

Field Testing Water-based Drilling Fluids

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Introduction

This standard is based on API Recommended Practice 13B-1, *Recommended Practice for Field Testing Water-based Drilling Fluids*, Fourth Edition, March 2009.

As with any laboratory procedure requiring the use of potentially hazardous chemicals and equipment, the user is expected to have received proper training and knowledge in the use and disposal of these potentially hazardous materials. The user is responsible for compliance with all applicable local, regional, and national requirements for worker and local health, safety, and environmental liability.

In this standard, quantities expressed in the International System of Units (SI) are also, where practical, expressed in the United States customary (USC) units in parentheses for information. The units do not necessarily represent a direct conversion of SI units to USC units, or USC units to SI units. Consideration has been given to the precision of the instrument making the measurement. For example, thermometers are typically marked in one-degree increments; thus, temperature values have been rounded to the nearest degree.

Calibrating an instrument refers to ensuring the accuracy of the measurement. Accuracy is the degree of conformity of a measurement of a quantity to its actual or true value. Accuracy is related to precision, or reproducibility, of a measurement. Precision is the degree to which further measurements or calculations will show the same or similar results. Precision is characterized in terms of the standard deviation of the measurement. The results of calculations or a measurement can be accurate but not precise, precise but not accurate, neither accurate nor precise, or both accurate and precise. A result is valid if it is both accurate and precise.

This document uses a format for numbers that follows the examples given in *API Document Format and Style Manual*, First Edition, June 2007 (Editorial Revision, November 2017). This numbering format is different than that used in API 13B-1, Fourth Edition. In this document, the decimal mark is a period and separates the whole part from the fractional part of a number. No spaces are used in the numbering format. The thousands separator is a comma and is only used for numbers greater than 10,000 (i.e. 5000 items; 12,500 bags).

Field Testing Water-based Drilling Fluids

Warning—As with any laboratory procedure requiring the use of potentially hazardous chemicals, the user is expected to have proper knowledge and to have received training in the use and disposal of these chemicals. The user is responsible for compliance with all applicable local, regional, and national requirements for worker and local health, safety, and environmental liability.

1 Scope

This recommended practice provides standard procedures for determining the following characteristics of water-based drilling fluids:

- a) drilling fluid density (mud weight);
- b) viscosity and gel strength;
- c) filtration;
- d) water, oil, and solids contents;
- e) sand content;
- f) methylene blue capacity;
- g) pH;
- h) alkalinity and lime content;
- i) chloride content;
- j) total hardness as calcium;
- k) low-gravity solids and weighting material concentrations.

Annexes A through K provide additional test methods that may be used for:

- chemical analysis for calcium, magnesium, calcium sulfate, sulfide, carbonate, and potassium;
- determination of shear strength;
- determination of resistivity;
- removal of air;
- drill-pipe corrosion monitoring;
- sampling, inspection, and rejection;
- rig-site sampling;
- calibration and verification of glassware, thermometers, timers, viscometers, retort cup, and drilling fluid balances;
- permeability plugging testing at high temperature and high pressure for two types of equipment;
- Sag testing.

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 13C, *Drilling Fluid Processing Systems Evaluation*

API Recommended Practice 13D, *Rheology and Hydraulics of Oil-well Drilling Fluids*

3 Terms and Definitions

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

3.1

ACS reagent grade

Chemical meeting the purity standards specified by the American Chemical Society (ACS).

3.2

bentonite equivalent value

A measure of the cation-exchange capacity of a drilling fluid sample volume, reported as a bentonite equivalent expressed in kilograms per cubic meter (kg/m^3) [pounds per barrel (lb/bbl)] of drilling fluid.

3.3

density of water

The volume of 1 kg of water is 1 L for the purposes of this standard, and the density of water in grams is numerically equivalent to the volume of the water measured in cubic centimeters or milliliters, i.e. $1 \text{ g} \equiv 1 \text{ mL}$. See Table I.1 for further details.

