Drilling fluid types

There are several different types of drilling fluids, based on both their composition and use. The three key factors that drive decisions about the type of drilling fluid selected for a specific well are:

- Cost
- Technical performance
- Environmental impact.

Selecting the correct type of fluid for the specific conditions is an important part of successful drilling operations.

Contents

Classification of drilling fluids

World Oil’s annual classification of fluid systems[1] lists nine distinct categories of drilling fluids, including:

- Freshwater systems
- Saltwater systems
- Oil- or synthetic-based systems
- Pneumatic (/Air_drilling) (air, mist, foam, gas) “fluid” systems

Three key factors usually determine the type of fluid selected for a specific well:

- Cost
- Technical performance
- Environmental impact

Water-based fluids (WBFs) are the most widely used systems, and are considered less expensive than oil-based fluids (OBFs) or synthetic-based fluids (SBFs). The OBFs and SBFs—also known as invert-emulsion systems—have an oil or synthetic base fluid as the continuous(or external) phase, and brine as the internal phase. Invert-emulsion systems have a higher cost per unit than most water-based fluids, so they often are selected when well conditions call for reliable shale inhibition and/or excellent lubricity. Water-based systems and invert-emulsion systems can be formulated to tolerate relatively high downhole temperatures. Pneumatic systems most commonly are implemented in areas where formation pressures are relatively low and the risk of lost circulation (/Lost_circulation) or formation damage is relatively high. The use of these systems requires specialized pressure-management equipment to help prevent the development of hazardous conditions when hydrocarbons are encountered.

Water-based fluids

Water-based fluids (WBFs) are used to drill approximately 80% of all wells.[2] The base fluid may be fresh water, seawater, brine, saturated brine, or a formate brine. The type of fluid selected depends on anticipated well conditions or on the specific interval of the well being drilled. For example, the surface interval typically is drilled with a low-density water- or seawater-based mud that contains few commercial additives. These systems incorporate natural clays in the course of the drilling operation. Some commercial bentonite or attapulgite also may be added to aid in fluid-loss control and to enhance hole-cleaning (/Hole_cleaning) effectiveness. After surface casing (/Casing_and_tubing#Surface_casing) is set and cemented, the operator often continues drilling with a WBF unless well conditions require displacing to an oil- or synthetic-based system.

WBFs fall into two broad categories: nondispersed and dispersed.

Nondispersed sytems

Simple gel-and-water systems used for tophole drilling are nondispersed, as are many of the advanced polymer systems that contain little or no bentonite. The natural clays that are incorporated into nondispersed systems are managed through dilution, encapsulation, and/or flocculation. A properly designed solids-control system (/Drilling_waste_management) can be used to remove fine solids from the mud system and help maintain drilling efficiency. The low-solids, nondispersed (LSND) polymer systems rely on high- and low-molecular-weight long-chain polymers to provide viscosity and fluid-loss control. Low-colloidal solids are encapsulated and flocculated for more efficient removal at the surface, which in turn decreases dilution requirements. Specially developed high-temperature polymers are available to help overcome gelation issues that might occur on high-pressure, high-temperature (HP/HT) wells.[3] With proper treatment, some LSND systems can be weighted to 17.0 to 18.0 ppg and run at 350°F and higher.

Dispersed systems

Dispersed systems are treated with chemical dispersants that are designed to deflocculate clay particles to allow improved rheology control in higher-density muds. Widely used dispersants include lignosulfonates, lignitic additives, and tannins. Dispersed systems typically require additions of caustic soda (NaOH) to maintain a pH level of 10.0 to 11.0. Dispersing a system can increase its tolerance for solids, making it possible to weight up to 20.0 ppg. The commonly used lignosulfonate system relies on relatively inexpensive additives and is familiar to most operator and rig personnel. Additional commonly used dispersed muds include lime and other cationic systems. A solids-laden dispersed system also can decrease the rate of penetration significantly and contribute to hole erosion.

