Filtration Control

Introduction

A basic drilling fluid function is to seal permeable formations and control filtration (fluid loss). Potential problems related to thick filter cakes and excessive filtration include tight hole, increased torque and drag, stuck pipe, lost circulation, poor log quality, and formation damage. Adequate filtration control and the deposition of a thin, low-permeability filter cake are often necessary to prevent drilling and production problems.

Potential problems from excessive filter-cake thickness:

1. Tight spots in the hole that cause excessive drag.
2. Increased surges and swabbing due to reduced annular clearance.
3. Differential sticking of the drillstring due to increased contact area and rapid development of sticking forces caused by higher filtration rate.
4. Primary cementing difficulties due to inadequate displacement of filter cake.
5. Increased difficulty running casing.

Potential problems from excessive filtrate invasion:

1. Formation damage due to filtrate and solids invasion. Damaged zone too deep to be remedied by perforation or acidization. Damage may be precipitation of insoluble compounds, changes in wettability, changes in relative permeability to oil or gas, formation plugging with fines or solids, and swelling of *in-situ* clays.
2. Invalid formation-fluid sampling test. Formation-fluid flow tests may give results for the filtrate rather than for the reservoir fluids.
3. Formation-evaluation difficulties caused by excessive filtrate invasion, poor transmission of electrical properties through thick cakes, and potential mechanical problems running and retrieving logging tools. Erroneous properties measured by logging tools (measuring filtrate-altered properties rather than reservoir fluid properties).
4. Oil and gas zones may be overlooked because the filtrate is flushing hydrocarbons away from the wellbore, making detection more difficult.

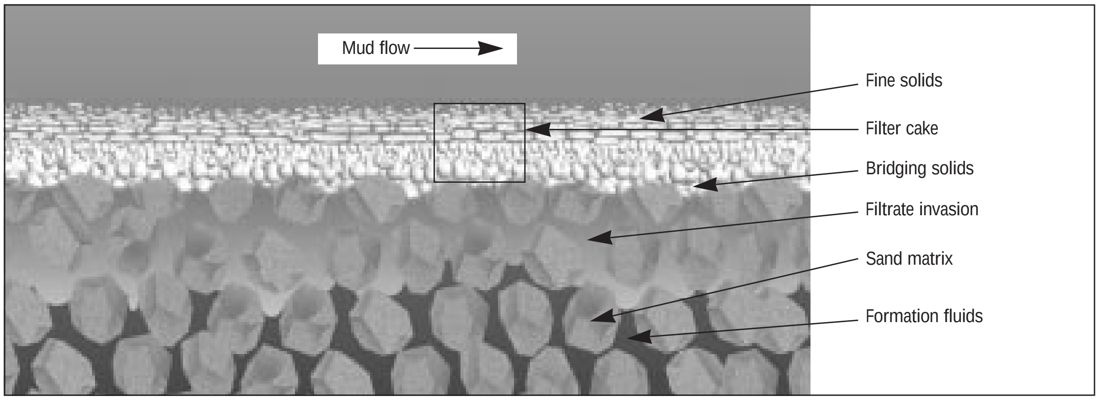

Figure 1: Filtration characteristics.

Fundamentals of Filtration

Drilling fluids are slurries composed of a liquid phase and solid particles. *Filtration* refers to the liquid phase of the drilling mud being forced into a permeable formation by differential pressure. During this process, the solid particles are *filtered out*, forming a *filter cake* (see Figure 1). If the liquid phase also contains an immiscible liquid — such as a brine in an oil-base mud — then the immiscible liquid droplets will also be deposited in the filter cake and will assist in filtration control. Permeability refers to the ability of fluid to flow through porous formations.

The API has standardized two static filtration test procedures.

Mud systems should be designed to seal permeable zones as quickly as possible with thin, slick filter cakes. In highly permeable formations with large pore throats, whole mud may invade the formation (depending on the size of the mud solids). In such situations, bridging agents must be used to block the openings so the mud solids can form a seal. Bridging agents should be at least one-half the size of the largest openings. Such bridging agents include calcium carbonate, ground cellulose and a wide variety of other lost-circulation materials.

Mud systems should...seal permeable zones as quickly as possible...

Filtration occurs under both dynamic and static conditions during drilling operations. Filtration under dynamic conditions occurs while the drilling fluid is circulating. Static filtration occurs at other times — during connections, trips or when the fluid is not circulating. The American Petroleum Institute (API), low-pressure, low-temperature and the High-Temperature, High-Pressure (HTHP) filtration and filter-cake measurements made by the mud engineer are static tests. These tests are very good at evaluating the overall filtration tendencies of the mud and are somewhat indicative of the laminar flow, dynamic filtration characteristics. More sophisticated, labor-intensive tests using laboratory instruments are available for measuring dynamic filtration, but they are not practical for routine testing.

STATIC FILTRATION TESTS

The API has standardized two static filtration test procedures. One is the low-pressure, low-temperature test and the other is the HTHP filtrate test. Normally, the low-pressure, low-temperature test is referred to as the "API filtration test."

The API filtration procedure is run for 30 min at ambient temperature with 100 psi differential pressure across the filter paper. Temperature variations affect this test, so care should be taken to run it at about the same temperature each time. In the temperature range from 70 to 140°F, the filtrate volume will increase about 50% or approximately 10% for each 15° of temperature increase. The API filtrate is reported as the cubic centimeters (cm^3) of filtrate collected after 30 min. The thickness of the API filter cake deposited during the API filtration test is reported in $\frac{1}{32}$ of an inch. In some areas, operators require metric measurements, and the filter-cake thickness is reported in millimeters (mm).

The HTHP test is run for 30 min at 300°F or a temperature near the formation temperature with 500 psi differential pressure across the filter paper. This test is run at temperatures as low as 200°F and as high as 450°F. The HTHP filtrate is reported as two times (2x) the cubic centimeters (cm^3) of filtrate collected after 30 min. The filtrate volume is doubled because the HTHP filtration cell has one-half the filtration area of the API filtrate cell. The thickness of the HTHP filter cake deposited during the HTHP filtration test is reported in either $\frac{1}{32}$ of an inch or millimeters (mm).

The filtrate receiver for HTHP testing is pressurized to prevent heated filtrate from flashing off as steam. This pressure must be greater than the vapor pressure of water at the test temperature. At test temperatures of 300°F or lower, the receiver pressure is run at 100 psi with the cell pressure at 600 psi. For test temperatures greater than 300°F, the receiver pressure in the HTHP test should be determined from the water vapor pressure at the test temperature. The top assembly or cell pressure is run at the receiver pressure plus 500 psi, to create the standard 500 psi pressure differential. Whatman No. 50 filter paper or its equivalent is used at test temperatures below 350°F. Filter paper chars (burns) at temperatures approaching 400°F. Dynalloy X-5 stainless steel disks or an equivalent should be used instead of filter paper at test temperatures greater than 350°F. Dynalloy X-5 disks are NOT reusable.

Another type of HTHP static filtration test, the Permeability Plugging Apparatus (PPA), is used occasionally to evaluate the filtration rate through simulated cores (aloxite or ceramic disks). This test is called the Permeability Plugging Test (PPT) and measures a "spurt loss" and a 30-min fluid loss at very high pressures (500 to 2,500 psi) and high temperatures. The PPA is a modified HTHP cell with a floating piston and hydraulically pressurized mud chamber. The unit has the simulated core located in the top of the cell and filtrate is collected from the top.

FILTRATION THEORY

For filtration to occur, three conditions are required:

1. A liquid or a liquid/solids slurry fluid must be present.
2. A permeable medium must be present.
3. The fluid must be at a higher pressure than the permeable medium.

During drilling, a fluid is circulated through the well. Permeable zones such as sandstones are drilled, and the hydrostatic pressure of the mud column is usually kept at a pressure higher than the pore pressure. Once these conditions are satisfied, a filter cake of mud solids will build up on permeable formations. Meanwhile, the liquid phase of the mud, the filtrate, will flow through the filter cake and into the formation. The filter-cake thickness and depth of filtrate invasion are controlled by the concentration of solids, differential pressure, permeability of the filter cake and length of exposure time.

At the initial exposure of a permeable formation to a drilling fluid, when the mud solids are building a low-permeability filter cake on the wellbore, a high rate of filtration occurs and fine mud solids invade the formation. This high rate of initial filtration is called the *spurt loss*.

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STATIC FILTRATION

Static filtration occurs under static conditions, i.e., any time the mud is not circulating. Several factors control the filtration rate under such conditions. Darcy's law, a classical fluid-flow model, helps to identify the factors that affect filtration. It also can be used to illustrate filtrate volume and cake thickness.