NOTE Deionized or distilled water is used for equipment calibration.

3.4

drill solids

Solid substrate materials incorporated into the drilling fluid as a result of drilling formations.

3.5

low-gravity solids

Any solid substrate material in the drilling fluid having a density less than or equivalent to 2.6 g/cm^3 (21.7 lb/gal).

3.6

quarter (quartered)

A verb: mix and divide a sample into four specimens to ensure homogeneity of specimens.

NOTE API 19C provides apparatus and procedure to quarter a sample.

3.7

spurt loss

The volume of fluid that passes through the filtration medium before a filter cake is formed.

3.8

tube sampling

A sampling method consisting of the withdrawal of powdered sample from bag or bulk via a cylindrical device pushed into the sample, locked shut and withdrawn.

4 Symbols and Abbreviations

4.1 Symbols

NOTE Subscript “SI” to symbol denotes metric units. Subscript “USC” to symbol denotes United States customary units.

A_{SI}	area, expressed in square centimeters
A_{USC}	area, expressed in square inches
B_{VSST}	weight-material sag, expressed in pounds-mass per gallon
b	slope of the annular velocity and shear stress at the wall in laminar flow [see K.7.2.8]]
C_{MBT}	methylene blue capacity of drilling fluid, expressed in milliequivalents per milliliters of drilling fluid
C_{th}	thermometer correction factor to be added to the working thermometer reading, expressed in degrees Celsius (degrees Fahrenheit)
c_{Ca}	concentration of calcium ion, expressed in milligrams per liter
$c_{CaSO_4,SI}$	concentration of calcium sulfate, expressed in kilograms per cubic meter
$c_{CaSO_4,USC}$	concentration of excess, undissolved calcium sulfate, expressed in pounds per barrel
c_{Ca+Mg}	concentration of calcium and magnesium ions (total hardness), expressed in milligrams per liter
c_{Cl}	concentration of chloride ion, expressed in milligrams per liter
$c_{CO_2+CO_3+HCO_3}$	concentration of total soluble carbonates, expressed in milligrams per liter
$c_{ex-CaSO_4,SI}$	concentration of excess, undissolved calcium sulfate, expressed in kilograms per cubic meter
$c_{ex-CaSO_4,USC}$	concentration of excess, undissolved calcium sulfate, expressed in pounds per barrel
$c_{K,f-VQAS}$	concentration of potassium ion in filtrate (QAS titration), expressed in milligrams per liter
$c_{K,f}$	concentration of potassium ion in filtrate, expressed in milligrams per liter
$c_{KCl,SI}$	concentration of potassium chloride in diluted filtrate test sample, expressed in kilograms per cubic meter
$c_{KCl,USC}$	concentration of potassium chloride in diluted filtrate test sample, expressed in pounds per barrel
$c_{KCl,f,SI}$	concentration of potassium chloride in filtrate, expressed in kilograms per cubic meter

