APPENDICES

APPENDIX A

PROPERTIES

AND PERFORMANCE

OF DRILLING MUD

NL Baroid

PROPERTIES AND PERFORMANCE OF DRILLING MUD

The reason for additives to water in making a rotary drilling fluid is to improve performance in hole cutting, hole cleaning, hole stability, and productivity. Properly formulated and maintained drilling fluids enable the driller to carry out his operations with increased efficiency and improved results. The drilling fluid should be thought of by the driller as a useful tool at his disposal.

The circulating (drilling) fluid performs many functions in rotary drilling applications:

FUNCTION

Primary Functions

- Lubricate drill pipe
- Cool the bit
- Clean the cuttings from the bit and the bottom of the hole
- Remove the cuttings from the hole

Secondary Functions

- Drop the cuttings at the surface
- Facilitate the movement of the drill string (and casing)
- Prevent caving and wash outs
- Stop losses into thief zones
- Control formation pressures
- Mitigate wear and corrosion of the drilling equipment

How effectively the circulating fluid performs its functions depends on many physical properties. These properties can and should be measured periodically to determine how well the mud will perform its functions.

The test procedures described conform to American Petroleum Institute Standard 13-B, "Standard Procedure For Testing Drilling Fluids," Fifth Edition, February, 1974.

MUD WEIGHT: DENSITY

The most significant, yet simple measurement the driller can make is that of mud weight or density. No visual estimate can be made. Density must be measured by weighing a known volume. Density can be stated in any convenient units, such as lb/gal, lb/ft^3 grams/cm^3.

To prevent the flow of formation fluids into the hole, the drilling mud must exert a greater pressure than that of the fluids in the porous rocks that are penetrated by the bit. The pressure exerted by the drilling mud at any depth is related directly to its density.

Hydrostatic pressure, psi = [lb/gal x 0.052] depth

Loss of circulation may result from excessive pressure due to mud that is too dense or heavy.

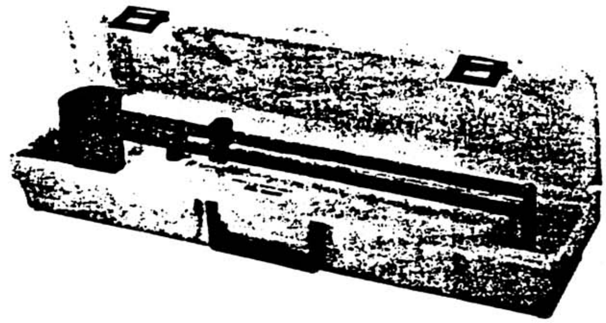
With simple water-base muds, density is a reliable measure of the amount of suspended solids.

EFFECT OF SOLIDS CONTENT ON MUD WEIGHT
(Assumed Solids Specific Gravity = 2.65)

Percent Solids	Mud Weight lbs/gallon
0	8.33
1	8.47
2	8.60
3	8.74
4	8.88
5	9.02
6	9.15
7	9.29
8	9.43
9	9.57
10	9.70
11	9.84
12	9.98
13	10.12
14	10.25
15	10.39
16	10.53
17	10.67
18	10.80
19	10.94
20	11.08

Solids that do not contribute useful properties (i.e., most drilled solids) are definitely objectionable. Abrasive solids, like sand, cause excessive wear on pumps, drill string and bit. The drilling rate is reduced; a thick filter cake is deposited on permeable formations, and the pump does unnecessary work recirculating solids which have been allowed to collect in the mud.

For the water well driller, a most objectionable effect of useless solids is the formation of a thick filter cake on the water-bearing section. The thick filter cake on the water-bearing formation may not be removed completely and consequently impairs the flow of water. By weighing the mud regularly, the solids content can be estimated so that corrective steps can be taken before damage is done.



Procedure for using the Baroid Mud Balance:

1. Fill the cup to capacity with fresh, screened mud.
2. Replace lid and rotate until firmly seated, making sure some mud is squeezed out the vent hole. Wipe or wash excess mud from the exterior of the balance, and dry. Then seat the balance with its knife edge on the stand and level it by adjusting the rider.
3. Read mud density from the inside edge of the rider as indicated by marker on the rider. Use any of the four scales to express the mud density as required. (Pounds per gallon is the normal scale.)
4. Calibration can be checked by filling the cup with fresh water. It should read 8.34 lb/gal.

