# Drilling Fluid Processing Systems Evaluation

## 1 Scope

This recommended practice specifies procedures for assessing and modifying the performance of solids control equipment systems commonly used in the field in petroleum and natural gas drilling fluids processing.

The procedures described in this standard are not intended for the comparison of similar types of individual pieces of equipment.

## 2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 13B-1, *Field Testing Water-based Drilling Fluids*

API Recommended Practice 13B-2, *Field Testing Non-Aqueous Drilling Fluids*

ASTM E11[1] Standard Specification for Wire Cloth and Sieves for Testing Purposes

## 3 Terms, Definitions, Symbols, and Abbreviations

### 3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

**3.1.1**
**addition section**
Compartment(s) in the surface drilling fluid system, between the removal section and the suction section, which provides (a) well-agitated compartment(s) for the addition of commercial products such as chemicals, necessary solids, and liquids.

**3.1.2**
**agitator**
**mechanical stirrer**
Mechanically driven mixer that stirs the drilling fluid by turning an impeller near the bottom of a mud compartment to blend additives, suspend solids, and maintain a uniform consistency of the drilling fluid.

[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

**3.1.3**
**aperture**
**(screen cloth)**
Opening between the wires in a screen cloth.

**3.1.4**
**aperture**
**(screen surface)**
Opening in a screen surface.

**3.1.5**
**apex**
Opening at lower end of a hydrocyclone

**3.1.6**
**API screen number**
Number in an API system used to designate the measured D100 separation of a screen cloth based on the ASTM E11 separation range (See 3.1.24).

NOTE See 9.6 and Table 5 for further information. The thirty one API Screen numbers listed in Table 5 are the only acceptable API number designations.

**3.1.7**
**backing plate**
Support plate attached to the back of screen cloth(s).

**3.1.8**
**baffle**
Plate or obstruction built into a compartment to change the direction of fluid flow.

**3.1.9**
**barite**
Natural barium sulfate ($BaSO_4$) used for increasing the density of drilling fluids.

NOTE The two grades of API barite have a minimum specific gravity of 4.20 or 4.10, see Reference [1] API Specification 13A. Commercial API 13A barite can be produced from a single ore or a blend of ores and can be a straight-mined product or processed by flotation or other purification methods. They contain accessory minerals other than barium sulfate. Because of mineral impurities, commercial barite can vary in color from off-white to grey to red or brown. Common accessory minerals are silicates such as quartz and chert, carbonate compounds such as siderite and dolomite, and metallic oxide or sulfide compounds.

**3.1.10**
**Base fluid**
Water to prepare a water-based drilling fluid or a non-aqueous fluid (NAF) to prepare a non-aqueous drilling fluid (NADF) (see 3.1.57)

**3.1.11**
**blinding**
Reduction of open area in a screening surface caused by coating or plugging. Most often the plugging is caused by particles that are similar in size to the screen openings. Blinding may be prevented by installing finer screens.

**3.1.12**
**bonding material**
Material used to secure screen cloth to a backing plate or support screen.

**3.1.13**
**capture**
Mass fraction of incoming suspended solids that are conveyed to the reject stream.

**3.1.14**
**centrate**
Discharge stream from a centrifugal separation that contains a higher percentage of liquids than the feed does.

**3.1.15**
**centrifugal pump**
Machine for moving fluid by spinning it using a rotating impeller in a casing with a central inlet and a tangential outlet.

NOTE The path of the fluid is an increasing spiral from the inlet at the center to the outlet, tangent to the impeller annulus. In the annular space between the impeller vane tips and the casing wall, the fluid velocity is roughly the same as that of the impeller vane tips. Useful work is produced by the pump when some of the spinning fluid flows out of the casing tangential outlet into the pipe system. Power from the motor is used to accelerate the fluid entering the inlet up to the speed of the fluid in the annulus. Some of the motor power is expended as friction of the fluid in the casing and impeller.

**3.1.16**
**centrifuge**
Device, rotated by an external force, for the purpose of separating materials of various masses (depending upon specific gravity and particle sizes) from a slurry to which the rotation is imparted primarily by the rotating container walls.

**3.1.17**
**clay mineral**
Soft, variously colored earth, commonly hydrous silicate of alumina.

NOTE Clay minerals are essentially insoluble in water but disperse under hydration, grinding, heating, or velocity effects. Particle sizes of clay mineral can vary from submicrometer to larger than 100 µm.

**3.1.18**
**clay particle**
Colloidal particles of clay mineral having less than 2 µm equivalent spherical diameter ( see colloidal solid 3.1.21)

**3.1.19**
**coating**
**(substance)**
Processing material adhering to a surface to change the properties of the surface.

NOTE Engineered material adhering type material are not covered by this definition.

**3.1.20**
**coating**
**(physical process)**
Procedure by which material forms a film that covers the apertures of the screening surface ( see blinding (3.1.11)

**3.1.21**
**colloidal solid**
Particle of diameter less than 2 µm.

NOTE This term is commonly used as a synonym for clay particle size.

**3.1.22**
**conductance**
Permeability per unit thickness of a static (not in motion) shale shaker screen.

NOTE Conductance is expressed in units of kilodarcys per millimeter [2].

**3.1.23**
**cuttings**
Formation pieces dislodged by the drill bit and brought to the surface in the drilling fluid.

NOTE Field practice is to refer to all solids removed by the shaker screen as "cuttings," although some can be sloughed material.

**3.1.24**
**D100 separation**
Particle size, expressed in micrometers, determined by plotting the percentage of aluminum oxide (AlO) sample separated by the test screen on the plot of cumulative mass fraction (expressed as a percentage) retained versus standard sieve opening (expressed in micrometers) for the sieve analysis of the AlO test sample.

NOTE 100 % of the particles larger than the D100 separation are retained by the test screen.

**3.1.25**
**decanting centrifuge**
Centrifuge that removes solids from a feed slurry by rotating the liquid in cylindrical bowl at high speed and discharges the higher mass particles as a damp underflow.

NOTE Colloidal solids are discharged with the liquid overflow or light slurry. The decanting centrifuge has an internal auger that moves solids that have settled to the bowl walls out of a pool of liquid and to the underflow.

**3.1.26**
**density**
**(relative density or volumic mass)**
Mass divided by volume.

NOTE 1 In SI units, density is expressed in kilograms per cubic meter; in USC units, it is expressed as pounds per gallon or pounds per cubic foot. Other units include what is commonly referred to as specific gravity with units of g/mL.

NOTE 2 Drilling fluid density is commonly referred to as "drilling fluid weight" or "mud weight."

**3.1.27**

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[2] The darcy is not an SI unit, but kilodarcys per millimeter (kD/mm) is the recommended unit for this standard. The SI unit of permeability to fluid flow is defined as the amount of permeability that permits 1 $m^3$ of fluid of a viscosity of 1 Pa•s to flow through a section that is 1 m thick with a cross-section of 1 $m^2$ in 1 s at a pressure difference of 1 Pa. Therefore, in SI units, permeability is expressed in square metres: 1 $m^2$ = 1.01325 x $10^{12}$ darcys.

**desander**
Hydrocyclone with an inside diameter of at least 152 mm (6 in.) that removes a high proportion of the particles with a diameter of at least 74 µm from a drilling fluid. Typically used to separate the highest mass solids from the lightest in the feed slurry of an unweighted drilling fluid.

**3.1.28**
**desilter**
Hydrocyclone with an inside diameter of less than 152 mm (6 in.).

**3.1.29**
**dilution**
Method of decreasing the drilled-solids content of a slurry by addition of (a) material(s) other than drilled-solids, usually a clean drilling fluid or the base fluid (water or non-aqueous fluid).

**3.1.30**
**drilled-solids**
Formation solids that enter the drilling fluid system, whether excavated solids produced by the drill bit (see 3.1.38) or from the enlargement of the borehole due to mechanical erosion, spalling, or dissolution..

**3.1.31**
**drilled-solids removal system**
Equipment and processes used while drilling a well that remove the solids generated from the hole and carried by the drilling fluid.

NOTE These processes include settling, screening, desanding, desilting, centrifuging, and dumping.

**3.1.32**
**drilled-solids removal system efficiency ($\eta_{DSR}$)**
**drilled-solids removal system performance**
Measure of the removal of drilled-solids by surface solids control equipment.

NOTE The calculation is based on a comparison of the dilution required to maintain the desired drilled-solids content with that which would have been required if none of the drilled-solids were removed.

**3.1.33**
**drilling fluid**
Liquid or slurry pumped down the drill string and up the annulus of a wellbore during the drilling operation, processed through the surface fluid processing system then recirculated.

**3.1.34**
**educator**
**pressure jet**
Device using a high-velocity jet to create a low-pressure region that draws liquid or dry material to be blended with the drilling fluid.

NOTE The use of a high-velocity jet to create a low-pressure region is known as the Bernoulli principle.

**3.1.35**

**eductor**
**(fluid stream)**
Device using a fluid stream that discharges under high pressure from a jet through an annular space to create a low-pressure region.

NOTE When properly arranged, it can evacuate degassed drilling fluid from a vacuum-type degasser or pull solids through a hopper.

**3.1.36**
**effluent**
Discharge of liquid, generally a stream, after some attempt at separation or purification has been made.

**3.1.37**
**equalizer**
Opening or piping for flow between compartments in the surface fluid processing system, which allows for the desired flow path and fluid levels. Often adjustable such that the inlet if from the bottom of the last processing pit and the outlet is into the upper section of the product additions or suction pit.

**3.1.38**
**Excavated drilled-solids**
Volume of solids drilled over a specified interval.

**3.1.39**
**flow capacity**
Rate at which equipment, such as a shaker or centrifuge, can process drilling fluid.

NOTE For a shale shaker, flow capacity is a function of many variables, including shaker configuration, design and motion, drilling fluid rheology, solids loading, screen design, open area, plus any blinding by near-size particles. No standard exists for reported flow capacity so reported values may not be indicative of actual performance with drilling fluids and excavated drilled-solids.

**3.1.40**
**flow line**
Piping or trough that directs drilling fluid from the rotary nipple to the surface drilling fluid system.

**3.1.41**
**flow rate**
The volume of liquid or slurry that passes per unit of time.

NOTE Flow rate is expressed as cubic meters per minute, gallons per minute, barrels per minute, etc.

**3.1.42**
**gumbo**
Drilled-solids that agglomerate and form a sticky mass as they are circulated up the wellbore.

**3.1.43**
**head**
Height that a fluid column would reach in an open-ended pipe if the pipe were attached to the point of interest.

NOTE The head at the bottom of a 300 m (1000 ft) well is 300 m (1000 ft), but the pressure at that point depends upon the density of the drilling fluid in the well.

**3.1.44**
**hook strip**
Hooks on the edge of a screen section of a shale shaker that accept the tension member for screen mounting.

**3.1.45**
**hopper**
**mud hopper**
Large funnel-shaped or coned-shaped device, into which dry (or liquid) components are poured to facilitate uniform blending with liquids or slurries that are flowing through the lower part of the cone.

**3.1.46**
**hydrocyclone**
**cone**
**cyclone**
Liquid-solids separation device using centrifugal force for settling. Desanders and desilters are hydrocyclones used most often for processing unweighted drilling fluids.

NOTE Fluid enters tangentially and spins inside the hydrocyclone. The heavier solids settle to the walls of the hydrocyclone and move downward until they are discharged at the hydrocyclone apex. The discharge from the apex of the cone is called the underflow. The spinning fluid travels part way down the hydrocyclone and back up to exit out the top of the hydrocyclone through a vortex finder. The discharged fluid from the top of the cone is called the effluent or overflow.

**3.1.47**
**impeller**
Spinning disc in a centrifugal pump with protruding vanes, used to accelerate the fluid in the pump casing.

**3.1.48**
**manifold**
Length of pipe with multiple connections for collecting or distributing drilling fluid.

**3.1.49**
**Marsh funnel viscosity**
**funnel viscosity**
Viscosity measured with the instrument used to monitor drilling fluid (see API 13B-1 or API 13B-2).

NOTE A Marsh funnel is a tapered container with a fixed orifice at the bottom so that when filled with 1500 mL of fresh water, 946 mL (1 qt) will drain in 26 s. It is used for comparison values only and not to diagnose drilling fluid problems.

**3.1.50**
**mud**
Slurry of insoluble and soluble solids in either an aqueous or non-aqueous continuous-phase fluid.

NOTE See drilling fluid (3.1.33).

**3.1.51**
**mud balance**
Beam-type balance used in determining drilling fluid density (see API 13B-1 or API 13B-2).

**3.1.52**
**mud cleaner**
Combination of hydrocyclones followed by screening equipment, where the screen separates out larger solids from the hydrocyclone underflow.

NOTE The hydrocyclone overflow returns to the drilling fluid, while the underflow of the hydrocyclones is processed through a vibrating screen. The screen is usually of size API 170 or finer. The screen solids discharge is discarded while the liquid and solids passing through the screen are returned to the drilling fluid.

**3.1.53**
**mud compartment**
Subdivision of the removal, addition, or check/suction sections of a surface system.

**3.1.54**
**mud gun**
Submerged nozzle used to stir drilling fluid with a high-velocity stream.

**3.1.55**
**near-size particle**
Particle whose size is close to the size of the openings in the screen through which its passage is under evaluation.

**3.1.56**
**Newtonian fluid**
A fluid such as water, oil or brine at constant temperature with a constant viscosity and with a zero shear stress at zero shear rate; the shear stress is directly proportional to the shear rate.

**3.1.57**
**non-aqueous drilling fluid (NADF)**
Drilling fluid in which the NAF continuous phase is not miscible with water, and water or brine is the dispersed phase.

**3.1.58**
**particle**
Discrete unit of solid material that consists of a single grain or of any number of grains stuck together.

**3.1.59**
**particle size distribution**
Mass or net volume classification of solid particles into each of the various size ranges, as a percentage of the total solids of all sizes in a fluid sample.

**3.1.60**
**plastic viscosity**
Measure of the high-shear-rate viscosity, which depends upon the concentration, shape, and size of solids and the viscosity of the liquid phase (see API 13B-1 or API 13B-2).

NOTE 1 Plastic viscosity is calculated by subtracting the 300 r/min reading from the 600 r/min reading using a direct indication concentric cylinder viscometer.

NOTE 2 In SI units, plastic viscosity is expressed in pascal•seconds; in USC units, plastic viscosity is expressed in centipoises.

**3.1.61**
**plugging**
Wedging or jamming of openings in a screening surface by near-size particles, which prevents the passage of undersize particles and leads to the blinding (see 3.1.11) of the screen.

**3.1.62**
**possum belly**
Compartment or back tank on a shale shaker, into which the flow line discharges and from which drilling fluid is either fed to the screens or is bypassed, if necessary.

**3.1.63**
**relative density**
Relative density is the ratio of the mass of a specific volume of material at a specified temperature when compared to an equal volume of reference material at the same (or another) temperature. Most commonly, the reference material is water.

NOTE 1 Relative density is commonly named specific gravity.

NOTE 2 For the purposes of this recommended practice, the symbol for density, $\rho$, will be used for specific gravity.

**3.1.64**
**removal section**
First section in the surface drilling fluid system, consisting of a series of compartments where processing equipment is located to remove gas and undesirable solids.

**3.1.65**
**retort**
Instrument used to distill oil, water, and other volatile material in a drilling fluid to determine the volume fraction of oil, water, and total solids (see API 13B-1 or API 13B-2).

**3.1.66**
**sand trap**
First compartment in a surface system, generally located directly below or after the shale shakers. Usually unstirred or unagitated with a high weir so that it functions as a settling compartment where coarser solids that by-pass the shakers accumulate.

**3.1.67**
**screen cloth**
Type of screening surface woven in square, rectangular or slotted openings.

**3.1.68**
**screening**
Mechanical process that results in a division of particles on the basis of size, based on their passing through or being rejection by a screening surface.

**3.1.69**
**shale shaker**
Mechanical device that separates drill cuttings and solids larger than the screen aperture from a drilling fluid.

NOTE The separation methods can include vibrating screens, rotating cylindrical screens, and screen cloth belts, etc.

**3.1.70**
**sieve**
Laboratory screen with wire-mesh or electronically-punched holes of known dimensions mounted in a frame.

**3.1.71**
**sieve analysis**
Classification (distribution) by mass of solid particles passing through or retained on a sequence of screens with decreasing aperture sizes.

NOTE Sieve analysis can be carried out by wet or dry methods (see API 13 TR3).

**3.1.72**
**slug tank**
Small compartment, normally adjacent to the suction compartment, used to mix special fluids to pump downhole.

NOTE Slug tanks are most commonly used to prepare a small volume of weighted drilling fluid before a drill string trip out of the borehole. Also commonly called a pill pit.

**3.1.73**
**suction section/compartment**
Last active section in the surface system that supplies drilling fluid to the suction of the drilling fluid pumps.

NOTE In general terms, a suction compartment is any compartment from which a pump removes fluid.

**3.1.74**
**sump**
Pan or lower compartment below the lowest shale shaker screen.

**3.1.75**
**tensioning**
Stretching of a screening surface of a shale shaker to the proper tension, while positioning it within the vibrating frame.

**3.1.76**
**total non-blanked area**
Net unblocked area that permits the passage of fluid through a screen.

NOTE 1 Total non-blanked area is expressed in $m^2$ ($ft^2$).

NOTE 2 Some screen designs can eliminate as much as 40 % of the gross screen panel area from fluid flow due to backing-plate and bonding-material blockage.

**3.1.77**
**trip tank**
Gauged and calibrated vessel used to account for fill and displacement volumes as pipe is pulled from and run into the hole.

NOTE Close observation allows early detection of formation fluid entering a wellbore and of drilling fluid loss to a formation.

**3.1.78**

**underflow**
**(centrifugal separator)**
Discharge stream from a centrifugal separator that contains a higher percentage of solids compared to the feed.

**3.1.79**
**underflow**
**(screen separator)**
Discharge stream from a screen separator that contains a lower percentage of solids compared to the feed.

**3.1.80**
**unoccluded**
Unobstructed area of a screen opening.

**3.1.81**
**unweighted drilling fluid**
Drilling fluid that does not contain commercial suspended solids added for the purpose of increasing the density of the drilling fluid.

**3.1.82**
**viscosity**
Ratio of shear stress to shear rate.

NOTE 1 In SI units, viscosity is expressed in pascal•seconds; in USC units, viscosity is expressed in centipoises.

NOTE 2 If the shear stress is expressed in the centimeter-gram-second (CGS) system of units (dynes per square centimeter) and the shear rate is expressed in reciprocal seconds, the viscosity is expressed in poises (P); 1 P = 1 dyn•s/cm$^2$ = 1 g•cm$^{-1}$•s$^{-1}$ = 10$^{-1}$ Pa•s; and 1 cP = 1 mPa•s.

**3.1.83**
**vortex**
Cylindrical or conical shaped core of air or vapor that lies along the central axis of the rotating slurry inside a hydrocyclone.

**3.1.84**
**water-based drilling fluid**
Drilling fluid in which water is the suspending medium for solids and is the continuous phase, whether oil is present or not.

**3.1.85**
**weighted drilling fluid**
Drilling fluid to which solids have been added in order to increase its density.

**3.1.86**
**weighting material**
High relative density solids added to a drilling fluid specifically to increase drilling-fluid density.

NOTE This material is commonly barite (relative density 4.1 or 4.2) or hematite (relative density 5.05); in special applications, it might be calcium carbonate.

## 3.2 Symbols and Abbreviations

### 3.2.1 Symbols

For the purposes of this document, the following symbols apply:

| | |
|---|---|
| $A$ | cross-sectional area, expressed in square centimeters ($A_{SI}$) or square inches ($A_{USC}$) |
| $C$ | conductance, expressed in kilodarcys per millimeter |
| $D_H$ | hole diameter, expressed in millimeters ($D_{H,SI}$) or in inches ($D_{H,USC}$) |
| $h$ | head, expressed in meters ($h_{SI}$) or in feet ($h_{USC}$); |
| $h_T$ | head for testing, expressed in millimeters ($h_{T,SI}$) or inches ($h_{T,USC}$) |
| $K$ | permeability, expressed in darcys |
| $L$ | length of the porous medium, expressed in centimeters |
| $L_H$ | wellbore length, expressed in meters ($L_{H,SI}$) or feet ($L_{H,USC}$) |
| $m_{C1}$ | mass of the weighing container and one liter of base fluid, either expressed in grams ($m_{C1,SI}$) or in pounds ($m_{C1,USC}$) |
| $m_{C2}$ | final mass with one half volume of the discarded wet drilled-solids, the weighing container, and one half volume of base fluid, expressed either in grams ($m_{C2,SI}$) or in pounds ($m_{C2,USC}$) |
| $m_{DF\text{-}Dgas}$ | mass of the same volume sample than for $m_{DF\text{-}Unpr}$ of degassed drilling fluid, expressed in grams. |
| $m_{DF\text{-}Unpr}$ | mass of a sample volume of unpressurized drilling fluid, expressed in grams |
| $m_{LOST}$ | lost mass after retorting ,expressed in grams |
| $m_{R1}$ | mass of the empty retort sample cup, lid, and retort upper cell body packed with steel wool, expressed in grams, |
| $m_{R2}$ | mass of retort sample cup filled with wet drilled-solids sample, lid, and retort body packed with steel wool, expressed in grams |
| $m_{R3}$ | mass of retort sample cup filled with wet drilled-solids sample and topping base fluid, lid, and retort body packed with steel wool, expressed in grams |
| $m_{R4}$ | mass of empty, clean, dry liquid receiver, expressed in grams |
| $m_{R5}$ | mass of liquid receiver and its condensed liquid content (oil and water), expressed in grams |

$m_{R6}$ mass of cooled retort assembly (retort sample cup with retorted solids, lid, and retort body packed with steel wool), expressed in grams

$m_S$ retained sample mass, expressed in grams

$m_1$ mass of empty container, expressed in grams

$m_2$ mass of container plus sample, expressed in grams

$m_3$ mass of dried/retorted container, expressed in grams

$\dot{m}_1$ feed mass flow rate, expressed in kilograms per minute (pounds per minute)

$\dot{m}_2$ overflow mass flow rate, expressed in kilograms per minute (pounds per minute)

$\dot{m}_3$ underflow mass flow rate, expressed in kilograms per minute (pounds per minute)

$p$ pressure, expressed in kilopascals ($p_{SI}$) or pounds-force per square inch ($p_{USC}$)

$Q_1$ volumetric flow rate for discard 1, expressed in cubic meters per minute (barrels per minute)

$Q_2$ volumetric flow rate for discard 2, expressed in cubic meters per minute (barrels per minute)

$q$ flow rate through a porous medium, expressed in milliliters per second

$q_S$ flow rate through test screen, expressed in milliliters per minute ($q_{S,SI}$) or gallons per minute ($q_{S,USC}$)

$R_{DF\text{-}DS}$ drilling-fluid to wet drilled-solids ratio (discarded solids), expressed as a volumetric ratio (v/v)

$R_{DF\text{-}DS1}$ drilling-fluid to drilled-solids ratio of discard 1, expressed as a volumetric ratio (v/v)

$R_{DF\text{-}DS2}$ drilling-fluid to drilled-solids ratio of discard 2, expressed as a volumetric ratio (v/v)

$R_{NAF}$ ratio of the volume fraction of NAF to the sum of the volume fractions of NAF and pure water, from retort analysis, expressed as a percentage.

$R_{DF\text{-}DS\text{-}Tot}$ total (volume weighted) drilling-fluid to drilled-solids ratio for all waste stream discards expressed as a volumetric ratio (v/v)

$R_W$ ratio of the volume fraction of water to the sum of the volume fractions of NAF and condensed water from the retort analysis, expressed as a percentage

$V_{BF}$ volume of base fluid added to system for dilution, expressed in cubic meters (barrels)

$V_{DDS}$ volume of discarded wet drilled-solids, expressed in cubic meters (barrels)

$V_{DDF}$ volume of discarded drilling fluid in the discarded drilled-solids, expressed in cubic meters (barrels)

$V_{DIL}$ volume of clean drilling fluid (zero drilled-solids) used for dilution to maintain the target drilled-solids concentration, expressed in cubic meters (barrels)

$\frac{V_{DIL}}{V_{DS}}$ dilution volume of clean drilling fluid (zero drilled-solids) per unit volume of excavated drilled-solids to maintain target concentration of drilled-solids, dimensionless volumetric ratio (v/v). [i.e. cubic meters per cubic meter (barrels per barrel)]

$V_{DIL_i}$ volume of clean fluid used for dilution for each portion "i" of the interval (total $n$ portions), usually daily, expressed in cubic meters (barrels)

$V_{DIL\text{-}Exc}$ volume of excess drilling fluid used for dilution, expressed in cubic meters (barrels)

$V_{DIL\text{-}Itval}$ total volume of clean fluid used for dilution for the interval, expressed in cubic meters (barrels)

$V_{DIL+RDS}$ volume of drilling fluid used for dilution including the retained drilled-solids, expressed in cubic meters (barrels)

$V_{DS}$ excavated volume of drilled-solids, expressed in cubic meters ( $V_{DS,SI}$) or barrels ($V_{DS,USC}$)

$V_{F,SI}$ final volume, expressed in liters, (as per recommended procedure 2 L)

$V_{F,USC}$ final volume, expressed in quarts, (as per recommended procedure 2 qt)

$V_R$ total volume of condensed liquid collected in the liquid receiver, expressed in milliliters

$V_{RDS}$ volume of retained drilled-solids, expressed in cubic meters (barrels)

$V_{TOP}$ volume of topping fluid, expressed in milliliters

$V_W$ volume of condensed water collected in the liquid receiver, expressed in milliliters

$V_{Waste}$ overall waste volume of drilling fluid, expressed in cubic meters (barrels)

$w$ mass fraction of suspended solids , expressed as a decimal fraction

$w_{NAF\text{-}DS}$ mass fraction of NAF for the wet drilled-solids sample, expressed as a decimal fraction

$w_a$ mass fraction of suspended solids removed ("capture"), expressed as a decimal fraction

$w_1$ mass fraction of suspended solids in the feed to a piece of separator equipment, expressed as a decimal fraction

| | |
|---|---|
| $w_2$ | mass fraction of suspended solids in the overflow from a piece of separator equipment, expressed as a decimal fraction |
| $w_3$ | mass fraction of suspended solids in the underflow from a piece of separator equipment, expressed as a decimal fraction |
| $w_4$ | mass fraction of weighting material, expressed as a decimal fraction |
| $w_5$ | mass fraction of low-gravity solids (LGS), expressed as a decimal fraction |
| $\Delta p$ | pressure differential, expressed in atmospheres |
| $\varphi_{BF}$ | base fluid volume fraction for the drilling fluid with target (or average) drilled-solids concentration, expressed as a percentage |
| $\varphi_{BDF}$ | base fluid volume fraction for the clean drilling fluid (zero-drilled-solids), expressed as a percentage |
| $\varphi_{DF\text{-}DS}$ | volume fraction of drilling-fluid of the wet drilled-solids sample, expressed as a percentage |
| $\varphi_{DS}$ | target drilled-solids concentration of the drilling fluid, expressed as a percentage |
| $\varphi_{DS\text{-}Tot}$ | volume fraction of total solids in the wet drilled-solids sample, expressed as a percentage |
| $\varphi_{E}$ | volume fraction of wellbore enlargement, expressed as a percentage |
| $\varphi_{G\text{-}DF}$ | volume fraction of gas or air in the drilling fluid, expressed as a percentage |
| $\varphi_{G\text{-}DF\text{-}Gdis}$ | volume fraction of gas dissolved in the drilling fluid, expressed as a percentage |
| $\varphi_{LG\text{-}DS}$ | volume fraction of LGS in the wet drilled-solids sample, expressed as a percentage |
| $\varphi_{LG\text{-}Tot}$ | volume fraction of LGS for the total solids content, expressed as a percentage |
| $\varphi_{NAF\text{-}DF}$ | volume fraction of NAF of the whole NAF drilling-fluid, expressed as a percentage |
| $\varphi_{NAF\text{-}DS}$ | volume fraction of NAF of the wet drilled-solids sample expressed as a percentage |
| $\varphi_{WM\text{-}DF}$ | volume fraction of weighting-material associated with the drilling fluid in the wet drilled-solids sample, expressed as a percentage |
| $\varphi_{W\text{-}DS}$ | volume fraction of condensed water of the wet drilled-solids sample, expressed as a percentage |
| $\varphi_{WM}$ | volume fraction of weighting-material solids of the whole drilling-fluid, expressed as a percentage |

$\varphi_{\text{WM-DS}}$ volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage

$\varphi_{\text{WM-Ex}}$ excess volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage

$\varphi_{\text{WM-Tot}}$ volume fraction of weighting-material solids for the total solids content, expressed as a percentage

$\mu$ fluid viscosity, expressed in centipoises (pascal•seconds);

$\eta_{\text{DSR}}$ drilled-solids removal system efficiency, expressed as a percentage

$\eta_{\text{DSR-Opt}}$ optimum drilled-solids system removal efficiency, expressed as a percentage

$\rho$ density of NAF or oil, expressed in kilograms per cubic meter ($\rho_{\text{SI}}$) or pounds per gallon ($\rho_{\text{USC}}$)

$\rho_{\text{BF}}$ density of the base NAF used for topping, expressed either in kilograms per cubic meter ($\rho_{\text{BF,SI}}$) or in pounds per gallon ($\rho_{\text{BF,USC}}$)

$\rho_{\text{BF-DS}}$ NAF density from retort procedure, expressed either in kilograms per cubic meter ($\rho_{\text{BF-DS,SI}}$) or in pounds per gallon ( $\rho_{\text{BF-DS,USC}}$)

$\rho_{\text{DF}}$ density of the drilling fluid, expressed in kilograms per cubic meter ( $\rho_{\text{DF,SI}}$) or pounds per gallon ($\rho_{\text{DF,USC}}$)

$\rho_{\text{DF-Pr}}$ pressurized drilling fluid density, expressed in kilograms per cubic meter ( pounds per gallon)

$\rho_{\text{DF-Unp}}$ unpressurized drilling fluid density, expressed in kilograms per cubic meter ( pounds per gallon)

$\rho_{\text{DS}}$ density of the drilled-solids, expressed in kilograms per cubic meter ( pounds per gallon)

$\overline{\rho_{\text{DS-D}}}$ uncorrected average density (volumic mass) of dry retorted drilled-solids sample, expressed in either in kilograms per cubic meter ( $\overline{\rho_{\text{DS-D,SI}}}$ ), or pounds per gallon ( $\overline{\rho_{\text{DS-D,USC}}}$ )

$\rho_{\text{DS-W}}$ density of the wet drilled-solids sample, expressed in kilograms per cubic meter ($\rho_{\text{DS-W,SI}}$), or in pounds per gallon ($\rho_{\text{DS-W,USC}}$)

$\rho_{\text{LG}}$ density of the LGS, expressed in kilograms per cubic meter (pounds per gallon)

$\rho_{\text{WDS}}$ density of the discarded wet drilled-solids, expressed either in kilograms per cubic meter ($\rho_{\text{WDS,SI}}$) or in pounds per gallon ( $\rho_{\text{WDS,USC}}$)

$\rho_{\text{WM}}$ density of the weighting material, expressed in kilograms per cubic meter (pounds per gallon)

$\rho_1$ average relative density of all dried separated solids (see 6.7.3 and 6.8)

$\rho_2$ relative density of weighting-material (see 6.7 and 6.8)

### 3.2.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

AlO aluminum oxide ($Al_2O_3$) with a specific gravity of 3.5 to 3.9

ASTM American Society of Testing Materials (the former name and prefix used for ASTM International standards)

LGS low gravity solids

NADF non-aqueous drilling fluid

NAF non-aqueous fluid

PVC polyvinyl chloride

ROC retained oil (NAF) on cuttings

TC to contain

## 4 Requirements

**4.1** This recommended practice is organized such that a method of assessing the performance of an equipment set is presented first. A procedure for assessing the performance of individual equipment pieces is then presented. A collection of proven operating guidelines for the equipment and the overall system is then given. The principles shall be used to design a new system or to modify the operation of the equipment and removal system on an existing drilling rig and thereby comply with this standard.

**4.2** Use of this practice allows direct comparison of the results achieved by modifications made to the system at the drill site. Improved drilled-solids removal performance can be recognized through lower trouble costs and improved drilling performance.

**4.3** Shale shaker screen designations and labeling are included as a means for manufacturers to mark screens in a consistent manner. The screen identification tag describes the equivalent screen aperture opening, the conductance and the non-blanked area of the screen. Screen manufacturers shall use this designation to comply with this standard.

# 5 System Performance of Drilling-fluid Processing Equipment

## 5.1 Principle

**5.1.1** For any combination of drilling-fluid processing equipment, system performance can be evaluated by determining the drilled-solids removal system efficiency ($\eta_{DSR}$) and the drilling-fluid to drilled-solids ratio ($R_{DF-DS}$) of the discarded wet drilled-solids, see References [2-5].

NOTE The drilling-fluid to drilled-solids ratio ($R_{DF-DS}$) is often referred to as the mud-to-cuttings ratio and designated as MCR. The drilled-solids removal system efficiency ($\eta_{DSR}$) is often referred to as the solids removal efficiency and designated as SRE.

**5.1.2** The purpose of drilling fluid processing equipment is to minimize the volume of drilling fluid required for dilution and the volume of drilling related waste for a given well, while balancing a number of considerations. The term "drilling-fluid conservation" is used to mean the minimization of required drilling-fluid. Drilling-fluid processing equipment is also an important factor for reducing the size of drilling locations by eliminating or minimizing the use of earthen settling basins.

In terms of reducing the volume of drilling-fluid required to drill a well, two considerations are of overriding importance. The first is the target concentration of drilled-solids to be maintained in the drilling fluid. The second is the drilled-solids removal efficiency of the drilling fluid processing equipment. Figure 1 demonstrates how relatively small changes in the target drilled-solids concentration (x-axis) results in large changes in required dilution volumes, particularly for the lower range of values.