$c_{\text{KCl,f,USC}}$	concentration of potassium chloride in filtrate, expressed in pounds per barrel
$c_{\text{LG,SI}}$	concentration of low-gravity solids, expressed in kilograms per cubic meter
$c_{\text{LG,USC}}$	concentration of low-gravity solids, expressed in pounds per barrel
$c_{\text{lime,SI}}$	lime content of the drilling fluid, expressed in kilograms per cubic meter
$c_{\text{lime,USC}}$	lime content of the drilling fluid, expressed in pounds per barrel
c_{Mg}	concentration of magnesium ion, expressed in milligrams per liter
$c_{\text{NaCl,SI}}$	concentration of sodium chloride, expressed in milligrams per liter
$c_{\text{NaCl,PPM}}$	concentration of sodium chloride, expressed in parts per million by mass
c_{S}	concentration of sulfide ion, expressed in milligrams per liter
$c_{\text{SS,SI}}$	concentration of suspended solids, expressed in kilograms per cubic meter
$c_{\text{SS,USC}}$	concentration of suspended solids, expressed in pounds per barrel
$c_{\text{WM,SI}}$	concentration of weighting material, expressed in kilograms per cubic meter
$c_{\text{WM,USC}}$	concentration of weighting material, expressed in pounds per barrel
D	outer pipe diameter, expressed in inches
D_{TVD}	true vertical depth, expressed in feet
d	inner pipe diameter, expressed in inches
d_1	distance from the outer wall, expressed in inches
E	pump efficiency, expressed as a percentage
$E_{\text{BE,SI}}$	bentonite equivalent, expressed in kilograms per cubic meter
$E_{\text{BE,USC}}$	bentonite equivalent, expressed in pounds per barrel
F_{W}	volume fraction of water in the drilling fluid, expressed as a decimal
f_{CO_2}	tube factor for CO ₂ gas detection tube, from Table A.2
f_{S}	tube factor for H ₂ S gas detection tube, from Table A.1
G'	storage modulus, expressed in pascals (= N/m ²)
G''	loss modulus, expressed in pascals (= N/m ²)

K	cell constant, expressed in square meters per meter
k_C	drilling fluid consistency factor (Herschel-Bulkley model), expressed in $\text{lb}\cdot\text{s}^n/100\text{ ft}^2$
k_{cor}	correction factor
L	length of the hydraulic section, expressed in feet
l_{SI}	submerged length of shear tube, expressed in centimeters
l_{st}	gas detection Dräger (or equivalent) tube stain length, expressed in units marked on the tube
l_{USC}	submerged length of shear tube, expressed in inches
M_f	methyl orange alkalinity of the filtrate, expressed as the number of millimeters of 0.01 mol/L sulfuric acid solution required to reach the methyl orange endpoint per milliliter of filtrate
m_{F1}	initial mass of the 10 mL sample of drilling fluid (plus syringe), expressed in grams
m_{F2}	mass of 10 mL sample of drilling fluid (plus syringe) taken at the sag shoe following 30 min shear at 100 r/min, expressed in grams
m_{F3}	mass of 10 mL sample of drilling fluid (plus syringe) taken at the sag shoe following 20 min shear at 600 r/min, expressed in grams
m_W	mass of water, filling receiver at a specified mark, expressed in grams
m_{dmb}	mass of the methylene blue dried sample, expressed in grams
m_{mb}	corrected mass of methylene blue powder to be used per liter water, expressed in grams
m_{st}	mass of the shear tube, expressed in grams
m_{tot}	total shear mass (sum of platform and weights), expressed in grams
P	pressure (heating or back-pressure), expressed in kilopascals (pounds-force per square inch)
P_{USC}	measured pressure, expressed in pounds-force per square inch
P_{df}	phenolphthalein alkalinity of the drilling fluid, expressed as the number of millimeters of 0.01 mol/L sulfuric acid solution required to reach the phenolphthalein endpoint per milliliter of drilling fluid
P_f	phenolphthalein alkalinity of the filtrate, expressed as the number of millimeters of 0.01 mol/L sulfuric acid solution required to reach the phenolphthalein endpoint per milliliter of filtrate
Q	pump flow rate, expressed in gallons per minute