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Darcy's law applies to the flow of fluids through permeable materials (sand, sandstone or mud filter cake). It can be used to relate filtration rate to permeability, cross-sectional area, differential pressure, filtrate viscosity and filter-cake thickness (see Figure 2). For the flow of filtrate through a filter cake, the permeability of the *filter cake* is the controlling permeability, since it is much lower than the permeability of the formation. Darcy's law can be written as:

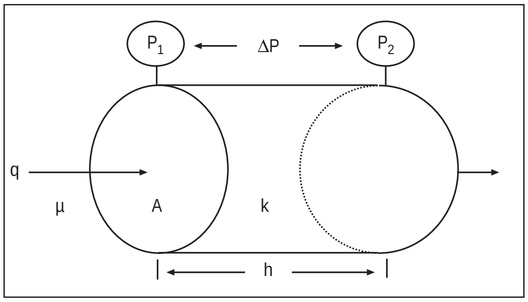


Figure 2: Illustration of Darcy's law flow.

$$q = \frac{k\,A\,\Delta P}{\mu h}$$

Where:

q = Filtrate flow rate (cm^3/sec)
k = Permeability (darcies)
A = Area, cross sectional (cm^2)
ΔP = Pressure differential (atmospheres)
μ = Viscosity (cP)
h = Thickness of filter cake (cm)

As this equation illustrates, fluid loss is lower with lower filter-cake permeability, smaller area and lower differential pressure. Filtration also decreases with increasing filtrate viscosity and increasing filter-cake thickness, if the thicker filter cake has the same permeability.

During static periods, the filter-cake thickness increases with time, but the rate of deposition decreases with time. A thick filter cake can cause a number of problems and is undesirable. Therefore, static filtration is a primary concern, and it is desirable to have the lowest practical fluid loss for any given drilling situation.

> ***...it is desirable to have the lowest practical fluid loss...***

The filtration rate of a drilling fluid is evaluated by measuring the volume of filtrate collected over a standard period of time. For this reason it is desirable to modify Darcy's law to determine filtrate volume V_F. The filtration rate, *q*, is equal to the change in filtrate volume divided by the change in time, dV_F/dt. The filter-cake thickness, *h*, can be defined mathematically as:

$$h = \frac{(V_F)\,F_{SLDS\text{-}MUD}}{A\,[F_{SLDS\text{-}CAKE} - F_{SLDS\text{-}MUD}\,]}$$

Where:

V_F = Volume filtrate
$F_{SLDS\text{-}MUD}$ = Volume fraction solids in mud
$F_{SLDS\text{-}CAKE}$ = Volume fraction solids in filter cake

Substituting this into Darcy's law and solving (integrating) for the filtrate volume:

$$V_F = A\sqrt{\frac{2kt[F_{SLDS\text{-}CAKE} - F_{SLDS\text{-}MUD}]\Delta P}{\mu\,(F_{SLDS\text{-}MUDV})}}$$

Where:

t = Time

This equation shows that filtrate volume is related to area and to the square roots of time, permeability and differential pressure. So, filtrate volume is lower with shorter periods of time, lower filter-cake permeability and lower differential pressure. Filtrate volume is also inversely related to the square roots of viscosity and the mud solids fraction. So, filtrate volume will be lower with increased filtrate viscosity. The effect of solids concentrations is complex and does not influence filtrate volume to the same degree as do the other variables. From this relationship, it is often helpful to use filtration measurements, V_{F1}, made at one set of conditions to predict filtration, V_{F2}, at another set of conditions.

FACTORS AFFECTING FILTRATION

Time. When all other conditions are constant (pressure, area, viscosity, permeability), the filtration rate and filter-cake growth become progressively slower with time, as predicted by Darcy's law. To predict the filtrate volume, V_{F2}, over a time period of interest, t_2, from a filtration measurement, V_{F1}, made at a time period, t_1, the filtrate volume collected will be a function of the square root of the ratio of the two time intervals:

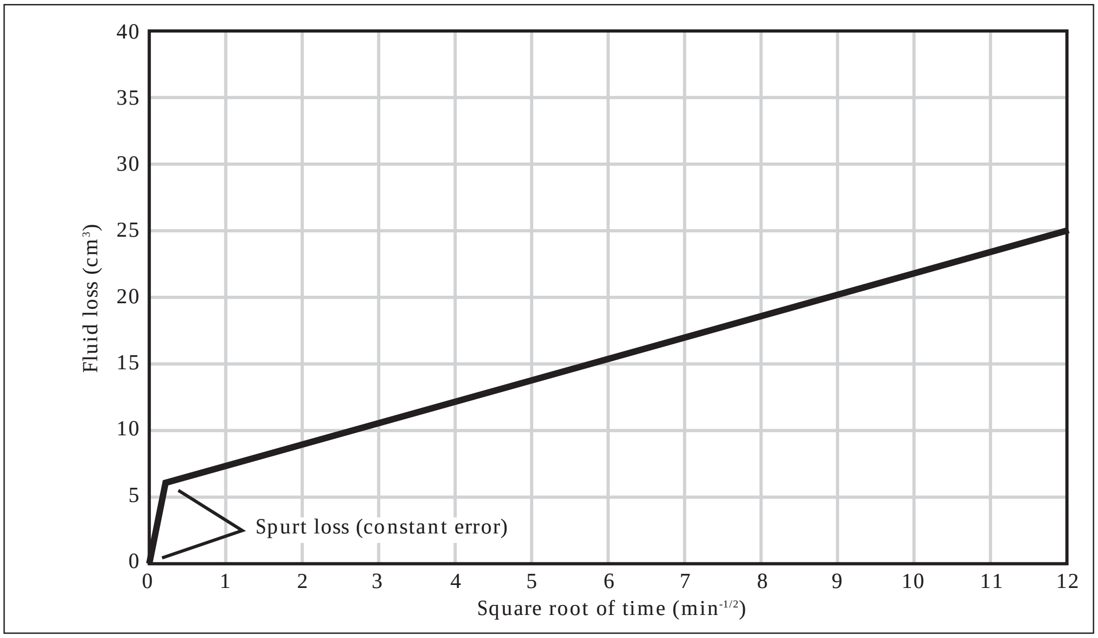


Figure 3: Relationship of fluid loss to square root of time.

$$V_{F2} = V_{F1}\sqrt{\frac{t_2}{t_1}}$$

Where:

V_{F2} = Unknown filtrate volume at time t_2
V_{F1} = Filtrate volume at time t_2
t_2 = Time period of interest
t_1 = Time period for V_{F1}

If the filtrate volume, V_{F1}, is measured after 1 hr and again after 4 hr, the second filtrate volume, V_{F2}, will be 2 times the volume of the first filtrate, not 4 times the volume.

$$V_{F2} = V_{F1}\sqrt{\frac{4}{1}} \quad = V_{F1} \times 2$$

If the filtrate volume is known for one test time, the volume can be predicted for a second test time. The API filtration test time is 30 min. It is common field practice to use a 7½-min test time and double the filtrate volume to estimate the 30-min API value.

$$V_{F2} = V_{F1}\sqrt{\frac{30}{7.5}} \quad = V_{F1} \times 2$$

Caution: This practice can lead to gross errors in the reported API filtrate volume. If the mud has a high spurt loss, the doubled 7½-min filtrate volume will be greater than the true API 30-min filtrate volume. If the mud has a low filtration rate, the volume of filtrate which fills the empty flow path in the filter cell before fluid is collected (hold-up volume) will make the doubled 7½-min filtrate volume lower than the true API 30-min filtrate volume.

The API HTHP filtration test must always be run for 30 min. The thermal effects and cell hold-up volume make a 7½-min HTHP test meaningless.

As Figure 3 illustrates, the filtration rate is linear when the filtration volume is plotted against the square root of time or on a semi-log scale. The filtrate volume increases in direct proportion to the square root of time. A straight line plotted at various times does not ordinarily go through the origin; therefore, at least two points on the line must be used to extrapolate to longer time periods.