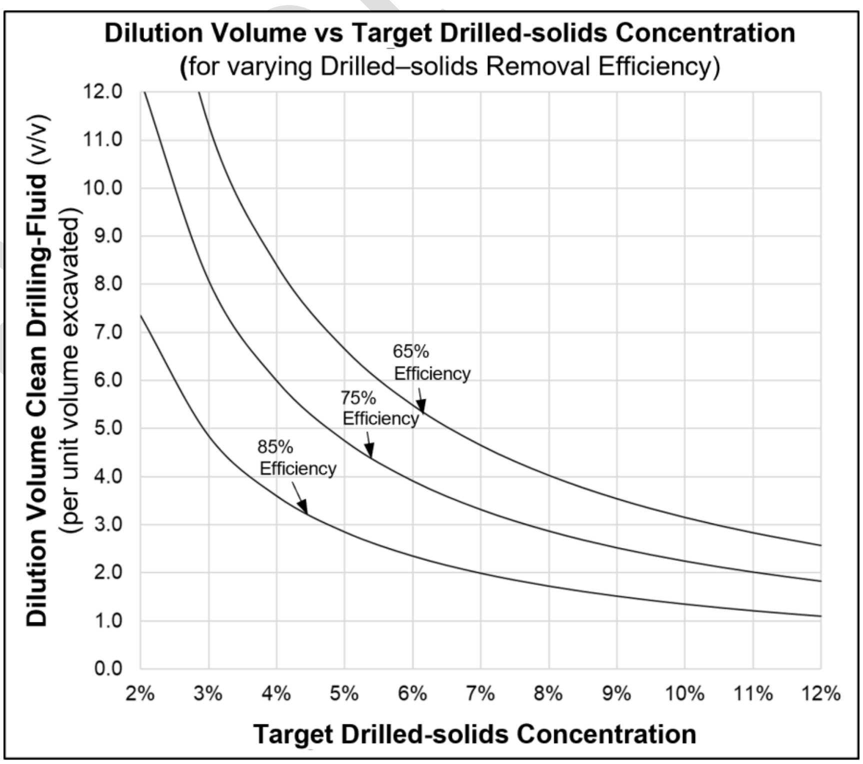


**Figure 1—Dilution Volume Dependency on Target Drilled-solids Concentration**

Figure 2 demonstrates how improvements in the drilled-solids removal system efficiency (x-axis) results in significant reductions in the required drilling fluid dilution volume.

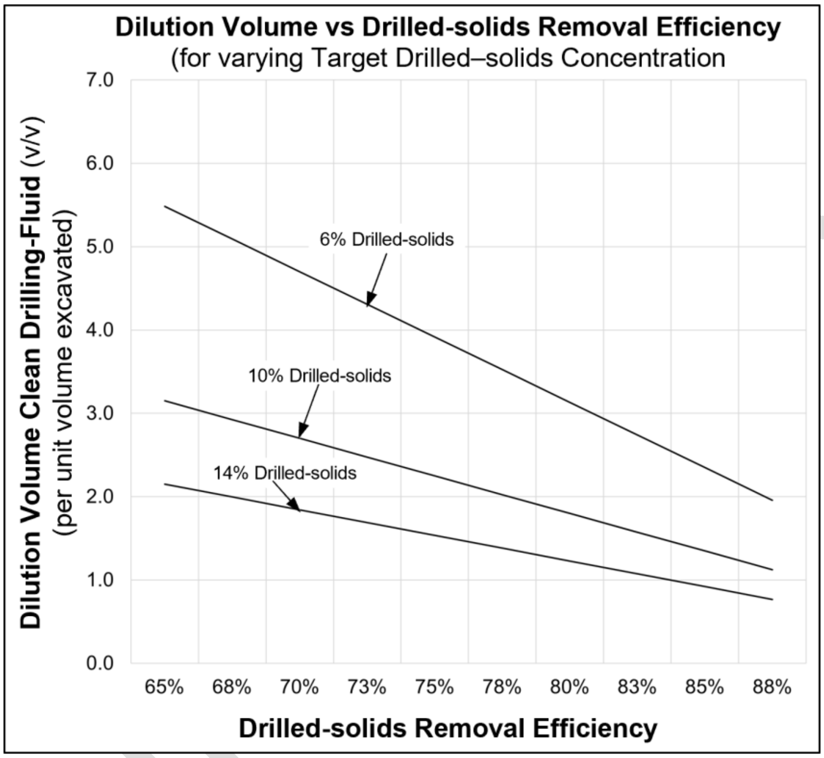



**Figure 2—Dilution Volume Dependency on Drilled-solids Removal System Efficiency**

**5.1.3** The criteria used to select processing equipment are many and include regulatory, logistical, cost, product supply, disposal, and other pragmatic considerations specific to a planned well or series of wells. All of these considerations fall outside the scope of this document. However, once drilling-fluid processing equipment is selected, it is always desirable to improve system performance by increasing drilled-solids removal and improving drilling-fluid conservation.

**5.1.4** When additional mechanical processing equipment is used in an effort to increase drilled-solids removal efficiency, more drilling fluid is discarded and the drilling-fluid to drilled-solids ratio of the overall discard will increase such that drilling-fluid conservation will normally decrease. Conversely, methods used to increase drilling-fluid conservation by reducing the drilling-fluid to drilled-solids ratio of the combined discard will reduce drilled-solids removal system efficiency. This interdependency creates a practical maximum for drilled-solids removal system efficiency that can be achieved by mechanical processing equipment. An illustration of this interdependency is shown in Figure 3. The combination of values closer to the origin being the easiest to achieve and those in the upper right quadrant being more difficult or technically not achievable. The objective for having the best system performance is to operate as far as possible into the upper right quadrant as is possible.

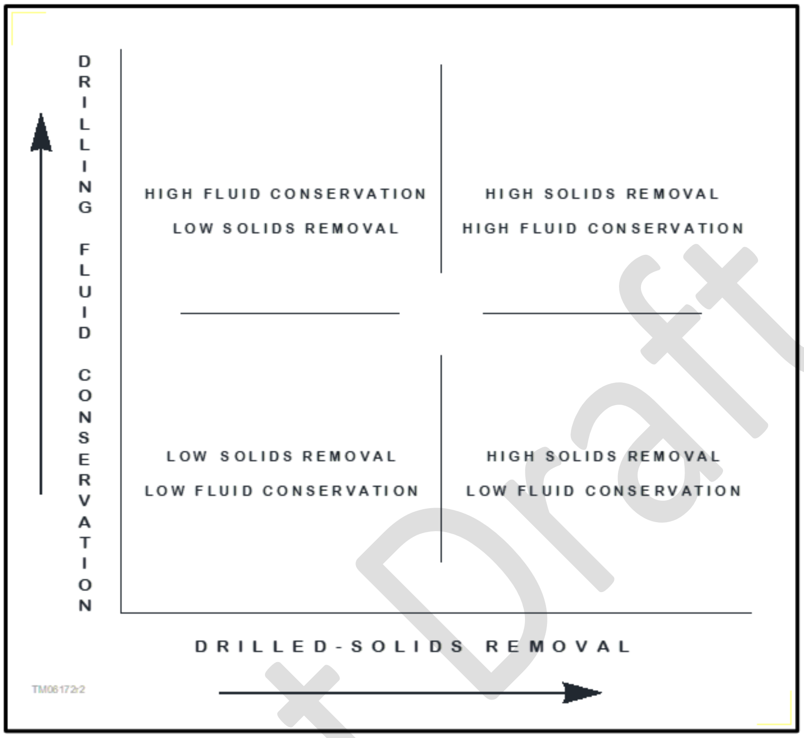



**Figure 3—Interdependency of Drilled-solids Removal and Drilling-fluid Conservation**

**5.1.5** This section provides a procedure for determining:

a) the overall drilled-solids removal system efficiency, $\eta_{\text{DSR}}$;

b) the drilling-fluid to drilled-solids ratio for discarded wet drilled-solids $R_{\text{DF-DS}}$; and

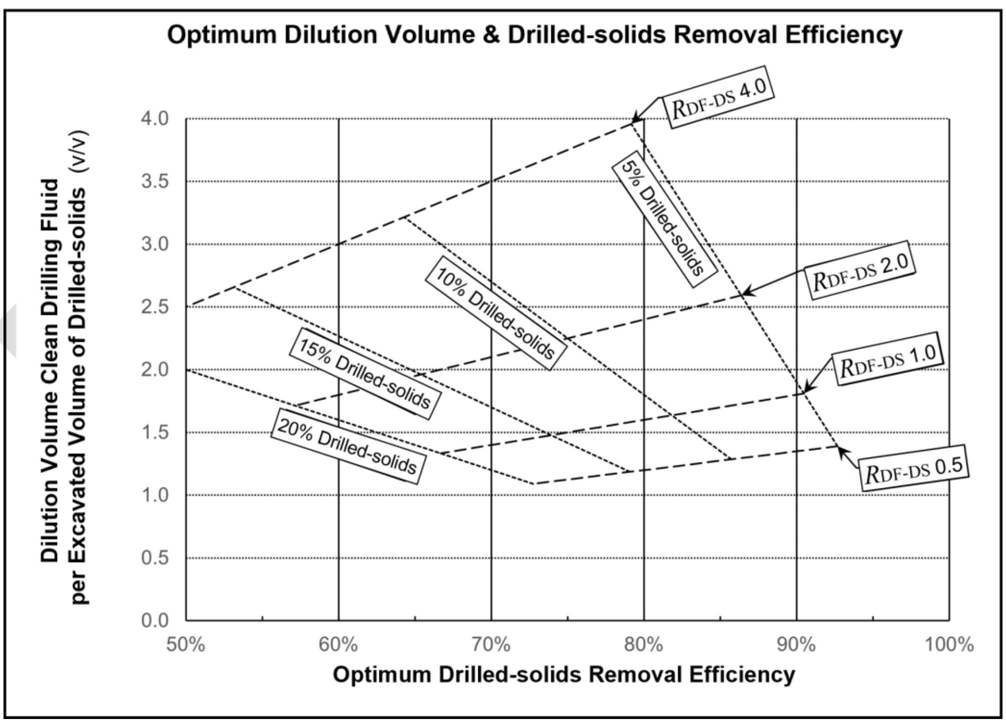
c) overall waste volumes for any combination of processing equipment, $V_{\text{Waste}}$.

The drilled-solids removal system efficiency refers to the percent of excavated drilled-solids that is discarded by the processing equipment. It can be determined from the volume of drilling fluid used for dilution by measuring the base fluid (water or non-aqueous fluid) added to the system or by using the actual volume of drilling fluid added to dilute the retained drilled-solids (i.e. drilled-solids not removed by the processing equipment).

**5.1.6** Drilling fluid conservation is important to the economics and environmental impact of most drilling programs. Strictly speaking, drilling-fluid conservation efficiency is the percentage of the drilling fluid reporting to the processing equipment that returns to the surface pit system. Drilling-fluid conservation efficiency is difficult to measure directly in real world drilling conditions. In this document, the drilling-fluid to drilled-solids ratio will be used to quantify drilling-fluid losses due to processing equipment and to evaluate system performance. The drilling-fluid to drilled-solids ratio indicates the volume of drilling fluid discarded when a “unit volume of drilled-solids” is removed from the active drilling fluid by the processing equipment. A drilling-fluid to drilled-solids ratio of “2:1” means that a sample of discarded wet drilled-solids is composed of 2 parts "drilling fluid" and 1 part “dry cuttings”. The drilling-fluid to drilled-solids ratio is 1:1 when a unit volume of drilling fluid is "retained on" or "commingled with" a unit volume of drilled-solids discarded by processing equipment. Lower ratios indicate better drilling-fluid conservation by processing equipment as shown in Equation (13). When circulating drilling fluid is being dumped open ended to disposal with no drilling fluid being returned to the surface pit system, it would be the worst case for drilling-fluid conservation.

NOTE The term “discarded wet drilled-solids” is used to mean the material is a combination of drilling-fluid and drilled-solids. This term applies universally to drilled-solids from both water base and NADF. All discarded drilled-solids will contain some fraction of drilling fluid even if they look dry or dusty.

**5.1.7** It is generally desirable to maintain constant surface pit volume while drilling and not build excess pit volume to control the target drilled-solids concentration. The optimum dilution ratio is defined as the dilution volume used to drill a unit volume of new hole while meeting two conditions. The first condition is maintaining a constant drilling-fluid volume in the surface pits. The second condition is maintaining the target drilled-solids concentration in the surface pits. The first condition is met when dilution volume built equals the new hole volume drilled plus the volume of drilling fluid lost with the discarded wet drilled-solids. The second condition is met when the solids removal efficiency is sufficiently high to ensure that the dilution volume built is the exact volume needed to entrain those drilled-solids (not removed by processing equipment) at the target drilled-solids concentration. Figure 4 shows the relationship between the drilling-fluid to drilled-solids ratio and the necessary drilled-solids removal system efficiency to maintain constant surface pit volume while drilling.




**Key**

$R_{DF\text{-}DS}$ drilling-fluid to drilled-solids ratio of discard

**Figure 4—Optimum Dilution Volume & Drilled-solids Removal System Efficiency**
(no excess drilling-fluid built)

**5.1.8** Drilled-solids may be removed via settling, screening, desanding, desilting, centrifuging, drilling fluid lost with the effluent from processing equipment, discarding whole drilling fluid, and or both losing drilling fluid to drilled formations. However, the drilled-solids removal system efficiency methods presented here are based solely on dilution volumes required to maintain a target drilled-solids concentration in the drilling fluid when volume built for downhole losses are excluded. Calculations for situations where the drilled-solids concentration changes or where volumes used to due to lost circulation can easily be expanded based on the concepts and definitions presented.

## 5.2 Volume of Drilling Fluid Built for Dilution

**5.2.1** The volume of drilling fluid built for dilution of retained drilled-solids can be determined several ways. The preferred method is to calculate the dilution volume from the measured volume of base fluid used and the base fluid volume fraction for a drilled-solids-free (clean) drilling fluid. This volume is most accurate when done on a daily or more frequent basis and summed over a given interval since density, base fluid volume fractions, and system volumes change over an interval. Alternatively, the dilution volume can be calculated for the entire interval using a volume weighted average value for the base fluid volume fraction and drilled-solids concentration.

Regardless of how dilution volumes are determined, it is recommended that meters be used to measure volumes. Meters can be mechanical or electrical devices that measure and indicate the volume (or mass) flow rate. Meters should be used when measuring the volume of base fluid and other liquid additions to the circulating system. The fluids which require metering can be solids-free water, brine, NAF, solids laden premix or spike, or drilling fluid. The selection and the specification for a particular meter application is outside of the scope of this document.

**5.2.2** The volume of clean drilling fluid used for dilution, $V_{DIL}$, expressed in cubic meters (barrels), shall be calculated using to Equation (1).

$$V_{DIL} = \frac{100 \times V_{BF}}{\varphi_{BDF}} \tag{1}$$

where:

$V_{BF}$ is the volume of base fluid added to system for dilution, expressed in cubic meters (barrels);

$\varphi_{BDF}$ is the base fluid volume fraction for the clean drilling fluid (zero-drill-solids), expressed as a percentage.

**5.2.3** If the base fluid volume fraction, $\varphi_{BDF}$, for the clean drilling fluid (zero-drilled-solids) is not known, it shall be calculated using Equation (2), expressed as a percentage.

$$\varphi_{BDF} = \varphi_{BF} \times \left[ \frac{100}{(100 - \varphi_{DS})} \right] \tag{2}$$

where:

$\varphi_{BF}$ is the base fluid volume fraction for the drilling fluid with target (or average) drilled-solids concentration, expressed as a percentage;

$\varphi_{DS}$ is the target concentration (volume fraction) of drilled-solids content in the drilling fluid, expressed as a percentage.

**5.2.4** If the volume of drilling-fluid built for dilution is tracked on a periodic basis over an interval, the total volume of fluid used for dilution for the interval is the summation of the periodic values and shall be calculated using Equation (3). For intermediate intervals the cumulative volume to that point should be used.

$$V_{\text{DIL-Itval}} = \sum_{i=1}^{n} \left( V_{\text{DIL}_1} + V_{\text{DIL}_2} + V_{\text{DIL}_3} + \cdots + V_{\text{DIL}_n} \right) \tag{3}$$

where:

$V_{\text{DIL-Itval}}$ is the total volume of clean fluid used for dilution for the interval, expressed in cubic meters (barrels);

$V_{\text{DIL}_i}$ is the volume of clean fluid used for dilution for each portion ''i' of the interval (i = 1 to *n*), usually daily , expressed in cubic meters (barrels).

NOTE The volume of clean drilling fluid built for dilution excludes drilled-solids.

**5.2.5** An alternative method to determine the dilution volume is to use accurate volumes of base fluid, products, and weight material added to the system. Extra effort should be made to ensure that these volumes are correct as measuring them accurately is often difficult and reported dilution volumes are often inaccurate. These volumes can be tracked daily or on a more frequent basis and summed over a given interval and totaled as described above and shown in Equation (3).

### 5.3 Volume of Excavated Drilled-solids

**5.3.1** The volume of excavated drilled-solids (i.e. drilled hole volume) should be calculated from the dimensions of the wellbore, i.e. length and diameter including any known enlargement. If caliper log data is available, the calculated volume from the caliper data shall be used for the excavated drilled-solids volume.

**5.3.2** The excavated volume of drilled-solids, $V_{\text{DS}}$, shall be calculated from Equation (4) or Equation (5).

a) Excavated volume $V_{\text{DS, SI}}$ expressed in cubic meters Equation (4):

$$V_{\text{DS,SI}} = \frac{\pi}{4} \times \left( \frac{D_{\text{H,SI}}}{1000} \right)^2 \times L_{\text{H,SI}} \times \left( 1 + \frac{\varphi_{\text{E}}}{100} \right) = 0.7854 \times 10^{-6} \times D_{\text{H,SI}}{}^2 \times \left( 1 + \frac{\varphi_{\text{E}}}{100} \right) \tag{4}$$

where:

$D_{H,SI}$ is the hole diameter, expressed in millimeters

$L_{H,SI}$ is the wellbore length, expressed in meters;

$\varphi_E$ is the volume fraction of wellbore enlargement, expressed as a percentage.

b) Excavated volume $V_{DS,USC}$ expressed in barrels Equation (5):

$$V_{DS,USC} = 0.1781 \times \frac{\pi}{4} \times \left(\frac{D_{H,USC}}{12}\right)^2 \times L_{H,USC} \times \left(1 + \frac{\varphi_E}{100}\right) = \frac{D_{H,USC}^{\;2}}{1029.4} \times L_{H,USC} \times \left(1 + \frac{\varphi_E}{100}\right) \quad (5)$$

where:

$D_{H,USC}$ is the hole diameter, expressed in inches;

$L_{H,USC}$ is the wellbore length, expressed in feet;

$\varphi_E$ is the volume fraction of wellbore enlargement, expressed as a percentage.

**5.3.3** If the system evaluation is being performed on a on a periodic basis over an interval, such as reporting daily data as shown in Annex D , the excavated volume of drilled-solids, or daily drilled hole volume, should be summed to get a cumulative value such that interval intermediate values can be used to better determine performance. Although daily values may vary widely, generally drilled-solids removal system efficiency and drilling-fluid conservation efficiency converge over just a few intervals or days.

### 5.4 Drilled-Solids Removal System Efficiency

**5.4.1** The drilled-solids removal system efficiency ( $\eta_{DSR}$) is the percentage of excavated drilled-solids that are discarded by processing equipment. It can be determined if the volume of drilling fluid ($V_{DIL}$) built to dilute retained drilled-solids is known. Retained drilled-solids are those drilled-solids not discarded by the processing equipment. The volume of drilling fluid ($V_{DIL}$) used to calculate the drilled-solids removal system efficiency ($\eta_{DSR}$) is the volume of drilling fluid built and added while drilling, excluding volume built for lost circulation or other upset conditions. The preferred method to determine the volume of clean drilling fluid ($V_{DIL}$) built for dilution, shall be from the volume of base fluid data as described in 5.2.1 using Equation (1). Alternatively, the drilling fluid volume data may be used as described in 5.2.4. For drilling programs using NADF, drilled-solids removal efficiencies will be in the range from 65 to 85 percent. Depending on reactivity of the formation drilled, drilled-solids removal efficiencies for drilling programs using water-based fluids may be lower.

NOTE The presence of wellbore strengthening material, lost circulation material or and both, in the circulating drilling fluid system complicates the process of solids control and makes measurement of drilled-solids concentration and measurement of drilled-fluid to drilled-solids ratio difficult. Calculation of drilled-solids removal system efficiency when drilling with high concentrations of these materials is outside the scope of this document.

**5.4.2** The drilled-solids removal system efficiency, $\eta_{DSR}$ , expressed as a percentage, shall be calculated from Equation (6).

$$\eta_{DSR} = \frac{\text{drilled solids removed}}{\text{drilled solids generated}} = 100 - \frac{(100 \times V_{DIL} \times \varphi_{DS})}{[V_{DS} \times (100 - \varphi_{DS})]} \quad (6)$$

where:

$V_{DIL}$ is the volume of clean drilling fluid (zero drilled-solids) used for dilution to maintain the target drilled-solids concentration, expressed in cubic meters (barrels);

$V_{DS}$ is the excavated volume of drilled-solids, expressed in cubic meters ( $V_{DS,SI}$) or barrels ($V_{DS,USC}$);

$\varphi_{DS}$ is the target drilled-solids concentration of the drilling fluid, expressed as a percentage.

If the system evaluation is being performed on a periodic basis over an interval, such as reporting daily data as shown in Annex D section D.3, the overall interval drilled-solids removal system efficiency should be calculated using cumulative values for $V_{DIL}$, volume of clean drilling fluid used for dilution, and $V_{DS}$, excavated volume of drilled-solids (daily drilled hole volume).

**5.4.3** The volume of retained drilled-solids, $V_{RDS}$, expressed in cubic meters (barrels) shall be calculated using the drilled-solids removal system efficiency and the excavated volume of drilled-solids, using Equation (7).

$$V_{RDS} = V_{DS} \times \left(1 - \frac{\eta_{DSR}}{100}\right) \quad (7)$$

where:

$\eta_{DSR}$ is the drilled-solids removal system efficiency, expressed as a percentage;

$V_{DS}$ is the excavated volume of drilled-solids, expressed in cubic meters ( $V_{DS,SI}$) or barrels ($V_{DS,USC}$).

**5.4.4** The volume of fluid used for dilution including the target retained drilled-solids percent, $V_{DIL+RDS}$, shall be the sum of the clean dilution drilling fluid volume plus the retained drilled-solids, as calculated using Equation (8), expressed in cubic meters (barrels)

$$V_{DIL+RDS} = V_{DIL} + V_{RDS} \quad (8)$$

where:

$V_{DIL}$ is the volume of clean drilling fluid used for dilution, expressed in cubic meters (barrels);

$V_{RDS}$ is the volume of retained drilled-solids incorporated into the clean drilling fluid.

**5.4.5** Alternatively, if the volume of drilling fluid used for dilution with the retained drilled-solids, $V_{\text{DIL+RDS}}$, is accurate and a preferred value to utilize, the drilled-solids removal system efficiency, $\eta_{\text{DSR}}$, may be calculated, expressed as a percentage, from Equation (9)

$$\eta_{\text{DSR}} = 100 - \left[ \frac{\varphi_{\text{DS}} \times V_{\text{DIL+RDS}}}{V_{\text{DS}}} \right] \tag{9}$$

where:

$V_{\text{DIL+RDS}}$ is the volume of drilling fluid used for dilution with the retained drilled-solids;

$V_{\text{DS}}$ is the excavated volume of drilled-solids;

$\varphi_{\text{DS}}$ is the target drilled-solids concentration of the drilling fluid, expressed as a percentage.

**5.4.6** The volume of discarded drilled-solids, $V_{\text{DDS}}$, expressed in cubic meters ( barrels) shall be calculated using the drilled-solids removal efficiency and the excavated volume of drilled-solids, using Equation (10).

$$V_{\text{DDS}} = \frac{\eta_{\text{DSR}} \times V_{\text{DS}}}{100} \tag{10}$$

where:

$\eta_{\text{DSR}}$ is the drilled-solids removal system efficiency, expressed as a percentage;

$V_{\text{DS}}$ is the excavated volume of drilled-solids, expressed in cubic meters ( $V_{\text{DS,SI}}$) or barrels ($V_{\text{DS,USC}}$).

## 5.5 Procedure for Measuring Drilling-fluid to Drilled-solids Ratio of Shale Shaker Discard

### 5.5.1 Principle

**5.5.1.1** The drilling-fluid to drilled-solids ratio ($R_{\text{DF-DS}}$) for discarded wet drilled-solids from shale shakers is an important metric for evaluating system performance and for calculating the volume of drilling fluid lost. Under normal drilling conditions, shale shakers will discard the majority of the drilled-solids excavated. Shale shakers will also discard the majority of the lost drilling fluid attributable to processing equipment operation. Discarded wet drilled-solids from shale shakers typically have drilling-fluid to drilled-solids ratios that range from 0.75 to 3.0. In the procedure described in this section, the drilling-fluid to drilled-solids ratio is calculated from the measured density of the discarded wet drilled-solids, the measured drilling fluid density, and the density of the formation being drilled. When applicable, this density-based procedure is easier to perform, less time consuming, and can be more accurate than retort-based procedures.

**5.5.1.2** Drilling-fluid to drilled-solids ratios are highly dependent on the particle size of the drilled-solids. As the particle size of the drilled-solids decreases, the surface area increases and the drilling-fluid to drilled-solids ratio increases. Large-diameter fast-drilling intervals produce large sized drilled-solids which will have lower drilling-fluid to drilled-solids ratios due to the decreased surface area per mass of drilled-solids when compared to smaller sized drilled-solids.

**5.5.1.3** An accurate drilling-fluid to drilled-solids ratio can be determined from the density difference between the discarded wet drilled-solids and the density of drilling-fluid using the procedure in this section, exceptions to the application of this procedure are noted below. The procedure works for both water-base drilling fluids and NADF. When unweighted drilling fluids are used, it is applicable to all types of equipment, including shale shakers, centrifuges, and hydrocyclones.

When weighted drilling fluids are in use, the procedure can provide accurate results from shale shakers with screen sizes API 140 and below. However, this procedure should not be used for weighted drilling fluids when shakers screens API 170 and finer are used, because the wet drilled-solids may have a higher concentration of weighting material than represented by the drilling fluid. Therefore, the retort procedure in Annex C shall be used to determine the drilling-fluid to drilled-solids ratio for weighted fluids with shaker screens API 170 and higher. Similarly, the procedure in Annex C should be used to determine the drilling-fluid to drilled-solids ratio for discarded wet drilled-solids from centrifuges or hydrocyclones when weighted drilling fluids are used. Figure 5 shows a graphic illustration of this method.

NOTE This procedure is also not applicable when significant quantities of lost circulation material is present in a drilling fluid because it will similarly be concentrated in the discarded wet drilled-solids by the processing equipment.



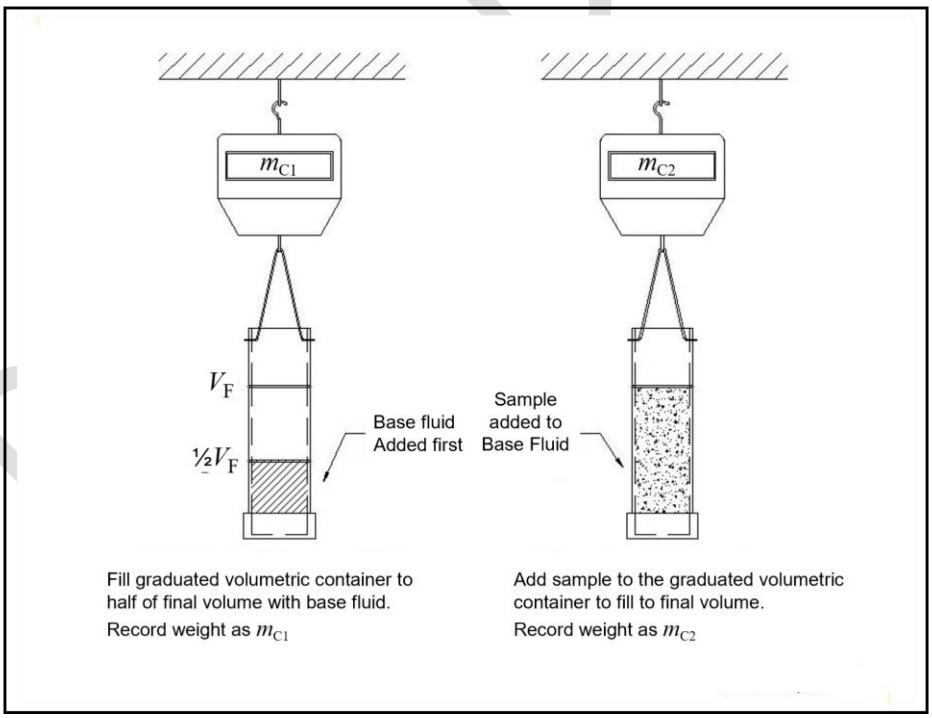



**Figure 5—Density Method for Measuring Drilling-fluid to Drilled-solids Ratio**

### 5.5.2 Apparatus

**5.5.2.1** Open top weighing container such as a pail, small bucket, can, or preferably a see-through, closed bottom plastic tube with a capacity of 2 to 5 L (0.5 to 1.0 gal).

When using handheld or hanging scales, it is recommended that the container have a handle.

**5.5.2.2** Graduated cylinder or graduated volumetric container, with graduations of at least 10 mL (0.5 oz.).

**5.5.2.3** Scale or top-loading balance, capable of weighing 10 kg (22 lb) with an accuracy of ±0.01 kg (±0.02 lb).

**5.5.2.4** Scoop or large spoon suitable for transferring the discarded wet drilled-solids into the open top weighing container.

**5.5.2.5** Ruler

**5.5.2.6** Shaker discard sample collection container such as a pail, small bucket, or can of sufficient size to collect a volume of shaker discard greater than the final volume of the procedure.

### 5.5.3 Procedure

The density of discarded wet drilled-solids shall be determined applying the following procedure.

a) Determine the final volume, $V_F$, to be used for the procedure, this volume should be at least 75% of the capacity of the open top weighing container. The recommended final volume is 2 L (2 qt).

b) Using the graduated cylinder or graduated volumetric container, measure $V_F$ base fluid (water or NAF) volume equal to the final volume to be used for the procedure and pour into the open top weighing container. Use the ruler and measure and record the height of the liquid at the side of the weighing container.

c) Empty the base fluid and clean and dry the weighing container. Mark the inside of the weighing container at the final volume liquid level height with an easy to see permanent marker or paint pen that is resistant to the base fluid.

d) Using the graduated cylinder or graduated volumetric container, add one half (1/2 $V_F$) of the final volume (water or NAF) to be used for the procedure. Using the scale weigh the open top weighing container with one-half the final volume of base fluid, record as $w_{C1}$ in grams (pounds).

e) Collect a representative sample of discarded wet drilled-solids from the shale shaker(s) and homogenize. Using the scoop or large spoon, transfer the discarded wet drilled-solids into the open top weighing container until the liquid level reaches the final volume $V_F$-mark. Using the scale weigh the container with base fluid and wet discarded solids, record as $w_{C2}$ in grams (pounds)

f) When using a final volume of two liters ($V_{F,SI}$ = 2), the density of the discarded wet drilled-solids, $\rho_{WDS,SI}$, expressed in kg/m$^3$ shall be calculated using Equation (11).

$$\rho_{\text{WDS,SI}} = \frac{m_{\text{C2,SI}} - m_{\text{C1,SI}}}{0.5 \times V_{\text{F,SI}}} = m_{\text{C2,SI}} - m_{\text{C1,SI}} \tag{11}$$

where:

$m_{\text{C1,SI}}$ is the weight of the weighing container and one half volume (1/2 $V_{\text{F}}$) of base fluid (one liter recommended), expressed in grams;

$m_{\text{C2,SI}}$ is the final weight with one half volume (1/2 $V_{\text{F}}$) of the discarded wet drilled-solids, the weighing container, and one half volume (1/2 $V_{\text{F}}$) of base fluid, expressed in grams;

$V_{\text{F,SI}}$ is the final volume, expressed in liters, as per recommended procedure $V_{\text{F,SI}}$ = 2 L.

NOTE When using a scale or top-loading balance that has a tare feature, after taring at item d) $m_{\text{C1,SI}} = 0$.

g) When using a final volume of two-quarts ($V_{\text{F,USC}}$ = 2), the density of the discarded wet drilled-solids, $\rho_{\text{WDS,USC}}$, expressed in lb/gal shall be calculated using Equation (12).

$$\rho_{\text{WDS,USC}} = \frac{4 \times \left(m_{\text{C2,USC}} - m_{\text{C1,USC}}\right)}{V_{\text{F,USC}}} = 2 \times \left(m_{\text{C2,USC}} - m_{\text{C1,USC}}\right) \tag{12}$$

where:

$m_{\text{C1,USC}}$ is the mass of the weighing container and one half volume (1/2 $V_{\text{F}}$) of base fluid ( one quart recommended), expressed in pounds;

$m_{\text{C2,USC}}$ is the final mass with one half volume (1/2 $V_{\text{F}}$) of discarded wet drilled-solids, the weighing container, and one half volume (1/2 $V_{\text{F}}$) of base fluid, expressed in pounds;

$V_{\text{F,USC}}$ is the final volume, expressed in quarts, as per recommended procedure $V_{\text{F,USC}}$ = 2 qt.

NOTE When using a scale or top-loading balance that has a tare feature, after taring at item d) $m_{\text{A,USC}} = 0$.

### 5.5.4 Drilling-fluid to drilled-solids ratios calculations

**5.5.4.1** The drilling-fluid to drilled-solids ratio ($R_{\text{DF-DS}}$) of the discarded wet drilled-solids from shale shakers should be calculated from the density of the discarded wet drilled-solids using Equation (13) with all density terms having the same units. This is the ratio expressed as a volumetric ratio (v/v) of the drilling-fluid content divided by the drilled-solids content for the discarded wet drilled-solids.

$$R_{\text{DF-DS}} = \frac{\text{drilling} - \text{fluid content}}{\text{drilled} - \text{solids content}} = \frac{\left(\rho_{\text{DS}} - \rho_{\text{WDS}}\right)}{\left(\rho_{\text{WDS}} - \rho_{\text{DF}}\right)} \tag{13}$$

where:

$\rho_{DS}$ is the density of the drilled-solids, expressed in kg/m³ (lb/gal);

$\rho_{WDS}$ is the density of the discarded wet drilled-solids, expressed in kg/m³ (lb/gal);

$\rho_{DF}$ is the density of the drilling fluid, expressed in kg/m³ (lb/gal).

Drilling fluid density ($\rho_{DF}$) shall be measured using a mud balance and the procedure described in API 13B-1 or API 13B-2.

If the system evaluation is being performed on a periodic basis over an interval, such as reporting daily data as shown in Annex D section D.3, the overall interval drilling-fluid to drilled-solids ratio can be calculated by the ratio of cumulative volume of discarded drilling fluid with retained drilled-solids to the volume of discarded drilled-solids.