q_{SI}	corrosion rate, expressed in kilograms per square meter·year
q_{USC}	corrosion rate, expressed in pounds per square foot·year
R	temperature reading for the working thermometer, expressed in degrees Celsius (degrees Fahrenheit)
R_{BPU}	calculated bed pickup measurement ratio, expressed as a percentage
$R_{QAS/STPB}$	ratio of the concentration of QAS to that of STPB
R_{cor}	corrected temperature reading for the working thermometer, expressed in degrees Celsius (degrees Fahrenheit)
R_r	resistivity-meter reading, expressed in ohms
R_1	average temperature reading for the standard thermometer, expressed in degrees Celsius (degrees Fahrenheit)
R_2	average temperature reading for the working thermometer, expressed in degrees Celsius (degrees Fahrenheit)
R_3	viscometer dial reading at 3 r/min, expressed in degrees of deflection
R_6	viscometer dial reading at 6 r/min, expressed in degrees of deflection
R_{30}	viscometer dial reading at 30 r/min, expressed in degrees of deflection
R_{60}	viscometer dial reading at 60 r/min, expressed in degrees of deflection
R_{100}	viscometer dial reading at 100 r/min, expressed in degrees of deflection
R_{200}	viscometer dial reading at 200 r/min, expressed in degrees of deflection
R_{300}	viscometer dial reading at 300 r/min, expressed in degrees of deflection
R_{600}	viscometer dial reading at 600 r/min, expressed in degrees of deflection
r_{df}	drilling fluid resistivity, expressed in ohm·meters
r_f	filtrate resistivity, expressed in ohm·meters
S	Sag register
t	exposure time, expressed in hours, or lagged time, expressed in minutes
t_1	initial reading time (taken at 7.5 min), expressed in minutes

t_2	final reading time (taken at 30 min), expressed in minutes
V_{EDTA}	titration volume of EDTA solution, expressed in milliliters
$V_{\text{EDTA,df}}$	titration volume of EDTA solution of whole drilling fluid, expressed in milliliters
$V_{\text{EDTA,f}}$	titration volume of EDTA solution of the drilling fluid filtrate, expressed in milliliters
V_L	volume of condensed liquids (oil and water) after retorting, expressed in milliliters
V_M	receiver volume at a specified mark, expressed in milliliters
V_O	volume of oil, expressed in milliliters
V_{PPT}	PPT volume, expressed in milliliters
V_{QAS}	volume of QAS, expressed in milliliters
V_{RC}	retort cup volume, expressed in milliliters
V_{USC}	annular volume, expressed in barrels
V_W	volume of condensed water, expressed in milliliters, or mass of condensed water, expressed in grams (1 mL $\equiv$ 1 g)
V_{df}	volume of whole drilling fluid sample, expressed in milliliters
V_f	volume of the filtrate or filtrate test sample, expressed in milliliters
V_{mb}	volume of methylene blue solution, expressed in milliliters
V_s	volume of sample (drilling fluid or filtrate), expressed in milliliters
V_{sn}	volume of silver nitrate solution, expressed in milliliters
V_1	spurt loss, expressed in milliliters
$V_{7.5}$	filtrate volume after 7.5 min, expressed in milliliters
V_{30}	filtrate volume after 30 min, expressed in milliliters
$Y_{\text{P,SI}}$	yield point, expressed in pascals
$Y_{\text{P,USC}}$	yield point, expressed in pounds-force per one hundred square feet
$\beta_{10\text{m}}$	10 min gel strength, expressed in pounds-force per one hundred square feet

β_{10s}	10 s initial gel strength, expressed in pounds-force per one hundred square feet
$\Gamma_{DFG,SI}$	drilling fluid depth gradient, expressed in kilopascals per meter
$\Gamma_{DFG,USC}$	drilling fluid depth gradient, in pounds per square inch, per foot
γ_i	shear rate at section i, expressed in reciprocal seconds
γ_{SI}	shear strength, expressed in pascals
γ_{USC}	shear strength, expressed in pounds-force per hundred square feet
$\Delta\left(\frac{P}{L}\right)_{USC}$	pressure gradient, expressed in pounds-force per square inch, per foot
ΔP_{rot}	anticipated pressure increase, expressed in pounds-force per square inch
Δm	mass loss, expressed in milligrams
$\Delta \rho$	maximum recorded drilling fluid density difference, expressed in pounds per gallon
$\Delta \rho_{ECD-rot}$	ECD increase due to drill pipe rotation, expressed in pounds per gallon
Δv_{USC}	change in annular velocity, expressed in feet per minute
ε	pipe eccentricity, expressed as a percentage
η	drill pipe rotation, expressed in revolutions per minute
η_{AV}	apparent viscosity, expressed in millipascal-seconds (centipoises)
η_{PV}	plastic viscosity, expressed in millipascal-seconds (centipoises)
ρ	drilling fluid relative density (specific gravity)
ρ_{ECD}	measured ECD of the drilling fluid while circulating, expressed in pounds per gallon
$\rho_{ECD-hyd}$	ECD of the drilling fluid including ESD, circulating pressure drop and extra density effects of drilled cuttings, expressed in pounds per gallon
$\rho_{ECD-tot}$	total predicted ECD of the drilling fluid in the annulus while circulating, expressed in pounds per gallon
ρ_{LG}	density of low-gravity solids, expressed in grams per milliliter (use 2.6 g/mL if unknown)
ρ_O	density of oil, expressed in grams per milliliter (use 0.8 if unknown)