A high spurt loss will cause the line to have a positive intercept on the y-axis, as in Figure 3. The positive intercept simply indicates that a spurt of filtrate passed through the filter paper before a cake was formed, restricting

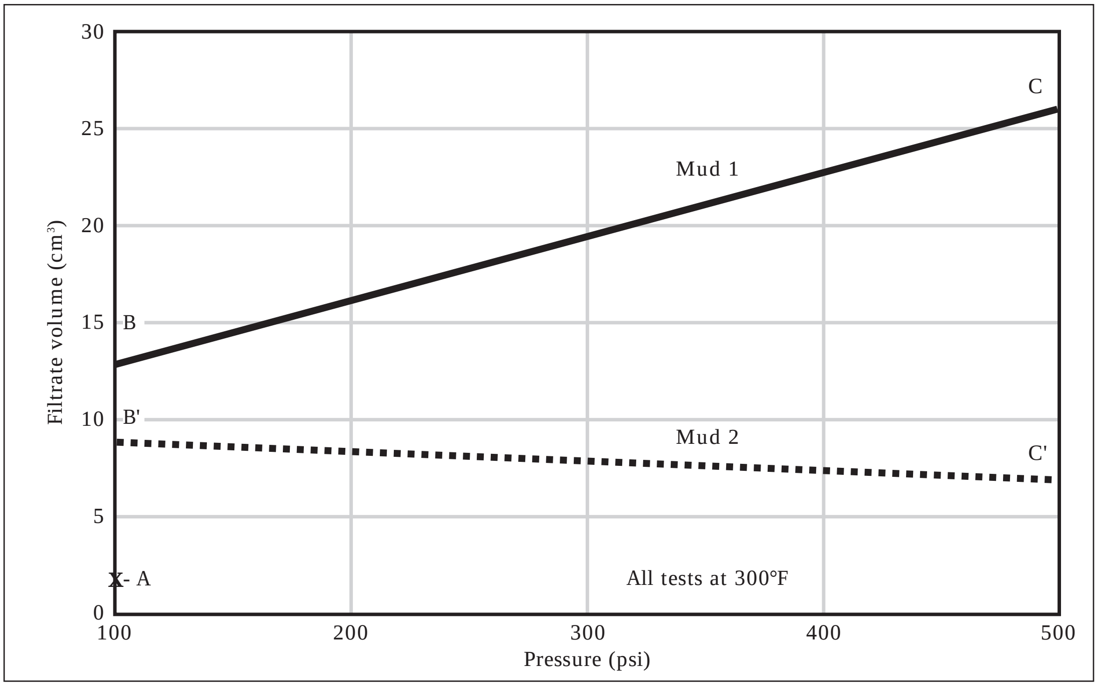


Figure 4: Effect of pressure-cake compressibility.

Filter-cake compressibility and permeability reduction are desirable…

the flow of filtrate. A low fluid loss and a dry cell with high hold-up volume will cause a negative y-axis intercept. This is because some filtrate must fill the empty flow path and drain line before the first drop can be collected, so the true filtrate volume is not collected. This error is most pronounced during short-time-period measurements and may be somewhat canceled by the spurt loss.

Pressure differential — filter-cake compressibility. When all other conditions are constant (time, area, viscosity and permeability), the filtrate volume at two different pressures should be proportional to the square roots of the pressures, as predicted by Darcy's law. But the filter cake of most drilling fluids is compressible, so the permeability decreases with increasing pressure. Filter-cake compressibility and permeability reduction are desirable features that limit filtration and filter-cake thickness. High-quality bentonite, when properly hydrated, is one of the best materials for increasing filter-cake compressibility. Regardless of filter-cake compressibility, however, higher differential pressure usually causes higher filtration rates.

Filter-cake compressibility can be evaluated by measuring the filtrate volume at two significantly different pressures. One method compares the filtrate volume collected at 500 and 100 psi, as shown in Figure 4. The two mud samples compared had the same API filtrate, labeled *Point A*. The high-temperature, 100-psi tests are labeled *Points B* and *B'*, while the HTHP filtrate is labeled *Point C* and *C'*. (Another common test procedure compares two tests run at 200 and 100 psi and ambient temperature.) These high-pressure tests, using an HTHP cell, can be performed at ambient or elevated temperatures.

If the mud solids form a compressible cake, the higher-pressure-filtrate volume should be only slightly higher than the lower-pressure filtrate. An incompressible filter cake will result in the higher-pressure-filtrate volume predicted by Darcy's law. This is equal to the lower-pressure-filtrate volume,

V_{F1}, times the square root of the ratio of $\Delta P_2/\Delta P_1$.

$$V_{F2} = V_{F1}\sqrt{\frac{\Delta P_2}{\Delta P_1}}$$

Where:

V_{F2} = Unknown filtrate volume at differential pressure ΔP_2

V_{F1} = Filtrate volume at differential pressure ΔP_1

ΔP_2 = Pressure differential of interest

ΔP_1 = Pressure differential for V_{F1}

This relationship **should not** be used to estimate filtration characteristics at another pressure. However, a comparison between V_{F2}/V_{F1} and the square root of $\Delta P_2/\Delta P_1$ is sometimes used to judge filter-cake compressibility. A V_{F2}/V_{F1} ratio less than the square root of $\Delta P_2/\Delta P_1$ indicates a compressible filter cake.

The square root of $\Delta P_2/\Delta P_1$ will indicate the slope of the line as plotted on Figure 4. Mud 1 (*B'*-*C'*) has a highly compressible filter cake as demonstrated by a negative slope. Mud 2 (*B*-*C*) has a relatively incompressible filter cake with a positive slope. The square root of $\Delta P_2/\Delta P_1$ for Mud 2 (incompressible cake) is 2.0, which approaches the multiplier of 2.23, ($\sqrt{500/100}$), calculated by Darcy's law.

Filter-cake permeability is the limiting factor that controls filtration...

Filter-cake permeability. Filter-cake permeability is the limiting factor that controls filtration into the formation. The size, shape and ability of the particles to deform under pressure are all important factors in the control of permeability. Slurries with high concentrations of small particles form filter cakes of lower permeability. Generally, colloidal-size particles (less than 2 microns), such as bentonite, provide the highest amount of the fluid-loss control. Optimum control, however, is obtained by having a wide range of particle sizes. Smaller particles seal openings between the larger particles to form a low-permeability cake.

Flat particles with large surface area, such as bentonite, can form a filter cake that resembles the shingled roof of a house. Flat particles are more effective than spherical or irregularly shaped particles since they form a more closely packed cake. In addition, as mentioned above, filter cakes that contain bentonite are compressible. Hydrated, high-quality bentonite is essential in obtaining a low-permeability filter cake. Bentonite particles are small (many less than 0.05 microns); have a large surface area; have a flat, plate-like shape and can be deformed easily. As the hydration of the particles is increased, the permeability of the resulting filter cake is decreased. Freshwater bentonite filter cakes have a permeability of about 1 microdarcy.

Low filter-cake permeability limits fluid loss and filter-cake thickness. Filter-cake permeabilities are measured in microdarcies. Reservoir permeability is measured in millidarcies. A good cake is about 1,000 times less permeable than the permeable formation on which it is deposited. Filter-cake quality is dependent on optimizing the solids composition of the fluid so the concentration of drill solids does not impair the performance of the bentonite and the filtration-control additives.

In a highly permeable formation with large pore openings, a bridging material may be required to prevent the flow of whole mud into the formation. Large particles must be laid down first to plug the large openings and start the deposition of a filter cake. Such bridging agents must be at least one-half the size of the largest openings. Medium and small particles seal the successively smaller holes that remain. The colloidal clays, other mud additives, filtration-control additives, asphalt, gilsonite and drops of emulsified oil (or brine) further reduce permeability. Bridging agents include calcium carbonate, ground cellulose (M-I-X II™) and a wide variety of other lost-circulation materials.

Temperature		Viscosity of water	Temperature		Viscosity of water
°F	°C	cP	°F	°C	cP
68	20	1.005	300	148.9	0.184
86	30	0.801	320	160	0.174
104	40	0.656	338	170	0.160
122	50	0.549	350	176.6	0.1535
140	60	0.469	356	180	0.150
158	70	0.406	374	190	0.142
176	80	0.356	392	200	0.134
194	90	0.316	410	210	0.127
212	100	0.284	428	220	0.121
230	110	0.256	446	230	0.116
248	120	0.232	450	232.2	0.1136
250	121	0.2316	500	260	0.1004
266	130	0.212	550	287.7	0.0899
284	140	0.196	572	300	0.086

Table 1: Viscosity of water at various temperatures.

Filter-cake thickness and filtration rate are square-root related to filter-cake permeability (like the relationship to time). This relationship is not used, however, due to the difficulty of measuring and controlling changes in filter-cake permeability.

Viscosity. When all other conditions are constant (time, area, pressure, permeability), the filtrate volume with two filtrates with different viscosities is inversely related to the square root of the viscosity ratio, as predicted by Darcy's law. Increases in filtrate viscosity reduce fluid loss and filter-cake thickness. Many filtration-control additives increase filtrate viscosity and reduce filter-cake permeability.

Increased temperature decreases the filtrate viscosity, which in turn increases fluid loss. Due to this reduction in filtrate viscosity, all muds have increased fluid loss at increased temperature, whether the base liquid is water, brine, oil or synthetic. One exception is a newly prepared freshwater bentonite mud, which may have a reduced fluid loss when first exposed to slightly elevated temperatures due to increased dispersion and hydration of bentonite particles.