**5.5.4.2** Each type of processing equipment discharging will have a different drilling-fluid to drilled-solids ratio of its discard. To calculate the total drilling-fluid to drilled-solids ratio, $R_{\text{DF-DS-Tot}}$, the individual streams of discarded wet drilled-solids shall be measured and the values shall be volume weighted as shown in Equation (14) for two (2) discard streams.

$$R_{\text{DF-DS-Tot}} = \left[\left(\frac{Q_1}{Q_1 + Q_2}\right) \times R_{\text{DF-DS1}}\right] + \left[\left(\frac{Q_2}{Q_1 + Q_2}\right) \times R_{\text{DF-DS2}}\right] \tag{14}$$

where:

$R_{\text{DF-DS-Tot}}$ is the total (volume weighted) drilling-fluid to drilled-solids ratio for all waste stream discards, expressed as a volumetric ratio (v/v)；

$Q_1$ is the volumetric flow rate for discard 1, expressed in cubic meters per minute (barrels per minutes);

$Q_2$ is the volumetric flow rate for discard 2, , expressed in cubic meters per minute (barrels per minutes);

$R_{\text{DF-DS1}}$ is the drilling-fluid to drilled-solids ratio of discard 1, expressed as a volumetric ratio (v/v);

$R_{\text{DF-DS2}}$ is the drilling-fluid to drilled-solids ratio of discard 2, expressed as a volumetric ratio (v/v).

## 5.5 Volume of Discarded Drilling Fluid

The volume of discarded drilling fluid in the discarded wet drilled-solids, $V_{DDF}$, shall be calculated from the aggregate or total drilling-fluid to drilled-solids ratio and the volume of discarded drilled-solids, expressed in cubic meters (barrels), using Equation (15).

$$V_{DDF} = R_{\text{DF-DS-Tot}} \times V_{DDS} \tag{15}$$

where:

$R_{\text{DF-DS-Tot}}$ is the total (volume weighted) drilling-fluid to drilled-solids ratio for all waste stream discards, expressed a volumetric ratio (v/v);

$V_{\text{DDS}}$ is the volume of discarded wet drilled-solids, expressed in cubic meters ( barrels).

## 5.6 Procedure for Calculating Drilling Waste Volumes

### 5.6.1 General

Due to the nature of drilling-fluid mechanical processing equipment and the difficulty with separating undesirable solids, waste volumes are an important metric for drilling operations. For many wells handling wastes is a significant logistical challenge and cost. The three primary wastes are:

a) drilled-solids,

b) drilling fluid commingled with the discarded wet drilled-solids, and

c) excess drilling fluid volumes used for dilution.

System volume changes which occur at the end of an interval or the end of the well that result in an excess drilling fluid volumes are not considered.

Determining the waste volume involves summing the active system addition and discard volumes and assumes the surface pits remain constant. The volume of discarded drilled-solids ($V_{\text{DDS}}$) and drilling fluid ($V_{\text{DDF}}$) are calculated as described in 5.4.6 and 5.6.

### 5.6.2 Volume of excess drilling fluid used for dilution

The volume of excess drilling fluid used for dilution, $V_{\text{DIL-Exc}}$ is the difference in the volume of drilling fluid used for dilution with the retained solids ($V_{\text{DIL+RDS}}$) from 5.4.4, less the volume of discarded drilling fluid in the discarded wet drilled-solids, from 5.6 less the excavated volume of drilled-solids, from 5.3. The volume of excess drilling fluid used for dilution, ($V_{\text{DIL-Exc}}$) shall be calculated, expressed in cubic meters (barrels) using Equation (16).

$$V_{\text{DIL-Exc}} = V_{\text{DIL+RDS}} - V_{\text{DDF}} - V_{\text{DS}} \quad (16)$$

where:

$V_{\text{DIL+RDS}}$ is the volume of drilling fluid used for dilution with the retained drilled-solids, expressed in cubic meters (barrels);

$V_{\text{DDF}}$ is the volume of discarded drilling fluid in the discarded wet drilled-solids, expressed in cubic meters (barrels);

$V_{\text{DS}}$ is the excavated volume of drilled-solids, expressed in cubic meters ( $V_{\text{DS,SI}}$) or barrels ($V_{\text{DS,USC}}$).

#### 5.6.3 Overall waste volume

The overall waste volume of drilling fluid, $V_{\text{Waste}}$, including the excess drilling fluid over what is needed for dilution and for the surface pits to remain constant, expressed in cubic meters (barrels) shall be calculated with Equation (17).

$$V_{\text{Waste}} = V_{\text{DDS}} + V_{\text{DDF}} + V_{\text{DIL-Exc}} \tag{17}$$

where:

$V_{\text{DDS}}$ is the volume of discarded wet drilled-solids, expressed in cubic meters (barrels);

$V_{\text{DDF}}$ is the volume of discarded drilling fluid in the discarded wet drilled-solids, expressed in cubic meters (barrels);

$V_{\text{DIL-Exc}}$ is the volume of excess drilling fluid used for dilution, expressed in cubic meters (barrels).

### 5.7 Procedure for Estimating Drilling Fluid Dilution and Waste Volumes

#### 5.7.1 General

In addition to evaluating system performance for ongoing operations, it is important to estimate the volume of drilling fluid which will be needed for dilution and waste volumes when planning wells. This can be done by assuming values for the drilled-solids removal system efficiency, target drilled-solids concentration, and the drilling-fluid to drilled-solids ratio. Once the dilution volume is calculated the associated waste volumes can be calculated using sections 5.4 through 5.7.

#### 5.7.2 Dilution volume of clean drilling fluid per excavated drilled-solids unit of volume

The dilution volume of clean drilling fluid per unit volume of excavated drilled-solids can be calculated from an assuming drilled-solids removal system efficiency and a target concentration of drilled-solids using Equation (18).

$$\frac{V_{\text{DIL}}}{V_{\text{DS}}} = \frac{(100 - \eta_{\text{DSR}}) \times (100 - \varphi_{\text{DS}})}{100 \times \varphi_{\text{DS}}} \tag{18}$$

where:

$\frac{V_{\text{DIL}}}{V_{\text{DS}}}$ is the dilution volume of clean drilling fluid (zero drilled-solids) per unit volume of excavated drilled-solids to maintain target concentration of drilled-solids, dimensionless volumetric ratio (v/v) [i.e. cubic meters per cubic meter ( barrels per barrel)];

$\eta_{\text{DSR}}$ is the drilled-solids removal system efficiency, expressed as a percentage;

$\varphi_{\text{DS}}$ is the target drilled-solids concentration of the drilling fluid, expressed as a percentage.

### 5.8 Procedure for Optimum Drilled-solids Removal System Efficiency

#### 5.8.1 General

For any value of drilling-fluid to drilled-solids ratio, there is an optimum solids removal system efficiency that will result in no excess drilling fluid being built for dilution to maintain the target concentration of drilled-solids. It is independent of the excavated drilled-solids and the starting pit volumes.

This optimum drilled-solids removal system efficiency ($\eta_{\text{DSR-Opt}}$) would only be the most efficient value for reducing overall wastes and drilling fluid requirements if the drilling-fluid to drilled-solids ratio of the discarded wet drilled-solids is the minimum value technically achievable.

For instance, after a certain screen size, if finer opening screens are used to try to improve solids removal efficiency, the drilling-fluid to drilled-solids ratio increases, such that more drilling fluid is both discarded and required for dilution. In this case, the optimum drilled-solids removal system efficiency is actually lower due to the increased volume of waste and required drilling fluid. As described in 5.1.3 it is this interdependent relationship that should be measured and balanced to find the best overall operating conditions.

#### 5.8.2 Calculation

The optimum solids-removal system efficiency, $\eta_{\text{DSR-Opt}}$, expressed as a percentage, that will result in no excess drilling fluid being required for dilution to maintain the target concentration of drilled-solids for a given drilling-fluid to drilled-solids ratio shall be calculated using Equation (19).

$$\eta_{\text{DSR-Opt}} = 100 \times \frac{\left(100 - \varphi_{\text{DS}}\right)}{\left[100 + \left(\varphi_{\text{DS}} \times R_{\text{DF-DS-Tot}}\right)\right]} \tag{19}$$

where:

$\varphi_{\text{DS}}$ is the target drilled-solids concentration of the drilling fluid, expressed as a percentage;

$R_{\text{DF-DS-Tot}}$ is the total (volume weighted) drilling-fluid to drilled-solids ratio for all waste stream discards expressed as a volumetric ratio (v/v).

## 6 Rigsite Evaluation of Drilled-solids Management Equipment

### 6.1 Principle

**6.1.1** This section presents a rigsite method for determining the effectiveness of individual pieces of solids control equipment, see References [6-8] . If mechanical separation equipment is used to remove suspended solids from liquid, one parameter that can be used to measure separator performance is capture (see definition 3.1.13).

**6.1.2** Capture analysis is not widely used in the drilling fluids solids control industry for at least two reasons:

a) the requirement for “representative samples” precludes successful use of capture to evaluate shale shaker performance;

b) solids concentrations in drilling fluids have traditionally been reported volumetrically rather than gravimetrically.

**6.1.3** Annex A shows the derivation of the capture equation.

## 6.2 Application

**6.2.1** Capture is usually expressed as a percentage of the system-suspended solids and can be easily calculated if the concentration (mass fraction, expressed as a percentage) of suspended solids is known for the process streams conveyed to and from a separator.

**6.2.2** If samples of the three process streams (feed slurry, overflow slurry, and underflow slurry) can be collected and assumed to be representative of steady-state operation of the separator, then calculated capture should be a good measure of the effectiveness of the separator.

**6.2.3** Capture analysis is a useful tool and should be considered when evaluation of equipment performance on drilling fluid systems is needed. However, the data generated apply only to the time at which the samples are collected.

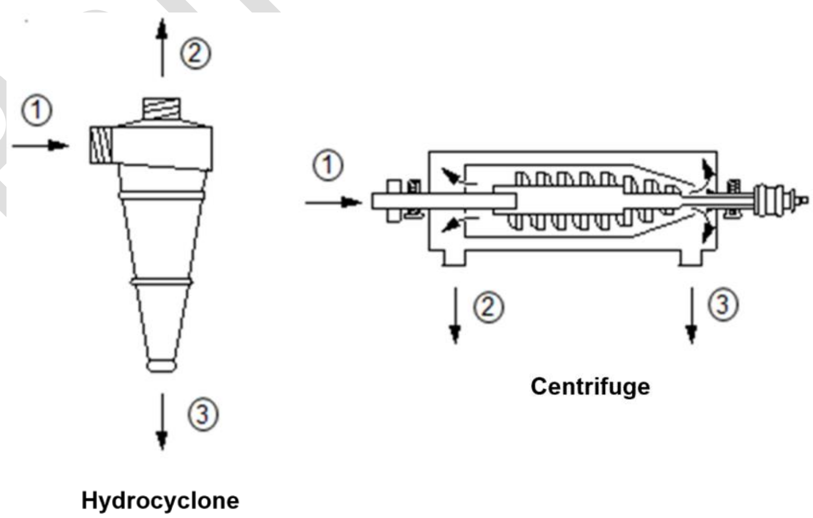
**6.2.4** Capture data can be extrapolated to predict the solids removed by the separator over longer time periods if the following conditions apply:

a) the separator is working under steady-state condition with consistent and homogeneous feed;

b) sufficient data are collected to establish average performance for the time period studied.

**6.2.5** Application of this analysis should be limited to evaluation of centrifuges and hydrocyclones. The procedure cannot be applied to shale shakers due to the difficulty in obtaining representative samples of the three process streams and the inherent inconsistency of shale shaker feed conditions.

**6.2.6** The process stream terminology is illustrated in Figure 6 and symbols are defined in 3.2.1.




**Key**

1 feed slurry, with mass fraction of solids, $w_1$
2 overflow slurry, with mass fraction of solids, $w_2$
3 underflow slurry, with mass fraction of solids, $w_3$

**Figure 6—Process Stream Terminology for Centrifugal Separators**

## 6.3 Sampling of Streams for Capture Analysis

**6.3.1** A sample set of each of the three process streams shall be obtained, sealed and labeled for identification.

**6.3.2** Each sample volume should be 100 mL to 150 mL.

**6.3.3** For each set, the sampling among streams should be done as quickly as possible.

## 6.4 Determination of Mass Fraction (Percent) Solids

**6.4.1** Mass fraction of suspended solids for each process-stream sample shall be determined by the following procedure.

a) Carry out an analysis to remove the water and NAF phase for each process-stream sample set.

For water-based drilling fluids containing no NAF, a simple oven moisture determination is required. NADF or fluids containing NAF require the use of a retort to vaporize and condense the liquids phases, see Annex C or API 13 B-1/API 13B-2 to proceed.

b) Weigh the empty evaporation container and record the mass as $m_1$.

c) Weigh into the container approximately 10 g of each process-stream slurry. Weigh the container plus sample, and record the mass as $m_2$.

d) Dry a water-based sample in a drying oven set to 105 °C (220 °F) for at least 1 h. If testing a non-aqueous sample, run the retort analysis.

e) Cool each sample container and reweigh. Record the mass as $m_3$.

**6.4.2** The mass fraction of suspended solids, $w$, expressed as a decimal fraction, shall be calculated using Equation (20).

$$w = \frac{(m_3 - m_1)}{(m_2 - m_1)} \qquad (20)$$

where:

$m_1$ is the mass of empty container, expressed in grams;

$m_2$ is the mass of container plus sample, expressed in grams;

$m_3$ is the mass of dried/retorted container, expressed in grams.

**6.4.3** Correction factors should be determined and applied in cases in which the base liquid contains more than 10,000 mg/L salt, or emulsified NAF.

**6.4.4** Unweighted drilling fluids are those not containing barite or other high relative density weighting material. The procedure outlined in 6.4.1 to 6.4.3 is sufficient to determine the mass fraction of suspended solids in each process stream.

**6.4.5** The quantitative determination of the effects of the solids removal process should be then obtained by using the capture calculation described in 6.5 and multiplying the mass fraction of the solids in the discharge stream by the rate at which solids enter the feed stream.

6.4.6 The mass flow rate of solids in the reject stream can be expressed as dry mass per hour.

## 6.5 Calculation of Capture

The mass fraction of suspended solids removed (capture), $w_a$, expressed as a decimal fraction , should be calculated using Equation (21).

$$w_a = \frac{w_3(w_1 - w_2)}{w_1(w_3 - w_2)} \tag{21}$$

where:

$w_1$ is the mass fraction of suspended solids in the feed to a piece of separator equipment, expressed as a decimal fraction;

$w_2$ is the mass fraction of suspended solids in the overflow from a piece of separator equipment, expressed as a decimal fraction;

$w_3$ is the mass fraction of suspended solids in the underflow from a piece of separator equipment, expressed as a decimal fraction.

NOTE If the discharge stream is very small in volume or has a very high solids content, capture derivation given Annex A [Equation (A.1)] can give more accurate results.

## 6.6 Interpretation of Results

**6.6.1** With centrifuges and hydrocyclones, the reject stream can be either heavy-phase discharge (underflow) or light-phase discharge (overflow).

**6.6.2** If the underflow stream contains the reject solids (heavy-phase discharge), the underflow is discarded. When used in combination with the feed rate, the capture equation permits calculation of the rate at which solids are being removed.

**6.6.3** If the overflow stream contains the reject solids (light-phase discharge), then the percent capture can be calculated by subtracting the capture calculated using Equation (21) from the light-phase discharge.

**6.6.4** If the overflow stream is being discarded, the capture (mass fraction) calculated, together with the feed rate, should be used to determine the rate of solids separation.

## 6.7 Procedure for Characterizing Removed Solids

**6.7.1** Segregated solids are characterized by their relative density and particle size.

**6.7.2** Solids in a drilling fluid are a mixture of weighting material (high relative density), clay, and excavated drilled-solids (low specific gravity). The mixture of clay and drilled-solids is referred to as LGS, and the amount is important for drilling fluid maintenance, rate of drilling progress, and potential for interfering events.

NOTE By "clay" are considered the mineral and clay and other mineral colloidal particles.

**6.7.3** A dried and weighed sample of the separated solids shall be added to a measured volume of water, and the average relative density of the solids is determined by the increase in volume and mass. Record this as $\rho_1$.

**6.7.4** The percentages of weighting-material and LGS shall be determined as per 6.8.

LGS are assumed to have an average relative density of 2.6, and the weighting-material relative density $\rho_2$ is known from the type of weighting material used. The mass fraction of solids being fed to the separator is taken from 6.5 and noted as $w_1$.

## 6.8 Calculation of Mass Fraction (Percent) of Weighting-material and Low-gravity Solids

The mass fraction of the weighting material, $w_4$, expressed as a decimal fraction, shall be calculated according to Equation (22):

$$w_4 = \frac{(\rho_1 - 2.6)}{(\rho_2 - 2.6)} \tag{22}$$

where:

$\rho_1$ is the average relative density of all dried separated solids in the sample;

$\rho_2$ is the relative density of weighting-material used in drilling fluid.

The mass fraction of LGS, $w_5$, expressed as a decimal fraction, shall be calculated according to Equation (23).

$$w_5 = w_1 - w_4 \tag{23}$$

where:

$w_1$ is the mass fraction of suspended solids in feed, expressed as a decimal fraction;

$w_4$ is the mass fraction of weighting-material, expressed as a decimal fraction.

## 6.9 Particle Size Assessment on Removed Solids

The primary function of centrifugal processing of weighted drilling fluids is the removal of colloidal particles. Removal of these particles limits the need for dilution.

Given the influence of average particle size on drilling fluid quality, it is recommended that occasional particle size distribution analyses be used to monitor the concentration of colloids and near-colloids to ensure that their concentration does not become excessive.

## 6.10 Economics

### 6.10.1 Unweighted Drilling Fluids

The economics of discarding the underflow of centrifuges used for drilled-solids reduction with unweighted drilling fluids can be evaluated by comparing the cost of the solids removal with the cost of the dilution required by the incorporation, rather than removal, of the separated drilled-solids and the differences in waste disposal costs.

The effect of centrifuging upon the drilling fluid cost can be determined by calculating the volume of dilution that would have been required to compensate for the incorporation of the separated solids and multiplying by the unit cost of the fluid.

All dilution adds directly to waste volume, thus the cost of disposing of the dilution volume needs to be added to the cost of preparing it.

### 6.10.2 Weighted Drilling Fluids

Traditionally, centrifuging is used with weighted fluids to reduce dilution requirements by eliminating the very small-sized drilled-solids and barite (colloidal particles).

Comparison of the cost of the centrifuging with the value of the barite recovered from the discarded fluid is frequently incorrectly used as a measure of its economic effectiveness. The purpose of solids removal equipment is to eliminate undesirable drilled-solids. Centrifuging has a direct effect on waste volume. The dilution volume of the centrifuge feed and the disposal of the liquid in the overflow increase waste volumes significantly.

Less obvious, but of greater importance, is the fact that disposal of the colloids and near-colloids with the liquid provides a better drilling fluid, reduces dilution requirements, and therefore reduces the volume of waste generated.

# 7 Practical Operational Guidelines

## 7.1 Principle

This section is intended as a guideline for the design of the surface drilling fluid processing system and includes recommendations for equipment installation and operation (see References [17] and [18]).

Following these practices maximizes the performance of the surface systems and improves drilling fluid quality. Deviating from these practices diminishes system performance, and increases dilution requirements, by allowing separable solids to recirculate in the drilling fluid system.

## 7.2 Apparatus

The Surface drilling fluid system consists of the flow line, active tanks, reserve tanks, trip tank(s), agitators, pumps, motors, solids and gas removal devices, mixing and shearing devices, and associated piping.

The surface drilling fluid system should be composed of six sections:

a) The removal section consists of the tanks and equipment used for the separation of drilled-solids and gas from the drilling fluid.

b) The addition section consists of the equipment and tanks utilized in the addition and blending of drilling fluid additives.

c) The suction section consists of the tank(s) from which the rig pumps take suction, and any associated pumps or mixing equipment.

d) The reserve section consists of the tank(s) or pit(s) and associated equipment used to isolate drilling fluid from the active system.

e) The discharge section consists of the tank(s) or pit(s) and equipment located at the well site used to store and process drilling fluid and cuttings for disposal.

f) The trip tank section consists of the tank(s) and associated equipment used to isolate drilling fluid from the active systems for gauging pipe displacement during tripping operations.

## 7.3 Procedure for System Design and Operation

### 7.3.1 General

Drilling fluid exits the wellbore via a flow line and progresses through the solids handling equipment until it is cleaned and taken into the wellbore via the suction tank. The equipment is arranged in a manner to remove successively smaller particles during fluid processing.

### 7.3.2 Flow Line

**7.3.2.1** The flow line is the exit port from the wellbore. The flow line diameter shall be sufficient to handle the maximum anticipated circulation rate at the maximum anticipated drilling fluid viscosity. The flow line shall have a minimum slope of 6° downhill (1:10 ratio of drop per horizontal run).

**7.3.2.2** If the flow line distributes drilling fluid to two or more shakers, a distribution system shall be used to divide the flow equally, minimize solids settling and avoid different rates of solids separation in the manifold.

### 7.3.3 Tank

**7.3.3.1** Tank(s) receive the flow line discharge and shall be of sufficient capacity to contain the active surface drilling fluid system. The minimum tank(s) volume shall be the sum of the volume and displacement of the drill string at maximum total depth, plus the volume at the bottom of the tanks that cannot be circulated, plus approximately 16 $m^3$ (100 bbl) safeguard.

**7.3.3.2** When fast-drilling a large diameter hole with high circulation rates, the surface volume as determined in 7.3.3.1 can reduce the surface time available for drilling fluid processing and treatment to below the acceptable minimum. In this case, additional tank volume should be provided, and the provision of an active reserve section may be desirable.

### 7.3.4 System Process Rate

**7.3.4.1** Equipment process rates are the limiting factor for drilling fluid retention time in the surface system. Solids removal equipment processing capacity requirements are a function of the circulation rate and the rate at which cuttings are generated. Minimum requirements are based on maximum circulation rates assuming that the equipment is properly assembled, maintained, and installed.

This does not, however, ensure that the capacity is adequate to permit removal of drilled-solids as quickly as they are generated during periods of fast drilling. Nor does it ensure adequate capacity if all fluid is not processed through the removal equipment.

**7.3.4.2** Each piece of equipment shall be capable of processing more fluid than enters its suction compartment. This ensures the ability to process all fluid at each step before proceeding to the next compartment.

**7.3.4.3** Since maximum penetration rates are difficult to forecast, temporary installation should be provided for additional equipment that is required during periods in which cuttings are generated more rapidly than can be handled by the permanently installed equipment.

### 7.3.5 Surface Tank

**7.3.5.1** Design guidelines for drilling fluid surface tanks require knowledge of the equipment capability and the anticipated drilling program. Tank depth should be approximately equal to the tank width or diameter. Significantly deeper tanks can present problems with achieving adequate mixing. Shallow tanks can lead to formation of vortices and air entrainment.

**7.3.5.2** The minimum surface area of compartments in square meters (square feet) should be equal to the flow rate, in cubic meters per minute, divided by 1.63 (in gallons per minute, divided by 40). This facilitates the release of entrained gas.

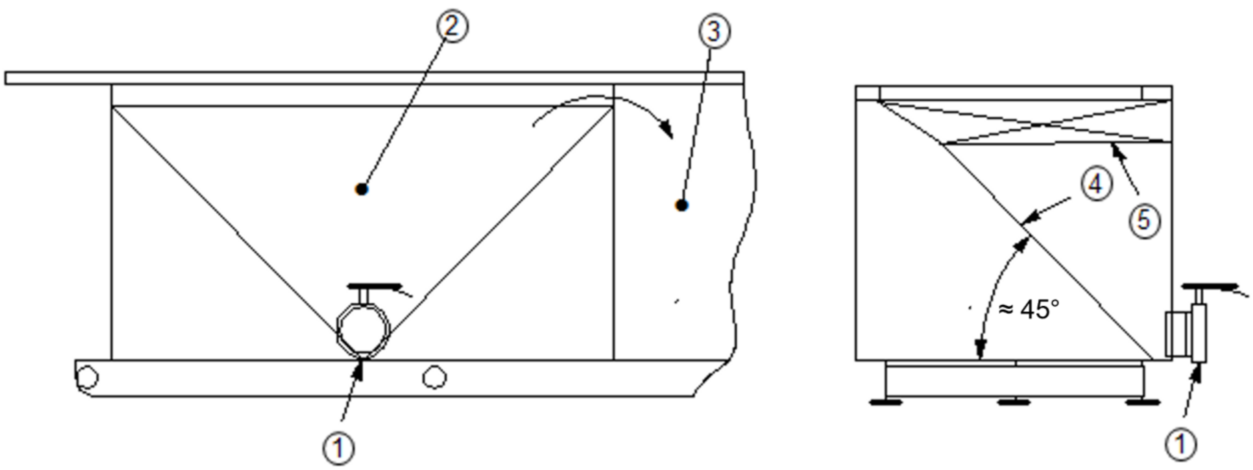
**7.3.5.3** The piping between tanks and tank bottom equalizers shall be sized large enough to allow the maximum flow rate anticipated for the surface system. Commonly used line pipe sizes are 10-in. (i.e. 25.4 cm) , 12-in. (i.e. 30.5 cm) or 14-in. (i.e.35.6 cm) pipes. These are adequate for circulation rates as high as 3.54 $m^3$/min (935 gal/min), 5.11 $m^3$/min (1350 gal/min), and 6.93 $m^3$/min (1830 gal/min), respectively.

NOTE Line pipe sizes are usually designed as per their nominal diameter (pipe OD is larger than the nominal diameter) and a schedule number, designating the pipe thickness. Standard line pipe is usually schedule 40.

**7.3.5.4** Baffles around each mechanical stirrer minimize air vortices and settling. A typical baffle is 2 cm to 3 cm thick by 30 cm wide (0.8 in. to 1.2 in. thick by 12 in. wide) and extends from the tank bottom to 15 cm (6 in.) above the top agitator blade. Four baffles are usually installed around each agitator. These four baffles should be installed 15 cm (6 in.) past the tips of the agitator blades along lines connecting the center of the agitator blades with the four corners of a square pit or compartment. For a long rectangular pit with two or more agitators, the tank is divided into imaginary square compartments and a baffle is pointed toward each corner.

### 7.3.6 Sand Trap

**7.3.6.1** Sand traps are designed to remove particles greater than 200 µm by settling. The sides of the sand trap shall slope at 45° or more from the horizontal to an area immediately in front of the discharge valve. Figure 7 illustrates a sand trap design.




**Key**

1 Dump gate valve

2 Sand trap

3 Degasser chamber

4 Sand trap floor

5 Overflow cut out into degasser chamber

**Figure 7—Sand Trap Design**



**7.3.6.2** The discharge valves (dump gate valves) on tanks should be large, non-plugging, and capable of quick opening and closing. When possible, it is recommended that the tank be designed to allow valve operation from the level of the tanks, and that flow from the valve is visible (for monitoring) from the position from which the valve is operated.

**7.3.6.3** Fluid shall enter the sand trap at its upstream end, and flow from it over a high weir (preferably tank-width) at its downstream end. The recommended weir height is 15 cm (6 in.) below the top of the tank.

**7.3.6.4** The sand trap shall receive the screen underflow from the shakers and should be designed to allow for bypassing when necessary.

**7.3.6.5** Most of the settled solids can be dumped with minimal loss of drilling fluid. The valve is opened, the discharge observed, and the valve closed when drilling fluid begins to flow from the sand trap.

### 7.3.7 Removal Section

**7.3.7.1** The removal section of drilling fluid handling equipment normally consists of five compartments, usually the sand trap, the degasser compartment, and the compartments from which the desander, desilter, and centrifuge(s) each process fluid. If any of these units are not used, then only four compartments (or fewer) are required.

**7.3.7.2** The solids removal equipment should be installed in a manner that permits the removal of progressively finer solid particles as the fluid moves through the system.

### 7.3.8 Flow Direction

**7.3.8.1** Proper flow direction between compartments is imperative for proper operation. Drilling fluid shall overflow from the sand trap into the degasser suction compartment, which is the next compartment downstream.

**7.3.8.2** Tank bottom equalization should be provided between all removal section compartments downstream of the degasser suction compartment. The equalization of the degasser suction pit should be designed to maintain a fluid level sufficient to maintain degasser pump prime.

**7.3.8.3** An adjustable riser or overflow should be installed on the downstream side of the equalizer between the removal and addition sections to permit control of the fluid level in the removal section.

### 7.3.9 Tank Agitation

**7.3.9.1** Drilling fluid tank agitation is necessary to prevent solids accumulation in the tank. With the sole exception of the sand trap, all compartments shall be mechanically agitated. Agitation needs to be able to prevent solids from setting out without entrapping air in the fluid. Consult the suppliers and manufacturers for the correct selection based on tank geometry and properties of the fluid to be agitated.

**7.3.9.2** If mud guns are chosen instead of mechanical agitators for some compartments, the mud guns should take suction from the same compartment into which they discharge.

**7.3.9.3** Agitator manufacturer's guidelines should be consulted for specific information on mechanical agitator blade size and geometry, and for power requirements.

### 7.3.10 Fluid Routing

**7.3.10.1** Fluid is routed through process equipment downstream into the next compartment (see Figure 8) . The centrifugal pump used to power the jet on vacuum degassers shall take suction from the same compartment into which the vacuum degasser discharges.

**7.3.10.2** The fluid shall be degassed before it reaches the pumps feeding downstream equipment.

**7.3.10.3** Suction and discharge line diameter requirements depend upon the volumes of fluid to be circulated. Lines shall be sized in accordance with the manufacturer's recommendations. See 7.8 and 7.9 for specifics.

**7.3.10.4** Desanders shall draw suction from the compartment immediately downstream from the degasser compartment. Desilters and mud cleaners shall draw from the compartment downstream from desanders, and centrifuges from the compartment downstream from the desilters and mud cleaners.

**7.3.10.5** Different types of equipment shall never take suction from the same compartment.

**7.3.10.6** Like types of equipment shall always take suction from the same compartment, assuming they are preforming the same task. For example, when operation centrifuges in parallel vs in series. In parallel, the centrifuges should pull from the same compartment.

**7.3.10.7** The desilter portion of a combination mud cleaner shall be plumbed following the desilter guidelines, and the desander portion following those for desanders.

**7.3.10.8** All solids removal equipment shall discharge processed fluid to the next downstream compartment.

**7.3.10.9** Drilling fluid from other compartments shall never be pumped into a removal compartment from points downstream through mud guns, mixers, or the eductor of a vacuum degasser.

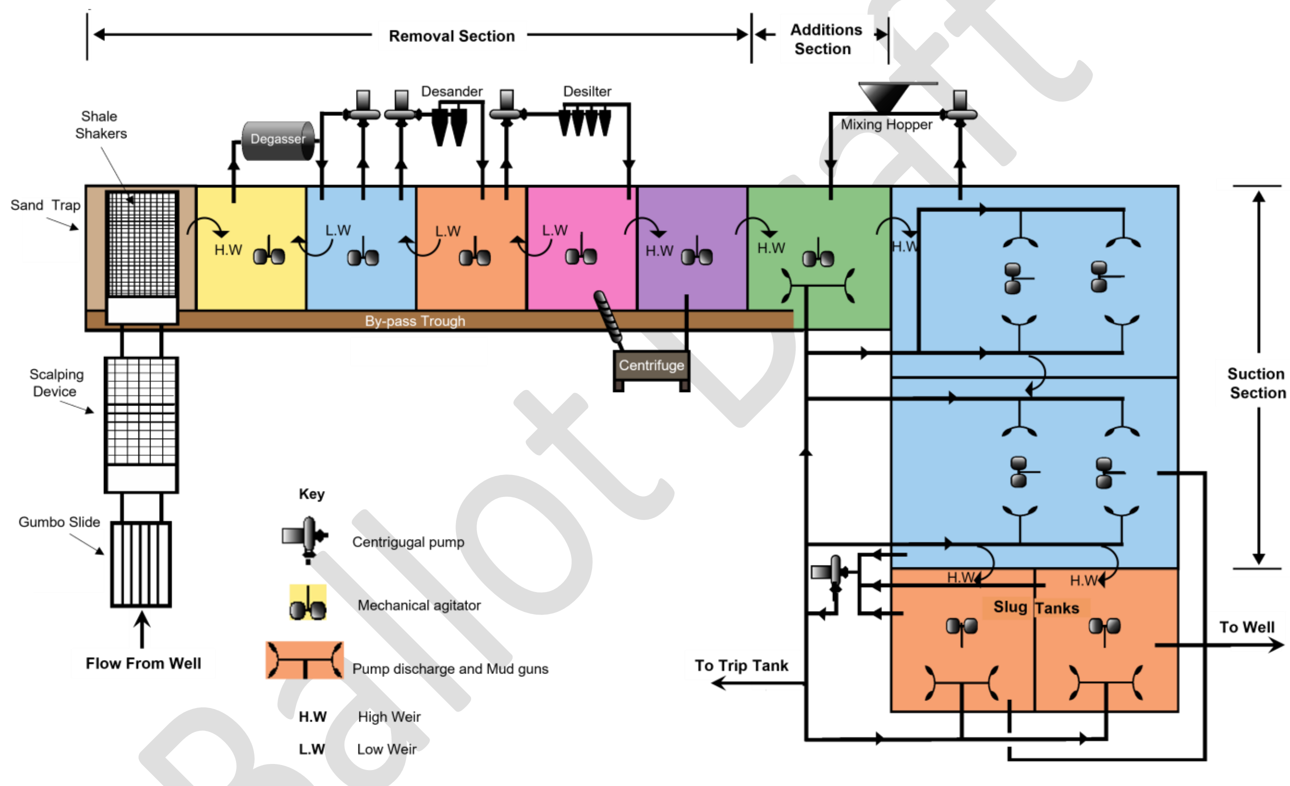



**Figure 8—Typical Basic Fluid Routing trough Processing Equipment**

## 7.4 Installation of Shale Shakers

**7.4.1** Shale shaker skids shall be level.

**7.4.2** Shakers shall be rigged with adequate space, walkways, and handrails to permit easy and safe servicing.

**7.4.3** If the shaker is equipped with a header box (possum belly), the flow line shall enter the header box with the inlet as close to the bottom as possible. Header boxes that have the bottom of the tank at the height of the weir to the shaker screens can help to minimize cuttings accumulation within the header box.

**7.4.4** If the flow line enters the rear tank via an "elbow" over its top, the elbow should extend to within one flow line diameter of the bottom of the tank.

**7.4.5** A means of diverting fluid from the flow line is recommended to permit the disposal of cement, spotting fluids, contaminated fluids, etc. before these fluids reach the shale shaker. This procedure shall not be used to dump the rear tank into the sand trap before trips.

## 7.5 Operation of Shale Shakers

**7.5.1** At a minimum, the screens should be washed and inspected once every tour (preferably every time circulation is interrupted). Additionally, the screens should be inspected when increase in solids is observed in the active fluid system.

**7.5.2** Shale shaker(s) should never by passed while circulating or on trips into the hole. This includes dumping the rear tank into the active system.

**7.5.3** All fluids should be screened before they enter the active system tanks, including fluids shipped to the rig from elsewhere.