WEIGHT—(Density)

Measures	Hydrostatic pressure in the bore hole, and solids content of unweighted muds
Affects	Drilling rate, hole stability, transportation and settling rate of cuttings Useless solids accumulation slows drilling rate, wastes fuel, causes equipment wear, loss of circulation, differential sticking, and damages the productive formation
Desirable Limits	Below 9.0 lb/gal (water is 8.34 lb/gal)
Control	BAROID® to increase weight; water dilution to decrease weight Good mud pit design Shale shakers, desander cones

VISCOSITY

Flow Properties

The removal of rock chips from the cutting face of the bit and the carrying of these cuttings to the surface depend on the flow properties (viscosity) and the velocity of the drilling fluid.

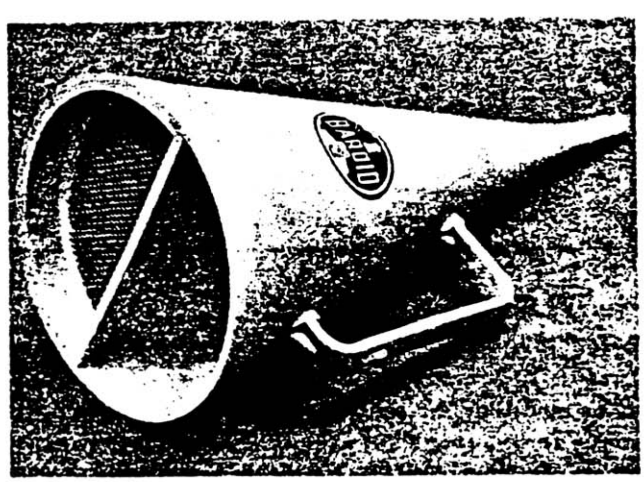
Viscosity is defined as the resistance offered by a fluid (liquid or gas) to flow. The well driller recognizes this as thickness.

The Marsh funnel is a simple means of making comparative viscosity measurements which with experience becomes very useful. "Low viscosity" is favored for effective cleaning at the bit face and rapid settling of cuttings at the surface. "High viscosity" may be necessary to remove coarse sand from the hole or to stabilize gravel but will retard settling of the cuttings at the surface.

Gel Development

The property of gel development is associated closely with the flow properties of most water-base muds. When the mud stops moving it tends to thicken or "gel." The force necessary to break the gel is called the "gel strength." High gel strength may require such high pump pressure to break circulation after a period of shutdown that the mud can be lost to a weak formation. Rapid gel development retards settling of cuttings. Gel strength can be used to advantage to hold loose sand and gravel in place during shutdowns.

High viscosities and gel strength result in increased circulating pressures that can result in loss of circulation and increased pumping costs.



Procedure For Using The Baroid Marsh Funnel:

1. Hold or mount the funnel in an upright position and place a finger over the outlet.
2. Pour the test sample, freshly taken from the mud system, through the screen in the top of the funnel until the level just reaches the under side of the screen.
3. Immediately remove the finger from the outlet tube and measure the number of seconds for a quart of mud to flow into the measuring cup.
4. Record time in seconds as "funnel viscosity." NOTE: Calibration time for fresh water at 70 F is 26 seconds.
5. The funnel viscosity measurement obtained is influenced considerably by the gelation rate of the mud sample and its density. Because of these variations, the viscosity values obtained with the Marsh Funnel cannot be correlated directly with other types of viscometers and/or rheometers.

The 1000cc measuring cup, graduated in cubic centimeters and fluid ounces, is designed specifically for use with the Baroid Marsh Funnel Viscometer. A quart volume is clearly marked on the measuring cup.

VISCOSITY—(Thickness)

Measures	Carrying capacity and gel development
Affects	Hole cleaning, drilling rate, hole stability, cuttings settling rate, circulating pressure
Desirable Limits	Thin as practical and still retain formation stability and cuttings lifting capacity Usual range 32 to 38 sec/qt higher when necessary (water is 26 sec/qt)
Control	QUIK-GEL®, QUIK-TROL™, or CELLEX® to thicken. Water or BARAFOS® to thin

FILTRATION AND CAKE THICKNESS

The ability of the solid components of the mud to rapidly form a thin filter cake of low permeability on a porous formation is a desirable property closely related to hole stability, freedom of movement of the drill string, and the information and production derived from the hole.