Increased temperature decreases the filtrate viscosity…

Although water is not considered viscous, changes in temperature affect its viscosity enough to increase filtrate volume significantly. Table 1 gives the viscosity of water at various temperatures. Using this data and the equation below, the filtrate volume at a different temperature can be estimated. The relationship of filtrate volume to changes in viscosity is:

$$V_{F2} = V_{F1}\sqrt{\frac{\mu_2}{\mu_1}}$$

Where:

V_{F2} = Unknown filtrate volume with filtrate viscosity μ_2

V_{F1} = Filtrate volume with filtrate viscosity μ_1

μ_1 = Filtrate viscosity for V_{F1} (at temperature 1)

μ_2 = Filtrate viscosity of interest (at temperature 2)

If the fluid loss at 68°F is 5 cm^3, then the fluid loss at a Bottom-Hole Temperature (BHA) of 300°F can be estimated by the change in filtrate viscosity. The viscosity of water at 68°F is 1.005 cP and at 300°F is 0.184 cP. Substituting into the equation, this increase in temperature would increase the fluid loss to:

Viscous polymer fluids can be used to control filtration called leak-off...

$$V_{F2} = 5\sqrt{\frac{1.005}{0.184}} = 5\sqrt{5.46}$$

$$= 5 \times 2.34 = 11.7 \text{ cm}^3$$

Caution: This example uses an extreme change in temperatures. This type of calculation is more accurate for smaller temperature changes. At extreme temperatures, clays may flocculate, increasing the permeability of the cake, and filtration-control additives may degrade, making these methods inaccurate.

This method is most useful for determining the thermal stability of a fluid. Thermally stable fluids have HTHP fluid loss values closer to calculated values.

Fluids with highly viscous filtrates — such as brines with high concentrations of biopolymers — can control fluid loss based on viscosity alone. Viscous polymer fluids can be used during both drilling and workover operations to control filtration (called *leak-off* during completion operations) with ultra-high viscosity. This is true even when these fluids contain no bridging agents and few solids, so that a true filter cake is not deposited. Polymer fluids that exhibit non-Newtonian behavior (become more viscous at low shear rates) are preferred for this application. As these fluids flow radially into the formation away from the wellbore, the shear rate decreases due to the larger flow area of the increasing diameter. This lower shear-rate flow allows the viscosity to recover (increase), reducing filtration even more.

Equal concentrations of different solids will have vastly different fluid losses.

Figure 5: Deflocculated mud.

Figure 6: Flocculated mud.

Solids composition and orientation. Solids in muds range from highly reactive clays and biopolymers to unreactive solids such as calcium carbonate, barite and hematite. The shape, size and distribution of the solid particles; the ratio of reactive solids to nonreactive solids; and the way the solids react to their chemical environment determine how the solids will affect the filtration rate. Equal concentrations of different solids will have vastly different fluid losses.

Deflocculation and dispersion of clays also are important for filtration control. Figure 5 is a picture of a deflocculated mud in which there is a smooth flow with no evidence of clay platelets held together by electrochemical charges. Bentonite and clay particles are very thin, flexible solids with large, planar surfaces. It is convenient to think of a bentonite particle being like a microscopic piece of cellophane or wet sheet of paper. When the clay platelets are deflocculated, they are deposited in more of a flat orientation in the filter cake. They overlap to obtain a low-permeability filter cake with good filtration control. However, if the mud system is flocculated, the bentonite particles will not lay flat but will orient themselves in an edge-to-face matrix, which causes high-permeability filter cakes and poor filtration control.

Figure 6 is a picture of a flocculated mud in which the flow is not smooth and the clay platelets form groups of particles with edge-to-edge orientation (flocks). When this occurs, the filtrate can pass easily between the porous flocks, resulting in high filtration rates. This can be corrected by adding chemical deflocculants, which neutralize the electrochemical charges on the clays or by using filtration-control additives, which are more effective for flocculated fluids. Deflocculants allow the clay platelets to disperse and overlap to provide a tougher filter cake.

High solids concentrations are also detrimental to effective fluid-loss control. When the solids are too high, the available water is not adequate to solubilize the deflocculants or to allow the filtration-control additives to function. Therefore, treatments act as additional solids, compounding the situation and do not function as intended. This is a classic problem in deflocculated systems with lignosulfonate and complex salt muds with starch. In this case, adding liquid for dilution or new volume allows the chemicals to be effective, resulting in a reduction in filtration rates.

The increase in filter-cake thickness with time also can be minimized by controlling the undesirable low-gravity solids content of the mud. Solids must be considered not only in terms of the volume percent, but also with regard to the quality and function. Desirable drilling fluids solids include weight materials, viscosifiers, filtration-control additives and various other chemical additives.

Desirable drilling fluids solids include weight materials…

Hydrated Wyoming bentonite is highly compressible and beneficial in water-base filter cakes. Drilling in shales generates clay-rich drill solids, but they are much less hydratable and compressible than premium bentonite. A clay's ability to hydrate can be predicted by its Cation Exchange Capacity (CEC), with higher values indicating greater hydration. The CEC of a mud's low-gravity solids is a good indicator of its overall solids quality. The Methylene Blue Test (MBT) can be used to determine the equivalent pounds per barrel (lb/bbl) of bentonite in a mud and is a measure of the CEC. The concentration of drill solids and bentonite in the mud can be "roughly" calculated from the retort, chlorides and MBT with a material balance solids analysis. For good filtration control, the drill solids content of the mud should be kept as low as practical. A rule of thumb many operators use is to keep the drill solids below a ratio of 2 lb of drill solids for every 1 lb of bentonite, as per the PCMOD™ calculated D:B ratio.

The function of weight material is not related either to filtration control or cake quality. In most circumstances, the concentration of weight material cannot be reduced. The use of a weight material of higher density may improve cake quality by lowering the mud's total solids content. The use of 5.0 Specific Gravity (SG) hematite (FER-OX®) instead of 4.2 SG barite (M-I BAR®) will reduce the volume of weight material in a mud by roughly 20%. Weight material does not contribute to cake compressibility, but often provides a particle size distribution that aids in primary bridging and particle plugging of permeable formations.

Care should be taken when evaluating HTHP fluid loss. Both HTHP and API filter cakes should be examined for weight material settling, which will be indicated by a distinct layer of weight material on the filter medium. Weight material settling can lead to inaccurate filtrate values. But more important, it may indicate settling at downhole temperatures and the need for increased rheology.

DYNAMIC FILTRATION

Dynamic filtration is significantly different from static filtration, often with considerably higher filtration rates. No direct correlation exists between API and HTHP static filtration measurements and dynamic filtration. Experience has shown that a mud which exhibits good static filtration characteristics and stability will have satisfactory performance under actual drilling conditions, indicating the dynamic fluid loss is in a satisfactory range.

As soon as the bit exposes permeable rock, dynamic filtration begins.

As soon as the bit exposes permeable rock, dynamic filtration begins. An overbalance in hydrostatic pressure will cause immediate filtrate flow into the formation at a high rate. As filtration continues, larger mud solids bridge porous formations and a filter cake begins to form — under dynamic conditions. As with static filtration, the permeability of the filter cake limits filtration, not the permeability of the formation. The turbulence of the fluid flow at the bit and adjacent to the drill collars tends to keep these filtration rates high by eroding the cake. Under dynamic conditions, filtration rates do not decrease with time as with static filtration. What's more, the filter cake does not continue to increase in thickness. Instead, an equilibrium of filter-cake deposition and hydraulic erosion is established so the dynamic filtration rate becomes somewhat constant. It may not be true erosion as much as it is the tendency of the fluid motion to hinder the deposition of solid particles in an organized manner. The filter-cake equilibrium is governed chiefly by the characteristics of the mud solids (particle size, composition and concentration), and to a lesser degree by hydraulic conditions (turbulent or laminar flow) and filtrate viscosity.

Dynamic filter cakes are thinner and firmer than static filter cakes.

Dynamic filter cakes are thinner and firmer than static filter cakes. As drilling continues, the wellbore is subjected to changing conditions. Once the drill collars are past the permeable formation, laminar flow conditions normally prevail and hydraulic erosive forces are reduced. Under laminar conditions, dynamic filtration rates are considerably lower than under turbulent conditions, and some correlation can be made to static filtration characteristics. During connections and trips, static conditions deposit a static filter cake and filtration rates are reduced (square root of time). Once circulation is resumed, the static cake deposited on the dynamic cake begins to be eroded (possibly completely, depending on hydraulic conditions) until once again it reaches equilibrium at a constant filtration rate.

