight polymers are utilized to either encapsulate drill solids to prevent dispersion and coat shales for inhibition, or for increasing viscosity and reducing fluid loss. Various types of polymers, including acrylamide, cellulose and natural gum-based products.

Frequently, inhibiting salts such as KCl or NaCl are used to provide greater shale stability. These systems normally contain a minimum amount of bentonite and may be sensitive to divalent cations such as calcium and magnesium.

Most polymers have temperature limits below 150 °C, but under certain conditions may be used in wells with appreciably higher BHTs. The polymer-based fluid is shear thinning, providing good hole cleaning properties which can be adjusted, as needed, to meet specific wellbore requirements. The systems polymer blend can be utilized effectively in both low density and high density brines to achieve desired rheological properties. Because it contains polymers, the system is naturally lubricious. Additionally, the filter cakes polymer coating imparts surface lubricity – minimizing torque and drag. This feature is especially critical in horizontal wells. Different polymer fluids have been applied during drilling horizontal wells in France, Canada, Texas, Alaska, China, etc. (Zamora et al. 1993; Yan and Zong, 1995; Dearing and Ali, 1996) Polymer systems (NEW DRILL/KCl, PERFFLOW DIF) have been applied during drilling horizontal wells in Croatia as well.

Oil-based systems

Oil based systems (Invert emulsion muds, Oil-based muds) are used for a variety of applications where fluid stability and inhibition are necessary such as high-temperature wells, deep holes, and where sticking and hole stabilization is a problem (Hemphill and Larsen, 1993). All oil systems require higher additional gelling agents for viscosity. Specialized oil-based mud additives include: emulsifier and wetting agents (commonly fatty acids and amine derivates), high-molecular-weight soaps, surfactants, amine treated organic materials, organo clays and lime for alkalinity. Oil-based muds are more expensive than water-based ones and they are difficult to dispose of in an environmentally satisfactory manner. In fact, when oil-based mud has not been the fluid used for drilling neighbouring vertical wells, this mud type should never been chosen for drilling horizontal wells. The main reason for this is that when properly designed (choice of salt and concentration) and when enhanced with specific additives (lubricants, asphalts, diesel or mineral oil), low solid brine water-base fluid has successfully competed with oil-base fluid.

Synthetic-based systems

Synthetic fluids are designed to mirror performance of oil-based muds, without the environmental hazards (Dearing and Ali, 1996). Primary types of synthetic fluids are esters, ethers, poly alpha olefins. They are environmentally friendly, can be discharged offshore and are non-sheeting and biodegradable. The non-aqueous PAO (polyalphaolefin) system has been used on several wells in the Gulf of Mexico to drill problematic formations previously drilled with either inhibitive water-based or oil-based fluids (Park et al., 1993). Benefits in hole stability, cuttings integrity, lubrication, and gauge wellbores, all leading to increased penetration rates and subsequent reduction in drilling days, can be seen.

Glycol system

Glycols are compounds containing two hydroxyl groups attached to separate carbon atoms in an aliphatic chain. Although there are a few exceptions nearly all glycols consist solely of carbon, hydrogen and oxygen. Simple glycols are those in which both hydroxyl groups are attached to an otherwise unsubstituted hydrocarbon chain as represented by the general formula, $C_nH_{2n}(OH)_2$. The more complex glycols are given the name polyglycols and are distinguished by intervening ether linkages in the hydrocarbon chain (Jachnik, 1995).

Two common simple glycols are ethylene glycol and propylene glycol. Ethylene and propylene oxide are often the building blocks of the more complex polyglycols used as drilling fluid additives. The end result is a big range of products with varying molecular weights and characteristics used in water based drill-in and specialized coring fluids. Glycols have been used in horizontal wells in the North Sea.

Typical features of a glycol based drill-in fluid are (Jachnik, 1995):

- high lubricity, approaching that of an oil based mud,
- minimal invasion,
- improved inhibition and
- good environmental characteristics (low toxicity and vapour pressure and biodegradability).