**7.5.4** Spray bars should be used only when required for the handling of gumbo or sticky clays. The orifices or jets on the bar shall be small enough to deliver water in a mist, rather than in a spray.

**7.5.5** Shaker screens should be used with the smallest openings that do not cause excessive drilling fluid loss. Some liquid loss through the discharge of wet drilled-solids off the shaker is often desirable for improving overall solids control efficiency and reducing the need for whole mud dilution as this discharge will contain more undesirable solids than an equivalent volume of whole mud.

**7.5.6** Under normal operating conditions and when using a single-deck shaker with multiple screens, all screens should have the same API designation (as defined Section 11).

**7.5.7** All torn or damaged screens shall be replaced or repaired promptly.

**7.5.8** Adjustable deck shakers should not be routinely operated in the maximum upwards position. This practice will cause degradation of cuttings, and on some shakers permit fluid to spill over the back of the screen bed.

**7.5.9** Screen selection with weighted drilling fluids involves a compromise to accommodate the need to maximize cuttings removal while not separating excessive quantities of weighting material. Usually API 170 and coarser size screens do not remove excessive quantities of weighting material (i.e. barite).

NOTE Some weighting material loss is inevitable when screening weighted drilling fluids. Drilled-solids retain drilling fluid as they leave the shaker screens.

**7.5.10** Manufacturer's recommendations shall be observed on screen installation and tensioning as well as routine general maintenance such as shaker vibration for proper motion and conveyance of solids.

**7.5.11** When using shaker screens that need tensioning, tension should be checked 15 min to 30 min after installation and hourly thereafter.

## 7.6 Installation of Degassers

**7.6.1** The degasser shall draw suction from the compartment immediately downstream from the sand trap.

**7.6.2** When the sand trap is in use, flow to the degasser compartment shall be over a long, high weir.

**7.6.3** While the degasser is in use, there shall be no tank bottom equalization between the degasser compartment and those adjacent to it.

**7.6.4** Fluid should be degased before it reaches the pumps feeding the downstream equipment.

**7.6.5** The pump used to power the jet on vacuum degassers shall take suction from the same compartment into which the vacuum degasser discharges.

**7.6.6** Manufacturer's recommendations should be referenced for proper degasser installation.

**7.6.7** The centrifugal pump feeding the educator jet of vacuum degassers shall provide the feed head recommended by the manufacturer. Install a pressure gauge to permit the head to be verified.

**7.6.8** The degasser processing capacity should be at least equal to the planned circulation rate in all of the hole intervals in which gas intrusion is considered to be a hazard and shall be 10 % to 25 % higher than the flow rate of material entering the suction compartment of the equipment. This will also be 10 % to 25 % higher than the maximum anticipated circulation rate only if each piece of equipment is properly assembled.

## 7.7 Operation of Degassers

**7.7.1** Degassers should be operated to process all drilling fluid from the lowest portion of the borehole ("bottoms") after trips. Crews should be familiar with start-up procedures and provide regular checks to confirm that the equipment is working properly.

**7.7.2** The density difference of an unpressurized drilling fluid and a pressurized density can be used to calculate the volume fraction of gas or air, $\varphi_{\text{G-DF}}$, in the drilling fluid expressed as a percentage using Equation (24).

$$\varphi_{\text{G-DF}} = 100 \times \frac{\left(\rho_{\text{DF-Pr}} - \rho_{\text{DF-Unpr}}\right)}{\rho_{\text{DF-Pr}}} \tag{24}$$

where:

$\varphi_{\text{G-DF}}$ is the volume fraction of gas or air in the drilling fluid, expressed as a percentage;

$\rho_{\text{DF-Pr}}$ is the pressurized drilling fluid density, expressed in kilograms per cubic meter (pounds per gallon);

$\rho_{\text{DF-Unpr}}$ is the unpressurized drilling fluid density, expressed in kilograms per cubic meter (pounds per gallon).

The calculation can be expanded to include the possibility of dissolved gas by subtracting from 100 % the mass of unpressurized drilling fluid divided by the mass of the same volume of degassed drilling fluid. The volume fraction of dissolved gas in the drilling fluid, $\varphi_{\text{G-DF-Gdis}}$, expressed as a percentage can be calculated using Equation (25).

$$\varphi_{\text{G-DF-Gdis}} = 100 - \left( \frac{m_{\text{DF-Unp}}}{m_{\text{DF-Dgas}}} \right) \tag{25}$$

where:

$m_{\text{DF-Unpr}}$ is the mass of a sample volume of unpressurized drilling fluid, expressed in grams;

$m_{\text{DF-Dgas}}$ is the mass of the same sample than for $m_{\text{DF-UnPr}}$ of degassed drilling fluid, expressed in grams.

## 7.8 Installation of Desanders and Desilters

**7.8.1** The processing capacity of desanders and desilters should be 10 % to 25 % higher than the flow rate of material entering the suction compartment of the equipment. This will also be 10 % to 25 % higher than the maximum anticipated circulation rate only if each piece of equipment is properly assembled.

**7.8.2** Desanders should draw suction from the compartment immediately downstream from the degasser compartment. Desilters and mud cleaners should draw from the compartment immediately downstream from the desander. Centrifuges should draw from the compartment immediately downstream from the desilters and mud cleaners.

For example, if the sand trap is designated compartment 1 and the following downstream compartments are numbered sequentially, the degasser should draw suction fluid from compartment 2 and discharge fluid to compartment 3.

1) The desanders then process the fluid from compartment 3 and discharge it to compartment 4.

2) The desilter or mud cleaner(s) then process the fluid from compartment 4 and discharge it to compartment 5.

3) If a centrifuge or centrifuges are used on the active system, the centrifuges process fluid from compartment 5 and discharge it to compartment 6.

**7.8.3** Each hydrocyclone (desander or desilter) feed manifold should have its own pump and motor (dedicated centrifugal pumps).

**7.8.4** “Roping” hydrocyclone discharge indicates solids overload, insufficient feed pressure or a partially plugged inlet, as well as the need to:

— add additional equipment, or

— reduce penetration rate, or

— accept the contamination of the drilling fluid with recirculated drilled-solids.

**7.8.5** The piping between the pump and the input manifold for this equipment should be as short and straight as possible. There should be no elbows, reducers or swages within three pipe diameters of the flange connecting the piping to the manifold.

**7.8.6** Suction piping should be designed for linear flow velocity of 1.22 m/s (4 ft/s) to 2.44 m/s (8 ft/s). API 5L standard 6-in. pipe [OD 16.8 cm (6.625 in.)] for planned flow rates from 1.33 $m^3$/min (350 gal/min) to 2.65 $m^3$/min (700 gal/min), and standard 8-in. pipe [outer diameter 21.9 cm (8.625 in.)] to 4.54 $m^3$/min (1200 gal/min). Volumetric rates beyond these ranges shall follow equipment recommendations generally provided with equipment specifications from suppliers.

NOTE API 5L pipes are designed as per their nominal diameters and a schedule number; standard pipe is the schedule 40.

**7.8.7** Discharge lines should be larger than suction piping, to prevent back pressure from affecting the hydrocyclone performance. For example a hydrocyclone with a standard 6-in.suction line shoud use a standard 8-in. discharge pipe .

**7.8.8** Pressure gauges should be installed on the input manifolds to permit the head at the manifold to be monitored. Many oilfield hydrocyclones are designed to operate at 23 m (75 ft) of head, check with equipment manufacturer for correct operating head. The head corresponding to the measured pressure should be verified using Equations (26) or (27):

– With SI units, the head, $h_{SI}$, expressed in meters, shall be calculated according to Equation (26):

$$h_{SI} = \frac{p_{SI}}{(9.8 \times \rho_{DF,SI})} \tag{26}$$

where:

$p_{SI}$ is the pressure, expressed in kilopascals;

$\rho_{DF,SI}$ is the drilling fluid density, expressed in kilograms per cubic meter.

In SI units, a head of 25 m requires a pressure 245 times the drilling fluid density, in kilograms per cubic meter.

– With USC units, the head, $h_{USC}$, expressed in feet, shall be calculated according to Equation (27):

$$h_{USC} = \frac{19.2 \times p_{USC}}{\rho_{DF,USC}} \tag{27}$$

where:

$p_{USC}$ is the pressure, expressed in pounds-force per square inch;

$\rho_{DF}$ is the drilling fluid density, expressed in pounds per gallon.

In USC units, a 75 ft head requires a pressure 3.9 times the drilling fluid density, in pounds per gallon.

**7.8.9** Proper installation requires to install the hydrocyclone unit at an elevation that will prevent siphoning of fluid from the drilling fluid tank when the unit is not in operation. The manifolds should be higher than the maximum fluid level in the compartments to which they are connected.

**7.8.10** If the vertical distance between the discharge manifold and the end of the pipe carrying the discharged fluid to the next compartment is more than 1.8 m (6 ft), a vent should be provided in the discharge manifold near the hydrocyclones to prevent siphoning.

**7.8.11** The discharge line to the tank receiving the discharged fluid shall end above the maximum fluid level in the tank.

**7.8.12** For proper operation of this equipment, provide sufficient space, walkways, ladders, and handrails to permit easy and safe service.

## 7.9 Installation of Mud Cleaners

**7.9.1** The processing capacity of mud cleaners should be 10 % to 25 % higher than the flow rate of material entering the suction compartment of the equipment. This will also be 10 % to 25 % higher than the maximum anticipated circulation rate only if each piece of equipment is properly assembled.

**7.9.2** Installation of mud cleaner hydrocyclones should follow the rules for desanders and desilters, as appropriate (see 7.8) . Mud cleaners remove additional drilled-solids even after the fluid has been processed by API 200 screens on the main shale shakers.

**7.9.3** Mud cleaners are applicable when commercial weighting agents are added to the drilling fluid.

**7.9.4** Plugged desilter cones often indicate that drilling fluid is bypassing shale shaker screens and that the use of a mud cleaner would be beneficial.

**7.9.5** Screened throughput from mud cleaners shall be returned to a well-agitated location in the drilling fluid tanks. Screened throughput from mud cleaners has very little carrying capacity and will not transport solids well.

## 7.10 Installation of Centrifuges

**7.10.1** Normally, the underflow (cake, heavy slurry) should be discharged while centrifuging unweighted fluids. The overflow (centrate, effluent light slurry), containing most of the viscosity-building colloidal particles, should be discharged when centrifuging weighted fluids. Accordingly, centrifuges should be installed in a manner that permits either stream to be discharged or be returned to the active drilling fluid system.

**7.10.2** The centrifuge feed should be taken from a well-agitated area of the compartment immediately upstream from the discharge compartment.

**7.10.3** If the centrifuge underflow (heavy slurry) is returned to the drilling fluid system, it should discharge to a well-agitated area of the receiving compartment.

**7.10.4** The receiving compartment should be on the upstream side of the adjustable riser.

**7.10.5** When processing unweighted drilling fluids, the centrifuge(s) shall be used for drilled-solids removal. In some cases, it is recommended to process as much fluid as possible and discard the underflow (cake, heavy slurry).

**7.10.6** .With weighted drilling fluids, it is recommended that centrifuges are used to improve drilling fluid quality by removing colloidal and near-colloidal particles by discarding the overflow and retaining the desirable weight material in the underflow.

**7.10.7** While processing weighted fluids, the feed fluid should be diluted to control the overflow funnel viscosity to no more than 35 s/L (37 s/qt) for water-based fluids and under 38 s/L (40 s/qt) for NAFD as measured by the Marsh funnel.

NOTE Seconds per liter (seconds per quart) are the units traditionally used to describe viscosity as measured by a Marsh funnel.

## 7.11 Use of Addition Sections

**7.11.1** Any fluid introduced into the drilling fluid tank system should pass through the shale shaker screens, including drilling fluid from other sources and drilling fluid dumped from trip tanks.

**7.11.2** All commercial material additions should enter the system in the addition section, which may be one or several compartment(s).

**7.11.3** In order to facilitate complete blending before circulation, material additions should take place as far as possible from the compartment(s) from which the fluid is pumped downhole, but not in a solids removal section.

**7.11.4** A premix tank is recommended. Bentonite should be prehydrated before it is added to the active system.

## 7.12 Use of Drilling Fluid Mixing and Blending Equipment

**7.12.1** Drilling fluid mixing hoppers are often designed with a jet nozzle and a Venturi tube for proper mixing, although other designs are available and effective.

**7.12.2** In order to avoid aeration of the circulated fluid, hopper discharge lines should not extended below the maximum fluid level in the tank.

**7.12.3** In order to avoid aeration of the circulated fluid, the hopper should be turned off when not in use.

**7.12.4** Shearing devices are recommended for accelerating the activation of some products. Solids-laden fluids should not be circulated through shearing devices. The shear accelerates solids size degradation, thereby diminishing fluid quality.

## 7.13 Use of Suction Section

**7.13.1** The suction section should be the section of largest volume in the surface system.

**7.13.2** The suction section should be well agitated to provide uniform drilling fluid properties.

**7.13.3** The suction section should include a small slugging tank with submerged mud guns for stirring and suspension. The suction for the pump feeding these guns should come from the slug tank.

### 7.14 Use of Discharge Section

**7.14.1** The space, equipment, and personnel available in the discharge section should be adequate for handling the amount of waste to be generated.

**7.14.2** The surface volume of collected wet drilled-solids is often at least three times the gauge-hole volume. With poor solids removal performance the volume of discarded waste can be significantly larger.

**7.14.3** The volume of excess drilling fluid generated while drilling is highly variable and can vary from 3 to 15 times the gauge hole drilled volume.

**7.14.4** The drilled-solids removal efficiency of the equipment and the target drilled solids are the primary factors that determine the volume of drilling fluid waste (see section 5).

**7.14.5** Larger waste volumes should be expected when drilling reactive clay or dispersive formations with water-based drilling fluid.

## 8 Conductance of Shale Shaker Screens

### 8.1 Principle

Shaker screens are not simple weaves that are easily described. Sections 8, 9, and 10 describe methods of measuring the characteristics of shale shaker screens by conductance, equivalent aperture opening size, and non-blanked area values, see References [2-3] and [9-10].

### 8.2 Conductance

#### 8.2.1 General

Conductance of a shale shaker screen is determined by measuring the flow rate of a Newtonian fluid with a known viscosity, flowing through a shaker screen, with a measured area perpendicular to the flow, and a known pressure drop. Conductance is expressed in meters (SI units) or darcys per inch (USC units). For the purposes of this standard, the conductance, $C$, is expressed in kilodarcys per millimeter (kD/mm). Screen conductance is used to compare various screens that have different appearances and different API designations.

#### 8.2.2 Darcy's Law

Darcy's law provides a method of calculating the permeability of a porous medium. A shale shaker screen could be considered a porous medium. The permeability divided by the height of flow path through the porous medium is called the conductance.

Darcy's law states that the flow rate through a porous medium, $q$, is directly proportional to the differential pressure, $\Delta p$, and the cross-sectional area of the porous medium, $A$, and is inversely proportional to the fluid viscosity, $\mu$, and the length of the porous medium, $L$.

The constant of proportionality, $K$, is called the permeability. If the flow rate is measured in milliliters per second, the cross-sectional area in square centimeters, the fluid viscosity in centipoises, the pressure differential in atmospheres and the length in centimeters, then the permeability as per its definition shall be expressed in darcys (see 3.1.22).

Darcy's law can be stated as in Equation (28).

$$q = \frac{K\left(\Delta p \times A\right)}{\mu \times L} \tag{28}$$

where:

$q$ is the flow rate through a porous medium, expressed in milliliters per second;

$K$ is the constant of proportionality, or permeability, expressed in darcys;

$\Delta p$ is the differential pressure, expressed in atmospheres [3];

$A$ is the cross-sectional area, in square centimeters;

$\mu$ is the fluid viscosity, expressed in centipoises (millipascal•seconds);

$L$ is the length of the porous medium, expressed in centimeters.

NOTE 1 cP = 1 mPa•s

Solve Darcy's law for the permeability per unit length, or conductance, $C$, shall be given by Equation (29).

$$C = 10^{-4} \times \frac{K}{L} = 10^{-4} \times \frac{\mu \times q}{\Delta p \times A} \tag{29}$$

where:

$C$ is the conductance, expressed in kilodarcys per millimeter;

$K$ is the permeability, expressed in darcys;

$L$ is the length of the porous medium, expressed in centimeters;

$\mu$ is the fluid viscosity, expressed in centipoises (millipascal•seconds);

$q$ is the flow rate through a porous medium, expressed in milliliters per second;

$\Delta p$ is the differential pressure, expressed in atmospheres;

$A$ is the cross-sectional area, in square centimeters.

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[3] 1 Pa = 9.8692 × $10^{-6}$ atm (1 lbf/in.$^2$ = 6.8046 × $10^{-2}$ atm). The atmosphere (atm) is neither an SI nor a USC unit of pressure. At the tenth General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM) in 1954, standard atmosphere was defined as being precisely equal to 101,325 Pa (14.696 lbf/in.$^2$). This value was intended to represent the mean atmospheric pressure at mean sea level at the latitude of Paris, France (in practical terms, this value also corresponds to the mean sea level pressure for many industrialized nations whose latitudes are similar to that of Paris).

The flow rate through the screen needs to be laminar to provide a reproducible number.

For a particular fluid (of known viscosity) and the same pressure differential across the screen, the conductance is proportional to the velocity of fluid through the screen, $q/A$.

## 8.3 Apparatus for Measurement of Conductance

### 8.3.1 General

Schematic of conductance testing equipment set-up used to measure the conductance of a test screen is provided Figure 9. Main components are a fluid reservoir, a discharge flow line, a test screen holder with the screen to be tested, a capture reservoir, an excess fluid reservoir, electronic balance and data acquisition.

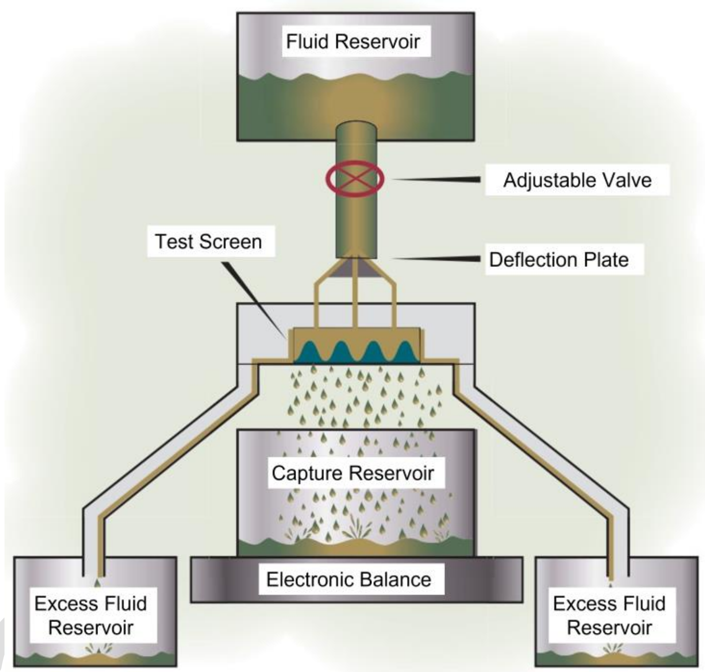



**Figure 9—Typical Screen Conductance Testing Equipment Set-up**

**8.3.1 Fluid reservoir:** to provide the necessary volume of fluid needed for the test.

The suggested size of the fluid reservoir is about 200 L (50 gal). The fluid reservoir can be mounted above the test screen for gravity feed or utilize a pump to obtain the steady state flow rate. Either option shall be designed such that the discharge into the screen holder does not add additional applied pressure or surge to the flow through the screen. Constand head pressure is critical for an accurate measurement and repeatability.

**8.3.2 Discharge flow line from the reservoir:** having a valve to adjust the flow rate from the reservoir and deflection plate at the end of the discharge piping to prevent the reservoir fluid from directly impacting the screen.

### 8.3.3 Test screen

Conductance test screen shall be prepared by mounting and sealing a section of shaker screen between two short sections of plastic pipe or an appropriately designed holder so that the flow rate of test fluid passing through the screen can be measured. It is recommended that screens be collected from screens at drilling rigs.

a) Screens shall be mounted as they are used on shale shakers. Continuous cloth shaker screens (i.e. not pretensioned) shall be mounted so that they are in tension. Pretensioned panel screens shall be mounted as they are. The screen shall be sealed between two (2) short pieces of PVC Schedule 80 pipe or in an appropriately designed screen holder. The screen holder diameter or exposed screen diameter shall be chosen so that the flow rate through the screen shall be laminar with the velocity below 2.5 cm/s (approximately 1 in./s). The screen holder diameter or exposed screen diameter for this test depends on the range of flow rates for the conductance test apparatus, the size of the screen openings, and non-blanked area when fitted to the screen holder. With schedule 80 PVC pipe, this range of diameters is generally between 19.21 cm (7.565 in.) for a 8-in. nominal diameter pipe to 7.28 cm (2.864 in.) for a 3-in. nominal diameter pipe.

   NOTE 8- in . PVC schedule 80 pipe outside diameter 21.9 cm (8.625 in.), minimum wall thickness 1.27 cm ( 0.5 in.); 3-in. PVC schedule 80 pipe outside diameter 8;89 cm ( 3.5 in.), minimum wall thickness 0.762 cm (0;3 in.).

b) Three test screen mountings shall be constructed such that height above the screen surface is either fixed or adjustable to be approximately 3 cm (1 in.), 5 cm (2 in.) and 8 cm (3 in.).

   For 3 dimensional screens, this height shall be the measurement from one-half the vertical thickness of the screen to the top of the mounting which may require a taller screen holder than is used for flat screens. Care shall be taken to ensure that the intersection between the mounting and the screen is completely sealed so that fluid cannot escape from the sides of the screen holder.

c) The screens shall be placed in the mounting in such a way as to minimize the blanked area from the screen mounting plate. When successfully mounted, the screen will appear to have mirror images perpendicularly and horizontally.

**8.3.4 Screen set-up for conductance test:** mounted in the screen holder and placed below the test fluid discharge pipe and diverter plate.

The top of the screen holder shall have a mounting that allows it to be leveled horizontally. The fluid flowing through the screen shall be routed to a capture reservoir mounted on an electronic balance (see 8.3.5). A seal shall be required to separate the overflow of test fluid from the test fluid flowing through the screen. The excess fluid that overflows the screen holder is captured in a separate excess fluid reservoir container (see 8.3.6).

**8.3.5 Capture reservoir—Balance and data acquisition:** to receive and weigh the fluid flowing through the screen

Capture reservoir shall be mounted on an electronic balance with an accuracy of 10 g (0.01 kg). A data collection system with automatic electronic measurement of the change in mass as a function of time is recommended. The mass measurements shall be used to determine the flow rate through the screens.

**8.3.6 Excess fluid reservoir:** to receive the excess fluid that overflows the test screen.

**8.3.7 Pump** (optional)**:** to transfer the fluid from the capture reservoir and the excess fluid reservoir to the fluid reservoir for additional tests.

**8.3.8 Temperature device:** with an accuracy of 0.05 °C (0.1 °F).

**8.3.9 Viscometer:** capable of measuring viscosity to an accuracy of 0.2 mPa•s (0.2 cP).

**8.3.10 Balance, digital:** with 0.01 g resolution

**8.3.11 Density cup (volumetric pycnometer):** suitable for measuring test fluid density at various temperatures

## 8.4 Procedure for Measuring Conductance

### 8.4.1 Principle

The procedure for measuring conductance should involve:

a) measuring the changes in test fluid density and viscosity with temperature,

b) measuring the flow rate through the test screen with the test fluid at three different pressure drops,

c) determining the head pressure during each flow rate test, and

d) calculating the average conductance for the three tests.

### 8.4.2 Measuring test fluid density and viscosity

Measuring the test fluid density and viscosity shall be as per the procedure hereafter.

a) Using a viscometer (see 8.3.9) capable of measuring viscosity to an accuracy of 0.2 mPa•s (0.2 cP), the viscosity of the test fluid shall be measured at 5 or more temperatures with at approximately 2.5 °C (5.0 °F) degrees between each measurement. These measurements shall include at least two measurements above and two temperatures below the **actual** conductance flow rate test temperature.

b) Using a digital balance (see 8.2.10) and a density cup (volumetric pycnometer, see 8.3.11), the density of the test fluid shall be measured at 5 or more temperatures with at approximately 2.5 °C (5.0 °F) degrees between each measurement. These measurements shall include at least two measurements above and two temperatures below the **actual** conductance flow rate test temperature.

c) The density and viscosity data should be graphed, or curve fit so that the values at the **measured actual** conductance flow rate test temperature can be determined in section 8.5. For curve fit equations, 2$^{nd}$ order polynomials are recommended.

Example: If the anticipated test temperature 20 °C (70 °F), then for items a) and b) measurements would be taken at 15°C, 17.5°C, 20 °C, 22.5 °C and 25 °C (60 °F, 65 °F, 70 °F, 75 °F and 80 °F).

### 8.4.3 Measuring test screen flow rate

Flow rate shall be measured according the following procedure.

a) Using a test screen holder and apparatus as described in 8.3, mount and level the top of the test screen holder horizontally using a bubble level so that the test fluid flowing into the holder will maintain a constant height of liquid above the screen surface. Verify that there is a seal providing isolation between the overflow and fluid flowing through the test screen so that the overflow flows into the trough surrounding the screen holder and to the excess fluid reservoir (see 8.3.6).

b) Use a viscous liquid test fluid to maintain a steady state flow rate through the screen with a constant liquid level above the screen.

NOTE A motor oil (e.g. 5W30 or 10W40 oil) are examples of preferred test fluids because they provide oil wetting of the screens. A water-wet screen has a much lower conductance or permeability to oil than an oil-wet screen.

c) Adjust the test fluid flow rate onto the screen so that a small amount overflows the top of the screen holder. The test fluid level should be approximately 0.3 cm (0.125 in.) above the upper edge of the screen holder. This will keep the pressure drop constant.

d) When the flow rate reaches a steady state, measure the increase in mass of the capture reservoir as a function of time for the duration of the test time. It is recommended that the duration of the test time be at least 5 min. As described in 8.3.3 item a), for screens with larger sized openings (low API number) and less blanked area, the screen holder diameter or exposed screen diameter may need to be reduced to decrease the flow rate required to reach a steady state condition with the small amount of overflow.

e) For each flow rate test, measure, and record:

1) average temperature of the test fluid collected in the capture reservoir,

2) mass of the test fluid collected in the capture reservoir during test time,

3) length of time for the test, and

4) head ($h_T$), height of the test fluid above the screen surface.

f) Repeat the 8.4.3 test procedure for three head heights. Recommended head heights are approximately 3 cm (1 in.), 5 cm (2 in.) and 8 cm (3 in.).

## 8.5 Calculation of Conductance

For each of the three flow rate tests with different head, the test screen conductance shall be calculated using the following parameters and equations:

a) Using the average temperature of test fluid in the capture reservoir during the test, determine the test fluid density ($\rho$) from the data measured in 8.4.2.

b) Determine the pressure differential ($\Delta p$) across the screen from the test fluid density ($\rho$) and the head ($h_T$).

Darcy's law requires this pressure differential to be expressed in atmospheres (pressure) calculated from the testing head.

1) If the head for testing, $h_T$, and the density of test fluid, $\rho$, are measured in SI units, the pressure differential, $\Delta p$, expressed in atmospheres, is calculated using Equation (30):

$$\Delta p = 0.09678 \times 10^{-6} \times h_{\mathrm{T,SI}} \times \rho_{\mathrm{SI}} \qquad (30)$$

where:

$h_{\mathrm{T,SI}}$ is the head for testing, measured in millimeters;

$\rho_{\mathrm{SI}}$ is the test fluid density, measured in kilograms per cubic meter.

2) If the head for testing, $h_{\mathrm{T}}$, and the density of the test fluid, $\rho$ , are measured in USC units, the pressure differential, $\Delta p$, expressed in atmospheres, is calculated using Equation (31):

$$\Delta p = 0.2946 \times 10^{-3} \times h_{\mathrm{T,USC}} \times \rho_{\mathrm{USC}} \qquad (31)$$

where:

$h_{\mathrm{T,USC}}$ is the head for testing, expressed in inches;

$\rho_{\mathrm{USC}}$ is the test fluid density, measured in pounds per gallon.

d) Using the average measured temperature of test fluid in the capture reservoir during the test, determine the test fluid viscosity ($\mu$) from the data measured in 8.4.2.

e) Calculate the average volumetric flow rate ($q_{\mathrm{S}}$) during the test by dividing the mass of test fluid collected in the capture reservoir by the product of the density of the test fluid times the test time, see example below.

f) Measure the inside diameter of the screen holder (or exposed screen diameter) and calculate the cross sectional screen area in square centimeters (square inches).

g) Calculate the conductance for each of the three 8.4.3 item f) head values 8.4.3 item f). The conductance value used for labeling and designating the screen is the average of the three values.

1) If the SI units are used, the conductance, $C$, of the test screen, expressed in kilodarcys per millimeter (kD/mm), is calculated using Equation (32):

$$C = 1.67 \times 10^{-6} \times \frac{\mu \times q_{\mathrm{S,SI}}}{\Delta p \times A_{\mathrm{SI}}} \qquad (32)$$

where:

$\mu$ is the test fluid viscosity, in millipascal-seconds (centipoises);

$q_{\mathrm{S,SI}}$ is the flow rate through the test screen , in milliliters per minute;

$\Delta p$ is the differential pressure, in atmospheres;

$A_{SI}$ is the cross-sectional area of the test screen, in square centimeters.

2) If the USC units are used, the conductance, $C$, of the test screen, expressed in kilodarcys per millimeter (kD/mm), is calculated according to Equation (33):

$$C = 0.9779 \times 10^{-3} \times \frac{\mu \times q_{S,USC}}{\Delta p \times A_{USC}} \tag{33}$$

where:

$\mu$ is the test fluid viscosity, in centipoises;

$q_{S,\,USC}$ is the flow rate through test screen, in gallons per minute;

$\Delta p$ is the differential pressure, in atmospheres;

$A_{USC}$ is the cross-sectional area of the test screen, in square inches.EXAMPLE

Example of one test conductance, test data and parameters are given Table 1.

**Table 1—Example of Conductance Test Data and Parameters**

| Test Data and Parameters | | |
|---|---|---|
| | SI – Metric Units | USC Units |
| Test fluid viscosity ($\mu$) | 100 mPa•s | 100 cP |
| Test fluid density ($\rho$) | 900 kg/m$^3$ (0.9 g/mL) | 7.51 lb/gal |
| Head ($h_T$) | 54 mm | 2.126 in. |
| Screen holder (exposed screen) internal diameter | 14.6 cm | 5.75 in. |
| Mass of test fluid passing through the test screen during the 5 min test time | 13.5 kg (13,500 g) | 29.76lb |

a) Example of testing and calculation using SI units

Calculate test pressure differential using Equation (30):

$$\Delta p = 0.09678 \times 10^{-6} \times h_{T,SI} \times \rho_{SI} = 0.09678 \times 10^{-6} \times 54 \times 900 = 0.470 \times 10^{-2} \text{atm}$$

Calculate the test screen cross section area in square centimeters:

$$A_{SI} = \pi \times \left(14.6/2\right)^2 = 167.42 \text{ cm}^2$$

Calculate the volumetric flow rate through the test screen in milliliters per minute by dividing the mass of test fluid collected by the density of the test fluid and the test time:

$$q_{\text{S,SI}} = \frac{13{,}500}{0.9 \times 5} = 3000 \text{ mL / min}$$

Calculate the screen conductance using Equation (32):

$$C = 1.67 \times 10^{-6} \times \frac{\mu \times q_{\text{S,SI}}}{\Delta p \times A_{\text{SI}}} = 1.67 \times 10^{-6} \times \frac{(100 \times 3000)}{(0.470 \times 10^{-2} \times 167.42)} = 0.637 \approx 0.64 \text{ kD / mm}$$

b) Example of testing and calculation using USC units

Calculate test pressure differential using Equation (31):

$$\Delta p = 0.2946 \times 10^{-3} \times h_{\text{T,USC}} \times \rho_{\text{USC}} = 0.2946 \times 10^{-3} \times 2.126 \times 7.51 = 0.470 \times 10^{-2} \text{atm}$$

Calculate the test screen cross section area in square inches:

$$A_{\text{USC}} = \pi \times \left(5.75/2\right)^2 = 25.97 \text{ in.}^2$$

Calculate volumetric flow rate through the test screen in gallons per minute by dividing the mass of test fluid collected by the density of the test fluid and the test time:

$$q_{\text{S,USC}} = \frac{29.76}{7.51 \times 5} = 0.793 \text{ gal / min}$$

Calculate the screen conductance using Equation (33):

$$C = 0.9779 \times 10^{-3} \times \frac{\mu \times q_{\text{S,USC}}}{\Delta p \times A_{\text{USC}}} = 0.9779 \times 10^{-3} \times \frac{(100 \times 0.793)}{(0.470 \times 10^{-2} \times 25.97)} = 0.635 \approx 0.64 \text{ kD / mm}$$

# 9 Shale Shaker Screen Designation

## 9.1 Principle

This section provides a method for determining the API screen number, i.e. the U.S. sieve number equivalent of a shaker screen using a laboratory sieve shaker, standard test sieves, and sized AlO test media samples which are designated AlO. Screens are rated on the API number scale by the separations that are achieved in dry-sieving standard AlO samples and then comparing these separations to the separations of the same standard AlO samples with standard sieves. This procedure only describes the maximum opening in the screen and does not describe the performance of a screen.

A shale shaker screen that separates the AlO sample similar to a U.S. 100 test sieve is designated API 100.

The procedure uses AlO sample that has a specific gravity of 3.5 to 3.9.

All particles larger than the D100 separation (see definition 3.1.24) are retained by the test screen.

## 9.2 Materials and Apparatus

**9.2.1** AlO**,** sized into specific cuts.

**9.2.2** The testing sieve shaker provides simultaneous rotating and tapping action and accepts a sieve as described in 9.2.3.

The shaker shall be calibrated to the following: 290 r/min, 156 taps/min, tapper height 3.3 cm (1.3 in.) with a timer accuracy of ±5.0 s.