Studies have identified several important differences between dynamic filtration and static filtration. One difference is the effect of emulsified oil or other immiscible liquids. While these non-soluble liquids reduce static fluid loss and filter-cake thickness, they actually increase dynamic filtration by making the filter cake less cohesive and more erodible. Another difference is that increasing the concentration of filtration-control polymers to decrease the API fluid loss to ultra-low levels may actually increase dynamic filtration. These differences are due mostly to changing the resistance to erosion of the filter cakes.

Dynamic filter cakes deposited by flocculated fluids are thicker but more cohesive than cakes made by deflocculated fluids. The flocculated filter cakes' resistance to erosion appears to be related to the clay solids being held together by electrostatic charges. Filter cakes from deflocculated fluids appear to be more erodible because their charges are neutralized. This does not mean that flocculated fluids would be preferred on a dynamic filtration basis. The undesirable higher filtration rate and the increased filter-cake thickness outweigh any possible benefit from a tougher, less-erodible filter cake. As with static filtration, fluids and filter cakes containing a sufficient amount of high-quality bentonite produce the lowest filtration rates, thinnest filter cakes and most desirable overall filtration characteristics.

Fluid-Loss-Control Additives

API-grade bentonite is the primary clay used in water-base drilling fluids...

Three clays are used as mud additives: attapulgite, sepiolite and sodium bentonite.

FOR WATER-BASE DRILLING FLUIDS

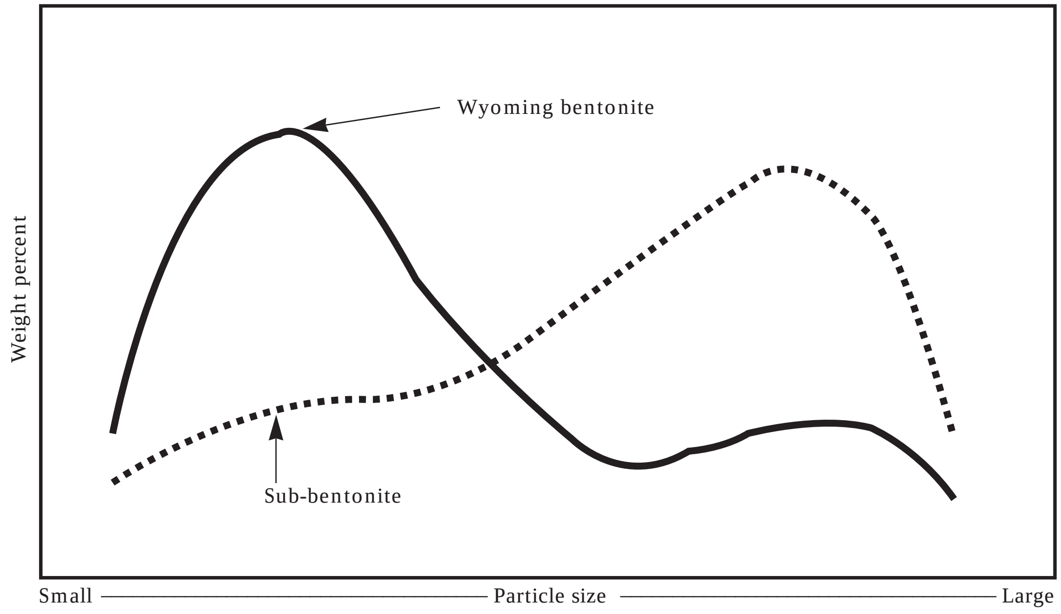
Several types of filtration-control additives are used in water-base muds. Recommendations for treatment are based on the mud system and its chemical environment.

Clays. Clays are classified into groups based on mineralogy. Each group may contain a wide variety of subgroups with significantly different properties. Similar clays can be formed in slightly different geological environments, and this affects the purity and characteristics of a particular clay source.

Three clays are used as mud additives: attapulgite, sepiolite and sodium bentonite. M-I GEL® and GEL SUPREME™ are sodium bentonite (or sodium montmorillonite), which is a member of the smectite group of clays. Attapulgite (SALT GEL®) and sepiolite (DUROGEL®) are needle-shaped clays used as mechanical colloidal viscosifiers in high-salinity brines. They do not provide filtration control and will not be discussed further in this chapter.

API-grade bentonite is the primary clay used in water-base drilling fluids and usually comes from Wyoming, hence the name “Wyoming” bentonite (sodium bentonite). It has one of the highest *yields* (i.e., it generates the largest volume of mud at a given viscosity) and is one of the most hydratable clays found anywhere; it is considered a premium product. Wyoming bentonite is the best product to use in formulating a mud with good filter-cake properties and filtration control. Bentonite not only provides filtration control, but also increases viscosity; therefore, quantities should be limited in weighted and high-temperature applications to the 7.5 to 15 lb/bbl range. Unweighted fluids often use 15 to 30 lb/bbl bentonite, depending on the makeup water chemistry and the desired viscosity. Any concentration above 7.5 lb/bbl will provide a good basis for filter cake and filtration characteristics.

Bentonite particles are very thin, sheet-like or plate-like particles with a



Wyoming bentonite has a larger percent of small particles as compared to other clays and provides superior rheological and filtration properties.

Figure 7: Particle size bentonite.

...the platelet structure allows bentonite to lay flat in the filter cake and seal it...

large surface area. Under microscopic examination, they look like thin, flat, flexible pieces of cellophane or sheets of wet paper. Premium-ground bentonite has a high percentage of particles of less than one micron in width (see Figure 7). While this may seem small, clay platelets have a thickness of only about 10 angstroms. These dimensions give bentonite platelets a very high diameter-to-thickness ratio (1,000 to 1) and a very high surface area per unit of weight (~45 m^2/g). When deflocculated, the platelet structure allows bentonite to lay flat in the filter cake and seal it in a manner often compared to shingles on a roof.

Sodium bentonite surfaces have a high electro-charge density. This high charge density promotes hydration in freshwater by attracting many layers of water molecules to its surface. These hydrated bentonite particles deform and compress readily under pressure and form very low-permeability, low-porosity filter cakes. An indication of the amount of water bound to a hydrated bentonite platelet can be seen by retorting a freshwater bentonite filter cake. These filter cakes will contain about 85 volume percent water and only 15 volume percent bentonite.

Sodium bentonite does not hydrate as rapidly or as much in water containing salts or calcium. In seawater or hard water, the filtration rate will be uncontrollable without the addition of deflocculants and/or supplementary filtration-control additives. Bentonite performance in salt or calcium muds can be greatly enhanced by prehydrating it in freshwater and treating it with deflocculants before adding it to the mud system. Bentonite that has been prehydrated and deflocculated may be used in saturated salt systems to improve the HTHP filtration. Prehydrated bentonite will eventually flocculate and dehydrate when added to salt or calcium muds. When this happens, additional treatments of prehydrated bentonite will be needed to maintain the system's properties.

To prehydrate bentonite:

1. Add the makeup water to the prehydration pit and treat the calcium to less than 100 mg/l with soda ash. (Do not treat the calcium to zero, since doing so may result in carbonate contamination!)
2. Add 30 to 40 lb/bbl of M-I GEL or 40+ lb/bbl GEL SUPREME to the makeup water, through the hopper.
3. Stir and shear the bentonite slurry for 3 to 4 hr.
4. For low-pH, non-dispersed mud systems, skip steps 5 and 6.
5. Add 0.5 to 1.0 lb/bbl of caustic soda to the prehydrated bentonite through the chemical barrel and shear for an additional hour.
6. Add 0.5 to 1.5 lb/bbl of either SPERSENE™ or SPERSENE CF® to the prehydrated bentonite through the hopper.
7. Stir and shear the deflocculated, prehydrated bentonite at least one hour before adding it to the mud system.

Dry bentonite can be added to inhibitive mud systems (calcium, potassium, salt, etc.) just to change the particle-size distribution. These fine, bentonite particles may act as bridging agents for other polymeric filtration-control agents, even though the bentonite is not hydrated. However, it is generally preferable to use prehydrated bentonite, if possible.

The total drill solids content and the ratio of drill solids to bentonite must be controlled...

The total drill solids content and the ratio of drill solids to bentonite must be controlled to optimize a drilling fluid's properties and performance. The total volume percent of low-gravity solids should be kept within predefined limits by dilution or through the use of solids-control equipment. Centrifuges used

Polymers are the filtration-control products used most often in water-base muds.

Starches are often classified as "non-ionic" materials...

for barite reclamation discard bentonite. Periodic bentonite treatments should be made when centrifuging.

Polymers. Polymers are the filtration-control products used most often in water-base muds. They can range from natural starches and modified cellulose to sophisticated synthetic polymers capable of providing filtration control under high temperatures and hostile conditions. These polymers are sometimes classified by their action within a mud system, as well as by their chemistry. The classification by action is based on whether the polymer adsorbs onto the solids or viscosifies the fluid phase.