ρ_W	water density at test temperature, expressed in grams per milliliter
ρ_{WM}	density of weighting material, expressed in grams per milliliter
ρ_{df}	drilling fluid density, expressed grams per milliliter
$\rho_{df,SI}$	drilling fluid density, expressed in kilograms per cubic meter
$\rho_{df,USC}$	drilling fluid density, expressed in pounds per gallon
$\rho_{df,USC2}$	drilling fluid density, expressed in pounds per cubic foot
ρ_f	density of filtrate, expressed in grams per milliliter
ρ_{max}	maximum recorded density of drilling fluid, expressed in pounds per gallon
ρ_{nom}	nominal density of drilling fluid, expressed in pounds per gallon
τ_Y	drilling fluid yield stress (Herschel-Bulkley model), expressed in pounds-force per one hundred square feet
τ_W	wall shear stress, expressed in pounds-force per one hundred square feet
τ_{Wi}	wall shear stress at section i, expressed in pounds-force per one hundred square feet
v_{USC}	annular velocity, expressed in feet per minute
v_{sf}	static filtration rate (volumetric flow rate), expressed in milliliters per square root of minute
ϕ_{LG}	volume fraction of low-gravity solids, expressed as a percentage of the drilling fluid volume
ϕ_O	volume fraction of oil, expressed as a percentage of the drilling fluid volume
ϕ_{SS}	volume fraction of suspended solids, expressed as a percentage of the drilling fluid volume
ϕ_W	volume fraction of water, expressed as a percentage of the drilling fluid volume
ϕ_{WM}	volume fraction of weighting-material solids, expressed as a percentage of the drilling fluid volume
ϕ_{ds}	volume fraction of dried solids from retort, expressed as a percentage of the drilling fluid volume

4.2 Abbreviations

ACS	American Chemical Society
BE	bentonite equivalent
CAS	Chemical Abstracts Service
DFG	drilling fluid gradient
DN	nominal diameter
ECD	equivalent circulating density
EDTA	ethylenediaminetetraacetic acid
ERD	extended-reach drilling
ESD	equivalent static density
HTHP	high-temperature high-pressure
LSYP	low-shear yield point
MBT	methylene blue test (often also used to mean the methylene blue capacity)
meq	milliequivalents
PPA	permeability plugging apparatus
PPE	personal protective equipment
PPT	permeability plugging test
PTFE	polytetrafluoroethylene
PV	plastic viscosity, in common oilfield terminology
psi	pound-force per square inch
QAS	quaternary ammonium salt
RMS	root mean square
RPM	revolutions per minute
STPB	sodium tetraphenylborate
TC	to contain
TD	to deliver
TVD	total vertical depth
VSST	viscometer sag shoe test
YP	yield point, in common oilfield terminology

5 Drilling Fluid Density (Mud Weight)

5.1 Principle

A procedure is given for determining the mass of a given volume of liquid (i.e. density) under ambient pressure conditions. The density of drilling fluid may be expressed as grams per milliliter or kilograms per cubic meter (pounds per gallon, or pounds per cubic foot).