**9.2.3** Standard 20 cm (8 in.) diameter test sieves (calibrated) shall be used for the testing. The sieves may be full or half height. A sieve cover and a sieve pan are also required. These sieves shall conform to ASTM E11 *Standard Specification for Wire Cloth and Sieves Properties for Testing Purposes* are summarized Table 2.

| **Standard Designation**<br><br>µm | **Alternate Designation**<br><br>US Sieve Number | **Variation for Average Opening**<br>µm | **Maximum Variation for Opening**<br>µm | **Maximum Individual Opening**<br>µm |
|---|---|---|---|---|
| 4000 | 5 | ±127 | 370 | 4370 |
| 3350 | 6 | ±107 | 320 | 3670 |
| 2800 | 7 | ±90 | 290 | 3090 |
| 2360 | 8 | ±76 | 250 | 2610 |
| 2000 | 10 | ±65 | 230 | 2230 |
| 1700 | 12 | ±56 | 200 | 1900 |
| 1400 | 14 | ±46 | 180 | 1580 |
| 1180 | 16 | ±40 | 160 | 1340 |
| 1000 | 18 | ±34 | 140 | 1140 |
| 850 | 20 | ±29.1 | 127 | 977 |
| 710 | 25 | ±24.7 | 112 | 822 |
| 600 | 30 | ±21.2 | 101 | 701 |
| 500 | 35 | ±18.0 | 89 | 589 |
| 425 | 40 | ±15.5 | 81 | 506 |
| 355 | 45 | ±13.3 | 72 | 427 |
| 300 | 50 | ±11.5 | 65 | 365 |

**Table 2— Test Sieve Designation** ( as per ASTM E11-19)

| | | | | |
|---|---|---|---|---|
| 250 | 60 | ±9.9 | 58 | 308 |
| 212 | 70 | ±8.7 | 52 | 264 |

**Table 2 (continued)—Test Sieve Designations** (as per ASTM E11-19)

| **Standard Designation** µm | **Alternate Designation** US Sieve Number | **Variation for Average Opening** µm | **Maximum Variation for Opening** µm | **Maximum Individual Opening** µm |
|---|---|---|---|---|
| 180 | 80 | ±7.6 | 47 | 227 |
| 150 | 100 | ±6.6 | 43 | 193 |
| 125 | 120 | ±5.8 | 38 | 163 |
| 106 | 140 | ±5.2 | 35 | 141 |
| 90 | 170 | ±4.6 | 32 | 122 |
| 75 | 200 | ±4.1 | 29 | 104 |
| 63 | 230 | ±3.7 | 26 | 89 |
| 53 | 270 | ±3.4 | 24 | 77 |
| 45 | 325 | ±3.1 | 22 | 67 |
| 38 | 400 | ±2.9 | 20 | 58 |
| 32 | 450 | ±2.7 | 18 | 50 |
| 25 | 500 | ±2.5 | 16 | 41 |
| 20 | 635 | ±2.3 | 15 | 35 |

**9.2.4** The API Screen designation is shown in Table 3.

All particles larger than the D100 separation retained by the test of a shale shaker screen shall be designated by an API number identical to the ASTM E11 alternate designation (U.S. Sieve number). Table 3 is showing API Number versus standard sieve openings.

**Table 3—API Screen Designation and ASTM Sieve Opening**

| **API Screen Designation** U.S Sieve Number | **Sieve Opening** µm | **API Screen Designation** U.S Sieve Number | **Sieve Opening** µm |
|---|---|---|---|
| 5 | 4000 | 60 | 250 |
| 6 | 3350 | 70 | 212 |
| 7 | 2800 | 80 | 180 |
| 8 | 2360 | 100 | 150 |
| 10 | 2000 | 120 | 125 |
| 12 | 1700 | 140 | 106 |
| 14 | 1400 | 170 | 90 |
| 16 | 1180 | 200 | 75 |
| 18 | 1000 | 230 | 63 |
| 20 | 850 | 270 | 53 |
| 25 | 710 | 325 | 45 |
| 30 | 600 | 400 | 38 |
| 35 | 500 | 450 | 32 |
| 40 | 425 | 500 | 25 |
| 45 | 355 | 635 | 20 |
| 50 | 300 | | |



**9.2.5** Test screen holder as described in 9.4.

**9.2.6** Digital balance with a capacity up to 3000 g and accuracy of ±0.01 g. The balance shall be capable of weighing the total combined mass of the test screen and the retained AlO test media, the latter being a maximum of 80 g.

**9.2.7** Sieve brush with a soft bristles shall be used on sieves U.S. No. 100 and finer to reduce the possibility of damage to the fine sieve cloth. Nylon or equivalent may cause damage to the sieve cloth.

NOTE From Table 3, an U.S. No. 100 sieve has an opening of 150 µm.

**9.2.8** Marked or labeled jars or other containers suitable for storing various U.S. sieve fractions of sized AlO.

**9.2.9** A large, shallow bowl with a 30 cm (12 in.) outer diameter at the top or a rectangular pan with a minimum 25.4 cm (10 in.) to 30.5 cm (12 in.) short side and a depth of 5 cm (2 in.).

**9.2.10** Container with sealing lid large enough to hold 50 g AlO and water.

**9.2.11** Deionized or distilled water.

**9.2.12** Oven regulated to between 105 °C (220 °F) and 120 °C (250 °F).

## 9.3 Preparation of AlO Test Media

### 9.3.1 Preparation of sized AlO samples

Sized AlO samples shall be prepared using the following procedure.

a) Sized stock AlO products are available from several suppliers. These range in size from very coarse to very fine. Due to the statistical (or probabilistic) nature of sieving, both stock AlO products and sized AlO fractions may contain particles finer and coarser than the indicated sieve size. After sizing using this procedure, four or five consecutive sizes of sized AlO fractions will be combined to prepare the actual test media as described in 9.3.2 and 9.5.

b) Pre-sieve stock AlO products into individual fractions of sized AlO using the indicated sieve size plus two screen sizes above and two screen sizes below.

c) Wash each individual sized AlO fraction by adding about 50 g of sized AlO into a container, adding deionized water, close container and shaking vigorously.

d) Decant water and repeat the washing three times.

e) Dry each sized AlO fraction for 8 hours in an oven set between 105 °C (220 °F) and 120 °C (250 °F).

f) Dry sieve each of the washed AlO fractions for 10 min in a stack of at least five consecutive test sieves containing at least two U.S. sieve sizes finer and two U.S. sieve sizes coarser than the indicated sieve size of the test screen.

   The amount sieved should be limited to less than 60 g, because larger samples will result in plugging and hold-up of smaller sizes on coarser screens.

g) If there is hold-up of fines due to plugging of the coarser sieves, remove each individual sieve fraction and collect it individually in a large container (see 9.2.9), then brush and clean the sieve over the same larger container. Then place the entire sieve fraction in a marked or labeled container. Repeat this procedure for each individual sieve fraction.

g) Each individual fraction can then be placed back on the sieve from which the fraction was originally removed and dry-sieved again for 5 min. Repeat this procedure as many times as necessary to obtain an accurately sized sieve fraction.

h) Carefully remove each sized AlO fraction retained on each consecutive sieve and place into individual marked or labeled containers.

### 9.3.2 Preparation of Sample for Test Range

**9.3.2.1** Using the sized AlO fractions obtained in accordance with 9.3.1, combined AlO test media samples shall be prepared, covering the range of screens to be tested.

Three examples of prepared AlO test media are given in Table 4.

**Table 4 —Examples of AlO Test Media Sample Preparation**

| API number | Opening µm | Mass of AlO Test Media I [a] g | Mass of AlO Test Media II [b] g | Mass of AlO Test Media III [c] g |
|---|---|---|---|---|
| 25 | 710 | 0 | | |
| 30 | 600 | 5.23 | | |
| 35 | 500 | 5.46 | | |
| 40 | 425 | 5.78 | | |
| 45 | 325 | 5.45 | | |
| 50 | 300 | 5.67 | | |
| 60 | 250 | | 0 | |
| 70 | 212 | | 7.12 | |
| 80 | 180 | | 7.23 | |
| 100 | 150 | | 7.45 | |
| 120 | 125 | | 7.57 | 0 |
| 140 | 106 | | 7.34 | 8.78 |
| 170 | 90 | | | 8.12 |
| 200 | 75 | | | 8.23 |
| 230 | 63 | | | 8.34 |
| 270 | 53 | | | 8.45 |
| 325 | 45 | | | |
| 400 | 38 | | | |
| 450 | 32 | | | |
| 500 | 25 | | | |
| 635 | 20 | | | |
| **Total mass**, g | | 27.59 | 36.71 | 41.92 |

NOTE Test media mass distributions are meant to serve as examples only.

[a] The distribution of sized AlO used for AlO test media I would be for a test screen with openings between 325 µm and 500 µm.

[b] The distribution of sized AlO used for AlO test media II would be for a test screen with openings between 125 µm and 180 µm.

[c] The distribution of sized AlO used for AlO test media III would be for a test screen with openings between 63 µm and 90 µm.



**9.3.2.2** For convenience, the number of sieves and the mass of AlO may be varied as described in 9.5. A minimum of four and a maximum of 10 consecutive sieves with no test media added for the coarsest sieve, (as shown as 0 g in Table 4 in the three example distributions).

## 9.4 Preparation of Test Screen

Test screen shall be prepared as per requirements below:

a) It is recommended to return any screen selected for tests to the manufacturer for test screen sample preparation with impartial third-party supervision.

b) Mount the test screen so that all layers are in contact and tensioned to simulate the installation on a shaker.

NOTE If the screen cloth is not tensioned properly, erroneous results are obtained. For example, a triple-layer screen cloth has two fine screening layers that should be held in contact with one another to achieve this screen's benefits. If the two fine layers are not in contact, any beneficial effect on solids separation gained by having the two layers is lost. Any test results obtained with the two layers not held in contact are invalid or are not representative of the separation capability of the screen.

c) Tension and mount all test screen samples in accordance with the manufacturer's specifications.

d) For screens with two or more layers, orient and mount the individual screen cloths relative to each other in the test screen sample in the same manner as an actual manufactured screen would be mounted on a shaker.

e) Center the mounted test screen sample [for multi-layer screens, place the finer screen(s) uppermost] between the top and bottom parts of the test screen holder.

f) The test screen holder should be constructed of light-weight aluminum or PVC pipe.

g) The test screen should be mounted securely between the top and bottom parts of the screen holder and fabricated to fit into the stack of regular 8-in. ASTM test sieves.

h) Place rubber gaskets or other sealing materials on the two sealing surfaces of the test screen holder, in order to contain all the test media inside the sieve stack. Seal any particle escape routes between the test screen sample and the sealing surfaces of the test screen holder.

i) Wash screens in a detergent solution to ensure that all oil is removed from the screens. Dry screen thoroughly before placing on the sieve shaker.

## 9.5 Test Procedure

The test to determine API screen designation shall be conducted as per the following procedure:

a) Weigh 5 g to 8 g of four or five consecutive sizes of sized AlO samples, using sizes larger than and smaller than the test screen as described in 9.3.2. Record each of the sample masses to the nearest 0.01 g.

b) Combine the sized AlO samples and weigh the AlO test media total to the nearest 0.01 g. Record the total AlO test media mass.

c) A minimum of four and a maximum of 10 consecutive sieves shall be used with the coarsest screen selected as the size corresponding to the next larger size than the largest size of test media used, (as indicated as 0 g in Table 4 for the three example distributions).

d) Weigh and record the initial mass of each empty sieve, the test screen holder, and the empty pan.

e) Arrange the sieves with the coarsest on top and the finest on bottom. Place the test screen in the middle of the stack. Nest the sieve stack with the sieve pan on the bottom.

NOTE An estimation of the test screen opening size and its' position in the stack can be determined by the Finder's method given Annex B.

f) Pour 20 g to 80 g of the AlO test media sample onto the top sieve, place a sieve cover on top of the sieve stack, and secure in the sieve shaker.

g) Mount the sieve stack securely in the sieve shaker and allow to vibrate for 10 min as determined by a timer.

h) Carefully remove the stack from the sieve shaker and separate the sieves. Weigh each sieve, the test screen holder and the pan with the retained AlO.

i) For a test to be valid, the test screen shall separate 10 % to 90 % of the test sample. If the lost mass of AlO test media during a test exceeds 1.0 g, the test is invalid and need to be repeated.

j) Repeat the a) through i) until three valid test results are obtained.

## 9.6 Calculation of D100 Separation for Test Screen Cloth

**9.6.1** Test screen cloth D100 separation shall be calculated as per the following:

a) Calculate the mass of AlO retained on each sieve by subtracting the initial empty sieve mass [see 9.5 item d)] from the final sieve mass, including the retained AlO. Record each mass with the corresponding sieve size.

b) Confirm that the AlO test media contains solids coarser than the test screen and finer than the test screen.

c) Calculate the cumulative mass of AlO retained on each sieve, from the smallest opening size to the largest.

d) Plot the cumulative mass on all sieves as a function of the screen opening size.

e) Determine the equation of a straight line connecting the two data points on either side of the test screen cumulative mass.

f) Using the cumulative mass captured on the test screen, determine the equivalent opening size, graphically or with the equation determined previously item e). This is the D100 separation for the test screen and is used to identify the screen designation.

g) Repeat the calculation procedure three times. Calculate the average D100 separation for the three tests.

**9.6.2** If the individual results from the three tests differ by more than the range permitted in a screen specification, the test is invalid and shall be repeated.

### 9.6.3 Test screen rating

Table 5 lists the D100 separation and the corresponding API screen number.

When the D100 separation falls at a point that is half or less of the difference between the openings of a finer and the next coarser sieve, the test screen shall be rated as the finer test sieve.

When the D100 separation falls at a point that is more than half of the difference between the openings of a finer and the next coarser sieve, the test screen shall be rated as the coarser sieve.

An example of the rating is if the D100 separation is between a U.S. 170 (90 µm) and a U.S. 200 (75 µm) sieve size; the test screen is rated as an API 170 if the D100 separation is greater than 82.5 µm and an API 200 if the D100 separation is 82.5 µm or less.

**Table 5—D100 Separation and API Screen Number**

| **D100 Separation** µm | **API Screen Number** | **D100 Separation** µm | **API Screen Number** |
|---|---|---|---|
| >3675 to 4375 | API 5 | >231 to 275 | API 60 |
| >3075 to 3675 | API 6 | >196 to 231 | API 70 |
| >2580 to 3075 | API 7 | >165 to 196 | API 80 |
| >2180 to 2580 | API 8 | >137.5 to 165 | API 100 |
| >1850 to 2180 | API 10 | >116.5 to 137.5 | API 120 |
| >1550 to 1850 | API 12 | >98.0 to 116.5 | API 140 |
| >1290 to 1550 | API 14 | >82.5 to 98.0 | API 170 |
| >1090 to 1290 | API 16 | >69.0 to 82.5 | API 200 |
| >925 to 1090 | API 18 | >58 to 69 | API 230 |
| >780 to 925 | API 20 | >49 to 58 | API 270 |
| >655 to 780 | API 25 | >41.5 to 49 | API 325 |
| >550 to 655 | API 30 | >35 to 41.5 | API 400 |
| >462.5 to 550 | API 35 | >28.5 to 35 | API 450 |
| >390 to 462.5 | API 40 | >22.5 to 28.5 | API 500 |
| >327.5 to 390 | API 45 | >18.5 to 22.5 | API 635 |
| >275 to 327.5 | API 50 | | |



### 9.6.3 EXAMPLE calculation of API screen number.

a) About 5 g to 6 g of AlO sized between 63 µm and 125 µm is placed on a stack of sieves with an unknown size test screen, *x*, below the 106 µm (API 140) sieve. After 10 min of shaking on the sieve shaker, the sieves were weighed and the mass of AlO on each screen calculated from the difference in masses of the empty sieve and the sieve after shaking. See Table 6.

**Table 6—Example Experimental Results**

| API Number | Opening Size<br>µm | Retained AIO Mass<br>g | Cumulative Retained AIO<br>g |
|---|---|---|---|
| 100 | 150 | 0 | 0 |
| 120 | 125 | 5.01 | 5.01 |
| 140 | 106 | 4.98 | 9.99 |
| ? | $x$ | 3.41 | 13.40 ($y$) |
| 170 | 90 | 2.61 | 16.01 |
| 200 | 75 | 5.02 | 21.03 |
| 230 | 63 | 4.98 | 26.01 |
| | | 26.01 | |

b) The mass captured on the unknown screen (13.4 g) indicates that the D100 separation of the unknown screen is between 90 µm (API 170) and 106 µm (API 140). See Figure 10 a).

c) With the data points of 9.99 g on the 106 µm (API 140) sieve and the 16.01 g on the 90 µm (API 170) sieve, an equation can be derived to describe a straight line between these two data points. See Figure 10b).

$$y = 49.872 - 0.3762\ x$$

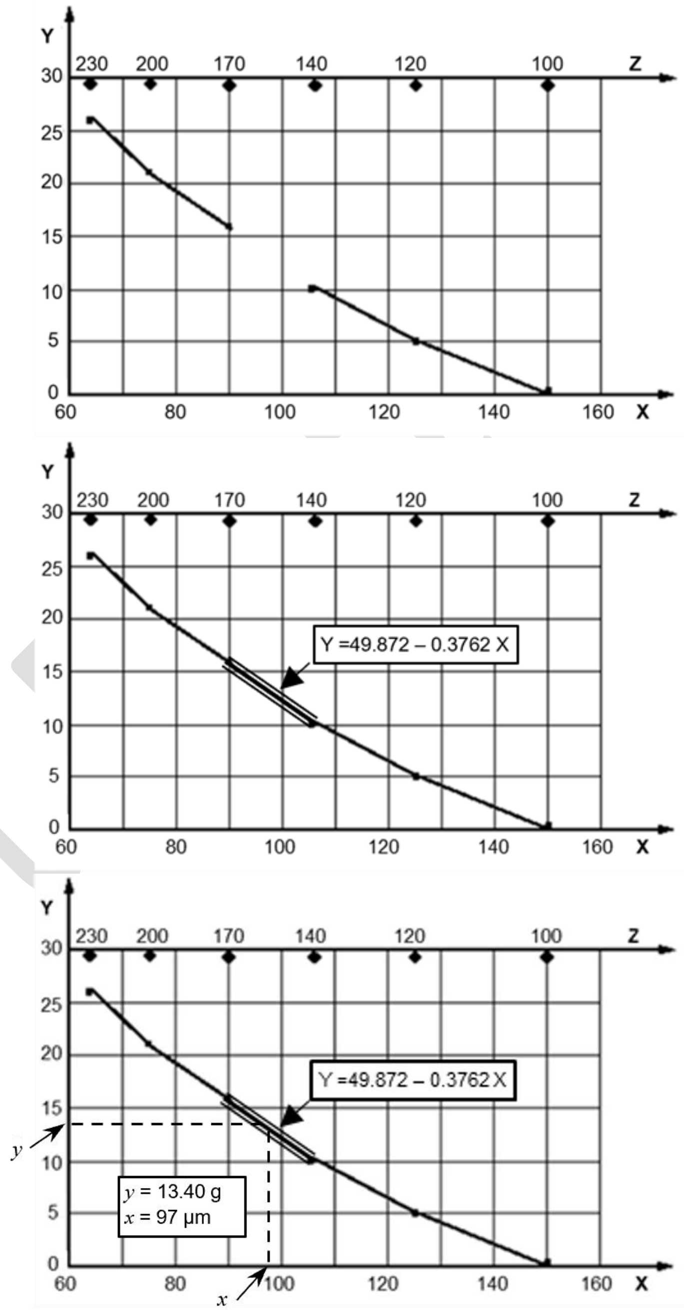
d) This equation indicates that the cumulative mass retained is equal to –0.3762 times the opening size, in micrometers, plus 49.872. The cumulative mass captured on the unknown screen was 13.40 g. Solving the equation for $\boldsymbol{x}$ when $\boldsymbol{y} = 13.40$, the opening size is 96.9 µm. Graphical determination is giving an opening size of 97 µm, See Figure 10 c).

e) Referring to 9.6.3 and Table 5, the API screen number for the D100 separation is greater than 82.5 µm and smaller than 98.0 µm. The new screen number shall be API 170 (90 µm).

**a) Cumulative Retained AIO versus Sieve Opening Size**

**b) Extrapolation straight line between Screens API 140 and API 170**

**c) Cumulative Mass on Unknown Screen indicates Opening Size**






**Key**

**X** opening size, µm

**Y** cumulative mass retained, g

**Z** API number

**Figure 10—Example of Sieve Analysis with Unknown Shaker Screen Sample**

# 10 Non-blanked Area of Shale Shaker Screen Panel

## 10.1 Principle

This procedure is a method for determining the total non-blanked area of a shale shaker screen panel using direct measurement and calculation techniques.

## 10.2 Apparatus

**10.2.1** Caliper**,** dial or digital, graduated in millimeters to measure smaller perforated panel or pretensioned panel openings.

**10.2.2** Ruler, marked in millimeters, to measure larger open-hook strip-type panels.

## 10.3 Procedure for Pretensioned or Perforated Panel-type Screens

**10.3.1** Data shall be obtained from, and all calculations shall be made with information gathered from “ordinary” or “regular” production-run screen panels; do not use “show,” “test,” or “special” panels.

**10.3.2** Two panels should be randomly chosen from a production run of at least 25 screened panels.

**10.3.3** All panel openings shall be marked for measurement, and number the openings consecutively.

**10.3.4** Necessary dimensions of each panel opening shall be measured to the nearest millimeter. These measurements are critical to obtain accurate and repeatable results. Do not include the space occupied by adhesive or bonding materials. Measure only the unconcluded panel opening space located between the panel webs.

## 10.4 Calculation for Pretensioned or Perforated Panel-type Screens

Pretensioned or perforated panel-type screens non-blanked area shall be determined with the following measurements.

a) Calculate the area of each panel opening, in square millimeters.

b) Sum the unoccluded areas of all panel openings to obtain the total non-blanked area of that particular panel, in square millimeters.

   If necessary, convert the total non-blanked area from square millimeters to square feet by dividing by 92,903.

c) Calculate the average non-blanked panel area by summing the total non-blanked areas of both randomly chosen panels and dividing by 2.

## 10.5 Procedure for Open-hook Strip Panels

**10.5.1** Data shall be obtained from and all calculations shall be made with information gathered from “ordinary or regular” production-run screen panels; do not use “show,” “test,” or “special” panels.

**10.5.2** Two panels should be randomly chosen from a production run of at least 25 screened panels.

**10.5.3** The width of each screen panel shall be measured from the inner edge of the hoop strips on either side, to the nearest millimeter.

**10.5.4** The length of each screen panel shall be measured from the inside of the top of the non-blanked wire cloth area to the inside of the bottom of the non-blanked cloth area, to the nearest millimeter.

## 10.6 Calculation for Open-hook Strip Panels

Open-hook strip panels non-blanked area shall be determined with the following measurements.

a) Calculate the total non-blanked area of each panel, in square millimeters.

   If necessary, convert the total non-blanked area from square millimeters to square feet by dividing by 92,903.

b) Calculate the average non-blanked panel area by summing the total non-blanked areas of both randomly chosen panels and dividing by 2.

## 10.7 EXAMPLES

**10.7.1** Calculation of Total Non-blanked Area for a Panel-mount Screen

The total non-blanked area for a panel-mount screen is calculated as follows (see 10.5).

a) Measure the length and width of a panel opening with a dial or digital caliper to the nearest millimeter and calculate its area. If, for example, it measures 24 mm wide by 25 mm long, its area is as follows:

   $24 \text{ mm} \times 25 \text{ mm} = 600 \text{ mm}^2$

b) Perform a similar calculation for all panel openings on both screens used in the analysis. Sum the individual results to obtain the total non-blanked area of each panel-mount screen, in square millimeters. In one set of calculations, the resultants sums are:

   $626{,}400 \text{ mm}^2$ and $618{,}734 \text{ mm}^2$ , or $6.264 \text{ cm}^2$ and $6.187 \text{ cm}^2$

   If necessary, convert the total non-blanked area to square feet by using the conversion factor.

   $626{,}400 \text{ mm}^2 / 92{,}903 = 6.74 \text{ ft}^2$

   $618{,}734 \text{ mm}^2 / 92{,}903 = 6.66 \text{ ft}^2$

c) Average the two non-blanked area results to obtain the final answer for total non-blanked area of a panel.

   $(6.264 + 6.187) / 2 = 6.23 \text{ cm}^2$ or $6.23 \times 10^{-4} \text{ m}^2$

   If using square feet:

   $(6.74 + 6.66) / 2 = 6.70 \text{ ft}^2$

**10.7.2** Calculation of Total Non-blanked Area for an open-hook strip screen panel.

The total non-blanked area for an open-hook strip screen panel is calculated as follows (see 10.6).

a) Measure the width of each screen panel from the inner edge of the hook strips on either side.

b) Measure the length of the non-blanked area of each screen panel, starting from inside edge of the top cloth fold and extending to the inside edge of the bottom cloth fold.

c) Calculate the total non-blanked area, in square millimeters, of each screen panel:

— screen panel 1: 1160 mm x 1520 mm = 1,763,200 $mm^2$ = 1.763 $m^2$

— screen panel 2: 1156 mm x 1522 mm = 1,759,432 $mm^2$ = 1.759 $m^2$

If necessary, convert the total non-blanked area of each screen panel from square millimeters to square feet by performing the following calculation:

— screen panel 1: 1,763,200 $mm^2$ / 92,903 = 18.98 $ft^2$

— screen panel 2: 1,759,432 $mm^2$ / 92,903 = 18.94 $ft^2$

d) Average the two non-blanked panel area results to obtain the final answer for the total non-blanked area of one open hook strip panel:

(1.763 + 1759 ) / 2 ) = 1.761 $m^2$

If necessary, calculate the average in square feet:

(18.98 + 18.94) / 2 = 18.96 $ft^2$

# 11 Shale Shaker Screen Labeling

## 11.1 API Screen Designation

### 11.1.1 General

In order to identify the characteristics of a screen determined by the procedures provided, a permanent label or tag that complies with all of the provisions of this section shall be affixed to the screen in a position that will be both visible and legible after the screen is installed on the screen frame.

This permanent label and adherence to the provision of this section are necessary to conform to or comply with Section 8, Section 9, and Section 10.

A similar label or tag is required for all packaging containing new screens and shall be clearly visible and placed on the same side as and adjacent to every location where a part number or other screen designation information is located.

All labels or tags, including other screen labels, packaging labels, part numbers, and other screen designation information, shall use text or font sized one-half of the font size used for the API screen number designation.

Each unique or different screen shall be tested in accordance with the test methods and procedures described in this section and in Section 8, Section 9, and Section 10, and conformity shall be indicated by the use of an appropriate expression, e.g. “conforms to API RP 13C” or “API RP 13C.” Each unique or different screen is defined as follows:

a) each unique or different combination of screen layers;

b) each unique or different construction method, including each unique or different bonding pattern, bonding material, or other material difference for the field of the screen panel.

The use of an expression such as "conforms to API RP 13C" or "API RP 13C" is only permitted if the signed and dated laboratory test results used to determine the values shown on each unique or different screen are made available to the purchaser, end user, or operator.

#### 11.1.2 Procedure—Label Design Information

**11.1.2.1** The API screen designation label shall consist of no fewer than the following minimum elements:

a) API screen number,

b) D100 separation in microns,

c) conductance in kilodarcys per millimeter,

d) non-blanked area in square meters or square feet,

e) manufacturer's designation/part number,

f) statement of conformance to this standard.

**11.1.2.2** Optional information that may be shown on the API screen designation label should be restricted to the following:

a) manufacturer's name,

b) application or description,

c) country of origin,

d) lot number,

e) date,

f) order number,

g) bar code.

This information shall comply with the screen label formatting requirements in 11.2.

#### 11.1.3 API Screen Number Designation and D100 Separation Potential

The API screen number designation shall be empirically determined by the test procedures described in Section 9 and using Table 5. This method determines the D100 separation of a given screen compared to the D100 separation of equivalent ASTM test sieves using AlO test media on a testing sieve shaker as described in 9.2.1. These two values allow any two screens to be compared to identify which has the potential to remove smaller solids.

#### 11.1.4 Screen Conductance

**11.1.4.1** Conductance, measured in units of kilodarcys per millimeter (kD/mm), defines the ability with which a Newtonian fluid will flow through a unit area of screen in a laminar flow regime, all other variables being equal. The screen conductance shall be determined by the test procedure described in Section 8. This allows any two screens that have been tested to be compared to identify which has the potential to process the highest flow rate per unit area. Conductance allows for screen comparisons regardless of other variables that may affect the actual flow capacity of a given screen in field use.

**11.1.4.2** Flow capacity of a shale shaker screen is the rate at which a screen can process a particular drilling fluid and drilled-solids combination under field conditions. It is a function of many variables, including the following:

a) shale shaker configuration,

b) shale shaker design,

c) shale shaker motion,

d) drilling fluid rheology,

e) solids loading,

f) particles size distribution,

g) shape and character of the drilled-solids,

h) screen opening size,

i) screen construction.

**11.1.4.3** This standard provides data determined under controlled conditions, such that these other factors can generally be ignored. A screen with the highest conductance values for the same API screen number should process the most flow and remove more solids under any set of variables in field application.

### 11.1.5 Non-blanked Area

The non-blanked area of a screen describes the net unblocked area in square meters or square feet, available to permit the passage of fluid. Generally, more area is better.

### 11.1.6 Manufacturer's Screen Designation

The manufacturer's designation is the combination of letters and numbers used by the manufacturer to identify the screen. The composition of the manufacturer's designation and part number remains the prerogative of the manufacturer. It is recommended that it contain the API screen number to avoid confusion.

### 11.1.7 API Screen Designation Label

The API screen designation label shall contain an appropriate expression, e.g. "conforms to API RP 13C" or "API RP 13C," as an indication that the data shown on the label has been determined using the methods and procedures contained in this standard. This phrase or similar language shall be only permitted if all of the conditions and procedures described in this section and in Section 8, Section 9, and Section 10 are satisfied.

### 11.1.8 Optional Information

Optional information, limited to that listed in 11.1.2.2, may be included on the API designation label.

## 11.2 Label and Tag Format

**11.2.1** The screen designation label shall be formatted as follows:

a) using either a side-by-side or top-and-bottom orientation;

b) all data determined in accordance with API 13C (API number, D100 separation potential, conductance, non-blanked area) shall be positioned on the left side or top portion of the label, as indicated in 11.3;

c) there should be a printed line or other visual delineation between the two one-half sections. Each one-half side or top/bottom section may have one or two columns;

d) optional information listed in 11.1.2.2 shall be shown on the right side or bottom portion of the label;

e) the wording "conforms to API 13C" may be located on either the one-half side or top/bottom section.

**11.2.2** Abbreviations, unit symbols, and acronyms are allowed.

**11.2.3** All information on the label shall use the same font style and color for printed text without bold or underlined text. The manufacturer's part number may be stamped (embossed), but it shall not be in an area where other text is presented. Colored borders and/or colored labels or tags are allowed as long as the text is clearly readable.

**11.2.4** The format of the determined data shall be that the API screen number is shown first at the top, or top left if side-by-side formatted, with the D100 separation potential in microns immediately below in parentheses on the left or top one-half section for the determined data.

**11.2.5** The size of the API screen number shall be no less than twice the font size of the manufacturer's screen designation and all other text. The API screen number shall be placed immediately adjacent to the manufacturer's screen designation, wherever displayed. This includes the screen label or tag, screen box, and any other label or tag.

**11.2.6** Compliance with this recommended practice shall not be construed as permitting the use of the API Monogram logo on the screen label or tag, screen box, or box label.

## 11.3 API Screen Designation Label Examples

The label is shown in the basic format orientations:

a) side-by-side (Figure 11 and Figure 12) and

b) top-and-bottom (Figure 13 and Figure 14).

If a screen conforms to the API 13C label designation, it shall also conform to this section.

Figure 11 shows an example of side-by-side orientation (minimum elements required).

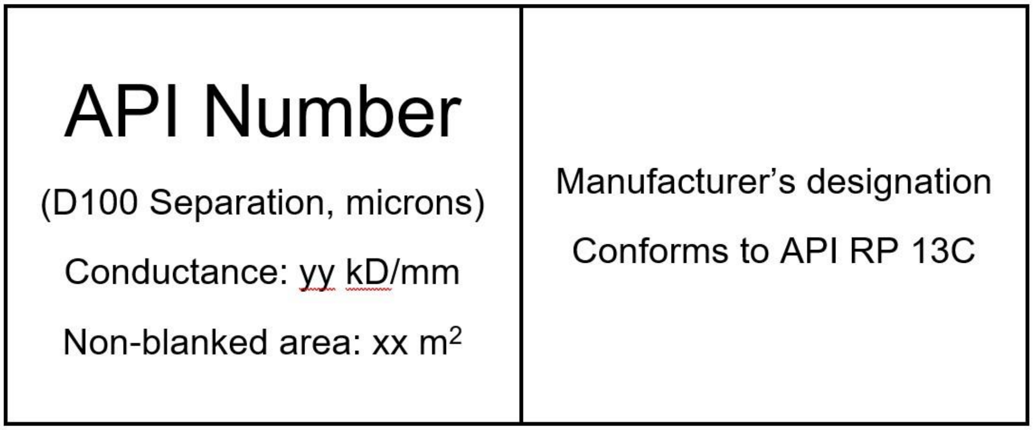



**Figure 11—Side-by-Side Basic Label**

Figure 12 shows an example of side-by-side orientation with example data (maximum data elements allowed). Typical SI units are shown.

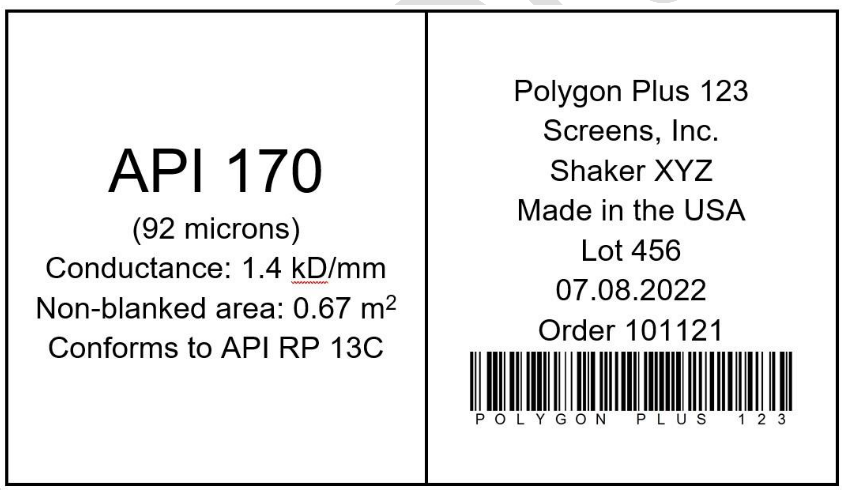



**Figure 12—Side-by-Side Example Label**

Figure 13 shows an example of top-and bottom orientation (minimum data required).