Most common fluid-loss polymers will not only viscosify the fluid phase, but when used in sufficient concentration, will adsorb to solids, providing encapsulation. Care should be taken when adding polymers to muds because of the possible interactions with other mud-system chemicals. For field operations, it is recommended that pilot testing be performed before using an unfamiliar filtration-control additive.

Polymers reduce fluid loss in several ways:

1. Plugging of openings of the filter cake by polymer particles.
2. Encapsulating solids forming a larger deformable coating or film which reduces the permeability of the filter cake.
3. Viscosification of the liquid phase.

Figure 8 illustrates the increase in liquid-phase viscosity as the concentrations of several filtration-control additives are increased. Figure 9 shows the fluid loss, plastic viscosity and yield point of the several filtration-control additives in a seawater mud with 30 lb/bbl of M-I GEL and 40 lb/bbl of simulated drill solids.

Starch. Starch, a natural carbohydrate polymer, has been used to control filtration in drilling fluids since the 1930s. It is widely available as yellow (untreated) and white (modified) starch. Starches can be used in seawater, salt water, hard water and complex brines. The most economical and widely used starches are made from corn or potatoes, but starches made from other agricultural products are also available.

Most of the starch used for filtration control is processed by separating and heating the starch grains to rupture their amylopectin shell. This releases amylose, which absorbs water and swells to form sponge-like bags. Amylose lowers the filtration by reducing the free water in the system and plugging the filter cake's pores. Starches processed in this manner are said to be *pregelatinized.* The performance of these starches should not be affected by pH, salinity, hardness or temperatures of less than 250°F. Starches are often classified as "non-ionic" materials, although they may have a very slight anionic character. Starch is sometimes used as a viscosifier in brine fluids, but starch solutions are more Newtonian and will not provide suspension for cuttings and weight material.

MY-LO-JEL™ pregelatinized corn starch is an economical filtration-control additive that is effective in all makeup waters from freshwater to saturated salt water. It is subject to fermentation unless the mud is a saturated-salt system or the pH is >11.5. If one of these conditions is not satisfied, an appropriate biocide (also called *bactericide* or *preservative*), acceptable under local regulations, should be used to prevent fermentation. Once fermentation begins, bacterial enzymes may be present, making further additions of starch ineffective even after the active bacteria are eliminated with biocide. Starch is subject to rapid degradation at temperatures above 250°F.

Starches... often require a minimum concentration before significant decreases in fluid loss are observed.

Normal concentrations of MY-LO-JEL range from 3 to 8 lb/bbl, depending on water chemistry and desired fluid loss. Starches like MY-LO-JEL often require a minimum, threshold concentration before significant decreases in fluid loss are observed. Daily treatments are required to maintain desired concentrations.

POLY-SAL™ is a preserved potato starch used for fluid-loss control in virtually every type of water-base mud, from freshwater to saturated salt and calcium systems. POLY-SAL is an effective filtration-control additive for drilling evaporite (salt) and hydratable shale sections. It is also very effective for stabilizing the filtration and rheology of high-salinity workover brines. POLY-SAL is thermally stable to about 250°F, after which it begins to experience thermal degradation.

Normal concentrations of POLY-SAL range from 2 to 6 lb/bbl, depending on water chemistry and desired fluid loss. Starches like POLY-SAL often require a minimum, threshold concentration before significant decreases in fluid loss are observed. Daily treatments are required to maintain desired concentrations.

FLO-TROL™ is a modified starch used for fluid-loss control primarily in the non-damaging FLO-PRO® drill-in fluid system. It is unique in that it actually helps increase low-shear-rate viscosity in the FLO-PRO system, whereas most other starches decrease this property. It can be used in other water-base mud systems, especially high-salinity workover and completion brines. FLO-TROL is thermally stable to above 250°F, after which it begins to experience thermal degradation.

Concentrations of FLO-TROL range from 2 to 6 lb/bbl, depending on water chemistry and desired fluid loss. Starches like FLO-PRO often require a minimum concentration before significant decreases in fluid loss are observed. Daily treatments are required to maintain desired concentrations.

THERMPAC® UL is a modified-starch filtration-control additive designed for use in most water-base systems, including freshwater, seawater, salt and low-solids muds. It has an Ultra-Low (UL) viscosity and does not generate as much viscosity as many other starches or cellulose additives. THERMPAC UL is not subject to bacterial degradation. Its effectiveness decreases in high-salinity (>100,000 mg/l chlorides) and high-hardness (>800 mg/l) fluids. Ultra-low-viscosity PAC products, such as POLYPAC® UL, should be used for saturated salt systems. THERMPAC UL is subject to thermal degradation at temperatures in the 250 to 275°F range.

THERMPAC UL reduces fluid loss in fresh or salt water. Normal concentrations range from 0.5 to 2.0 lb/bbl, depending on the water chemistry and desired fluid loss.

Sodium Carboxymethylcellulose (CMC) is a modified natural polymer used for filtration control. The structure of CMC is a long-chain molecule that can be polymerized into different lengths or grades. The material is commonly made in three grades, each varying in viscosity, suspension and fluid-loss-reduction qualities. The three grades are High-Viscosity (HV), medium- or regular-viscosity (R), and Low-Viscosity (LV). The CMC polymer also is available in purities ranging from a 75% technical grade to a 99.5+% refined grade. Technical-grade CMC contains sodium chloride salt, a byproduct of the manufacturing process.

CMC is an effective fluid-loss control additive in most water-base muds. It works particularly well in calcium-treated systems, where it acts to stabilize properties. CMC is not subject to bacterial degradation and performs well at an alkaline pH. CMC's effectiveness decreases at salt concentrations greater than 50,000 mg/l. CMC is subject to thermal degradation at temperatures exceeding 250°F.

The grade of CMC used will depend on which properties are desired. When viscosity as well as low fluid loss is desired, high- or medium-viscosity CMC is used. Low-viscosity CMC will reduce fluid loss with minimal increase in the viscosity. Because it is slightly anionic, the addition of small quantities of low-viscosity CMC may act as a thinner in low-solids, nondispersed muds. Normal concentrations vary with the different grades, but range from 0.5 to 3.0 lb/bbl, depending on the water chemistry and desired fluid loss.

POLYPAC Polyanionic Cellulose (PAC) is a modified natural polymer designed for use in most water-base systems, including freshwater, seawater, salt and low-solids muds. It is a high-molecular-weight, polyanionic cellulose similar to CMC, but has a higher degree of substitution. It is the most widely used fluid-loss control additive and is generally a much better product than CMC. POLYPAC is not subject to bacterial degradation and performs well at an alkaline pH. Its effectiveness decreases in saturated salt fluids. Ultra-low-viscosity PAC products, such as POLYPAC UL and PAC PLUS™ UL, should be used for saturated salt systems. POLYPAC is subject to thermal degradation at temperatures exceeding 275°F. It is anionic and may thin in non-dispersed muds.

SP-101 is especially useful in polymer systems...

POLYPAC increases viscosity and reduces fluid loss in fresh or salt water.

POLYPAC increases viscosity and reduces fluid loss in fresh or salt water. Normal concentrations range from 0.5 to 2.0 lb/bbl, depending on the water chemistry and desired fluid loss.

PAC PLUS polyanionic cellulose is high-quality polyanionic cellulose designed to function in more demanding conditions. It can be used in most water-base systems, including freshwater, seawater, salt and low-solids muds. PAC PLUS is available in a UL-viscosity grade, which performs better in high-salinity fluids. PAC PLUS is not subject to bacterial degradation and performs well at an alkaline pH. It is subject to thermal degradation at temperatures exceeding 275°F. PAC PLUS is anionic and may thin in non-dispersed muds.

PAC PLUS increases viscosity and reduces fluid loss in fresh or salt water. Normal concentrations range from 0.5 to 2.0 lb/bbl, depending on the water chemistry and desired fluid loss.

SP-101® sodium polyacrylonitrile is a medium-molecular-weight, acrylic copolymer sometimes referred to as a *sodium polyacrylate*. It is a calcium-sensitive, synthetic polymer. It is stable at high-temperatures and does not degrade bacterially. In addition to increasing the liquid phase viscosity to decrease fluid loss, the long-chain SP-101 molecule can adsorb onto the edges of clay particles (encapsulation), further reducing filter-cake permeability. SP-101 is especially useful in polymer systems such as POLY-PLUS, POLYPAC seawater and GELEX® Low-Solids, Non-Dispersed (LSND) systems.

When SP-101 is added to the system, at least 0.5 lb/bbl should be added rapidly, then maintained at or above this concentration level at all times. This quick treatment reduces the viscosity "hump" that will occur if the mud contains high solids. It is important to increase the concentration of SP-101 above the critical polymer concentration to reduce viscosity. Normal concentrations range from 0.5 to 2.0 lb/bbl, depending on the water chemistry and desired fluid loss.