Saltwater drilling fluids

Saltwater drilling fluids often are used for shale inhibition and for drilling salt formations. They also are known to inhibit the formation of ice-like hydrates that can accumulate around subsea wellheads and well-control equipment, blocking lines and impeding critical operations. Solids-free and low-solids systems can be formulated with high-density brines, such as:

- Calcium chloride
- Calcium bromide
- Zinc bromide
- Potassium and cesium formate

Polymer drilling fluids

Polymer drilling fluids are used to drill reactive formations where the requirement for shale inihbition is significant. Shale inhibitors frequently used are salts, glycols and amines, all of which are incompatible with the use of bentonite. These systems typically derive their viscosity profile from polymers such as xanthan gum and fluid loss control from starch or cellulose derivatives. Potassium chloride is an inexpensive and highly effective shale inhibitor which is widely used as the base brine for polymer drilling fluids in many parts of the world. Glycol and amine-based inhibitors can be added to further enhance the inhibitive properties of these fluids.

Drill-in fluids

Drilling into a pay zone with a conventional fluid can introduce a host of previously undefined risks, all of which diminish reservoir connectivity with the wellbore or reduce formation permeability. This is particularly true in horizontal wells, where the pay zone can be exposed to the drilling fluid over a long interval. Selecting the most suitable fluid system for drilling into the pay zone requires a thorough understanding of the reservoir. Using data generated by lab testing on core plugs from carefully selected pay zone cores, a reservoir-fluid-sensitivity study should be conducted to determine the morphological and mineralogical composition of the reservoir rock. Natural reservoir fluids should be analyzed to establish their chemical makeup. The degree of damage that could be caused by anticipated problems can be modeled, as can the effectiveness of possible solutions for mitigating the risks.

A drill-in fluid (DIF) is a clean fluid that is designed to cause little or no loss of the natural permeability of the pay zone, and to provide superior hole cleaning and easy cleanup. DIFs can be:

- Water-based
- Brine-based
- Oil-based
- Synthetic-based

In addition to being safe and economical for the application, a DIF should be compatible with the reservoir’s native fluids to avoid causing precipitation of salts or production of emulsions. A suitable nondamaging fluid should establish a filter cake on the face of the formation, but should not penetrate too far into the formation pore pattern. The fluid filtrate should inhibit or prevent swelling of reactive clay particles within the pore throats.

Formation damage commonly is caused by:

- Pay zone invasion and plugging by fine particles
- Formation clay swelling
- Commingling of incompatible fluids
- Movement of dislodged formation pore-filling particles
- Changes in reservoir-rock wettability
- Formation of emulsions or water blocks

Once a damage mechanism has diminished the permeability of a reservoir, it seldom is possible to restore the reservoir to its original condition.

Oil-based fluids

Oil-based systems were developed and introduced in the 1960s to help address several drilling problems:

- Formation clays that react, swell, or slough after exposure to WBFs
- Increasing downhole temperatures
- Contaminants
- Stuck pipe and torque and drag

Oil-based fluids (OBFs) in use today are formulated with diesel, mineral oil, or low-toxicity linear olefins and paraffins. The olefins and paraffins are often referred to as "synthetics" although some are derived from distillation of crude oil and some are chemically synthesised from smaller molecules. The electrical stability of the internal brine or water phase is monitored to help ensure that the strength of the emulsion is maintained at or near a predetermined value. The emulsion should be stable enough to incorporate additional water volume if a downhole water flow is encountered.

Barite is used to increase system density, and specially-treated organophilic bentonite is the primary viscosifier in most oil-based systems. The emulsified water phase also contributes to fluid viscosity. Organophilic lignitic, asphaltic and polymeric materials are added to help control HP/HT(High pressure/High temperature) fluid loss. Oil-wetting is essential for ensuring that particulate materials remain in suspension. The surfactants used for oil-wetting also can work as thinners. Oil-based systems usually contain lime to maintain an elevated pH, resist adverse effects of hydrogen sulfide (H_2S) and carbon dioxide (CO_2) gases, and enhance emulsion stability.