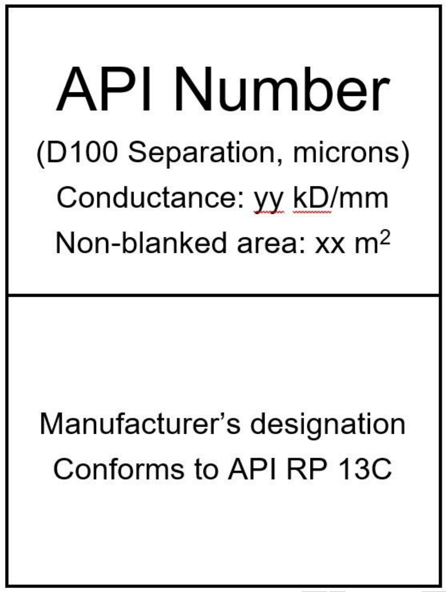



**Figure 13—Top-and-Bottom Basic Label**

Figure 14 shows an example of top-and-bottom orientation with example data (maximum data elements allowed). Typical USC units are shown.


**Figure 14—Top-and-Bottom Example Label**

## 11.4 Other Screen Label and Tags

**11.4.1** Manufacturers may use a second screen label or tag on the screen panel and packaging in order to include supplementary information.

**11.4.2** The supplementary information shall conform to the following:

a) the style of font remains identical on all screen labels and tags;

b) the second label is including the API screen number if the manufacturer's screen designation (or part number) is shown;

c) the size of the API screen number is at least twice the font size of the manufacturer's screen designation and all other text on all labels and tags;

d) all text is of a single, legible identical font style and color of the manufacturer's choosing;

e) the API screen designation tab is placed immediately adjacent to the manufacturer's screen designation, wherever displayed, whether on screen box, label, or screen tag;

f) compliance with API 13C is not construed as permitting the use of the API Monogram logo on the screen label or tag, screen box, or box label.

# Annex A
(informative)

# Derivation of Capture Equation

## A.1 Principle

**A.1.1** Calculation of capture is based on gravimetric analyses of the three process streams common to solid-liquid separators (i.e. feed, underflow, and overflow). The procedure yields good results when homogeneous and representative samples of the process streams are collected.

**A.1.2** This procedure is most often used with hydrocyclone units and centrifuges.

**A.1.3** The capture equation derived below is based on a material balance of solids. By analyzing small samples of the three process streams for suspended solids, the following information can be obtained:

a) percent capture;

b) mass flow rate of suspended solids reporting to discard. This is reported as dry mass of solids per hour removed, expressed as kilograms per hour (tons per hour).

## A.2 Procedure of Derivation

The capture equation should be derived as follows:

a) definition of capture expressed as a decimal fraction:

$$w_a = \frac{w_3 \dot{m}_3}{w_1 \dot{m}_1} \tag{A.1}$$

b) conservation of total mass in and out:

$$\dot{m}_1 = \dot{m}_3 + \dot{m}_2 \tag{A.2}$$

c) conservation of suspended solids:

$$w_1 \dot{m}_1 = w_3 \dot{m}_3 + w_2 \dot{m}_2 \tag{A.3}$$

d) multiply Equation (A.2) by mass fraction out:

$$w_2 \dot{m}_1 = w_2 \dot{m}_3 + w_2 \dot{m}_2 \tag{A.4}$$

e) rearrange Equation (A.4):

$$w_2 \dot{m}_2 = w_2 \dot{m}_1 - w_2 \dot{m}_3 \tag{A.5}$$

f) solve Equation (A.3) for overflow mass flow rate times mass fraction suspended solids in the overflow:

$$-w_2 \dot{m}_2 = w_3 \dot{m}_3 - w_1 \dot{m}_1 \tag{A.6}$$

g) add Equations (A.5) and (A.6):

$$0 = w_3 \dot{m}_3 - w_2 \dot{m}_3 + w_2 \dot{m}_1 - w_1 \dot{m}_1 \tag{A.7}$$

h) group terms of Equation (A.7)

$$0 = \dot{m}_3 \left( w_3 - w_2 \right) + \dot{m}_1 \left( w_2 - w_1 \right) \tag{A.8}$$

i) rearrange and simplify Equation (A.8)

$$-\dot{m}_1 \left( w_2 - w_1 \right) = \dot{m}_1 \left( w_1 - w_2 \right) = \dot{m}_3 \left( w_3 - w_2 \right) \tag{A.9}$$

j) isolate mass flow rates from Equation (A.9)/

$$\frac{\dot{m}_3}{\dot{m}_1} = \frac{\left( w_1 - w_2 \right)}{\left( w_3 - w_2 \right)} \tag{A.10}$$

k) multiply Equation (A.8) by the ratio of mass fraction of underflow to mass fraction of feed:

$$\left( \frac{w_3}{w_1} \right) \times \left( \frac{\dot{m}_3}{\dot{m}_1} \right) = \left( \frac{w_3}{w_1} \right) \times \left( \frac{w_1 - w_2}{w_3 - w_2} \right) \tag{A.11}$$

l) left side of Equation (A.11) is found in Equation (A.1): percent capture can be expressed in terms of suspended solids concentrations:

$$w_{\mathrm{a}} = \frac{w_3 \times \left( w_1 - w_2 \right)}{w_1 \times \left( w_3 - w_2 \right)} \tag{A.12}$$

where:

$\dot{m}_1$ is the feed mass flow rate, expressed in kilograms per minute (pounds per minute);

$\dot{m}_2$ is the overflow mass flow rate, expressed in kilograms per minute (pounds per minute);

$\dot{m}_3$ is the underflow mass flow rate, expressed in kilograms per minute (pounds per minute)

$w_1$ is the mass fraction of suspended solids in feed, expressed as a decimal fraction;

$w_2$ is the mass fraction of suspended solids in overflow, expressed as a decimal fraction;

$w_3$ is the mass fraction of suspended solids in underflow, expressed as a decimal fraction;

$w_a$ is the mass fraction of suspended solids removed (“capture”), expressed as a decimal fraction.

Capture can be calculated from laboratory data by measuring mass fractions of suspended solids in each of the stream in and out of a separator. By extension the gravimetric retort procedure allows the “capture of LGS and HGS to determined from laboratory data if the recommended three retorts are done.

# Annex B
(informative)

# Finder's Method

## B.1 Principle

**B.1.1** The Finder's method is a quick method to determine where a test screen will fit relative to a range of sieves with known micron (ASTM sieve number) openings, see Reference [10].

**B.1.2** This procedure is useful in determining between which two standard sieves to place an unknown "test screen" for use in the test procedure described in 9.5.

**B.1.3** This is not designed to be a normative test and cannot be used in place of the normative procedure in Section 9.

## B.2 Materials and Reagents

**B.2.1** AlO sized into specific cuts.

## B.3 Apparatus

**B.3.1** Balance with an accuracy of ±0.1 g.

**B.3.2** Weighing pans or papers.

**B.3.3** Sieve cover.

**B.3.4** Sieve pan.

**B.3.5** Sieve shaker that provides simultaneous rotating and tapping and accept sieve as described in 9.2.3

**B.3.6** Test screen that is mounted in holder of equal proportions to sieve cover and pan.

**B.3.7** Electrical or mechanical timer.

## B.4 Procedure

Finder's method procedure should be as per following.

a) Prepare accurately sized AlO sample cuts in accordance with 9.3.1.

b) The test mix consists of approximately 5 g weighed to an accuracy of ±0.1 g of eight different consecutive size ranges, and total to 40 g ± 1.0 g.

EXAMPLE A test sample may consist of 5 g AlO from 212 µm (ASTM 70) sieve, 5 g from 180 µm (ASTM 80) sieve, 5 g from 150 µm (ASTM 100) sieve, 5 g from 125 µm (ASTM 120) sieve, 5 g from 106 µm (ASTM 140) sieve, 5 g from 90 µm (ASTM 170) sieve, 5 g from 75 µm (ASTM 200) sieve, and 5 g from 63 µm (ASTM 230) sieve.

Table B.1 shows an example distribution, and the cumulative mass of the test mix. A graphical representation is shown in Figure B.1.

c) Weigh the empty test screen holder and record the mass as m1, expressed in grams.

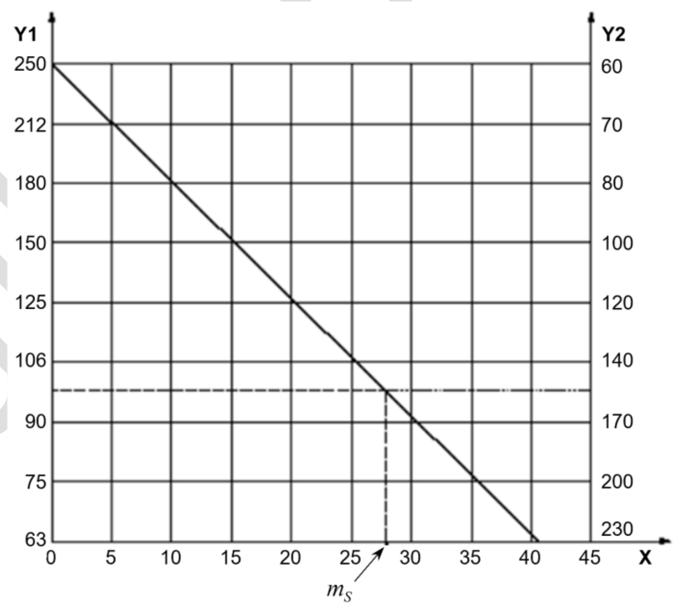
d) Place the test screen holder onto the sieve pan. Place the test mix of known mass [see B.4.b)] on the test screen and place the sieve cover on top. Mount the sieve stack securely in the sieve shaker and vibrate for 10 min as determined by a timer.

e) Reweigh the test screen holder with retained AlO and record the mass as m2, expressed in grams.

**Table B.1—Example of Finder's Method Sample Preparation**

| ASTM Sieve size* | | Mass of Individual Components<br>g | Cumulative Mass of Individual Components<br>g |
|---|---|---|---|
| **Sieve Opening**<br>µm | **US Sieve Number** | | |
| 250 | 60 | 0.0 | 0.0 |
| 212 | 70 | 5.4 | 5.4 |
| 180 | 80 | 5.2 | 10.6 |
| 150 | 100 | 4.8 | 15.4 |
| 125 | 120 | 5.1 | 20.5 |
| 106 | 140 | 5.7 | 26.2 |
| 90 | 170 | 4.9 | 31.1 |
| 75 | 200 | 4.4 | 35.5 |
| 63 | 230 | 5.3 | 40.8 |

* ASTM sieve designation is as per its opening in µm. US sieve number is the Alternate ASTM sieve designation.




**Key**

| | | | |
|---|---|---|---|
| **X** | cumulative mass, g | **Y1** | sieve opening, µm |
| $m_S$ | sample mass on test screen, g | **Y2** | US sieve number (alternative ASTM number) |

**Figure B.1—Graphical Example of Finder's Method**

## B.5 Calculation

The amount of test mix sample retained should be calculated using Equation (B.1) and recorded as the retained sample mass, $m_S$, expressed in grams.

$$m_S = m_2 - m_1 \qquad (B.1)$$

where:

$m_1$ is the mass of the empty test screen holder, expressed in grams;

$m_2$ is the mass of the test screen holder plus retained sample, expressed in grams.

The mass of AlO captured on the test screen indicates the equivalent size of the openings of the test screen.

EXAMPLE In the above example, if 27.6 g of AlOtest mix remained on the test screen, and by using Table B.1 or Figure B.1, the test screen opening should be between 90 µm and 106 µm then, for a sieve size between US no. 170 to US No. 140.

# Annex C
(normative)
# 50 mL Retort Procedure for Wet Drilled-solids Samples

## C.1 Principle

This procedure is intended for evaluating wet drilled-solids samples generated while using weighted drilling fluids that have larger solids or are a semi-solid paste. These types of samples cannot be analyzed using normal retort procedures based on direct volume or density measurements and shale shaker discharge for weighted drilling fluids from screens finer than API 170, centrifuge discharge, and other processing equipment discharge which contain a higher proportion of weighting materials (high relative density solids) than in the drilling fluid. This procedure provides a method to evaluate the types of processed wet drilled-solids samples described above and provides a method to calculate the correct drilling-fluid to drilled-solids ratio ($R_{\text{DF-DS}}$) and the excess quantity of weighting material being discharged. Portions of this procedure are intended for NAF fluids only.

This 50 mL retort procedure uses the drilling fluid base fluid as a topping fluid of known density to indirectly determine the volume of wet drilled-solids sample to be retorted plus mass measurements to perform a gravimetric analysis. Using the calculated wet drilled-solids sample volume and the mass measurements, the gravimetric evaluation is used to determine the mass and volume fractions of drilling fluid constituents in the sample.

## C.2 Apparatus

**C.2.1** Retort instrument, 50 mL as specified below**.**

a) Retort cell assembly, including an upper cell body, cup and lid constructed of 303 stainless steel, or equivalent.

   50 mL retort cup size with precision ±0.25 mL. The retort cup volume with lid shall be verified gravimetrically in accordance with the procedure and calculations given in API 13B-2.

b) Condenser, capable of cooling the oil and water vapors below their vaporization temperature.

c) Heating jacket, sufficient to heat to 500 °C ±40 °C (930 °F ±70 °F).

d) Temperature controller, capable of limiting the temperature of the retort to 500 °C ±40 °C (930 °F ±70 °F).

**C.2.2** Liquid receiver**,** to contain (TC), specially designed cylindrical glassware with a rounded bottom to facilitate cleaning and a funnel-shaped top to catch falling drops, meeting the following specifications:

a) precision: see Table C.1;

b) calibration (TC): at 20 °C (68 °F);

c) scale: milliliter or volume fraction (as a percentage);

d) material: transparent and inert to oil, water, and salt solutions at temperatures up to 32 °C (90 °F).

**Table C.1—Precision of Liquid Receiver**

| | | Total Volume | | |
|---|---|---|---|---|
| | | 10 mL | 20 mL | 50 mL |
| **Precision** | (0 % to 100 %) | ±0.05 mL | ±0.10 mL | ±0.25 mL |
| **Frequency of graduation marks** | (0 % to 100 %) | 0.10 mL | 0.10 mL | 0.50mL |

**C.2.3 Fine steel wool,** oil-free. Liquid steel wool or coated steel wool substitutes shall not be used for this application.

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**C.2.4 High-temperature-resistant silicone grease,** to be used as a thread sealant and lubricant.

**C.2.5 Pipe cleaners** and/or **T-drill.**

**C.2.6 Putty knife** or **spatula,** with blade diameter and shape to fit the inside dimensions of the sample cup of the retort.

**C.2.7 Corkscrew,** for removing steel wool and solids.

**C.2.8 Top-loading balance,** capable of weighing 2000 g with an accuracy of ±0.01 g.

**C.2.9 Small diameter metal rod** or **small lab spatula,** size appropriate for blending drilled-solids sample and topping base fluid inside retort cup.

**C.2.10 Base fluid,** for topping the retort cup, NAF for non-aqueous fluids or water for water-based drilling fluids. Base fluid should be identical to that used to build the mud in the sample analyzed.

**C.2.11 Squeeze bottle, transfer pipette, syringe,** or **dropper,** to add base fluid**.**

## C.3 Procedure

The following retort procedure shall be used for wet drilled-solids sample.

a) Ensure that the 50 mL retort sample cup, condenser passage and liquid receiver are clean, dry, and cooled from previous use. Thoroughly clean the inside of the sample cup and lid with a putty knife or spatula prior to each test. Periodically, the interior of the sample cup should also be lightly polished with steel wool. The condenser passage also will be cleaned and dried before each test using pipe cleaners. A build-up of material in the condenser can decrease condensation efficiency which can cause erroneous liquid readings in the test and, for some types of equipment, may present a safety hazard.

   **CAUTION—A moist or partially clogged condenser passage may be a safety hazard.**

b) If required, cool the heating jacket to less than 93 °C (200 °F).

c) Pack the upper cell retort body with steel wool.

d) Apply high-temperature-resistant silicone grease lubricant/sealant sparingly to the female threads of the upper cell body.

e) Apply high-temperature-resistant silicone grease lubricant/sealant sparingly to the threads on the condenser passage stem of the upper retort cell body.

f) Weigh and record the total mass of the empty retort assembly (retort sample cup, lid, and retort upper cell body, packed with steel wool). Record this as $m_{\mathrm{R1}}$, expressed in grams.

NOTE All mass values are recorded to the nearest 0.01 g.

g) Collect a representative sample of the wet drilled-solids sample.

h) Just prior to adding the sample to the cup, stir or mix the sample to be as homogenous as possible. Partially fill the retort sample cup to about 6 mm (0.25 in.) below the top of the cup.

i) Weigh and record the total mass of the wet drilled-solids sample in the retort assembly (retort sample cup, lid, and retort upper cell body, packed with steel wool). Record this as $m_{\mathrm{R2}}$, expressed in grams.

j) Using a squeeze bottle, transfer pipette, syringe, or dropper, add the topping base fluid (NAF or water) to the retort sample cup to about 3 mm (1/8 in.) below the top of the cup.

k) Using the metal rod or small lab spatula gently stir and blend the drilled-solids sample and base fluid to release any trapped air, being careful to not spill any base fluid or sample out of the top of the retort sample mud cup. Gently tapping the cup may help release trapped air. Scrape any solids adhering to the metal rod or spatula back into the retort sample cup.

l) Using the squeeze bottle, transfer pipette, syringe, or dropper, add topping base fluid (NAF or water) to fill the retort sample cup without spilling base fluid over the top.

m) Gently place the lid on the cup. Rotate the lid to obtain a proper fit. Ensure that a small excess of topping base fluid flows out of the hole in the lid. Wipe excess topping liquid from the lid and exterior of sample cup; avoid wicking any topping base fluid through the hole.

n) Screw the upper retort cell body onto the sample cup with lid while keeping the assembly vertical at all times. Weigh the assembled retort assembly (retort sample cup, lid, and upper cell body, packed with steel wool) filled with sample and topping base fluid. Record this as $m_{\mathrm{R3}}$, expressed in grams.

o) Attach the condenser to the retort assembly. Place the retort assembly into the heating jacket. Close the insulating lid.

p) Weigh an empty, clean, dry liquid receiver. Record this as $m_{\mathrm{R4}}$, expressed in grams. Place the receiver below the condenser passage outlet.

NOTE 1 It is recommended to use a liquid receiver whose capacity is the next size larger than the quantity of condensed liquid, based on previous tests. As an example, use a 20 mL liquid receiver instead of a 50 mL if previous tests have only collected 15 mL of condensate.

NOTE 2 Due to the rounded bottom of the liquid receiver, it might be helpful to place the liquid receiver in a 100 mL graduated cylinder to hold it on the top-loading balance while being weighed.

NOTE 3 The length of the liquid receiver might require that it be angled out from the retort condenser passage and perhaps supported off the edge of the worktable.

q) Turn on the heating jacket and allow the retort assembly to run a minimum of 1 h. Collect the condensate into the glass liquid receiver.

r) Turn off the retort heating jacket. Remove the liquid receiver and the retort assembly and allow them to air cool. Do not submerge or rinse retort assembly or liquid receiver in water to cool.

**CAUTION—The retort body is still extremely hot and will cause severe burns if contacted.**

s) Record the total condensed liquid volume, $V_R$, and water volume, $V_W$, collected in the liquid receiver.

Reading the meniscus correctly is extremely important for accuracy.

1) Always read the meniscus with the interface at eye level. Second,

2) For the air-to-liquid meniscus, read the volume at the “lowest point” of the meniscus which is in the middle of the liquid receiver. For opaque liquids it might be necessary to estimate the top of the liquid in the middle of the cylinder.

3) For the water-to-oil meniscus, read the water volume at the lowest point in the middle of the liquid receiver.

t) Weigh the glass liquid receiver and its condensed liquid content (oil and water). Record as $m_{R5}$, expressed in grams.

u) Remove the condenser from the passage stem of the cooled retort assembly and weigh the retort assembly (retort sample cup with retorted solids, lid, and retort body packed with steel wool). Record this as $m_{R6}$, expressed in grams.

v) Clean the retort assembly and condenser.

w) If the density of the base NAF topping fluid is not known, measure the density of the topping fluid using a mud balance, as described in API 13B-1 or API 13B-2. Gravimetric methods, such as a volumetric flask or density cup, are also acceptable. Alternatively, electronic portable handheld density-measuring devices may be used to measure the density of the topping fluid.

x) Record the base NAF topping fluid density as $\rho_{BF}$, to the nearest 0.01 g/mL, 10 kg/m3 (0.1 lb/gal).

## C.4 Calculation

### C.4.1 Testing Method Quality Control Limits

**C.4.1.1** Retort procedure using drilled-solids samples should be subject to operational error and inaccuracies. This procedure shall be considered valid only if accuracy criteria limits described below are met. The accuracy criteria limits which shall be met are described herafter.

a) Lost mass after retorting

Lost mass after retorting, $m_{\mathrm{LOST}}$expressed in grams, shall be calculated using Equation (C.1). The $m_{\mathrm{LOST}}$ value shall be less or equal to 1.50 g.

$$m_{\mathrm{LOST}} = m_{\mathrm{R3}} + m_{\mathrm{R4}} - \left(m_{\mathrm{R5}} + m_{\mathrm{R6}}\right) \leq 1.5 \text{ g} \tag{C.1}$$

where:

$m_{\mathrm{R3}}$ is the mass of retort sample cup filled with wet drilled-solids sample and topping base fluid, lid, and retort body packed with steel wool, expressed in grams;

$m_{\mathrm{R4}}$ is the mass of empty, clean, dry liquid receiver, expressed in grams;

$m_{\mathrm{R5}}$ is the mass of liquid receiver and its condensed liquid content (oil and water), expressed in grams;

$m_{\mathrm{R6}}$ is the mass of cooled retort assembly (retort sample cup with retorted solids, lid, and retort body packed with steel wool), expressed in grams;

NOTE A common cause of mass lost is the presence of organic additives, such as plant-based lost circulation materials, in the sample. These organic products undergo an oxidation – reduction reaction at high temperature where mass is loss to the formation of carbon dioxide gas that is not condensed.

b) Calculated NAF density from retort analysis

From retort procedure, for NADF, the base NAF density, $\rho_{\mathrm{BF\text{-}DS}}$, shall be calculated in SI units or in USC units, using respectively Equation (C.2) or Equation (C.3),where:

$m_{\mathrm{R5}}$ is the mass of liquid receiver and its condensed liquid content (oil and water), expressed in grams,

$m_{\mathrm{R4}}$ is the mass of empty, clean, dry liquid receiver, expressed in grams,

$V_{\mathrm{W}}$ is the volume of condensed water collected in the liquid receiver, expressed in milliliters,

$V_{\mathrm{R}}$ is the total volume of condensed liquid collected in the liquid receiver, expressed in milliliters.

NOTE The density of condensed water is 1.0 g/mL. Therefore, the mass in grams of the condensed water is numerically equivalent to the volume of the water measured in milliliters.

1) $\rho_{\text{BF-DS,SI}}$, expressed in kilograms per cubic meter,

$$\rho_{\text{BF-DS,SI}} = 1000 \times \frac{(m_{\text{R5}} - m_{\text{R4}} - V_{\text{W}})}{(V_{\text{R}} - V_{\text{W}})} \tag{C.2}$$

2) $\rho_{\text{BF-DS,USC}}$, expressed in pounds per gallon, shall be calculated using Equation (C.3).

$$\rho_{\text{BF-DS,USC}} = 8.345 \times \frac{(m_{\text{R5}} - m_{\text{R4}} - V_{\text{W}})}{(V_{\text{R}} - V_{\text{W}})} \tag{C.3}$$

3) Using Equation (C.4), the calculated base NAF density from this retort analysis $\rho_{\text{BF-DS}}$, shall be within ±5% of measured density , $\rho_{\text{BF}}$, of base NAF topping fluid from C.3 item x), using the same units.

$$0.95 \times \rho_{\text{BF}} \leq \rho_{\text{BF-DS}} \leq 1.05 \times \rho_{\text{BF}} \tag{C.4}$$

where:

$\rho_{\text{BF}}$ is the density of the base NAF used for topping expressed in kilograms per cubic meter (pounds per gallon).

c) Average density (volumic mass) of dry retorted drilled-solids sample

The uncorrected average density (volumic mass) of dry retorted drilled-solids sample, $\overline{\rho_{\text{DS-D}}}$ **,** shall be calculated expressed in SI units or in USC unites, using respectively Equation (C.5) or (C.6) ,where :

$m_{\text{R6}}$ is the mass of cooled retort assembly (retort sample cup with retorted solids, lid, and retort body packed with steel wool), expressed in grams,

$m_{\text{R1}}$ is the mass of the empty retort sample cup, lid, and retort upper cell body packed with steel wool, expressed in grams,

$V_{\text{R}}$ is the total volume of condensed liquid collected in the liquid receiver, expressed in milliliters.

NOTE 1 Equations (C.5) and (C.6) does not correct the dry retorted solids mass and volume or density for soluble salts, however, in most cases this is not significant due to the relatively larger volume of solids compared to the volume of drilling fluid and its soluble solids content.

NOTE 2 The number 50 in Equations (C.5) and (C.6) comes from the retort cup volume for the 50 mL retort.

1) $\overline{\rho_{\text{DS-D,SI}}}$ , expressed in kilograms per cubic meter

$$\overline{\rho_{\text{DS-D,SI}}} = 1000 \times \frac{(m_{\text{R6}} - m_{\text{R1}})}{(50 - V_{\text{R}})} \tag{C.5}$$

2) $\overline{\rho_{\text{DS-D,USC}}}$ , expressed in pounds per gallon

$$\overline{\rho_{\text{DS-D,USC}}} = 8.345 \times \frac{\left(m_{\text{R6}} - m_{\text{R1}}\right)}{\left(50 - V_{\text{R}}\right)} \qquad \text{(C.6)}$$

3) Using Equation (C.7), the value of uncorrected average density of dry retorted drilled-solids sample, $\overline{\rho_{\text{DS-D}}}$ shall be greater than the density of the LGS, i.e. formation drilled-solids, $\rho_{\text{LG}}$ (often 2600 kg/m$^3$ or 21.7 lb/gal) and less than the density of the weighting material, $\rho_{\text{WM}}$ (often 4200 kg/m$^3$ or 35.0 lb>gal), expressed in kilograms per cubic meter ( pounds per gallon).

$$\rho_{\text{LG}} \leq \overline{\rho_{\text{DS-D}}} \leq \rho_{\text{WM}} \qquad \text{(C.7)}$$

NOTE When drilling salt formation with a NADF, the relative density of the LGS or formation drilled-solids, $\rho_{\text{LG}}$, may be lower than 2600 kg/m$^3$ or 21.7 lb/gal.

where:

$\rho_{\text{LG}}$ is the density of the LGS, expressed in kilograms per cubic meter (pounds per gallon);

$\rho_{\text{WM}}$ is the density of the weighting materials, expressed in kilograms per cubic meter (pounds per gallon).

**C.4.1.2** The retort procedure shall be repeated if these criteria, C.4.1.1 item a), b-3) and c-3), are not met.

## C.4.2 Density of the Wet Drilled-solids Sample

### C.4.2.1 Volume of NAF topping fluid

The volume of topping base NAF , $V_{\text{TOP}}$ , is used to determine the volume of wet drilled-solids and the density of the wet drilled-solids sample.

According to the units used for the density of the base NAF, $\rho_{\text{BF}}$ , in SI units or USC units ,$V_{\text{TOP}}$ expressed in milliliters, shall be calculated using Equation (C.8) or Equation C.9) respectively, where:

$V_{\textbf{TOP}}$ is the volume of base NAF topping fluid , expressed in milliliters;

$m_{\text{R3}}$ is the mass of retort sample cup filled with wet drilled-solids sample and topping base fluid, lid, and retort body packed with steel wool, expressed in grams;

$m_{\text{R2}}$ is the mass of retort sample cup filled with wet drilled-solids sample, lid, and retort body packed with steel wool, expressed in grams;

a) with the density of the base NAF used for topping, $\rho_{\text{BF,SI}}$ ,expressed in kilograms per cubic meter:

$$V_{\mathrm{TOP}} = 1000 \times \frac{\left(m_{\mathrm{R3}} - m_{\mathrm{R2}}\right)}{\rho_{\mathrm{BF,SI}}} \quad \text{(C.8)}$$

and,

b) with the density of the base NAF used for topping, $\rho_{\mathrm{BF,USC}}$ ,expressed in pounds per gallon:

$$V_{\mathrm{TOP}} = 8.345 \times \frac{\left(m_{\mathrm{R3}} - m_{\mathrm{R2}}\right)}{\rho_{\mathrm{BF,USC}}} \quad \text{(C.9)}$$

#### C.4.2.2 Density of the wet drilled-solids sample

The density of the wet drilled-solids sample, $\rho_{\mathrm{DS\text{-}W}}$, expressed in SI units or USC units, shall be determined using respectively, Equation (C.10) or Equation (C.11), where:

$m_{\mathrm{R2}}$ is the mass of retort sample cup filled with wet drilled-solids sample, and retort body packed with steel wool, expressed in grams;

$m_{\mathrm{R1}}$ is the mass of the empty retort sample cup, lid, and retort upper cell body packed with steel wool, expressed in grams;

$V_{\mathrm{TOP}}$ is the volume of topping base fluid, expressed in milliliters.

NOTE The number 50 comes from the retort cup volume for the 50 mL retort.

a) density of the wet drilled-solids sample, $\rho_{\mathrm{DS\text{-}W,SI}}$, expressed in kilograms per cubic meter: density of the wet drilled-solids sample, $\rho_{\mathbf{DS\text{-}W,USC}}$, expressed in pounds per gallon:

$$\rho_{\mathrm{DS\text{-}W,USC}} = 8.345 \times \frac{\left(m_{\mathrm{R2}} - m_{\mathrm{R1}}\right)}{\left(50 - V_{\mathrm{TOP}}\right)} \quad \text{C.11)}$$

### C.4.3 Liquid and Solids Content of Wet Drilled-solids Sample

#### C.4.3.1 General

The liquid and solids content of the various retained and discarded processed wet drilled-solids streams are important to optimize processing equipment, reduce cost, and for performance reporting. This section provides calculations for determining the water, NAF, total solids, LGS and weighting-material solids contents and concentration on the wet drilled-solids sample.

NOTE The calculations in this section do not correct the solids and liquid contents for soluble solids (i.e. salts). However, in most cases this is not significant due to the relatively larger volume of solids compared to the volume of drilling fluid and its soluble solids content.

#### C.4.3.2 Water content

The volume fraction of water for the wet drilled-solids sample, $\varphi_{\text{W-DS}}$, expressed as a percentage, shall be calculated using Equation C.12.

$$\varphi_{\text{W-DS}} = 100 \times \frac{V_{\text{W}}}{\left(50 - V_{\text{TOP}}\right)} \quad \text{(C.12)}$$

where:

$V_{\text{W}}$ is the volume of condensed water collected in the liquid receiver, expressed in milliliters;

$V_{\text{TOP}}$ is then volume of topping base fluid in the liquid receiver, expressed in milliliters.

NOTE The number 50 comes from the retort cup volume for the 50 mL retort.

#### C.4.3.3 Non-aqueous content

##### C.4.3.3.1 NAF content of wet drilled-solids and "retained oil" on wet cuttings

The content of base NAF for a wet drilled-solids waste stream is important to optimize processing equipment, reduce cost, and for performance reporting. While this is primarily intended for NADF operations, this procedure also measures the volume of NAF in water base drilled-solids wastes where the water base drilling fluid contains a significant portion of NAF, such as for direct emulsion fluids. The NAF content is expressed as a mass percent for the wet drilled-solids sample, $w_{\text{NAF-DS}}$. It is the same value as the retained NAF on wet cuttings, or the "retained oil (NAF) on cuttings" (ROC) for wet cuttings (see API 13B-2). However, $w_{\text{NAF-DS}}$ determined using this procedure may not comply with regulatory requirements. Also, ROC values may be based on post-retorting dry solids mass, not wet pre-retorting sample mass, and reported using different units, such as mass fraction, or milligrams per kilogram.

##### C.4.3.3.2 NAF mass fraction

The mass fraction of NAF for the wet drilled-solids sample, $w_{\text{NAF-DS}}$, expressed as a decimal fraction, shall be calculated using Equation (C.13).

$$w_{\text{NAF-DS}} = \frac{\left[\left(m_{\text{R5}} - m_{\text{R4}}\right) - \left(m_{\text{R3}} - m_{\text{R2}}\right) - V_{\text{W}}\right]}{\left(m_{\text{R2}} - m_{\text{R1}}\right)} \quad \text{(C.13)}$$

where:

$m_{\text{R5}}$ is the mass of liquid receiver and its condensed liquid content (oil and water), expressed in grams;

$m_{\text{R4}}$ is the mass of empty, clean, dry liquid receiver, expressed in grams;

$m_{\text{R3}}$ is the mass of retort sample cup filled with wet drilled-solids sample and topping base fluid, lid, and retort body packed with steel wool, expressed in grams;

$m_{R2}$ is the mass of the wet drilled-solids sample in the retort sample cup, lid, and retort upper cell body packed with steel wool, expressed in grams;

$m_{R1}$ is the mass of the empty retort sample cup, lid, and retort upper cell body packed with steel wool, expressed in grams;

$V_W$ is the volume of condensed water collected in the liquid receiver, expressed in milliliters.

#### C.4.3.3.3 NAF volume fraction

The volume fraction of NAF for the wet drilled-solids sample, $\varphi_{NAF\text{-}DS}$, expressed as a percentage, shall be calculated using Equation (C.14).

$$\varphi_{NAF\text{-}DS} = 100 \times \frac{(V_R - V_W - V_{TOP})}{(50 - V_{TOP})} \quad \text{(C.14)}$$

where:

$V_R$ is the total volume of condensed liquid collected in the liquid receiver, expressed in milliliters;

$V_W$ is the volume of condensed water collected in the liquid receiver, expressed in milliliters;

$V_{TOP}$ is the volume of topping base fluid in the liquid receiver, expressed in milliliters.

NOTE The number 50 comes from the retort cup volume for the 50 mL retort.

### C.4.3.4 NAF-to-Water ratio

#### C.4.3.4.1 General

For NADF and high NAF content water-based drilling fluid, the NAF and water ratio values, $R_{NAF}$ and $R_W$, for the liquid phase of the wet drilled-solids samples should be similar to the values for the drilling fluid (see API 13B-2). If these values for the wet drilled-solids samples are significantly different, it may indicate that the weighting-material is water wet and being disproportionally separated or that NAF base fluid is being added to processing equipment such as a decanting centrifuge or rotary cuttings-dryer.

#### C.4.3.4.2 Ratio of NAF for the liquid phase of the wet drilled-solids sample ($R_{NAF}$)

The $R_{NAF}$ is the ratio of the volume fraction of NAF to the sum of the volume fractions of NAF and pure water from retort analysis. The $R_{NAF}$ expressed as a percentage, shall be calculated using Equation (C.15).

$$R_{NAF} = 100 \times \frac{\varphi_{NAF\text{-}DS}}{(\varphi_{NAF\text{-}DS} + \varphi_{W\text{-}DS})} \quad \text{(C.15)}$$

where:

$\varphi_{NAF\text{-}DS}$ is the volume fraction of NAF, of the wet drilled-solids sample, expressed as a percentage;

$\varphi_{\text{W-DS}}$ is the volume fraction of condensed water, expressed as a percentage, of the wet drilled-solids sample.

