

Drilling Fluid Basics

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Drilling fluids serve many functions: controlling formation pressures, removing cuttings from the wellbore, sealing permeable formations encountered while drilling, cooling and lubricating the bit, transmitting hydraulic energy to downhole tools and the bit and, perhaps most important, maintaining wellbore stability and well control. Often referred to as mud, drilling fluid was first introduced around 1913 for subsurface pressure control. The 1920s and '30s saw the birth of the first US companies specializing in the distribution, development and engineering of drilling fluids and components. In the decades that followed, drilling fluid companies introduced developments in chemistry, measurement and process engineering that led to significant improvements in drilling efficiency and well productivity.

Drilling fluid compositions vary based on wellbore demands, rig capabilities and environmental concerns. Engineers design drilling fluids to control subsurface pressures, minimize formation damage, minimize the potential for lost circulation, control erosion of the borehole and optimize drilling parameters such as penetration rate and hole cleaning. In addition, because a large percentage of modern wellbores are highly deviated, drilling fluid systems must help manage hole cleaning and stability problems specific to these wells.

Drilling Fluid Systems

Drilling fluid systems have a *continuous phase*, which is liquid, and a *discontinuous phase* comprising solids. On occasion, they also have a *gas phase*—either by design or as a result of formation gas entrainment. The continuous phase may be used to categorize drilling fluid types as gas, aqueous fluids or nonaqueous systems. These fluids are a blend of liquid and solid components, each designed to modify a specific property of the drilling fluid such as its viscosity and density.

Aqueous drilling fluids, generally referred to as water-base muds, are the most common and the most varied of the three drilling fluid types (above right). They range in composition from simple blends of water and clay to complex *inhibitive*, or clay stabilizing, drilling fluid systems that include many components. In recent years, engineers and scientists have focused on improving the inhibitive and thermal performance of water-base systems in efforts to compete with the nonaqueous fluids typically used in challenging drilling environments.

In nonaqueous drilling fluids, commonly referred to as synthetic-base muds, the continuous phase may consist of mineral oils, biodegradable esters, olefins or other variants. Although typically more costly than aqueous drilling fluids, these systems tend to provide excellent borehole control, thermal stability, lubricity and penetration rates, which may help reduce overall cost for the operator.

In fractured rock or environments where the borehole will not support a column of water without significant fluid loss to the formation, drillers use air, mist or foam systems to help remove cuttings from the hole and maintain wellbore integrity.



▲ Bentonite drilling fluid being mixed and agitated.

Basic Functions

Drilling fluids are formulated to carry out a wide range of functions. Although the list is long and varied, key performance characteristics are the following:

Controlling formation pressures—Drilling fluid is vital for maintaining control of a well. The mud is pumped down the drillstring, through the bit, and back up the annulus. In open hole, hydrostatic pressure exerted by the mud column is used to offset increases in formation pressure that would otherwise force formation fluids into the borehole, possibly causing loss of well control. However, the pressure exerted by the drilling fluid must not exceed the fracture pressure of the rock itself; otherwise mud will escape into the formation—a condition known as *lost circulation*.

Removing cuttings from the borehole—Circulating drilling fluid carries *cuttings*—rock fragments created by the bit—to the surface. Maintaining the fluid's ability to transport these solid pieces up the hole—its *carrying capacity*—is key to drilling efficiently and minimizing the potential for stuck pipe. To accomplish this, drilling fluid specialists work with the driller to carefully balance mud rheology and flow rate to adjust carrying capacity while avoiding high *equivalent circulating density* (ECD)—the actual mud density plus the pressure drop in the annulus above a given point in the borehole. Unchecked, high ECD may lead to lost circulation.

Cooling and lubricating the bit—As the drilling fluid passes through and around the rotating drilling assembly, it helps cool and lubricate the bit. Thermal energy is transferred to the drilling fluid, which carries the heat to the surface. In extremely hot drilling environments, heat exchangers may be used at the surface to cool the mud.