Shale inhibition is one of the key benefits of using an oil-based system. The high-salinity water phase helps to prevent shales from hydrating, swelling, and sloughing into the wellbore. Most conventional oil-based mud (OBM) systems are formulated with calcium chloride brine, which appears to offer the best inhibition properties for most shales.

The ratio of the oil percentage to the water percentage in the liquid phase of an oil-based system is called its oil/water ratio. Oil-based systems generally function well with an oil/water ratio in the range from 65/35 to 95/5, but the most commonly observed range is from 70/30 to 90/10.

The discharge of whole fluid or cuttings generated with OBFs is not permitted in most offshore-drilling areas. All such drilled cuttings and waste fluids are processed, and shipped to shore for disposal. Whereas many land wells continue to be drilled with diesel-based fluids, the development of synthetic-based fluids (SBFs) in the late 1980s provided new options to offshore operators who depend on the drilling performance of oil-based systems to help hold down overall drilling costs but require more environmentally-friendly fluids. In some areas of the world such as the North Sea, even these fluids are prohibited for offshore discharge.

Synthetic-based drilling fluids

Synthetic-based fluids were developed out of an increasing desire to reduce the environmental impact of offshore drilling operations, but without sacrificing the cost-effectiveness of oil-based systems.

Like traditional OBFs, SBFs can be used to:

- Maximize rate of penetrations (ROPs)
- Increase lubricity in directional and horizontal wells
- Minimize wellbore-stability problems, such as those caused by reactive shales

Field data gathered since the early 1990s confirm that SBFs provide exceptional drilling performance, easily equaling that of diesel- and mineral-oil-based fluids.

In many offshore areas, regulations that prohibit the discharge of cuttings drilled with OBFs do not apply to some of the synthetic-based systems. SBFs' cost per barrel can be higher, but they have proved economical in many offshore applications for the same reasons that traditional OBFs have: fast penetration rates and less mud-related nonproductive time (NPT). SBFs that are formulated with linear alphaolefins (LAO) and isomerized olefins (IO) exhibit the lower kinematic viscosities that are required in response to the increasing importance of viscosity issues as operators move into deeper waters. Early ester-based systems exhibited high kinematic viscosity, a condition that is magnified in the cold temperatures encountered in deepwater risers. However, a shorter-chain-length (C_8), low-viscosity ester that was developed in 2000 exhibits viscosity similar to or lower than that of the other base fluids, specifically the heavily used IO systems. Because of their high biodegradability and low toxicity, esters are universally recognized as the best base fluid for environmental performance.

By the end of 2001, deepwater wells were providing 59%; of the oil being produced in the Gulf of Mexico.[4] Until operators began drilling in these deepwater locations, where the pore pressure/fracture gradient (PP/FG) margin is very narrow and mile-long risers are not uncommon, the standard synthetic formulations provided satisfactory performance. However, the issues that arose because of deepwater drilling and changing environmental regulations prompted a closer examination of several seemingly essential additives.

When cold temperatures are encountered, conventional SBFs might develop undesirably high viscosities as a result of the organophilic clay and lignitic additives in the system. The introduction of SBFs formulated with zero or minimal additions of organophilic clay and lignitic products allowed rheological and fluid-loss properties to be controlled through the fluid-emulsion characteristics. The performance advantages of these systems include:

- High, flat gel strengths that break with minimal initiation pressure
- Significantly lower equivalent circulating densities (ECDs)
- Reduced mud losses while drilling, running casing, and cementing (/Cementing_operations)

All-oil fluids

Normally, the high-salinity water phase of an invert-emulsion fluid helps to stabilize reactive shale and prevent swelling. However, drilling fluids that are formulated with diesel- or synthetic-based oil and no water phase are used to drill long shale intervals where the salinity of the formation water is highly variable. By eliminating the water phase, the all-oil drilling fluid can preserve shale stability throughout the interval.

