

ROTARY DRILLING

# Drilling Fluids



Petroleum Extension-The University of Texas at Austin

First Edition

UNIT II • LESSON 2



## ROTARY DRILLING SERIES

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- Lesson 2: The Bit
- Lesson 3: Drill String and Drill Collars
- Lesson 4: Rotary, Kelly, Swivel, Tongs, and Top Drive
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# Units of Measurement



Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is almost the only country that employs the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, for example, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the *Système International (SI) d'Unités*. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The *Rotary Drilling Series* gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is *metre*, not *meter*. (Note, however, that the unit of weight is *gram*, not *gramme*.)

To aid U.S. readers in making and understanding the conversion to the SI system, we include the following table.

## English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m <sup>3</sup> )
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m <sup>3</sup> /stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches (in. <sup>3</sup> )	16.387	cubic centimetres (cm <sup>3</sup> )
	cubic feet (ft <sup>3</sup> )	28.3169	litres (L)
		0.0283	cubic metres (m <sup>3</sup> )
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m <sup>3</sup> )
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m <sup>3</sup> )
barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m <sup>3</sup> /t)	
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m <sup>3</sup> /min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m <sup>3</sup> /h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m <sup>3</sup> /stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m <sup>3</sup> /min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Thermal gradient	1°F per 60 feet	—	1°C per 33 metres
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m <sup>3</sup> )
	pounds per cubic foot (lb/ft <sup>3</sup> )	16.0	kilograms per cubic metre (kg/m <sup>3</sup> )
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft <sup>2</sup> )	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft <sup>2</sup> )	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.7	kilowatts (kW)
Area	square inches (in. <sup>2</sup> )	6.45	square centimetres (cm <sup>2</sup> )
	square feet (ft <sup>2</sup> )	0.0929	square metres (m <sup>2</sup> )
	square yards (yd <sup>2</sup> )	0.8361	square metres (m <sup>2</sup> )
	square miles (mi <sup>2</sup> )	2.59	square kilometres (km <sup>2</sup> )
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

# Introduction



Without a circulating drilling fluid, rotary drilling would be difficult if not impossible in some cases. A fluid is any substance that flows, so drilling fluid may be either liquid, gas, or a mixture of the two. If liquid, drilling fluid may be water, oil, or a combination of water and oil. Operators often put special substances (additives) in these liquids to give them characteristics that make it possible or easier to drill the hole. Most oilfield workers call liquid drilling fluid drilling mud. A gaseous drilling fluid may be (1) dry air or natural gas, (2) air or gas mixed with a special foaming agent, which forms mist or foam or, (3) air or gas mixed with liquid, which is an aerated drilling mud.

Drilling fluids were simple in the early days of rotary drilling; operators usually just used whatever water was available. They dug an open pit in the ground next to the rig and filled it with water. If they wanted to stabilize the hole—that is, keep the hole from caving in where it penetrated soft formations—they stirred up the pit holding the water. Stirring the pits mixed the natural clays in the soil with the water. The solid clay particles plastered the sides of the hole with wall cake. This wall cake often prevented soft formations from caving or sloughing (pronounced sluffing) into the hole. Legend has it that the Hamil brothers, who successfully drilled the Spindletop well in 1901, ran cattle through their water pits to stir up the clay. Whatever they did to make mud, it worked. The solids in the natural clay formed a wall cake on a troublesome formation that enabled the Hamils to successfully drill it. The formation had thwarted several previous attempts when the drillers merely used clear water as a drilling fluid.

Today, drilling fluid choices are complex. The development of special types of fluids and additives to cure all sorts of downhole problems brings its own difficulties. Research and field employees of drilling fluid companies, often called mud engineers, must ask, for example, what additive will best correct a particular drilling problem? How will the mud react to changes in the formation? Will a certain additive interfere with or cancel the effect of another? Will the expense of disposing of a fluid with toxic additives outweigh the benefits of using it?

A great deal of study, analysis, and expense go into a *mud program*, which is the plan for the type and properties of drilling fluid to use. A good mud program ensures that the physical and chemical properties of the fluid are the best ones possible for a particular drilling situation. Miscalculation can result in unnecessary costs in time and money. Although the design and maintenance of a mud program are the responsibility of the mud engineer, all rig personnel will be better equipped to do their jobs if they understand the basics of drilling fluids.



# Functions of Drilling Fluids



When drilling with a rotary rig, the rig operator normally circulates some type of fluid. Drilling fluid is necessary because it—

1. cleans the bottom of the hole,
2. transports bit cuttings to the surface,
3. cools and lubricates the bit and drill stem,
4. supports the walls of the wellbore,
5. prevents the entry of formation fluids into the well,
6. transmits hydraulic power to downhole equipment,
7. reveals the presence of oil, gas, or water that may enter the circulating fluid from a formation being drilled, and
8. reveals information about the formation by means of the cuttings the fluid brings up to the surface.