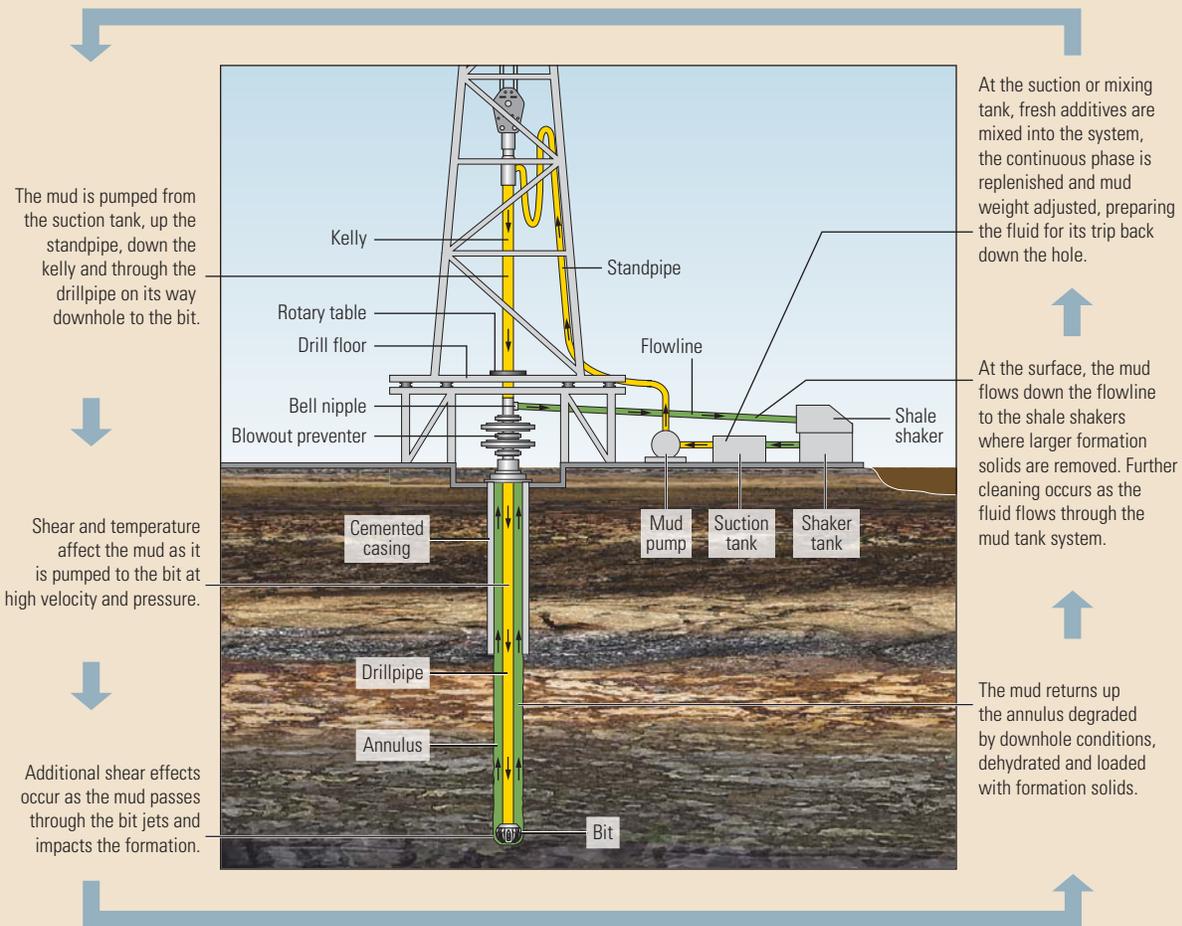
Transmitting hydraulic energy to the bit and downhole tools—Drilling fluid is discharged through nozzles at the face of the bit. The hydraulic energy released against the formation loosens and lifts cuttings away from the formation. This energy also powers downhole motors and other hardware that steer the bit and obtain drilling or formation data in real time. Data gathered downhole are frequently transmitted to the surface using *mud pulse telemetry*, a method that relies on pressure pulses through the mud column to send data to the surface.

Maintaining wellbore stability—The basic components of wellbore stability include regulating density, minimizing hydraulic erosion and controlling clays. Density is maintained by slightly overbalancing the weight of the mud column against formation pore pressure. Engineers minimize hydraulic erosion by balancing hole geometry against cleaning requirements, fluid carrying capacity and annular flow velocity. The process of clay control is complex. Clays in some formations expand in the presence of water, while others disperse. To some degree, these effects can be controlled by modifying the properties of the drilling fluid. Regardless of the approach used, controlling the fluid's effect on the formation helps control the borehole and the integrity of the cuttings and leads to a cleaner, more easily maintained drilling fluid.

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▲ Drilling fluid life cycle. Throughout the circulation cycle, the mud is subjected to a number of processes that alter its physical parameters. The drilling fluid treatment plan must evolve to keep pace with these changes.

Drilling Fluid Life Cycle

Drilling fluid design and maintenance are iterative processes affected by surface and downhole conditions. These conditions change as the well is drilled through deeper formations and encounters gradual increases in temperature and pressure and the mud undergoes alterations in chemistry brought about by different types of rock and formation fluids (above). Onsite fluid specialists and staff engineers use continuous process engineering to fine-tune the drilling fluid in response to changing borehole conditions then evaluate fluid performance and modify fluid properties in an ongoing cycle.

Initial design—In the planning phase, fluid experts select mud system types and designs for each borehole section. The systems are designed to meet several specifications, including density requirements, borehole stability, thermal gradients, logistics and environmental concerns. Drilling may begin with a simple fluid system. Water is often the first fluid used for drilling to the initial casing point. As the borehole deepens, increasing formation pressure, rising temperature and more-complex formations require higher levels of mechanical wellbore control and hole cleaning capacity. Simple fluid systems may be displaced or converted to weighted water-base inhibitive mud, followed at greater depths by nonaqueous drilling fluids.

Circulation—The drilling fluid's character constantly evolves. In one circulation cycle, the fluid has expended energy, lifted cuttings, cooled the

bit and hole and then released waste at the surface. This requires engineers and fluid specialists to continuously evaluate and recharge the system with fresh fluids and other additives.

Measurement and redesign—The drilling fluids specialist measures certain properties of the returning mud. The specific properties measured are generally a function of the fluid type that is used, but typically include density, rheology, filtration rate, continuous phase content and ratios and solids content and classification. The fluid is further analyzed for pH, hardness, alkalinity, chlorides, acid gas content and other parameters specific to certain fluid types. The specialist then designs a treatment program for the next 12 to 24 hours. The driller, derrickman and fluids specialist constantly monitor borehole conditions and characteristics of the returning fluid then make adjustments to the mud as hole and drilling conditions dictate.

A Century of Continual Development

From humble beginnings about 100 years ago, drilling fluids have evolved as a science, an engineering discipline and an art. Scientists and product developers create new fluid designs that address the many demands placed on modern drilling fluids, while engineers and fluid specialists in the field continue to find new ways to monitor, measure, simulate and manage the drilling fluid life cycle.