SP-101 should not be used in muds that contain more than trace amounts of calcium. The calcium should be precipitated with soda ash before adding SP-101. It has been used in 400+°F temperatures and has application in deep, hot holes.

RESINEX® is a resin/lignite complex which provides both filtration control and improved thermal stability. It is non-viscosifying, and can be used at

Chemical thinners reduce filtration rates...

THERMEX is a synthetic liquid resin which provides...

temperatures in excess of 400°F and in the presence of moderate concentrations of electrolytes. It has broad application and can be used in virtually any water-base mud. RESINEX can be used in high-density muds where increases in viscosity are detrimental. Normal concentrations range from 2 to 6 lb/bbl.

RESINEX has many field-proven benefits:

- Non-viscosifying fluid-loss control. RESINEX controls fluid loss but does not significantly increase viscosity. It will have about the same effect on viscosity as an equal amount of lignite.
- Filter cake improver. RESINEX reduces the filter-cake thickness and permeability by providing a better distribution of colloid-size particles.
- Rheology stabilizer. RESINEX stabilizes the rheological properties of water-base muds exposed to hostile conditions and helps prevent gelation.
- Thermal stabilizer. RESINEX is temperature stable and controls fluid loss to temperatures >400°F.
- Salt tolerant. RESINEX reduces filter cake permeabilities in muds with salinity ranging from freshwater to 110,000-mg/l chlorides.
- Hardness resistant. RESINEX functions in fluids with soluble calcium and magnesium. This makes RESINEX ideally suited for use in seawater, gyp and lime muds.
- Economical. RESINEX outperforms many additives on a cost/performance basis, especially in high-hardness and high-temperature applications.

THERMEX™ is a synthetic liquid resin which provides both filtration control and improved thermal stability. It is non-viscosifying, and can be used at temperatures in excess of 400°F and in the presence of moderate concentrations of electrolytes. It has broad applications and can be used in virtually any water-base mud. THERMEX is more effective in systems which also use lignite-based products. THERMEX can be used in high-density muds, where viscosity increases are detrimental. Normal concentrations range from 4 to 12 lb/bbl.

CHEMICAL THINNERS

Chemical thinners reduce filtration rates by deflocculating the clays, by increasing the fluid phase viscosity and by changing the solids distribution. QUEBRACHO,® TANNATHIN,® XP-20,® SPERSENE CF® and SPERSENE™ are effective at deflocculating and lowering fluid loss.

SPERSENE and XP-20 help provide filtration control at temperatures far beyond those in which starch or CMC can be used effectively. They are not subject to bacterial degradation in active mud systems and can be used effectively in high-salt or high-calcium concentrations. SPERSENE and XP-20 will reduce both the API and the HTHP fluid losses. At temperatures above 315°F, more XP-20 than SPERSENE should be used. XP-20 is stable at temperatures above 450°F and should be used (when applicable) to provide fluid-loss control in high-temperature, dispersed systems. *Note: SPERSENE and XP-20 contain trivalent chrome (a more acceptable form) which may not be acceptable for all applications, depending on local environmetal regulations and considerations.*

OIL- AND SYNTHETIC-BASE DRILLING FLUIDS

The API fluid loss of these systems is normally zero, or too low to be an effective measure. The filtration rate of oil muds, unless otherwise noted, refers to the HTHP filtration.

The oldest oil-base systems were “all-oil” and did not contain added brine. They usually contained 1 to 5 volume percent water as a contaminant from formation fluids. All-oil systems are still used for special applications like coring and where changes caused by strong emulsifiers cause formation damage. These systems often use

Most oil- and synthetic-base fluids are emulsions.

asphaltic materials and organophilic clay for filtration control and viscosity. Some systems use viscosity modifiers designed for lubricating oil and other, more sophisticated chemicals for viscosity and filtration control.

Most oil- and synthetic-base fluids are emulsions. Their fluid phase is an emulsion with oil or synthetic as the continuous phase and brine as the emulsified phase. These systems contain from 10 to 50 volume percent brine, usually calcium chloride. The emulsified brine forms colloid-sized droplets, which are immiscible in the oil or synthetic. These brine droplets become trapped in the filter cake and reduce filter-cake permeability and fluid loss. Invert emulsion muds may contain emulsifiers, wetting agents, organophilic clays, asphalts and/or amine-treated lignite, polymers, lime and weight material. The chemistry of these additives and their interrelationships are complex and are discussed in greater detail in the chapters dealing with oil- and synthetic-base muds. The filtration rate of invert-emulsion muds is affected by additives other than the filtration-control additives.

Base liquid. The oil- or synthetic-base liquid can affect filtration rates and the choice of additives that must be used to control filtration. The viscosity of the base fluids will only slightly affect filtration rates, as per Darcy's law.

In regions where extremely cold winters can be expected, anti-gellants are added to fuel oils during the cold periods. These anti-gellants can make diesel oil unsuitable for use in drilling fluids. Field tests cannot detect these anti-gellants, but pilot testing can determine if diesel oil is suitable for use in invert emulsions.

Brine. Invert emulsion muds use either sodium chloride or calcium chloride brine in the internal phase of the emulsion. The emulsified brine phase acts as a fine colloidal solid in invert emulsion muds and the small droplets contribute significantly to filtration control. The brine content affects many properties and is not increased simply to reduce fluid loss. This is especially true in weighted muds, where the increased brine acts like a solid, increasing the viscosity.

Emulsifiers. Although emulsifiers are not true filtration-control additives, they can reduce filtration by increasing the emulsion strength if the emulsion is unstable. Indications that more emulsifier is needed are a low or decreasing trend in the Electrical Stability (ES) and/or water in the collected HTHP filtrate. A sufficiently stable emulsion should be established before treating with filtration-control additives. If an emulsifier requires lime to be activated, excess lime should be maintained in the mud.

Wetting agents. Solids (clays, drill solids and weight material) must be "wetted" by the base liquid or they will tend to settle, increasing both viscosity and fluid loss. The appropriate wetting agents and emulsifiers should be used in sufficient concentrations to keep all solids adequately "wet." If sufficient wetting agent is not present, adding it will reduce the rheological properties. Pilot testing can determine whether an increased wetting agent is needed.

Viscosifiers. The primary viscosifier in invert emulsion muds is organophilic clay. Although this clay does not hydrate, it will reduce the filtration rate by providing a colloidal solid for forming a basic filter cake.

Filtration-control additives. The primary filtration-control additives for invert emulsion muds are asphalt, gilsonite (natural asphalt), amine-treated lignite and various other resins and specialized polymers. The asphaltic materials usually provide better filtration control than the amine-treated lignite at equal concentrations and temperature. Some operators prohibit asphaltic materials for fear they may damage formation permeability. **Local environmental regulations and M-I policies should be considered before using VERSATROL® or any other asphaltic materials in a synthetic-base mud.**

…"solids-free" and "clear" are often used to describe brines used for drilling…

WORKOVER AND COMPLETION BRINES

The terms "solids-free" and "clear" are often used to describe brines used for drilling into production zones, setting gravel packs, and for other completion and workover operations. Occasionally, calcium carbonate and sized salt (sodium chloride) are used in these brines to prevent lost circulation (leak-off). Ideally, these brines are free of acid-insoluble solids (clays, sand, barite, etc.). Sodium chloride, calcium chloride, sodium bromide, calcium bromide, and sometimes zinc bromide brines are used for these applications. Zinc bromide brines are not widely used because they are corrosive and very expensive.

Brines can provide density for well control without introducing potentially damaging solids to the formation. The high salinity also inhibits the swelling of formation clays. Although these brines are not as damaging to the formation as freshwater or seawater, their loss must be controlled. Filtration-control additives for these systems usually consist of polymers and bridging agents. The most often-used polymer for viscosity is Hydroxyethylcellulose (HEC).

Polymers are used for viscosity and fluid-loss control. Bridging agents are required to plug formation openings that are too large to be plugged by polymers. M-I supplies large, medium and fine grinds of sized calcium carbonate (marble or limestone) particles for use as bridging agents. Typical median particle sizes for these products are: coarse (104 microns), medium (43 microns) and fine (13 microns). The average particle size for a bridging agent should be at least one-half the size of the pore opening. Since grind sizes cover a much broader range than just the median particle size, there will be enough large particles to initiate bridging.