#### C.4.3.4.3 Ratio of water for the liquid phase of the wet drilled-solids sample ($R_{\text{W}}$)

The $R_{\text{W}}$ is the ratio of the volume fraction of water to the sum of the volume fractions of NAF and condensed water from the retort analysis. The $R_{\text{W}}$ expressed as a percentage, shall be calculated using Equation (C.16).

$$R_{\text{W}} = 100 - R_{\text{NAF}} \quad \text{(C.16)}$$

where:

$R_{\text{NAF}}$ is the ratio of the volume fraction of NAF to the sum of the volume fractions of NAF and condensed water, from retort analysis, expressed as a percentage.

NOTE The NAF-to-water ratio is commonly named oil-to-water ratio and sometimes expressed as OWR, and the numerical values are normally rounded to the nearest whole number.

### C.4.3.5 Solids Content

#### C.4.3.5.1 General

The solids content and constituents of various retained and discarded processed wet drilled-solids streams is important to optimize processing equipment, reduce cost, and for performance reporting. In particular this assist in being able to quantify the valuable weighting material and base fluid that is retained or discarded relative to the low-gravity solids for each processing stream.

#### C.4.3.5.2 Total solids in wet drilled-solids

The volume fraction of total solids in the wet drilled-solids sample, $\varphi_{\text{DS-Tot}}$, expressed as a percentage, shall be calculated using Equation (C.17).

$$\varphi_{\text{DS-Tot}} = 100 - \varphi_{\text{NAF-DS}} - \varphi_{\text{W-DS}} \quad \text{(C.17)}$$

where:

$\varphi_{\text{NAF-DS}}$ is the volume fraction of NAF of the wet drilled-solids sample expressed as a percentage;

$\varphi_{\text{W-DS}}$ is the volume fraction of pure water of the wet drilled-solids sample, expressed as a percentage.

**C.4.3.5.3 Weighting-material solids in wet drilled-solids**

The volume fraction of weighting-material solids in the wet drilled-solids sample, $\varphi_{\text{WM-DS}}$, expressed as a percentage, shall be calculated using Equation (C.18) with all density terms using the same units.

$$\varphi_{\text{WM-DS}} = \varphi_{\text{DS-Tot}} \times \frac{\left(\overline{\rho_{\text{DS-D}}} - \rho_{\text{LG}}\right)}{\left(\rho_{\text{WM}} - \rho_{\text{LG}}\right)} \tag{C.18}$$

where:

$\varphi_{\text{DS-Tot}}$ is the volume fraction of total solids in the wet drilled-solids sample, expressed as a percentage;

$\overline{\rho_{\text{DS-D}}}$ is the uncorrected average density (volumic mass) of the dry drilled-solids sample, expressed in kilograms per cubic meter (pounds per gallon);

$\rho_{\text{WM}}$ is the density of the weighting-material solids, expressed in kilograms per cubic meter (pounds per gallon);

$\rho_{\text{LG}}$ is the density of the LGS, expressed in kilograms per cubic meter (pounds per gallon).

**C.4.3.5.4 Low-gravity solids in wet drilled-solids**

The volume fraction of LGS in the wet drilled-solids sample, $\varphi_{\text{LG-DS}}$, expressed as a percentage, shall be calculated using Equation (C.19).

$$\varphi_{\text{LG-DS}} = \varphi_{\text{DS-Tot}} - \varphi_{\text{WM-DS}} \tag{C.19}$$

where:

$\varphi_{\text{DS-Tot}}$ is the volume fraction of total solids in the wet drilled-solids sample, expressed as a percentage,

$\varphi_{\text{WM-DS}}$ is the volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage.

**C.4.3.5.5 Weighting-material solids for total solids content**

The volume fraction of weighting-material solids for the total solids content, $\varphi_{\text{WM-Tot}}$, expressed as a percentage, shall be calculated using Equation (C.20).

$$\varphi_{\text{WM-Tot}} = 100 \times \frac{\varphi_{\text{WM-DS}}}{\varphi_{\text{DS-Tot}}} \tag{C.20}$$

where:

$\varphi_{\text{DS-Tot}}$ is the volume fraction of total solids in the wet drilled-solids sample, expressed as a percentage;

$\varphi_{\text{WM-DS}}$ is the volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage.

#### C.4.3.5.6 LGS for total solids content

The volume fraction of LGS for the total solids content, $\varphi_{\text{LG-Tot}}$, expressed as a percentage, shall be calculated using Equation (C.21).

$$\varphi_{\text{LG-Tot}} = 100 - \varphi_{\text{WM-Tot}} \tag{C.21}$$

where:

$\varphi_{\text{WM-Tot}}$ is the volume fraction of weighting-material solids for the total solids content, expressed as a percentage.

## C.4.4 Drilling-fluid to Drilled-solids Ratio

### C.4.4.1 General

For NADF, the drilling-fluid to drilled-solids ratio ($R_{\text{DF-DS}}$) of the discarded wet drilled-solids samples evaluated with this topped-up retort procedure shall be calculated with the equations provided in C.4.4. These equations assume that all of the base NAF in the discarded wet drilled-solids sample come from the NADF and not from other sources, such as when base NAF is added to a decanting centrifuge or rotary cuttings-dryer. Using the base NAF content of the NADF, the quantity of drilling fluid can be determined plus the excess quantity of weighting-material in the discarded wet drilled-solids sample. If the NAF ratio from this procedure differs substantially from the NAF ratio for the drilling fluids the calculations in C.4.4 cannot be applicable.

### C.4.4.2 Drilling fluid in the wet drilled-solids

The volume fraction of drilling fluid in the wet drilled-solids sample, $\varphi_{\text{DF-DS}}$, expressed as a percentage, shall be calculated using Equation (C.22).

$$\varphi_{\text{DF-DS}} = 100 \times \frac{\varphi_{\text{NAF-DS}}}{\varphi_{\text{NAF-DF}}} \tag{C.22}$$

where:

$\varphi_{\text{NAF-DS}}$ is the volume fraction of NAF of the wet drilled-solids sample, expressed as a percentage;

$\varphi_{\text{NAF-DF}}$ is the volume fraction of NAF of the whole NADF, expressed as a percentage.

#### C.4.4.3 Weighting-material solids associated with the drilling fluid in wet drilled-solids

The volume fraction of weighting-material solids associated with the drilling fluid content in the wet drilled-solids sample, $\varphi_{\text{WM-DF}}$, expressed as a percentage, shall be calculated using Equation (C.23).

$$\varphi_{\text{WM-DF}} = \frac{\varphi_{\text{WM}} \times \varphi_{\text{DF-DS}}}{100} \quad \text{(C.23)}$$

where:

$\varphi_{\text{WM}}$ is the volume fraction of weighting-material solids of the whole drilling-fluid, expressed as a percentage;

$\varphi_{\text{DF-DS}}$ is the volume fraction of drilling fluid of the wet drilled-solids sample, expressed as a percentage.

#### C.4.4.4 Excess volume fraction of weighting-material solids of the wet drilled-solids

The volume fraction of excess weighting-material solids in the wet drilled-solids sample, $\varphi_{\text{WM-Ex}}$, expressed as a percentage, shall be calculated using Equation (C.24).

$$\varphi_{\text{WM-Ex}} = \varphi_{\text{WM-DS}} - \varphi_{\text{WM-DF}} \quad \text{(C.24)}$$

where:

$\varphi_{\text{WM-DS}}$ is the volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage;

$\varphi_{\text{WM-DF}}$ is the volume fraction of weighting-material solids associated with the drilling fluid in the wet drilled-solids sample, expressed as a percentage.

NOTE If the volume fraction of excess weighting-material solids in the wet drilled-solids sample from Equation (C.24,) is a negative number, use zero for $\varphi_{\text{WM-Ex}}$ in Equation (C.25).

#### C.4.4.5 Drilling-fluid to drilled-solids ratio of the wet drilled-solids

The drilling-fluid to drilled-solids ratio of the wet drilled-solids sample, $R_{\text{DF-DS}}$, expressed as a decimal fraction, shall be calculated using Equation (C.25).

$$R_{\text{DF-DS}} = \frac{\left(\varphi_{\text{DF-DS}} + \varphi_{\text{WM-Ex}}\right)}{\left[100 - \left(\varphi_{\text{DF-DS}} + \varphi_{\text{WM-Ex}}\right)\right]} \quad \text{(C.25)}$$

where:

$\varphi_{\text{DF-DS}}$ is the volume fraction of drilling-fluid of the wet drilled-solids sample, expressed as a percentage;

$\varphi_{\text{WM-Ex}}$ is the excess volume fraction of weighting-material solids in the wet drilled-solids sample, expressed as a percentage.

# Annex D
**(informative)**

# Example Calculations System Performance of Drilling-fluid Processing Equipment

## D.1 Principle

The example calculations in this annex are intended to show how the equations in Section 5 and Annex C are used to evaluate system performance processing equipment. Three different cases are presented:

— System Performance by entire interval, shale shaker discharge (D.2);

— System Performance by daily data with cumulative totals, shale shaker discharge (D.3);

— System Performance single daily data with shale shaker and centrifuge discharge, using Annex C topped-up retort method for centrifuge discharge (D.4).

This annex includes examples in which the units are typical for the relevant application. Calculations are limited to using USC units. The calculated values are rounded for simplicity and may not exactly match values determined from spreadsheet calculations where more exact values are carried from one calculation to the next.

NOTE The term "wet" is used to mean that the material is a combination of drilling-fluid and drilled-solid.

## D.2 System Performance by Entire Interval, Shale Shaker Discharge

### D.2.1 General

The example calculations in this section illustrate the use of equations from Section 5 for evaluating system performance by interval with discharge from shale shakers only.

Drilling fluid processing system is schematized Figure D.1. Interval data are provided Table D.1 and results of the procedure to determine the density of discarded drilling-solids ( see 5.5) by the shale shaker are provided Table D.2.

NOTE Example calculations are done using only USC units, therefore symbols subscripts "USC" are not reported for symbols and Equations as it should be generally done by users in the field.

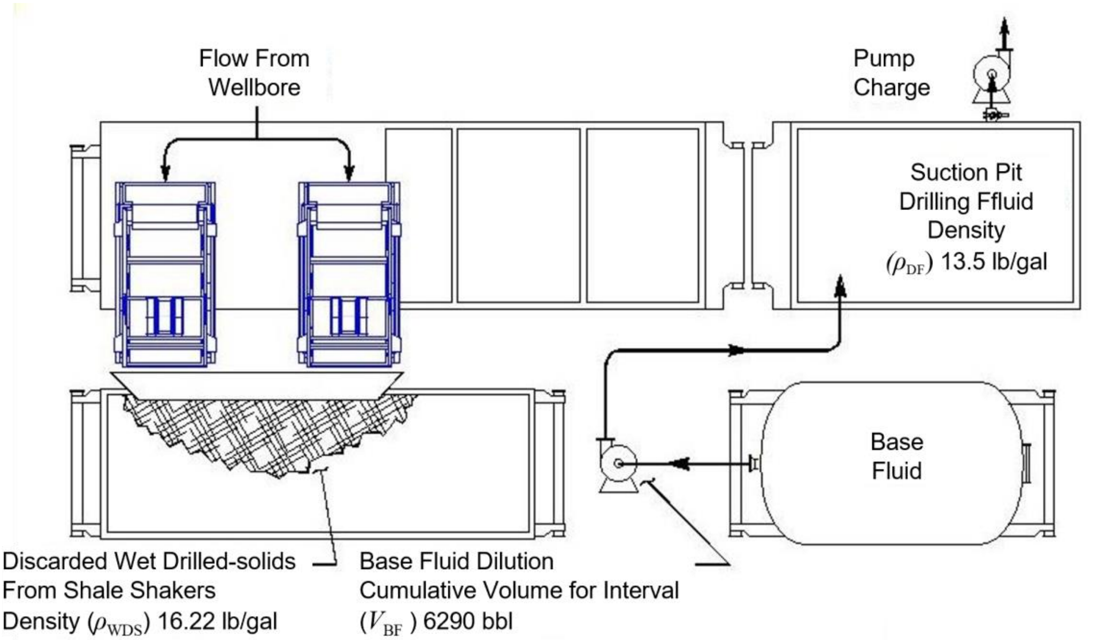


**Figure D.1—Drilling-fluid Processing Equipment (System Performance Calculation Example D.2)**

**Table D.1—Interval and Drilling-fluid Input Data (System Performance Calculation Example D.2)**

| **Interval and Input Data** | |
|---|---|
| Parameter | USC Units |
| Drilling fluid density, $\rho_{DF}$ | 13.5 lb/gal |
| Base fluid added for dilution, $V_{BF}$ | 6290 bbl |
| Discarded wet drilled-solids density from shale shakers $\rho_{WDS}$, | 16.22 lb/gal |
| Base fluid volume fraction for drilling fluid with target drilled-solids) concentration, $\varphi_{BF}$ | 80 % |
| Hole diameter, $D_H$ | 12.25 in. |
| Wellbore length, $L_H$ | 10,795 ft |
| Wellbore enlargement, $\varphi_E$ | 0.0 % |
| Target drilled-solids concentration, $\varphi_{DS}$ | 5 % |

**Table D.2—Measuring Density of Discarded Drilling-solids by Shale Shaker (System Performance Calculation Example D.2)**

| **Test procedure data** | |
|---|---|
| Final Volume, $V_{F,USC}$ | 2 qt |
| Density of drilled-solids, $\rho_{DS}$ | 21.7 lb/gal |
| Density of drilling fluid, $\rho_{DF}$ | 13.5 lb/gal |
| Mass of the weighing container and ½ final volume of base fluid, $m_{C1}$ | 2.75 lb |
| Mass of the weighing container plus ½ final volume of wet discarded solids and ½ final volume of base fluid, $m_{C2}$ | 10.86 lb |

## D.2.2 Example Calculations

**D.2.2.1** Calculations should be based on Equations provided in Section 5 and allow to determine the overall drilled-solids removal system efficiency, the drilling-fluid to drilled-solids ratio, overall waste volume and an optimum drilled-solids removal system efficiency for the entire interval with shale shakers only ( see D.2.2.2 to D.2.2.16).

**D.2.2.2** Calculate the base fluid volume fraction for the clean drilling fluid (zero-drilled-solids), $\varphi_{BDF}$, from the base fluid fraction for the target (or average) drilled-solids concentration using Equation (2). The base fluid fraction for the target drilled-solids concentration is the value reported on the daily drilling fluid report from a retort analysis, (for situations where this value changes significantly during an interval, volume-weighted average values should be used).

$$\varphi_{BDF} = \varphi_{BF} \times \left[ \frac{100}{(100 - \varphi_{DS})} \right] = 80 \times \left[ \frac{100}{(100 - 5)} \right] = 80 \times 1.0526 = 84.21 \approx 84.2 \quad \%$$

**D.2.2.3** Using the volume of base fluid added for the entire interval, $V_{\mathrm{BF}}$,calculate the volume of zero-drilled-solids (clean) drilling fluid used for dilution, $V_{\mathrm{DIL}}$, using Equation (1) in USC units.

$$V_{\mathrm{DIL}} = \frac{100 \times V_{\mathrm{BF}}}{\varphi_{\mathrm{BDF}}} = \frac{100 \times 6290}{84.21} = 7469 \ \text{bbl}$$

NOTE Equation (1) is also used for calculations in SI units.

**D.2.2.4** Calculate the excavated volume of drilled-solids, $V_{\mathrm{DS}}$, using Equation (5) for USC units.

$$V_{\mathrm{DS,USC}} == \frac{{D_{\mathrm{H,USC}}}^2}{1029.4} \times L_{\mathrm{H,USC}} \times \left(1 - \frac{\varphi_{\mathrm{E}}}{100}\right) = \frac{12.25^2}{1029.4} \times 10{,}795 \times \left(1 + \frac{0.0}{100}\right) = 0.1458 \times 10{,}795 \times 1.0 = 1574 \ \text{bbl}$$

NOTE Equation (4) is used for calculations in metric SI units

**D.2.2.5** Calculate drilled-solids removal system efficiency, $\eta_{\mathrm{DSR}}$, using Equation (6) for USC units

$$\eta_{\mathrm{DSR}} = 100 - \frac{(100 \times V_{\mathrm{DIL}} \times \varphi_{\mathrm{DS}})}{\left[V_{\mathrm{DS}} \times (100 - \varphi_{\mathrm{DS}})\right]} = 100 - \frac{(100 \times 7469 \times 5)}{\left[1574 \times (100 - 5)\right]} \approx 75 \ \%$$

NOTE Equation (6) is also used for calculations in SI units.

**D.2.2.6** Calculate the volume of retained drilled-solids, $V_{\mathrm{RDS}}$, using the drilled-solids removal system efficiency, $\eta_{\mathrm{DSR}}$, the excavated volume of drilled-solids, $V_{\mathrm{DS}}$, with Equation (7) and USC units.

$$V_{\mathrm{RDS}} = V_{\mathrm{DS}} \times \left(1 - \frac{\eta_{\mathrm{DSR}}}{100}\right) = 1574 \times \left(1 - \frac{75}{100}\right) = 393 \ \text{bbl}$$

NOTE Equation (7) is also used for calculations in SI units.

**D.2.2.7** Calculate the dilution drilling fluid volume including the retained drilled-solids percent, $V_{\mathrm{DIL+RDS}}$, using Equation (8) and USC units. This is simply the sum of the clean dilution drilling fluid volume plus the retained drilled-solids.

$$V_{\mathrm{DIL+RDS}} = V_{\mathrm{DIL}} + V_{\mathrm{RDS}} = 7469 + 393 = 7862 \ \text{bbl}$$

NOTE Equation (8) is also used for calculations in SI units.

**D.2.2.8** For situations where the measured dilution volume of drilling fluid is accurate and the preferred value to monitor, the drilled-solids removal system efficiency, $\eta_{\mathrm{DSR}}$, can be calculated using the alternative Equation (9) with UCS units.

$$\eta_{\mathrm{DSR}} = 100 - \left[\frac{\varphi_{\mathrm{DS}} \times V_{\mathrm{DIL+RDS}}}{V_{\mathrm{DS}}}\right] = 100 - \frac{5 \times 7862}{1574} \approx 75 \ \%$$

NOTE Equation (9) is also used for calculations in SI units.

**D.2.2.9** Calculate the volume of discarded wet drilled-solids, $V_{\text{DDS}}$, using the drilled-solids removal system efficiency and the excavated volume of drilled-solids with Equation (10) and USC units.

$$V_{\text{DDS}} = \frac{\eta_{\text{DSR}} \times V_{\text{DS}}}{100} = \frac{75 \times 1574}{100} = 1181 \ \text{bbl}$$

NOTE Equation (10) is also used for calculations in SI units.

**D.2.2.10** To calculate the drilling-fluid to drilled-solids ratio, the density of the wet drilled-solids discharged from shale shakers discharge shall be measured using the procedure detailed in 5.5.

When using USC units and a final volume of two quarts ($V_{\text{F,USC}}$ = 2 qt), calculate the density of the discarded wet drilled-solids using Equation (12).

$$\rho_{\text{WDS}} = \frac{4 \times \left(w_{\text{C2}} - w_{\text{C1}}\right)}{V_{\text{F,USC}}} = 2 \times \left(m_{\text{C2}} - m_{\text{C1}}\right) = 2 \times \left(10.86 - 2.75\right) = 16.22 \ \text{lb / gal}$$

NOTE Equation (11) is used for calculations in SI units with a final volume of two liters ($V_{\text{F,SI}}$ = 2 L ).

**D.2.2.11** Calculate the drilling-fluid to drilled-solids ratio , $R_{\text{DF-DS}}$, of the discharged wet drilled-solids from shale shakers using Equation (13) and USC units.

$$R_{\text{DF-DS}} = \frac{\left(\rho_{\text{DS}} - \rho_{\text{WDS}}\right)}{\left(\rho_{\text{WDS}} - \rho_{\text{DF}}\right)} = \frac{21.7 - 16.22}{16.22 - 13.5} = \frac{5.48}{2.72} = 2.0 \ \text{v / v}$$

NOTE Equation (13) is also used for calculations in SI units

**D.2.2.12** For this example, the shale shaker discharge is the only discharge, so the total volume of discarded drilling fluid with the discharged wet drilled-solids, $V_{\text{DDF}}$, is calculated from the drilling-fluid to drilled-solids ratio (see D.2.2.11) and the volume of discarded drilled-solids ($V_{\text{DDS}}$) using Equation (15) and USC units.

$$R_{\text{DF-DS-Tot}} = R_{\text{DF-DS}} = 2.0 \ \text{v / v}$$

$$V_{\text{DDF}} = R_{\text{DF-DS-Tot}} \times V_{\text{DDS}} = 2 \times 1181 = 2362 \ \text{bbl}$$

NOTE Equation (15) is also used for calculations in SI units.

**D.2.2.13** Calculate the volume of excess drilling fluid volume built, used for dilution, $V_{\text{DIL-Exc}}$, using Equation (16) and USC units:

$$V_{\text{DIL-Exc}} = V_{\text{DIL+RDS}} - V_{\text{DDF}} - V_{\text{DS}} = 7862 - 2362 - 1574 = 3926 \text{ bbl}$$

NOTE Equation (16) is also used for calculations in SI units.

**D.2.2.14** Calculate the overall waste volume including the excess drilling fluid (over what is needed for dilution and for the surface pits to remain constant), $V_{\text{Waste}}$, using Equation (17) and USC units.

$$V_{\text{Waste}} = V_{\text{DDS}} + V_{\text{DDF}} + V_{\text{DIL-Exc}} = 1181 + 2362 + 3926 = 7469 \text{ bbl}$$

NOTE Equation (17) is also used for calculations in SI units.

**D.2.2.15** To estimate the volume of drilling fluid which will be needed for dilution and the associated waste volumes when planning wells, 5.4 through 5.7 are used. The dilution volume to be used for 5.4 to 5.6 is calculated by assuming typical values for the drilled-solids removal system efficiency, target drilled-solids concentration, and the drilling-fluid to drilled-solids ratio.

Calculate the dilution volume of clean drilling fluid per unit volume of excavated drilled-solids, $V_{\text{DIL}}/V_{\text{DS}}$, using Equation (18).

$$\frac{V_{\text{DIL}}}{V_{\text{DS}}} = \frac{(100 - \eta_{\text{DSR}}) \times (100 - \varphi_{\text{DS}})}{100 \times \varphi_{\text{DS}}} = \frac{(100-75)\times(100-5)}{100\times 5} = 4.75 \text{ v/v}$$

**D.2.2.16** Calculate the optimum solids-removal-efficiency, $\eta_{\text{DSR-Opt}}$, that will result in no excess drilling fluid being required for dilution to maintain the target concentration of drilled-solids for a given drilling-fluid to drilled-solids ratio using Equation (19).

$$\eta_{\text{DSR-Opt}} = 100 \times \frac{(100 - \varphi_{\text{DS}})}{\left[100 + (\varphi_{\text{DS}} \times R_{\text{DF-DS-Tot}})\right]} = 100 \times \frac{(100 - 5)}{\left[100 + (5 \times 2.0)\right]} = 86.4 \text{ \%}$$

## D.3 System Performance by Daily Data with Cumulative Totals, Shale Shaker Discharge

### D.3.1 General

The example calculations in this section illustrate the use of equations from Section 5 for evaluating system performance from daily data with discharge from shale shakers only.

Drilling fluid processing system is schematized Figure D.2 for the first day ,Day 1, of the interval . Interval data are provided Table D.3.

NOTE Example calculations are done using only USC units, therefore symbols subscripts “USC” are not reported for symbols and Equations as it should be generally done by users in the field.

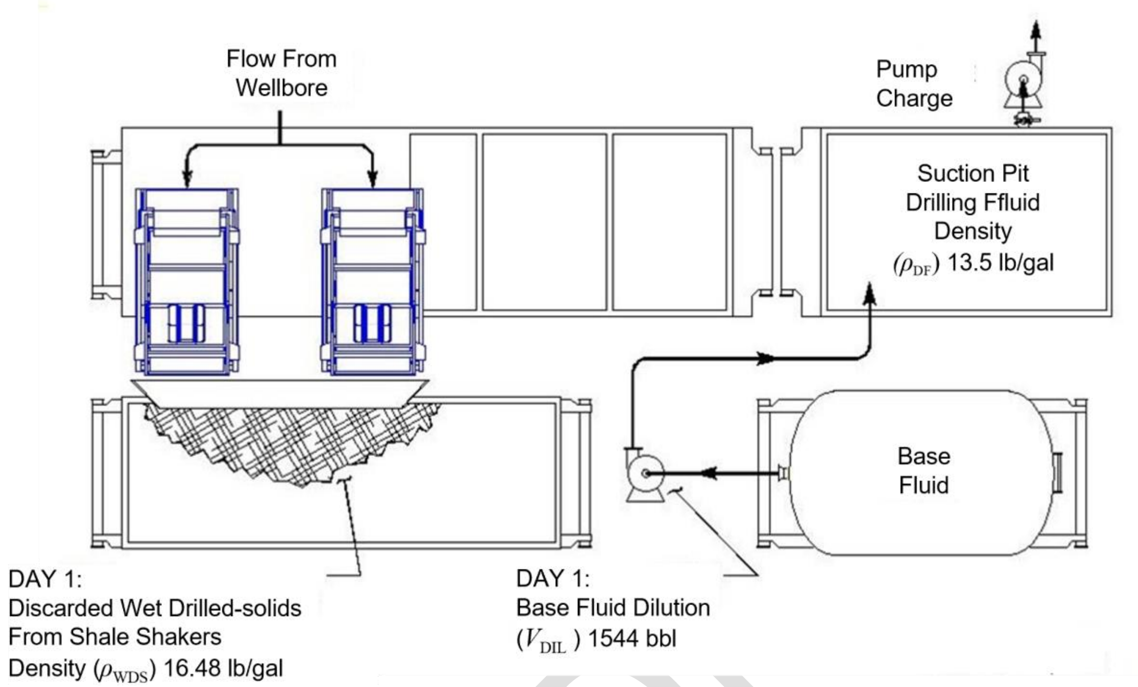


**Figure D.2—Drilling-fluid Processing Equipment, Day 1 (System Performance Calculation Example D.3)**

**Table D.3—Interval and Drilling-fluid Input Data (System Performance Calculation Example D.3)**

| **Interval and Input Data** | |
|---|---|
| Parameter | USC Units |
| Interval Total Base fluid added for dilution, $V_{BF}$ (Daily values listed in Table D.4) | 6290 bbl |
| Base fluid volume fraction for drilling fluid with target drilled-solids concentration, $\varphi_{BF}$ | 80 % |
| Hole diameter, $D_H$ | 12.25 in. |
| Wellbore length, $L_H$ | 10,795 ft |
| Wellbore enlargement, $\varphi_E$ | 0.0 % |
| Target drilled-solids concentration, $\varphi_{DS}$ | 5 % |
| Density of drilled-solids, $\rho_{DS}$ | 21.7 lb/gal |
| Density of drilling fluid, $\rho_{DF}$ | 13.5 lb/gal |
| NOTE Daily values for measured density of the discarded wet drilled-solids from shale shakers listed in Table D.4 in lb/gal | |

### D.3.2 Example Calculations

**D.3.2.1** The example calculations in this section illustrate the use of equations from Section 5 for evaluating system performance using daily data and cumulative interval data to that point.

For simplicity, only the USC values are shown and the individual Equations with data are only presented for the first day, Day 1, of the interval. Only the measured density of the wet drilled-solids is presented for calculating the drilling-fluid to drilled-solids ratio of the wet drilled-solids sample and not the measured mass values.

Subsequent data for Day 2 to Day 7 with daily and cumulative data is shown in Table D.4.

**D.3.2.2** Calculations should be based on Equations provided in Section 5 (see D.3.2.2 to D.3.2.15). The listed values in this section are rounded for simplicity and may not exactly match values determined from manual or spreadsheet calculations. These input values are the same as is used in the previous D.2 example calculations although the calculated values shown are slightly different. Calculate the base fluid volume fraction for the clean drilling fluid (zero-drilled-solids), $\varphi_{\mathrm{BDF}}$, from the base fluid fraction for the target (or average) drilled-solids concentration using Equation (2). The base fluid fraction for the target drilled-solids concentration is the value reported on the daily drilling fluid report from a retort analysis, (for situations where this value changes significantly during an interval, volume-weighted average values should be used).

$$\varphi_{\mathrm{BDF}} = \varphi_{\mathrm{BF}} \times \left[ \frac{100}{\left(100 - \varphi_{\mathrm{DS}}\right)} \right] = 80 \times \left[ \frac{100}{\left(100 - 5\right)} \right] = 80 \times 1.0526 = 84.21 \approx 84.2 \ \ \%$$

**D.3.2.3** Using $V_{\mathrm{BF}}$ = 1300 bbl, the volume of base fluid added for Day 1 from Table D.3, calculate the volume of zero-drilled-solids (clean) drilling fluid used for dilution, $V_{\mathrm{DIL}}$, using Equation (1).

$$V_{\mathrm{DIL}} = \frac{100 \times V_{\mathrm{BF}}}{\varphi_{\mathrm{BDF}}} = \frac{100 \times 1300}{84.21} = 1544 \ \ \mathrm{bbl}$$

NOTE Equation (1) is also used for calculations in SI units.

**D.3.2.4** Using $L_{\mathrm{H,USC}}$ = 1675 ft, the footage drilled for Day 1, calculate the excavated volume of drilled-solids, $V_{\mathrm{DS,USC}}$, using Equation (5).

$$V_{\mathrm{DS,USC}} == \frac{{D_{\mathrm{H,USC}}}^2}{1029.4} \times L_{\mathrm{H,USC}} \times \left(1 - \frac{\varphi_{\mathrm{E}}}{100}\right) = \frac{12.25^2}{1029.4} \times 1675 \times \left(1 + \frac{0.0}{100}\right) = 0.1458 \times 1675 \times 1.0 = 244 \ \ \mathrm{bbl}$$

NOTE Equation (4) is used for calculations in metric SI units.

**D.3.2.5** Calculate drilled-solids removal system efficiency, $\eta_{\mathrm{DSR}}$, for Day 1 using Equation (6).

$$\eta_{\mathrm{DSR}} = 100 - \frac{\left(100 \times V_{\mathrm{DIL}} \times \varphi_{\mathrm{DS}}\right)}{\left[V_{\mathrm{DS}} \times \left(100 - \varphi_{\mathrm{DS}}\right)\right]} = 100 - \frac{\left(100 \times 1544 \times 5\right)}{\left[244 \times \left(100 - 5\right)\right]} = 66.7 \ \ \%$$

NOTE Equation (6) is also used for calculations in SI units.

**D.3.2.6** Calculate the volume of retained drilled-solids for Day 1, using the drilled-solids removal system efficiency and the excavated volume of drilled-solids, $V_{\mathrm{RDS}}$, for Day 1, with Equation (7).

$$V_{\mathrm{RDS}} = V_{\mathrm{DS}} \times \left(1 - \frac{\eta_{\mathrm{DSR}}}{100}\right) = 244 \times \left(1 - \frac{66.7}{100}\right) = 81 \text{ bbl}$$

NOTE Equation (7) is also used for calculations in SI units.

**D.3.2.7** Calculate the dilution drilling fluid volume including the retained drilled-solids percent, $V_{\mathrm{DIL+RDS}}$, for Day 1, using Equation (8). This is simply the sum of the clean dilution drilling fluid volume plus the retained drilled-solids.

$$V_{\mathrm{DIL+RDS}} = V_{\mathrm{DIL}} + V_{\mathrm{RDS}} = 1544 + 81 = 1625 \text{ bbl}$$

NOTE Equation (8) is also used for calculations in SI units.

**D.3.2.8** For situations where the measured dilution volume of drilling fluid is accurate and the preferred value to monitor. Calculate the drilled-solids removal system efficiency, $\eta_{\mathrm{DSR}}$, for Day 1 using the alternative Equation (9).

$$\eta_{\mathrm{DSR}} = 100 - \left[\frac{\varphi_{\mathrm{DS}} \times V_{\mathrm{DIL+RDS}}}{V_{\mathrm{DS}}}\right] = 100 - \frac{5 \times 1625}{244} = 66.7 \text{ \%}$$

NOTE Equation (9) is also used for calculations in SI units.

**D.3.2.9** Calculate the volume of discarded wet drilled-solids, $V_{\mathrm{DDS}}$, for Day 1 using the drilled-solids removal system efficiency and the excavated volume of drilled-solids, with Equation (10).

$$V_{\mathrm{DDS}} = \frac{\eta_{\mathrm{DSR}} \times V_{\mathrm{DS}}}{100} = \frac{66.7 \times 244}{100} = 163 \text{ bbl}$$

NOTE Equation (10) is also used for calculations in SI units.

**D.3.2.10** To calculate the drilling-fluid to drilled-solids ratio, the density of the discarded wet drilled-solids from shale shakers discharge for Day 1 is $\rho_{\mathrm{WDS}}$ = 16.48 lb/gal. Calculate the drilling-fluid to drilled-solids ratio, $R_{\mathrm{DF\text{-}DS}}$, of the discarded wet drilled-solids from shale shakers using Equation (13).

$$R_{\mathrm{DF\text{-}DS}} = \frac{(\rho_{\mathrm{DS}} - \rho_{\mathrm{WDS}})}{(\rho_{\mathrm{WDS}} - \rho_{\mathrm{DF}})} = \frac{21.7 - 16.48}{16.48 - 13.5} = \frac{5.48}{2.72} = 1.8 \text{ v / v}$$

NOTE Equation (13) is also used for calculations in SI units.

**D.3.2.11** For this example the shale shaker discharge is the only discharge, so the total volume of discarded drilling fluid with the discarded wet drilled-solids, $V_{\text{DDF}}$, for Day 1 is calculated from the drilling-fluid to drilled-solids ratio and the volume of discarded wet drilled-solids, using Equation (15).

$$R_{\text{DF-DS-Tot}} = R_{\text{DF-DS}} = 1.8 \ \text{v / v}$$

$$V_{\text{DDF}} = R_{\text{DF-DS-Tot}} \times V_{\text{DDS}} = 1.8 \times 163 = 293 \ \text{bbl}$$

NOTE Equation (15) is also used for calculations in SI units.

**D.3.2.12** Calculate the volume of excess drilling fluid volume built, $V_{\text{DIL-Exc}}$, for Day 1 using Equation (16).

$$V_{\text{DIL-Exc}} = V_{\text{DIL+RDS}} - V_{\text{DDF}} - V_{\text{DS}} = 1625 - 293 - 244 = 1088 \ \text{bbl}$$

NOTE Equation (16) is also used for calculations in SI units.