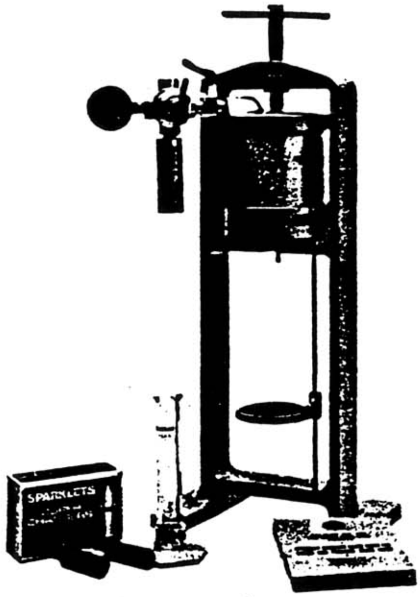
When water, carrying suspended solids, comes into contact with a porous, permeable formation such as sandstone, the solid particles immediately enter the openings. As the individual pores become bridged by the larger particles, successively smaller particles are filtered out until only a small amount of the liquid passes through the openings into the formation.

Thus, the mud solids are deposited as a filter cake on the hole wall. The thickness of the cake is related to the type and concentration of solids suspended in the mud. As soon as bridging of the openings has occurred, the sealing property of the mud becomes dependent upon the amount and physical state of the clay and other colloidal materials in the mud, and not on the permeability of the formation.

While the mud is being circulated, part of the cake is continually eroded away. The amount of liquid (filtrate) entering the porous rock depends on the sealing qualities of the thin sheath at the bore wall. Several problems (often attributed to other causes) may then arise if the mud has a high solids content and a high filtration rate.

If, when rotation is stopped, the drill pipe is in direct contact with filter cake on permeable, porous rock, the pipe may be held firmly in place by the differential pressure. The pipe becomes wall-stuck and cannot be rotated, even though there is free circulation of the mud. Even if the pipe is not stuck, severe swabbing may occur as the pipe is being pulled from the hole. On going back into the hole, the cake may be encountered and reported as "tight spots" or "bridges." The texture as well as the thickness of the filter cake is significant. A gritty, sticky texture indicates more frictional drag on the pipe than that of a smooth, slick cake.

Because the filter cake must be removed from an aquifer before unhindered flow of water can occur, the presence of filter cake may seriously affect the results of the water-well driller's efforts. For example, consider two muds—one made from natural mud, the other from premium-grade bentonite (AQUA-GEL® or QUIK-GEL), both having a funnel viscosity of 45 seconds. The natural mud weighs 10.3 lb per gallon, the AQUAGEL (or QUIK-GEL) weighs 8.6 lb per gallon. For the same time of filtration on a sandstone, the volume of filter cake formed from the natural mud is *36 times* as much as that from the AQUAGEL or QUIK-GEL!



Procedure for Using the Baroid Filter Press:

Pressure can be applied with any nonhazardous gas (never use oxygen). The photograph shows the small CO_2 cartridge used to supply pressure.

Turn the T-screw on the pressure regulator to the maximum outward position. Insert a CO_2 cartridge into the knurled thimble. Make it tight on the threaded connector to perforate the cartridge.

Assemble the cell. Fill with mud nearly to the top, and fit the cap into place. Place the assembled cell in the frame and secure with the T-screw. Put a graduated cylinder under the filtrate tube. Open the valve to the pressure source. Adjust the regulator T-screw until the gauge registers a pressure of 100 pounds per square inch. Maintain the pressure for 30 minutes. Turn the regulator T-screw on the pressure regulator, to the maximum outward position. Slowly open the relief valve and relieve the pressure. Note the volume of filtrate to the nearest tenth of a cubic centimeter.

Remove the cell from the frame. Discard the mud. Disassemble the cell. Wash the filter cake formed on the paper with a gentle stream of water, to remove excess mud. Measure the thickness to the nearest 1/32 inch. Feel the cake for gritty material, stickiness, or other features of texture that may relate to performance of the mud.

FILTRATION PROPERTIES— (Wall Cake and Filtrate)

Measures	Ability of the mud to form a controlled filter cake on the wall of the hole under static conditions
Affects	Hole stability, freedom of movement of the drill string, formation damage, and well development time
Desirable Limits	Cake very thin (less than 2/32 inch), slick, low permeability, easily removed on back flow
Control	Maintain high ratio of effective colloidal solids. QUIK-GEL and/or QUIK-TROL

SAND CONTENT

Measurement of the sand content of mud should be made regularly because excessive sand makes a thick filter cake, causes abrasive wear of pump parts, bit and pipe, may settle when circulation is stopped and interfere with pipe movement or setting of casing. Sand content (API method) is defined as the percentage by volume of solids in the mud that are retained on a 200-mesh sieve. Abrasiveness is not dependent on size alone, however, but upon the hardness and shape of the particles and may be severe with particles even smaller than 200-mesh (74 microns).