Summary

Offset well records are the best tools for determining the level of fluid-loss control required…

Fluid loss should not be considered an absolute value. Rather, it should be considered only an indication of the filtration properties of the mud in the well. Because many variables influence filtration properties, it is impossible to predict actual fluid loss to the formation from static tests. Offset well records are the best tools for determining the level of fluid-loss control required to drill a given well safely and successfully. Formations that are not water-sensitive can be drilled with a mud having an API fluid loss of 20 cm^3. Conversely, water-sensitive shales that slough, heave and hydrate may require a mud with an API fluid loss of 5 cm^3 or less. The mud engineer should recommend changes to the mud system to obtain acceptable drilling results based on the conditions for a particular well and the symptoms observed, i.e., tight hole, sticking tendencies, sloughing shale, etc.

Experience in an area will serve as a guide to determine the fluid-loss specifications for a drilling mud program. Every effort should be made to drill with the "right" level of fluid loss — that level at which drilling or production problems are avoided. Filtrates that are lower than necessary will increase the mud cost and may decrease drilling

With increasing well depth, it is necessary to reduce fluid loss to prevent problems.

rates. Filtration that is too high will cause tight hole, sticking, shale sloughing and other problems mentioned earlier.

With increasing well depth, it is necessary to reduce fluid loss to prevent problems. Consequently, it is common to drill a surface hole with a mud having a fluid loss of 20 cm^3, then complete the well with a mud having a fluid loss of 2 cm^3. It is necessary for the mud engineer to acquaint himself with the fluid-loss requirements of the area in which he is working. Acceptable filtration rates will vary from one area to another and are dependent on the formation, depth, differential pressure, temperature and mud type.

Once the desired value is established, fluid-loss control may be accomplished by applying the principles previously stated. Briefly, they are: minimizing drill solids, optimizing the colloidal solids and using the appropriate filtration-control additive. Figures 8 and 9, combined with Table 2, can be helpful in selecting a fluid-loss additive for a particular application. Table 2 shows the effectiveness of each fluid-loss-control agent in different types of mud systems.

Before applying any of the fluid-loss control agents, consider the following factors:

1. Can it be used in the presence of calcium?
2. Can it be used at high salt concentration?
3. Will it need a preservative?
4. Will it function at the required temperature?
5. Will it produce an unacceptable change in viscosity?
6. Will it support weight material with a minimum amount of solids?
7. Is it economical for the particular operation?
8. Is it the most efficient agent under the given circumstances?

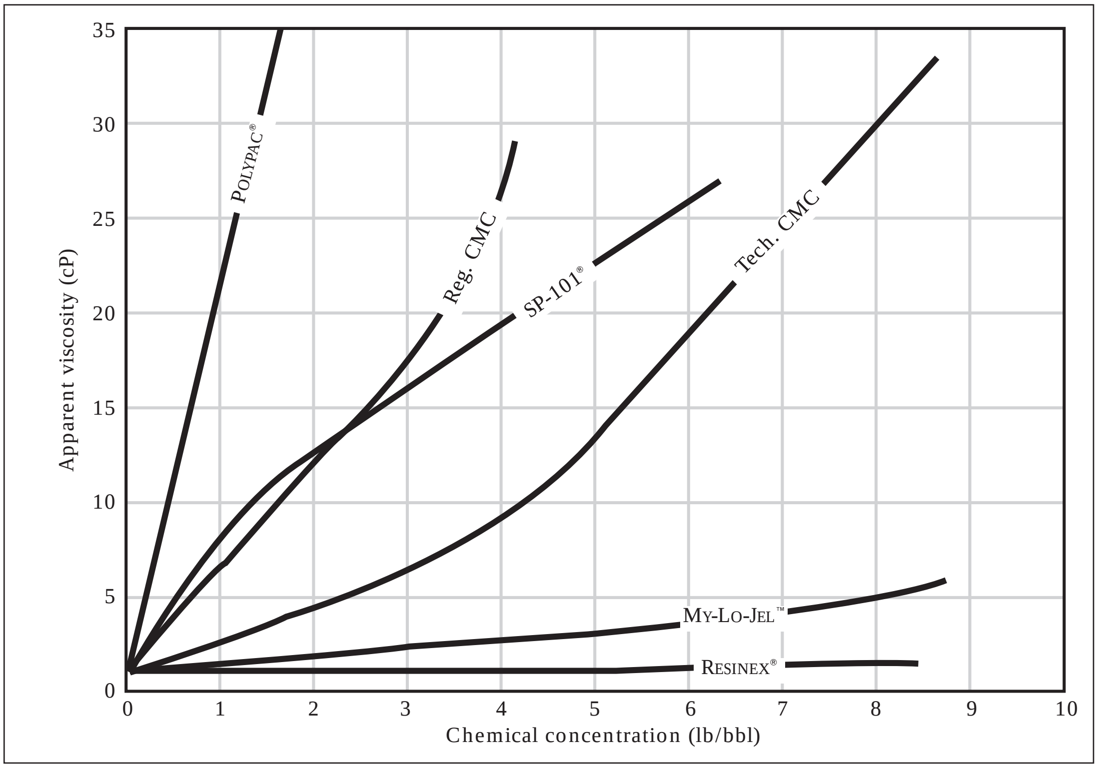


Figure 8: Viscosity vs. concentration, filtration-control additives.

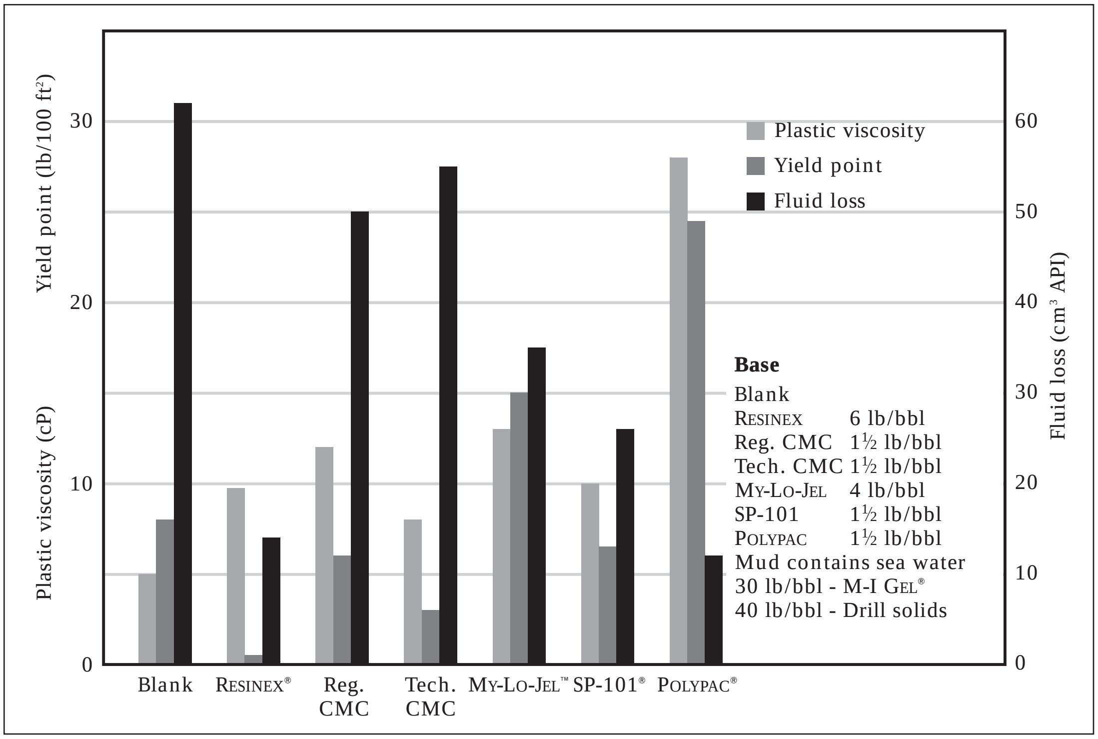


Figure 9: Flow properties and effectiveness in various treatments.

	Poly-Sal™	**My-Lo-Jel™**	**CMC (reg.)**	**CMC (LV)**	**SP-101®**	**Resinex®**	**Polypac® UL**
Low pH freshwater mud	F	F*	E	E	E**	F	E
High pH freshwater mud	F	E	E	E	E**	F	E
Seawater or brackish-water mud	F	F*	E	E	NU	E	E
Saturated seawater mud	E	E	F	F	NU	NU	G
Lime-treated mud	E	E	G	G	NU	E	G
KCl mud	E	E*	E	E	NU	F	E
Gyp mud	G	F*	E	E	NU	E	E

E — Excellent results	NU — Not used
G — Good results	* Preservative needed
F — Fair results	** Soluble calcium should be kept as low as possible

Note: Where extremely low fluid loss is desired, starch gives better results than CMC. Where better suspension qualities are desired, CMC or Polypac will give better results than either starch or SP-101. Where extremely high salt concentrations are present, starch, SP-101 or Polypac UL will give better results than CMC.

Table 2: Effectiveness of fluid-loss agents in various water-base muds.