Many kinds of drilling fluids are available, and all perform these functions in their own way. Air and gas have particular advantages and disadvantages compared to drilling muds.

# Drilling Fluid Composition



The type of drilling fluid an operator selects to drill a well depends on many factors, including the type of formation being drilled, whether the formations contain water, the pressure the formations exert in the hole, and how deep the hole is. Because operators usually want to drill as fast as possible, they use the lightest fluid they can, but one that nevertheless controls downhole conditions. Air and gas provide the highest ROP. Liquid based muds (those that are mainly water, oil, or a combination of oil and water) usually cannot provide an ROP as high as air or gas, for reasons discussed shortly. Because air or gas cannot successfully drill most formations, the most common drilling fluid is drilling mud.

The relationship between the functions, the composition, and the properties of a drilling mud is close. Indeed, they are so closely related that it is difficult to separate them. The mud engineer has to decide which functions are most important in a particular well, and then choose the correct mud composition that has the properties to carry out those functions. Designing the mud program is a balancing act between the relative importance of one function over another, one composition over another, and one property over another to get the best performance for each hole.

# Basic Properties of Drilling Muds



Some important properties of drilling mud are its density (weight), its viscosity, its gel strength, and its filtration properties. The effectiveness of the mud in performing its functions is directly related to these properties. Two problems in mud control are (1) determining what adjustments need to be made to the mud to give it the desired properties and (2) choosing how to make those adjustments.

In conventional rotary drilling, one of the chief functions of a drilling mud is to keep formation fluids, such as oil, gas, and water, in the formation. Under normal drilling conditions, preventing these fluids from flowing into the wellbore is crucial. An exception is when operators drill underbalanced. In this technique, also called drilling while producing, the operator deliberately keeps hydrostatic pressure below formation pressure, which allows formation fluids to flow into the wellbore while drilling. Operators primarily use underbalanced drilling in high-pressure but low-volume gas formations. A special sealing device at the surface—a rotating blowout preventer, or rotating head—vents the drilled gas through a special line away from the rig. Underbalanced drilling allows fast penetration rates because hydrostatic pressure is low and hole cleaning is therefore very efficient, which allows the bit cutters to constantly drill fresh, uncut formation.

## Density (Weight)

# Composition of Water-Base Drilling Muds



**W**ater-base muds are the most widely used drilling fluid. Because either fresh water or salt water is available in most of the world's drilling areas, water-base muds are easier to use and less expensive than oil-base muds or compressed air.

The quality of water used to make up and maintain water-base muds affects the way mud additives perform. For example, clays work best in distilled water. Hard water — water that contains large amounts of calcium and magnesium salts — and salt water reduce a clay's effect.

The composition of the mud used to start a well, or *spud in*, varies with drilling practices around the world. Sometimes the operator uses water alone from a nearby source such as a well, stream, or lake. The ideal situation is when the makeup water is soft and the formations near the surface make a good natural mud. If this is not the case, the operator may mix clay, lime, and soda ash into the mud. Lime thickens the mud and allows the operator to use less clay to build viscosity.

## Spud Muds

Sometimes the formations near the surface contain enough clay to make up a good *natural mud* when mixed with water. Natural muds that have low weight and viscosity, because they either do not hydrate well or need a lot of water to keep the weight and viscosity down, are useful at shallow depths, such as for surface drilling and for making hole below the conductor casing. In shallow holes, the formation pressures are usually normal, and mud does not need to be heavy to prevent kicks. These low-weight, low-viscosity muds provide a high rate of penetration and decrease the risk of stuck pipe and lost circulation.

## Natural Muds

# Composition of Oil Muds



Oil muds have oil, usually diesel or synthetic oil, as the liquid phase instead of water. Oil muds are more expensive, harder to handle, and harder to dispose of than water-base muds, but they are simple to prepare and not difficult to maintain. Because of the cost and environmental concerns, operators use them only when the downhole conditions require it. Operators commonly use oil muds for—

1. protecting producing formations,
2. drilling water-soluble formations,
3. drilling deep, high-temperature holes,
4. preventing differential pressure sticking,
5. coring,
6. minimizing gelation and corrosion problems (when used as a packer fluid),
7. helping to salvage casing (when used as a casing pack),
8. mitigating severe drill string corrosion,
9. preventing entrainment of gas, and
10. drilling troublesome shales.

The benefits of oil muds are many, in particular situations. Operators have long used oil muds for coring and completion. Nevertheless, their advantages in difficult formations and deep or directional drilling have made them a more widely used choice in recent years. When water-base muds cause a problem—in formations containing water-sensitive shales, corrosive gases, or water-soluble salts, for example—an oil mud can be the answer. The cost is relatively high, but proper handling, storage, and careful moving of the mud from well to well can make its use cost-effective.

## Advantages of Oil Muds

# Air, Gas, and Mist Drilling



Although operators don't use air or gas very often, it's a valuable method of drilling when the formation allows it.