**D.3.2.13** Calculate the overall waste volume including the excess drilling fluid (over what is needed for dilution and for the surface pits to remain constant), $V_{\text{Waste}}$, for Day 1, using Equation (17).

$$V_{\text{Waste}} = V_{\text{DDS}} + V_{\text{DDF}} + V_{\text{DIL-Exc}} = 163 + 293 + 1088 = 1544 \ \text{bbl}$$

NOTE Equation (17) is also used for calculations in SI units.

**D.3.2.14** To estimate the volume of drilling fluid which will be needed for dilution and the associated waste volumes when planning wells, sections 5.4 through 5.7 are used. The dilution volume to be used for these 5.4 to 5.6 sections is calculated below by using the Day 1 values as an example of the calculation and wide range of values day-today.

Calculate the dilution volume of clean drilling fluid per unit volume of excavated drilled-solids, $V_{\text{DIL}}/ V_{\text{DS}}$, using Equation (18).

$$\frac{V_{\text{DIL}}}{V_{\text{DS}}} = \frac{(100 - \eta_{\text{DSR}}) \times (100 - \varphi_{\text{DS}})}{100 \times \varphi_{\text{DS}}} = \frac{(100-66.7)\times(100-5)}{100\times 5} = 6.3 \ \text{v / v}$$

NOTE Equation (18) is also used for calculations in SI units.

**D.3.2.15** Calculate the optimum solids-removal-efficiency, $\eta_{\text{DSR-Opt}}$, for Day 1 that will result in no excess drilling fluid being required for dilution to maintain the target concentration of drilled-solids for a given drilling-fluid to drilled-solids ratio using Equation (19).

$$\eta_{\text{DSR-Opt}} = 100 \times \frac{(100 - \varphi_{\text{DS}})}{\left[100 + (\varphi_{\text{DS}} \times R_{\text{DF-DS-Tot}})\right]} = 100 \times \frac{(100 - 5)}{\left[100 + (5 \times 1.8)\right]} = 87.2 \ \%$$

NOTE Equation (19) is also used for calculations in SI units.

## Table D.4—System Performance Daily Data with Cumulative Totals, Shale Shaker Discharge only

| Symbol / Unit / Equation | Daily Wellbore Length<br>$L_H$<br>ft<br>- | Daily Volume Base Fluid Added for Dilution<br>$V_{BF}$<br>bbl | Daily Volume Clean Dilution Drilling-fluid<br>$V_{DIL}$<br>bbl<br>(1) | Base Fluid Volume Fraction for Clean Drilling-fluid<br>$\varphi_{BDF}$<br>%<br>(2) | Cumulative Volume Clean Dilution Drilling-fluid<br>$V_{DIL\text{-}Itval}$<br>bbl<br>(3) | Daily Volume Excavated Drilled-solids<br>$V_{DS}$<br>bbl<br>(5) | Cumulative Volume Excavated Drilled-solids<br>$\Sigma V_{DS}$<br>bbl | Daily Drilled-solids Removal Efficiency<br>$\eta_{DSR}$<br>%<br>(6) | Cumulative Drilled-solids Removal Efficiency<br>$\Sigma \eta_{DSR}$<br>% | Daily Volume Retained Drilled-solids<br>$V_{RDS}$<br>bbl<br>(7) | Daily Volume Dilution Drilling-fluid & Retained Drilled-solids<br>$V_{DIL+RDS}$<br>bbl<br>(8) | Daily Volume Discarded Drilled-solids<br>$V_{DDS}$<br>bbl<br>(10) | Cumulative Volume Discarded Drilled-solids<br>$\Sigma V_{DDS}$<br>bbl | Measured Density Wet Drilled-solids<br>$\rho_{WDS}$<br>lb/gal<br>(12) | Daily Ratio Drilling-fluid to Drilled-solids<br>$R_{DF\text{-}DS}$<br>v/v<br>(13) | Cumulative Ratio Drilling-fluid to Drilled-solids<br>$\Sigma R_{DF\text{-}DS}$<br>v/v<br>(14)* | Daily Volume Discarded Drilling-fluid with Retained Drilled-solids<br>$V_{DDF}$<br>bbl<br>(15) | Cumulative Volume Discarded Drilling-fluid with Retained Drilled-solids<br>$\Sigma V_{DDF}$<br>bbl | Daily Volume Excess Drilling Fluid<br>$V_{DIL\text{-}Exc}$<br>bbl<br>(16) | Daily Volume Overall Waste<br>$V_{Waste}$<br>bbl<br>(17) | Daily Ratio Clean Dilution Drilling-fluid per Drilled Volume<br>$\frac{V_{DIL}}{V_{DS}}$<br>v/v<br>(18) | Optimum Drilled-solids Removal Efficiency Cumulative<br>$\Sigma \eta_{DSR\text{-}Opt}$<br>%<br>(19) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Day 1** | 1675 | 1300 | 1544 | 84.2 | 1544 | 244 | 244 | 66.7 | 66.7 | **81** | **1625** | **163** | **163** | **16.48** | **1.8** | **1.8** | **293** | **293** | **1088** | **1544** | **6.3** | **87.2** |
| **Day 2** | 3969 | 1375 | 1633 | 84.2 | 3177 | 579 | 823 | 85.1 | 79.7 | 86 | 1719 | 493 | 656 | 15.98 | 2.3 | 2.2 | 1134 | 1443 | 6 | 1633 | 2.8 | 85.6 |
| **Day 3** | 1578 | 990 | 1176 | 84.2 | 4352 | 230 | 1053 | 73.1 | 78.2 | 62 | 1238 | 168 | 824 | 15.84 | 2.5 | 2.2 | 420 | 1813 | 588 | 1176 | 5.1 | 85.6 |
| **Day 4** | 1512 | 1400 | 1663 | 84.2 | 6015 | 220 | 1273 | 60.3 | 75.1 | 88 | 1750 | 133 | 957 | 16.65 | 1.6 | 2.1 | 213 | 2010 | 1317 | 1663 | 7.5 | 86.0 |
| **Day 5** | 668 | 550 | 653 | 84.2 | 6668 | 97 | 1371 | 64.7 | 74.4 | 34 | 688 | 63 | 1020 | 16.48 | 1.8 | 2.1 | 113 | 2142 | 478 | 654 | 6.7 | 86.0 |
| **Day 6** | 671 | 250 | 297 | 84.2 | 6965 | 98 | 1468 | 84.0 | 75.0 | 16 | 313 | 82 | 1102 | 16.78 | 1.5 | 2.1 | 123 | 2314 | 92 | 297 | 3.0 | 86.0 |
| **Day 7** | 722 | 425 | 505 | 84.2 | 7469 | 105 | 1574 | 74.8 | 75.0 | 27 | 531 | 79 | 1181 | 17.77 | 0.9 | 2.0 | 71 | 2362 | 355 | 503 | 4.8 | 86.4 |
| **Total Interval** | **10,795** | **6290** | **7469** | **84.2** | **7469** | **1574** | **1574** | | **75.0** | **393** | **7863** | | **1181** | | | **2.0** | | **2362** | **3927** | **7470** | **4.8** | **86.4** |

NOTE 1 Total Interval report cumulative data.
NOTE 2 For Example D.3, $R_{DF\text{-}DS\text{-}Tot} = R_{DF\text{-}DS}$

* $\Sigma R_{DF\text{-}DS}$ is calculated with Equation (14) using daily discarded drilled-solids volume day n and cumulative discarded drilled soids volume day n-1.

## D.4 System Performance Single Daily Data with Shale Shaker and Centrifuge Discharge

### D.4.1 General

For evaluating the system performance for a single daily data with discharges from shale shakers and centrifuge, **t**he example calculations in this section illustrate the use of equations from Section 5 and Annex C. These calculations combining the use of equations for shale shaker discharge based on wet cutting density (see Section 5) with the equations from Annex C from the topped-up retort procedure calculations for centrifuge discharge. The results are combined to determine a combined drilling-fluid to drilled-solids ratio.

Drilling fluid processing system is schematized Figure D.3. Calculation input data related to daily drilled interval, drilling fluid, shale shaker discharge, centrifuge discharge and topped retort procedure are given Table D.5.

NOTE Example calculations are done using only USC units, therefore symbols subscripts “USC” are not reported for symbols and Equations as it should be generally done by users in the field.

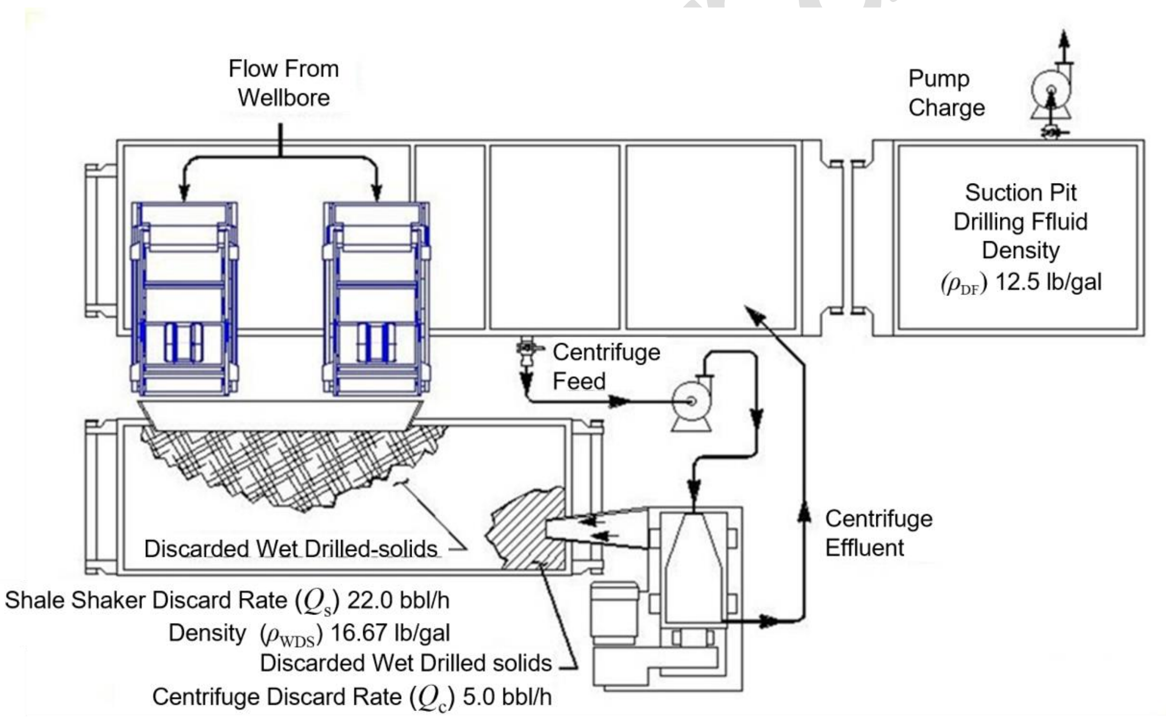


**Figure D.3—Drilling-fluid Processing Equipment (System Performance Calculation Example D.3)**

**Table D.5—Input Data Shale Shakers and Centrifuge Discharges (Calculation Example D.3)**

| | Parameter | USC Unit |
|---|---|---|
| **Daily Drilled Interval** | Interval total base fluid added for dilution, $V_{BF}$ | 1300 bbl |
| | Hole diameter, $D_H$ | 8.75 in. |
| | Wellbore length, $L_H$ | 4000 ft |
| | Wellbore enlargement, $\varphi_E$ | 0.0 % |
| **Drilling Fluid** | Density of drilling fluid (NADF), $\rho_{DF}$ | 12.5 lb/gal |
| | Density of NAF base fluid, $\rho_{BF}$ | 7.0 lb/gal |
| | Density of weighting -material, $\rho_{WM}$ | 35.0 lb/gal |
| | Volume fraction NAF of the whole NADF, $\varphi_{NAF\text{-}DF}$ | 60 % |
| | Volume fraction weighting-material, $\varphi_{WM}$ | 12.3 % |
| | Target drilled-solids concentration, $\varphi_{DS}$ | 5% |
| **Shale Shakers Discarded Wet Cuttings** | Density of discarded wet cuttings, $\rho_{WDS}$ | 16.67 lb/gal |
| | Density of drilled-solids, $\rho_{DS}$ | 21.67 lb/gal |
| | Volume fraction NAF discarded wet cuttings, $\varphi_{NAF\text{-}DS}$ | 60 % |
| | Volumetric rate of discarded wet cuttings at shakers, $Q_S$ | 22.0 bbl/h |
| **Centrifuge Discharge** | Volumetric rate of discarded wet cuttings at centrifuge, $Q_C$ | 5.0 bbl/h |
| **Top-up Retort Data for Centrifuge Discard (Annex C)** | Mass of the empty retort sample cup, lid, and retort upper cell body packed with steel wool, $m_{R1}$ | 1492.0 g |
| | Mass of the retort sample cup filled with wet drilled-solids sample, lid, and retort body packed with steel wool, $m_{R2}$ | 1580.8 g |
| | Mass of retort sample cup filled with wet drilled-solids sample and topping base fluid, lid, and retort body packed with steel wool, $m_{R3}$ | 1589.5 g |
| | Mass of empty, clean, dry liquid receiver, $m_{R4}$ | 101.5 G |
| | Mass of liquid receiver and its condensed liquid content (oil and water), $m_{R5}$ | 126.0 g |
| | Mass of cooled retort assembly (retort sample cup with retorted solids, lid, and retort body packed with steel wool), $m_{R6}$ | 1565.0 g |
| | Total volume of condensed liquid collected in the liquid receiver, $V_R$ | 29.0 mL |
| | Volume of condensed water collected in the liquid receiver, $V_W$ | 2.5 mL |

## D.4.2 Example Calculations

### D.4.2.1 Principle

The example calculations illustrate the use of equations from Section 5 to evaluate a single set of measurements for an equipment arrangement with two discharge points, the first is wet cuttings from shale shakers and the second is the wet drilled-solids discharge from a decanting centrifuge. These calculations combining the use of equations from Section 5 with the equations from Annex C from the topped-up retort procedure for centrifuge discharge. The results are combined to determine a combined drilling-fluid to drilled-solids ratio.

For simplicity, only the USC values are shown and the individual Equations with data are only presented for the first day, Day 1, of the interval. Only the measured density of the wet drilled-solids is presented for calculating the drilling-fluid to drilled-solids ratio of the wet drilled-solids sample and not the measured mass values. Subsequent data for Day 2 to Day 7 with daily and cumulative data is shown in Table D.4.

Calculations shall be based on Equations provided in Section 5 (see D.3.2.2 to D.3.2.19) and Annex C.

### D.4.2.2 Shale shaker discharge-measured wet drilled-solids density

Calculate the drilling-fluid to drilled-solids ratio, $R_{\text{DF-DS-}S}$, of the wet discharged solids (cuttings) from shale shakers using Equation (13) and USC units.

$$R_{\text{DF-DS-S}} = \frac{(\rho_{\text{DS}} - \rho_{\text{WDS}})}{(\rho_{\text{WDS}} - \rho_{\text{DF}})} = \frac{21.67 - 16.67}{16.67 - 12.5} = \frac{5.00}{4.17} = 1.2 \quad \text{v / v}$$

NOTE Equation (13) is also used for calculations in SI units.

### D.4.3.3 Centrifuge discharge-topped-up retort procedure—Quality control limits

Retort procedure to measure wet drilled-solids should satisfy quality control limits (see Annex C.4.1).

a) Lost Mass shall m be less than 1.5 g. Using Equation (C.1), calculate lost mass after retorting.

$$m_{\text{Lost}} = m_{\text{R3}} + m_{\text{R4}} - (m_{\text{R5}} + m_{\text{R6}}) = 1589.5 + 101.5 - (1260.0 + 15 + 1565.0) = 0.0 \qquad \textbf{PASS}$$

b) For NADF, calculate the base NAF density, $\rho_{\text{BF-DS,USC}}$, using Equation (C.3) ( see Annex C) which shall be within ±5% of measured base NAF density, $\rho_{\text{BF}}$.

$$\rho_{\text{BF-DS,USC}} = 8.345 \times \frac{(m_{\text{R5}} - m_{\text{R4}} - V_{\text{W}})}{(V_{\text{R}} - V_{\text{W}})} = 8.345 \times \frac{(126.0 - 101.5 - 2.5)}{(29.0 - 2.5)} = 8.345 \times \frac{22.0}{26.5} = 6.93 \quad \text{lb / gal}$$

NOTE Equation (C.2) is used for calculations in SI units.

Using Equation (C.4), compare the calculated value of $\rho_{\text{BF-DS}}$ to the ±5% limits from the measured NAF base fluid density, $\rho_{\text{BF}}$.

$$0.95 \times \rho_{\text{BF}} \le \rho_{\text{BF-DS}} \le 1.05 \times \rho_{\text{BF}} \qquad 50.95 \times 7.0 \le 6.93 \le 1.05 \times 7.0 \qquad 6.65 \le 6.93 \le 7.35$$

**PASS**

NOTE Equations (C.2) is used for calculations in SI units.

c) Calculate uncorrected average density (volumic mass) of dry retorted drilled-solids sample, $\overline{\rho_{\text{DS-D,USC}}}$, using Equation (C.6). Calculated uncorrected average density of dry retorted drilled-solids shall t be greater than the density of the low-gravity solids, $\rho_{\text{LG}}$, and less than the density of the weighting material, $\rho_{\text{WM}}$.

$$\overline{\rho_{\text{DS-D,USC}}} = 8.345 \times \frac{(m_{\text{R6}} - m_{\text{R1}})}{(50 - V_{\text{R}})} = 8.345 \times \frac{(1565.0 - 1492.0)}{(50 - 29.0)} = 8.345 \times \frac{73}{21} = 29.0 \text{ lb / gal}$$

NOTE 1 Equation C.6 does not correct the dry retorted solids mass and volume or density for soluble salts, however, in most cases this is not significant due to the relatively larger volume of solids compared to the volume of drilling fluid and its soluble solids content.1

NOTE 2 Equation (C.5) is used for calculations in SI units.

Compare the calculated value from Equation (C.6) to the density of the low-gravity and weighting material solids using Equation (C.7).

$$\rho_{\text{LG}} \leq \overline{\rho_{\text{DS-D}}} \leq \rho_{\text{WM}} \qquad 21.7 \leq 29.0 \leq 35 \qquad \textbf{PASS}$$

NOTE Equation (C.7) is used for calculations in SI units.

d) The data from the retort procedure passes all three quality control limits.

#### D.4.2.4 Centrifuge discharge—Density of the wet drilled-solids sample

The density of the wet drilled-solids sample should be calculated from the volume of wet drilled-solids and the density of the wet drilled-solids sample after the volume of topping fluid is determined and subtracted from the retort cell volume.

a) The volume of topping fluid, $V_{\text{TOP}}$ ,expressed in milliliters, is calculated using Equation (C.9) in USC units.

$$V_{\text{TOP}} = 8.345 \times \frac{(m_{\text{R3}} - m_{\text{R2}})}{\rho_{\text{BF}}} = 8.345 \times \frac{(1589.5 - 1580.8)}{7.0} = 8.345 \times \frac{8.7}{7.0} = 10.4 \text{ mL}$$

NOTE Equation (C.8) is used for calculations in SI units.

b) The density of the wet drilled solids sample, expressed as pounds per gallon, is calculated using Equation (C.11).

$$\rho_{\text{DS-W}} = 8.345 \times \frac{(m_{\text{R2}} - m_{\text{R1}})}{(50 - V_{\text{TOP}})} = 8.345 \times \frac{(1580.8 - 1492.0)}{(50 - 10.4)} = 8.345 \times \frac{88.8}{39.6} = 18.7 \text{ lb / gal}$$

NOTE Equation (C.10) is used for calculations in SI units.

#### D.4.2.5 Centrifuge discharge—Liquid and solids content of wet drilled-solids sample

Water, base NAF, total materials solids, LGS and weighting material solids content and concentration of wet drilled-solids sample should be calculated using Equations (C.12) to (C.21).

a) Water content of wet drilled-solids sample ( $\varphi_{\text{W-DS}}$)

Calculate the volume fraction of water for the sample, expressed as a percentage, using Equation (C.12.).

$$\varphi_{\text{W-DS}} = 100 \times \frac{V_{\text{W}}}{(50 - V_{\text{TOP}})} = 100 \times \frac{2.5}{(50\text{–}10.4)} = 100 \times \frac{2.5}{39.6} = 6.3 \ \%$$

b) Base NAF content of wet drilled-solids sample

1) NAF mass fraction for the wet drilled-solids sample ($w_{\text{NAF-DS}}$):

Calculate the mass fraction of NAF for the sample using Equation (C.13), expressed as a decimal fraction.

$$w_{\text{NAF-DS}} = \frac{[(m_{\text{R5}} - m_{\text{R4}}) - (m_{\text{R3}} - m_{\text{R2}}) - V_{\text{W}}]}{(m_{\text{R2}} - m_{\text{R1}})} = \frac{[(126.0\text{–}101.5) - (1589.5\text{–}1580.8) - 2.5]}{(1580.8 - 1429.0)} =$$

$$w_{\text{NAF-DS}} = \frac{[24.5 - 8.7 - 2.5]}{88.8} = \frac{13.3}{88.8} = 0.15$$

2) NAF volume fraction of NAF for the wet drilled-solids sample ($\varphi_{\text{NAF-DS}}$)/

The volume fraction of NAF for the sample, expressed as a percentage, is calculated using Equation (C.14).

$$\varphi_{\text{NAF-DS}} = 100 \times \frac{(V_{\text{R}} - V_{\text{W}} - V_{\text{TOP}})}{(50 - V_{\text{TOP}})} = 100 \times \frac{(29.0 - 2.5 - 10.4)}{(50 - 10.4)} = 100 \times \frac{16.1}{39.6} = 40.7 \ \%$$

3) NAF and Water Ratios of the condensed liquids:

Calculate the ratio of NAF, $R_{\text{NAF}}$, for the liquid phase of the wet drilled-solids, expressed as a percentage, using Equation (C.15).

$$R_{\text{NAF}} = 100 \times \frac{\varphi_{\text{NAF-DS}}}{(\varphi_{\text{NAF-DS}} + \varphi_{\text{W-DS}})} = 100 \times \frac{40.7}{(40.7 + 6.3)} = 100 \times \frac{40.7}{47.0} = 86.6 \ \%$$

Calculate the ratio of water ($R_{\text{W}}$) for the liquid phase of the wet drilled-solids, expressed as a percentage, using Equation (C.16).

$$R_{\text{W}} = 100 - R_{\text{NAF}} = 100 - 86.6 = 13.4 \ \%$$

c) Solids Content of wet drilled-solids sample:

1) Calculate the volume fraction of total solids in the sample, $\varphi_{\text{DS-Tot}}$, expressed as a percentage, using Equation (C.17).

$$\varphi_{\text{DS-Tot}} = 100 - \varphi_{\text{NAF-DS}} - \varphi_{\text{W-DS}} = 100 - 40.7 - 6.3 = 53.0 \ \%$$

2) Calculate the volume fraction of weighting-material solids in the sample, expressed as a percentage, using Equation (C.18).

$$\varphi_{\text{WM-DS}} = \varphi_{\text{DS-Tot}} \times \frac{\left(\overline{\rho_{\text{DS-D}}} - \rho_{\text{LG}}\right)}{\left(\rho_{\text{WM}} - \rho_{\text{LG}}\right)} = 53.0 \times \frac{(29.0 - 21.67)}{(35.0 - 21.67)} = 53.0 \times \frac{7.33}{13.33} = 29.1 \ \%$$

3) Calculate the volume fraction of low-gravity solids in the sample, $\varphi_{\text{LG-DS}}$, expressed as a percentage using Equation (C.19).

$$\varphi_{\text{LG-DS}} = \varphi_{\text{DS-Tot}} - \varphi_{\text{WM-DS}} = 53.0 - 29.1 = 23.9 \ \%$$

4) Calculate the volume fraction of weighting-material solids for the total solids content, $\varphi_{\text{WM-Tot}}$ ,expressed as a percentage, is calculated using Equation (C.20).

$$\varphi_{\text{WM-Tot}} = 100 \times \frac{\varphi_{\text{WM-DS}}}{\varphi_{\text{DS-Tot}}} = 100 \times \frac{29.1}{53.0} = 54.9 \ \%$$

5) The volume fraction of low-gravity solids for the total solids content, $\varphi_{\text{LG-Tot}}$ ,expressed as a percentage, using Equation (C.21).

$$\varphi_{\text{LG-Tot}} = 100 - \varphi_{\text{WM-Tot}} = 100 - 54.9 = 45.1 \ \%$$

#### D.4.2.6 Centrifuge discharge—Drilling-fluid to drilled-solids ratio

To calculate drilling-fluid to drilled-solids ratio in the wet-drilled solids for the centrifuge discharge, Equations (C.22) through (C.25) should be used.

a) Calculate the volume fraction of drilling fluid in the wet drilled solids sample, $\varphi_{\text{DF-DS}}$, expressed as a percentage, using Equation (C.22).

$$\varphi_{\text{DF-DS}} = 100 \times \frac{\varphi_{\text{NAF-DS}}}{\varphi_{\text{NAF-DF}}} = 100 \times \frac{40.7}{60.0} = 67.9 \ \%$$

b) Calculate the volume fraction of weighting-material solids associated with the drilling fluid content in the wet drilled solids sample, $\varphi_{\text{WM-DF}}$, expressed as a percentage, using Equation (C.23).

$$\varphi_{\text{WM-DF}} = \frac{\varphi_{\text{WM}} \times \varphi_{\text{DF-DS}}}{100} = \frac{12.3 \times 67.9}{100} = 8.3 \ \%$$

c) Calculate the volume fraction of excess weighting-material solids in the wet drilled solids sample, $\varphi_{\text{WM-Exc}}$, expressed as a percentage, is calculated using Equation (C.24).

$$\varphi_{\text{WM-Ex}} = \varphi_{\text{WM-DS}} - \varphi_{\text{WM-DF}} = 29.1 - 8.3 = 20.8 \ \%$$

d) Calculate the drilling-fluid to drilled-solids ratio of the wet drilled solids sample for the centrifuge discharge, $R_{\text{DF-DS-C}}$, using Equation (C.25).

$$R_{\text{DF-DS-C}} = \frac{\left(\varphi_{\text{DF-DS}} + \varphi_{\text{WM-Ex}}\right)}{\left[100 - \left(\varphi_{\text{DF-DS}} + \varphi_{\text{WM-Ex}}\right)\right]} = \frac{(69.7 + 20.8)}{\left[100 - (69.7 + 20.8)\right]} = \frac{88.7}{11.3} = 7.8 \quad \text{v / v}$$

### D.4.2.7 Combined discharges, shale shakers and centrifuge

#### D.4.2.7.1 Combined total drilling-fluid to drilled-solids ratio

The combined total drilling-fluid to drilled-solids ratio, $R_{\text{DF-DS-Tot}}$, for both discharges should be the sum of drilling fluid to drilled-solids weighted ratios using Equation (14).

$$R_{\text{DF-DS-Tot}} = \left[\left(\frac{Q_S}{Q_S + Q_C}\right) \times R_{\text{DF-DS-S}}\right] + \left[\left(\frac{Q_C}{Q_S + Q_C}\right) \times R_{\text{DF-DS-C}}\right] = \left[\frac{22.0}{22.0 + 5.0} \times 1.2\right] + \left[\frac{5.0}{22.0 + 5.0} \times 7.8\right]$$

$$R_{\text{DF-DS-Tot}} = 0.98 + 1.44 = 2.42 \approx 2.4 \quad \text{v / v}$$

With

$Q_S$ is the volumetric rate of discarded wet cuttings at shales shaker per hour;

$Q_C$ is the volumetric rate of discarded wet cuttings at shales centrifuge per hour;

$R_{\text{DF-DS-S}}$ is the drilling-fluid to drillled-solids ratio for the shale shakers discharge;

$R_{\text{DF-DS-C}}$ is the drilling-fluid to drillled-solids ratio for the centrifuge discharge.

#### D.4.2.7.2 Base fluid volume fraction for clean drilling-fluid ($\varphi_{\text{BFD}}$)

The base fluid volume fraction for the clean drilling fluid (zero-drilled-solids) from the base fluid fraction for the target (or average) drilled solids concentration should be calculated using using Equation (2). The base fluid fraction for the target drilled solids concentration is the value reported on the daily drilling fluid report from a retort analysis, (for situations where this value changes significantly during an interval, volume-weighted average values should be used).

$$\varphi_{\text{BFD}} = \varphi_{\text{BF}} \times \frac{100}{(100 - \varphi_{\text{DS}})} = 60 \times \frac{100}{(100 - 5.0)} = 60 \times 1.0526 = 63.2 \ \%$$

#### D.4.2.7.3 Volume of clean drilling fluid used for dilution ($V_{\text{DIL}}$)

Using the volume of base fluid added for the entire interval, the volume of zero-drilled-solids (clean) drilling fluid used for dilution, should be calculated using Equation (1) and USC units.

$$V_{\text{DIL}} = \frac{100 \times V_{\text{BF}}}{\varphi_{\text{BDF}}} = \frac{100 \times 1300}{63.2} = 2058 \ \text{bbl}$$

**D.4.2.7.4 Excavated volume of drilled-solids** ($V_{DS}$)

The excavated volume of drilled-solids should be calculated using Equation (5) for USC units.

$$V_{DS} == \frac{D_H{}^2}{1029.4} \times L_H \times \left(1 + \frac{\varphi_E}{100}\right) = \frac{8.75^2}{1029.4} \times 4000 \times \left(1 + \frac{0.0}{100}\right) = 0.0744 \times 4000 \times 1.0 = 298 \text{ bbl}$$

**D.4.2.7.5 Drilled-solids removal system efficiency** ($\eta_{DSR}$)

Drilled-solids removal system efficiency should be calculated using Equation (6).

$$\eta_{DSR} = 100 - \frac{(100 \times V_{DIL} \times \varphi_{DS})}{[V_{DS} \times (100 - \varphi_{DS})]} = 100 - \frac{(100 \times 2058 \times 5)}{[298 \times (100 - 5)]} = 63.6 \ \%$$

**D.4.2.7.6 Volume of retained drilled-solids** ($V_{RDS}$)

The volume of retained drilled-solids, using the drilled-solids removal system efficiency and the excavated volume of drilled-solids, should be calculated with Equation (7).

$$V_{RDS} = V_{DS} \times \left(1 - \frac{\eta_{DSR}}{100}\right) = 298 \times \left(1 - \frac{63.6}{100}\right) = 108 \text{ bbl}$$

**D.4.2.7.7 Dilution drilling-fluid volume** ($V_{RDS+RDS}$)

The dilution drilling -fluid volume including the retained drilled-solids percent, using Equation (8). This is simply the sum of the clean dilution drilling fluid volume plus the retained drilled-solids.

$$V_{DIL+RDS} = V_{DIL} + V_{RDS} = 2058 + 108 = 2166 \text{ bbl}$$

**D.4.2.7.8 Solids Removal Efficiency** ($\eta_{DSR}$)

For situations where the measured dilution volume of drilling fluid is accurate and the preferred value to monitor; the drilled-solids removal system efficiency should be calculated using the alternative Equation (9).

$$\eta_{DSR} = 100 - \left[\frac{\varphi_{DS} \times V_{DIL+RDS}}{V_{DS}}\right] = 100 - \left[\frac{5 \times 2167}{298}\right] = 63.6 \ \%$$

**D.4.2.7.9 Volume of discarded drilled-solids** ($V_{DDS}$)

The volume of discarded drilled-solids using the drilled solids removal efficiency and the excavated volume of drilled-solids should be calculated using with Equation (10).

$$V_{DDS} = \frac{\eta_{DSR} \times V_{DS}}{100} = \frac{63.6 \times 298}{100} = 189 \text{ bbl}$$

#### D.4.2.7.10 Total volume of discarded drilling fluid with the discharged wet drilled-solids ($V_{DDF}$)

For this example the total volume of discarded drilling fluid with the discharged wet drilled-solids is calculated from the total drilling-fluid to drilled-solids ratio and the volume of discarded wet drilled-solids, using Equation (15).

$$V_{DDF} = R_{DF\text{-}DS\text{-}Tot} \times V_{DDS} = 2.4 \times 189 = 454 \text{ bbl}$$

#### D.4.2.7.11 Volume of excess drilling fluid used for dilution ($V_{DIL\text{-}Exc}$)

The volume of excess drilling fluid volume built used for dilution should be calculated using Equation (16).00

$$V_{DIL\text{-}Exc} = V_{DIL+RDS} - V_{DDF} - V_{DS} = 2166 - 454 - 298 = 1414 \text{ bbl}$$

#### D.4.2.7.12 Overall waste volume ($V_{Waste}$)

The overall waste volume including the excess drilling fluid (over what is needed for dilution and for the surface pits to remain constant), should be calculated using Equation (17).

$$V_{Waste} = V_{DDS} + V_{DDF} + V_{DIL\text{-}Exc} = 189 + 454 + 1414 = 2057 \text{ bbl}$$

#### D.4.2.7.13 Estimating Dilution Volumes ($V_{DIL}/V_{DS}$)

To estimate the volume of drilling fluid which will be needed for dilution and the associated waste volumes when planning wells, sections 5.4 through 5.7 are used. The dilution volume to be used for these 5.4 to 5.6 sections is calculated by assuming typical values for the drilled-solids removal system efficiency, target drilled-solids concentration, and the drilling-fluid to drilled-solids ratio.

The dilution volume of clean drilling fluid per unit volume of excavated drilled-solids to maintain the target drilled-solids concentration, $V_{DIL}/V_{DS}$, should be calculated using Equation (18).

$$\frac{V_{DIL}}{V_{DS}} = \frac{(100 - \eta_{DSR}) \times (100 - \varphi_{DS})}{100 \times \varphi_{DS}} = \frac{(100 - 63.6) \times (100 - 5)}{100 \times 5} = 6.9 \text{ v/v}$$

#### D.4.2.7.14 Optimum solids-removal efficiency ($\eta_{DSR\text{-}Opt}$)

Optimum solids-removal-efficiency that will result in no excess drilling fluid being required for dilution to maintain the target concentration of drilled solids for a given drilling-fluid to drilled-solids ratio should be calculated using Equation (19).

$$\eta_{DSR\text{-}Opt} = 100 \times \frac{(100 - \varphi_{DS})}{[100 + (\varphi_{DS} \times R_{DF\text{-}DS\text{-}Tot})]} = 100 \times \frac{(100 - 5)}{[100 + (5 \times 2.4)]} = 100 \times \frac{95}{112} = 84.8 \text{ \%}$$

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