Procedure For Using The Baroid Sand Content Set:

1. Pour mud into the tube to the mark labeled "Mud to Here." Then add water to the mark labeled "Water to Here." Cover the mouth of the tube and shake.
2. Pour this mixture through the screen, and wash the solids from the tube with clean water onto the same side of the screen. Wash the sand on the screen with clean water to remove any residual mud.
3. Fit the funnel down over the top of the screen (side containing the sand) and invert, with the neck of the funnel in the mouth of the tube. Wash the sand back into the tube with clean water sprayed on the screen, and allow the sand to settle.
4. Observe the quantity of sand settled in the calibrated tube as sand content in percent by volume of the mud.

SAND CONTENT

Measures	Solids content of particles over 200 mesh size
Affects	Mud weight, equipment life, bit footage, drilling rate, formation damage and drilling problems
Desirable Limits	Less than 2% by volume
Control	Water Dilution Good pit design with maximum settling time and suspend pump suction off bottom of pit Mechanical separation (shakers, desanders) Thin with BARAFOS

pH MEASUREMENT

Alkalinity or acidity is commonly expressed as pH. On the scale 7 is neutral, less than 7 is acid and greater than 7 is alkaline. Each unit represents a tenfold change in hydrogen-ion concentration (for example, a pH of 5 means ten times as acid as a pH of 6; or a pH of 10 means ten times as alkaline as a pH of 9).

The optimum performance of some mud systems is based on control of pH. The effectiveness of bentonite is greatly reduced in an acid environment. Before mixing bentonite, pH of the water should be adjusted to 8 to 9. Contamination of mud by cement will raise the pH to 10 - 12. Sodium bicarbonate can be used to treat for cement contamination and reduce the pH of the mud to the desired range.

The Procedure for Using pHydrion Dispenser

In each pHydrion dispenser is a roll of test paper treated with a dye which undergoes changes in color with pH to correspond to the reference color strips on the side of the container. The broad-range test paper can be used in most cases to estimate to one pH unit. Narrow-range indicators are available for estimation to one-tenth pH unit.

Remove a one-inch strip of paper from the pHydrion Dispenser. Place the strip on the surface of the water or mud and allow it to remain until the surface has become wet and the color has stabilized (30 seconds to a minute). Estimate the pH by comparison of the color of the upper side of the paper with the chart on the dispenser from which the paper was taken.

pH

Measures	Alkalinity or acidity of mixing water and drilling fluids
Affects	Mud mixing, viscosity, gel and filtration of mud, hole stability, corrosivity of mud
Desirable Limits	8.5 to 9.5 (Neutral solutions pH = 7.0)
Control	Raise with soda ash (1 to 2 lb/100 gal), lower with sodium bicarbonate (for cement contamination)

WATER FOR DRILLING

Water is the primary constituent of most drilling fluids. The quantity, quality and on-site cost of the water used for drilling influences the types and amounts of mud additives necessary to control drilling fluid properties. The properties of bentonite in water are seriously impaired by dissolved acidic or salty substances. When water is acidic, it may carry traces of such heavy metals as copper and zinc and be unsatisfactory for use in mud without preliminary treatment. Hard water, caused by dissolved calcium and magnesium salts, impairs the suspending and sealing qualities of bentonite.

A few simple tests will establish the suitability of the water. Measurement of pH by means of indicator paper strips (pHydrion paper) and a semiquantitive test for hardness (Baroid Calcium Indicator) usually are sufficient.

If the water is acidic it should be treated with soda ash to raise the pH to 8 or 9 prior to the addition of any mud-making materials. Hardness is removed by soda ash but, if more convenient, treatment for hardness can be made along with the addition of the mud-making materials. Usually between 1 and 5 lb of soda ash per 100 gal of water is sufficient; however, the simple tests for pH and calcium should be made on the treated water. Strongly acidic water may require treatment with caustic soda. If sulfides are present, pH should be maintained above 10 to counteract corrosion.

Knowledge of the source of the water usually serves to indicate the possibility of contamination by other salts, such as halite. There is no treatment which will remove sodium and potassium salts. Consequently the mud program must be adapted to the composition of the salty water to be used. Organic polymers are used instead of bentonite in salty water.