Formate system

Formates are exotic salts, essentially being formic acid, HCOOH, with metal cations, K, Na, Mg and Cs. The density of the fluid is determined by which cation is used. Sized salt, NaCl, particles act as bridging solids and formate systems are barite free (Dearing and Ali, 1996). Very thin filter cakes are produced and the solid free nature of the fluids reduces equivalent circulating densities. This is particularly important in slimhole wells where problems can arise due to barite centrifuging out of the fluid on the internal section of the drill pipes as a consequence of high rotary speeds. The lower downhole pressures generated benefit all reservoirs. Formates have been used in horizontal wells in the North Sea (Ramsey and Shipp, 1996).

Advantages of the formate salts are:

- they can provide high-density brines that are non-hazardous and appear to be compatible with oilfield hardware,
- they are environmentally responsible and readily biodegradable,
- as powerful anti-oxidants, they can protect viscosifiers and fluid-loss polymers against thermal degradation up to temperature of at least 150 °C,
- they are compatible with formation waters containing sulphates and carbonates.

Sized calcium carbonate system

Sized calcium carbonate drill-in fluids originated as completion fluids and are now being used in the drilling of reservoir sections. Very pure metamorphic calcium carbonate with a carefully selected particle size distribution is used. The particle size mix has been carefully selected to effectively bridge the pore throat openings in formations with permeabilities ranging from a few milidarcies to more than 10 darcies (Dearing and Ali, 1996).

The concentration of bridging solids is carefully engineered to ensure optimum system performance. Solid concentration, as well as the particle size distribution, can be modified to fit particular reservoir applications. This bridging agent, combined with polymer viscosifiers and filtration control agents, forms a thin filter cake at the surface of the exposed formation. The filter cake forms quickly on the exposed surface of the wellbore to provide instantaneous leak-off control. This feature of these systems protects producing formations from damage by limiting fluid loss, fine solid migration, clay swelling, and solid invasion. The polymer coating allows the calcium carbonate particles to »break« apart for easy removal when the well is produced. These particles will even flow back through a 40–60 gravel pack without requiring special clean-up procedures to dissolve the particles (Dearing and Ali, 1996).

Mixed-metal hydroxide

Improved understanding of rheological properties and increased control of filtration characteristics has expanded the applications of mixed metal hydroxide (MMH) fluids, or more specifically, magnesium aluminium hydroxides (Sparling and Williamson, 1991). MMH fluid is a blend of complex chemical fundamentally different from conventional muds. There are two unique additives to the MMH system: a mixed metal hydroxide of aluminium and magnesium and an organic fluid loss reducer developed specifically for the system (Fraser and Enriquez, 1992). MMH fluids have unique rheological and pore bridging characteristics resulting from the interreaction of the synthetic mixed metal hydroxide (highly-charged cationic MMH crystals) with bentonite (smectite clay). The MMH fluid shows unusual physical properties, behaving like elastic solid when at rest or when under conditions of minimal mechanical displacement. This pseudo solid can be transformed into an extremely low viscosity fluid through application of displacement energy. The MMH fluids have low PVs, and extremely high values for YPs, gels, and low shear rate rheology, and good potential as non-damaging fluids in a variety of formations. They have been used in Australia, North and South America, UK, Indonesia, etc. (Fraser et al., 1994).

Conclusion

If actual horizontal drilling techniques appear to have been perfected nowadays in more or less favorable environment, it should nevertheless be taken in mind that numerous difficulties may arise and that a well-designed drill-in fluid will often solve such problems as:

- poor borehole stability, unconsolidated sands, swelling, fractures due to tectonic stress, shale sloughing, etc.,
- hole cleaning difficulties, incorrect appreciation of actual hole diameter and thus of mud velocity, difficult evacuation of cuttings according to angle, and possible build-up on the underside of well bore,
- annulus pressure instability in a constant pressure reservoir,
- formation damage, etc.

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