Penetration rates with air and gas are higher—partly because air or gas cleans the bottom of the hole more efficiently than mud. Mud is denser than air or gas and tends to hold the cuttings on the bottom of the hole. As a result, the bit cannot make hole as efficiently because the bit redrills some of the old cuttings instead of being constantly exposed to fresh, undrilled formation. With air or gas as a drilling fluid, the cuttings literally explode from beneath the bit cutters.

Air or gas drilling also gets more wear from the bit because air and gas are much less abrasive to the metal parts than drilling mud. Both air and gas do an excellent job of cooling, and both transport cuttings to the surface quickly. In addition, with air or gas circulation, the formation is easy to identify, and it is easy to detect the presence of gas, oil, or water.

Unfortunately, air or gas drilling has several disadvantages that overshadow the advantages. First, if the formation rock is soft and the walls of the well tend to slough into the hole, air or gas does not have enough hydrostatic pressure to prevent them from doing so. Sloughing walls could cause the drill stem to stick. Second, preventing formation fluids from entering the wellbore is impossible because neither air nor gas can exert enough pressure to keep them out. This second disadvantage is especially important because most wells encounter water-bearing formations at some time.

## Advantages

## Disadvantages

# Drilling Fluid Problems



Every well presents its own problems to drilling. Problem sources include the type of rock that makes up the formation, the pressures and temperatures in the well, and contaminants that affect the fluid. The mud engineer tailors the drilling program to each well to get the petroleum out in the most efficient manner, at the least cost, and while maintaining control of formation pressures.

In trying to achieve the best performance for all the functions a drilling fluid must perform, the mud engineer unfortunately comes across problems. For example, weighting up a mud to achieve the best transport of cuttings carries the risk of weighting it up so much that it fractures the formation. Drilling experts are always balancing the advantages of making a change in a drilling fluid against the problems that such a change could cause.

Shale is a porous rock but it has virtually no permeability. Frequently, however, salt water and other fluids such as hydrocarbons are contained in the pore spaces. The salt water is connate water, water that existed in the formation when it was formed in the ancient past. In a few cases, hydrocarbons also exist in impermeable shale. One example is in the western U.S., where vast shale deposits hold hydrocarbons that cannot flow into a well. Eventually, these deposits will be mined or extracted in some other way when the need arises. In any event, when a wellbore exposes shale to drilling fluid and where salt water is contained in the shale, the drilling fluid usually requires special attention.

## Drilling in Shale Formations

# Testing of Water-Base Drilling Muds



On land rigs, the derrickhand (and on some offshore rigs the derrickhand's assistant, the pit watcher) monitors the mud for any changes in weight, viscosity, and temperature by testing, as well as changes in the size of cuttings, flow rate, and the level of mud in the tanks. A mud engineer does more sophisticated testing. Mud characteristics that the derrickhand usually measures are density, viscosity and gel strength, filtration and wall-building, and sand content. The mud engineer may test the mud's pH, liquid and solids content, the presence of contaminants, and electrolytic properties. A mud that conducts an electric current increases corrosion of the metal components in the hole. Whoever tests the mud also records the measurements in a mud record.

Two API publications, *Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids, 13B-1* and *Recommended Practice Standard Procedure for Field Testing Oil-Based Drilling Fluids, 13B-2*, list detailed descriptions, equipment, and procedures for testing water-base and oil muds. The information that follows elaborates on these recommended practices.

To get accurate and useful results from mud tests, the samples must resemble the mud downhole, so most tests recreate some or all of the conditions in the well. For example, some tests require that the mud be stirred or agitated to simulate circulation; others require that the temperature of the mud sample be close to that which it experiences in the borehole.

## Preparing Mud Samples



# Treatment of Drilling Muds



The testing that the crew and mud engineer do tells them if and when to treat the mud so that its properties are suitable to the drilling conditions. Changing drilling conditions can make it necessary to change the composition of the mud or change its weight.

In many drilling operations, it becomes necessary to change the chemistry of the mud from one type to another. Such a change is referred to as a *conversion*, or *breakover*. The point in time when the properties of the mud actually change is called breakover. A breakover usually is quite a radical change in mud chemistry, and during breakover from one type of mud to another, there may be very severe “viscosity humps.” For example, you can change a normal bentonite-based mud system to a salt-saturated system by adding salt. As you add the salt, the viscosity will increase really dramatically to very high levels, but eventually you reach a breakover point when the viscosity starts to decrease the more salt you add. At this point you are breaking over from one type of mud system to another.

## Breakover

Reasons for making a breakover include—

- to maintain a stable wellbore
- to provide a mud that will tolerate higher weight
- to drill salt formations
- to reduce the plugging of producing zones

In some cases it is dangerous to break over a mud in an open hole because of the high viscosities usually encountered. It is usually best to do a breakover in a cased hole before drilling the next hole section.

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