If drilling is to be to or through the potable water zones, care should be taken to insure that the mud make-up water is not contaiminated with micro-organisms or other pollutants. The source of much aquifer bacterial contamination can be traced back to the introduction of micro-organisms during the drilling process.

HARD WATER

Hard water is a frequent cause of unsatisfactory performance of mud. Hard water contains dissolved calcium and magnesium salts. Calcium salts, such as anhydrite or gypsum, seriously impair the suspending and sealing properties of bentonite. A simple test for calcium ion in the makeup water will show the need for treatment, if the water is hard. After addition of soda ash to the water, a test should be made to make certain the water has been softened.

Procedure for Using Calcium Indicator Solution

The Baroid Calcium Indicator gives an approximation of the hardness of water due to dissolved calcium salts. To 2 cc of the water, or filtrate, add 2 drops of Baroid Calcium Indicator. Shake well and let stand two minutes. Estimate the calcium ion concentration from the amount of turbidity as follows:

Suspension	Approximate ppm Calcium	Soda Ash Treatment lb/100 gal
Translucent	100 to 200	0.5 to 1
Milk White	200 to 400	1 to 2
Dense White	Above 400	2 to 5

If a dense white precipitate forms, repeat the test with a smaller sample and make the appropriate correction in the estimation.

CALCIUM INDICATOR

Measures	Hardness of mixing water due to dissolved calcium salts
Affects	Mud mixing, increases filtration, wall cake; suppresses viscosity and gel development
Desirable Limits	Less than 100 ppm calcium
Control	Pre-treat mixing water with soda ash (1-5 lb/gal)

CHLORIDE CONTENT

Frequently it is desirable to know the salt content of muds to account for certain aspects of their performance. Filtration, suspension, viscosity, and gel properties are adversely affected by salt unless the mud is specifically designed to withstand salt contamination. Organic polymers, such as QUIK-TROL and LOLOSS, must be used to replace bentonite in salty waters.

To determine the chloride content, a sample of the makeup water or mud filtrate is titrated with a standard silver nitrate solution, using potassium chromate as an indicator. When the chloride is completely titrated, the addition of more silver nitrate produces a red color which is taken as the end point. Results are reported in parts per million of chloride ion.

Procedure for Using Chloride Content Kit

Apparatus and Reagents:

- Pipette, 1 cc
- Pipette, 10 cc
- Silver nitrate solution, 1 cc equivalent to .001 g Cl
- Distilled water
- Potassium chromate solution
- Polyethylene or porcelain titration dish
- Polyethylene or glass stirring rod

METHOD:

1. Pipette 1.00 cc of sample into the titration dish and dilute to 40 or 50 cc with distilled water.
2. Add four or five drops of potassium chromate indicator solution.
3. Add standard silver nitrate solution from a pipette dropwise and slowly, all the while stirring continuously with a stirring rod, until the sample just turns from yellow to orange or brick red.

RESULTS:

1. The number of cc of standard silver nitrate solution used to obtain this end point is multiplied by 1,000 when the 0.001 g silver nitrate solution is used to obtain parts per million (ppm) of chloride (Cl) ion.
2. The salt content in the sample is expressed as ppm Cl. Multiply ppm Cl by 1.65 for ppm NaCl.

CHLORIDE CONTENT (SALT)

Measures	Dissolved chlorides (usually salt)
Affects	Mud mixing, increases filtration and wall cake thickness; suppresses viscosity and gel development when present in makeup water; thickens fresh water mud
Desirable Limits	Less than 500 ppm
Control	Dilution with fresh water

ROUTINE TESTING PROGRAM

Time and money can be saved by keeping records of mud properties. The simple measurements of mud weight and funnel viscosity in many cases furnish sufficient information for adequate control of mud properties. Mud weight should be measured at the ditch and at the pump suction to determine how effectively the cuttings are being separated. Too much emphasis cannot be placed on the measurement of density. An increase of solids from cuttings means slower drilling; more wear on the bit; thicker filter cake and higher pressure downhole with greater danger of sticking the drill pipe, and more likelihood of losing circulation.

Funnel viscosity should be no higher than is necessary to carry the cuttings and provide a stable hole. Based on experience with mud of simple composition, limits can be set for weight and funnel viscosity which will assure satisfactory filtration properties. For example, if a fresh-water bentonite mud has a funnel viscosity of 32 to 38 seconds, and weighs less than 9.0 lb per gal, satisfactory performance usually can be expected for average drilling.