Pneumatic-drilling fluids

Compressed air or gas can be used in place of drilling fluid to circulate cuttings out of the wellbore. Pneumatic fluids fall into one of three categories:

- Air or gas only
- Aerated fluid
- Foam[5]

Pneumatic-drilling operations require specialized equipment to help ensure safe management of the cuttings and formation fluids that return to surface, as well as tanks, compressors, lines, and valves associated with the gas used for drilling or aerating the drilling fluid or foam.

Except when drilling through high-pressure hydrocarbon- or fluid-laden formations that demand a high-density fluid to prevent well-control issues, using pneumatic fluids offers several advantages[6]:

- Little or no formation damage
- Rapid evaluation of cuttings for the presence of hydrocarbons
- Prevention of lost circulation
- Significantly higher penetration rates in hard-rock formations

Specialty products

Drilling-fluid service companies provide a wide range of additives that are designed to prevent or mitigate costly well-construction delays. Examples of these products include:

- Lost-circulation materials (LCM) that help to prevent or stop downhole mud losses into weak or depleted formations.
- Spotting fluids that help to free stuck pipe (/Stuck_pipe).
- Lubricants for WBFs that ease torque and drag and facilitate drilling in high-angle environments.
- Protective chemicals (e.g., scale and corrosion inhibitors, biocides, and H_2S scavengers) that prevent damage to tubulars and personnel.

Lost-circulation materials

Many types of LCM are available to address loss situations:

- Sized calcium carbonate
- Mica
- Fibrous material
- Cellophane
- Crushed walnut shells

The development of deformable graphitic materials that can continuously seal off fractures under changing pressure conditions has allowed operators to cure some types of losses more consistently. The application of these and similar materials to prevent or slow down the physical destabilisation of the wellbore has proved successful. Hydratable and rapid-set lost-circulation pills also are effective for curing severe and total losses. Some of these fast-acting pills can be mixed and pumped with standard rig equipment, while others require special mixing and pumping equipment.

Spotting fluids

Most spotting fluids are designed to penetrate and break up the wall cake around the drillstring. A soak period usually is required to achieve results. Spotting fluids typically are formulated with a base fluid and additives that can be incorporated into the active mud system with no adverse effects after the pipe is freed and/or circulation resumes.

Lubricants

Lubricants might contain hydrocarbon-based materials, or can be formulated specifically for use in areas where environmental regulations prohibit the use of an oil-based additive. Tiny glass or polymer beads also can be added to the drilling fluid to increase lubricity. Lubricants are designed to reduce friction in metal-to-metal contact, and to provide lubricity to the drillstring in the open hole, especially in deviated wells, where the drillstring is likely to have continuous contact with the wellbore.

Corrosion, inhibitors, biocides, and scavengers

Corrosion causes the majority of drillpipe loss and damages casing, mud pumps, bits, and downhole tools. As downhole temperatures increase, corrosion also increases at a corresponding rate, if the drillstring is not protected by chemical treatment. Abrasive materials in the drilling fluid can accelerate corrosion by scouring away protective films. Corrosion, typically, is caused by one or more factors that include:

- Exposure to oxygen, H_2S, and/or CO_2
- Bacterial activity in the drilling fluid
- High-temperature environments
- Contact with sulfur-containing materials

Drillstring coupons can be inserted between joints of drillpipe as the pipe is tripped in the hole. When the pipe next is tripped out of the hole, the coupon can be examined for signs of pitting and corrosion to determine whether the drillstring components are undergoing similar damage.

H_2S and CO_2 frequently are present in the same formation. Scavenger and inhibitor treatments should be designed to counteract both gases if an influx occurs because of underbalanced drilling conditions. Maintaining a high pH helps control H_2S and CO_2, and prevents bacteria from souring the drilling fluid. Bacteria also can be controlled using a microbiocide additive.

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