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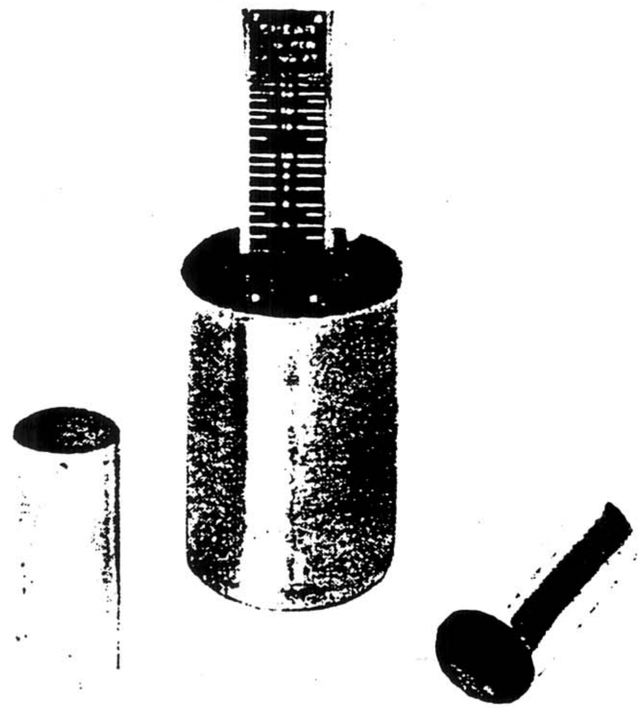
SHEAR OR GEL STRENGTH

The gel strength of drilling muds is a measure of the minimum shearing stress necessary to produce slip-wise movement.

Two readings are generally taken: the first, immediately after agitation of the mud in the cup; the second, after the mud in the cup has been quiescent for a period of ten minutes. The readings are referred to as the initial gel strength and the ten-minute gel strength respectively. Both gel strength readings so determined will be zero for true fluids no matter how viscous, e.g., clarified honey, but the difference in the readings may be appreciable for suspensions such as drilling muds. This difference is considered to be a measurement of the thixotropy of the mud system. Hole size, type of formations, depth, temperature and pressure of formation fluids or gases, and amount of weight material in the mud are factors that must be considered in prescribing desirable gel-strength properties of the mud.



Shearometer Set.

SHEAROMETER

The Shearometer is an auxiliary instrument for use in determining gel strengths of drilling muds. The readings are obtained directly from a calibrated scale and give gel strength in pounds per 100 square feet of area. The readings cannot be correlated with those obtained with the Baroid Viscometer or the Baroid Rheometer. The Shearometer is not recommended for use with very low or very high gel strength muds.

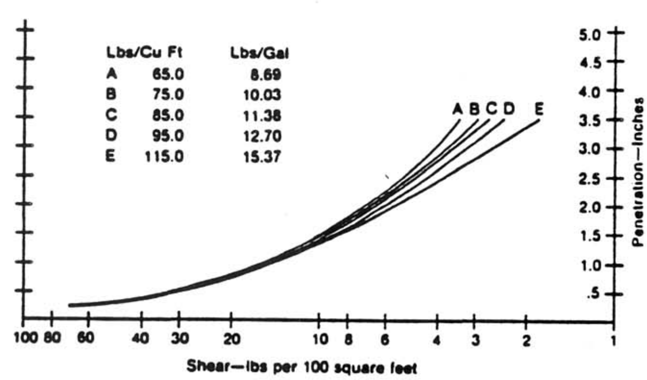
The Shearometer consists of a duraluminum tube 3.5 inches long, 1.4 inches in internal diameter, and weighing 5.0 grams; a special scale graduated in pounds per 100 ft^2 of shear; and a sample cup which also serves to support the scale.

PROCEDURE:

1. Wet the tube with water and wipe off excess water.
2. Lower the Shearometer tube over the scale support and place it on the surface of the freshly agitated mud which has been poured into the container to bottom line across scale. Allow the tube to sink vertically, guided by the fingers only if necessary.
3. With a stopwatch measure the time from the instant the tube is released. After allowing the tube to sink for one minute, read the scale directly opposite the top of the tube and record the shear strength in pounds per 100 ft^2.
4. Wait 10 minutes and repeat procedure to measure 10-minute shear.

RESULTS:

1. Report the shear strength in pounds per 100 ft^2.
2. If the tube sinks to bottom in one minute or less, report the shear strength as zero with a superscript indicating the number of seconds of fall. (Example: Initial shear, lb/100 ft^2 0^6.)



Shearometer Calibration Curves, 5 gram.