5.2 Apparatus

5.2.1 Any ambient pressure density-measuring instrument (mud balance), having an accuracy of ± 0.01 g/mL or ± 10 kg/m³ (± 0.1 lb/gal or ± 0.5 lb/ft³).

The mud balance is the density instrument generally used for drilling fluid density measurements at the rig site. The mud balance is designed such that the cup holding the drilling fluid, at one end of the beam, is balanced by a sliding-counterweight that moves along a graduated scale. A bubble-level is mounted on the beam to allow for accurate leveling. Attachments for extending the range of the balance may be used when necessary.

The mud balance should be calibrated frequently with fresh water, e.g. biweekly or weekly. Fresh water should give a reading of 1.00 g/mL or 1000 kg/m³ (8.345 lb/gal or 62.4 lb/ft³) at 21 °C (70 °F). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm, as required. A calibration of the upper density should be performed as specified by the manufacturer, and done on a less frequent basis, e.g. annually.

5.2.2 Thermometer, with a range of 0 °C to 105 °C (32 °F to 220 °F) and an accuracy of ± 1 °C (± 2 °F).

5.3 Mud Balance Procedure

In order to determine drilling fluid density, the following procedure shall be used.

- a) The mud balance instrument should be set on a flat, level surface.
- b) Measure and record the temperature of the drilling fluid.
- c) Start with a clean and dry mud balance. Fill the balance cup to the lip with the drilling fluid to be tested. Put the cap on the filled sample cup and rotate the cap, expelling any trapped air and excess drilling fluid. Ensure the cap is firmly seated.
- d) Holding the cap firmly on the filled sample cup (with cap hole covered by a finger), wash or wipe the outside of the cup clean and dry.
- e) Place the beam on the base support and level it by moving the rider along the graduated scale. Leveling is achieved when the bubble is under the centerline.
- f) The drilling fluid density is read from one of the four calibrated scales on the balance arm at the arrow side of the sliding-counterweight. As it is considered that the water density is 1 g/mL (see definition 3.3), the density can be read directly in units of grams per milliliter using relative density (specific gravity) scale, pounds per gallon, pounds per cubic foot, or as a drilling fluid depth gradient in pounds per square inch for each 1000 ft of vertical depth.

5.4 Calculation

Report the drilling fluid density to the nearest 0.01 g/mL or 10 kg/m³ (0.1 lb/gal or 0.5 lb/ft³).

To convert the relative density reading, ρ , which is numerically equivalent to the density, ρ_{df} , expressed in grams per milliliter to other units, use Equations (1) to (7) and Tables 1 and 2.

Equations (1) to (3) are used to convert the density, ρ_{df} , expressed in grams per milliliter, to other units:

$$\rho_{df,SI} = 1000 \times \rho_{df} \quad (1)$$

where

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

$$\rho_{df,USC} = 8.345 \times \rho_{df} \quad (2)$$

where

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

$$\rho_{df,USC2} = 62.43 \times \rho_{df} \quad (3)$$

where

$\rho_{df,USC2}$ is the drilling fluid density, expressed in pounds per cubic foot.

Table 1 provides the multiplication factor for conversion from one density unit to another.

Table 1—Conversion of Density Units

Measured in	Multiply to Convert to			
	g/mL	kg/m ³	lb/gal	lb/ft ³
g/mL	1	1000	8.345	62.43
kg/m ³	0.001	1	0.0083	0.06243
lb/gal	0.120	120	1	7.4805
lb/ft ³	0.0160	16.02	0.1337	1

Equations (4) to (7) are used to convert the density to the drilling fluid depth gradient, Γ_{DFG} , expressed in kilopascals per meter (pounds per square inch, per foot):

$$\Gamma_{DFG,SI} = 9.81 \times \rho_{df} \quad (4)$$

$$\Gamma_{DFG,SI} = 22.6 \times \Gamma_{DFG,USC} \quad (5)$$

$$\Gamma_{DFG,USC} = 0.0520 \times \rho_{df,USC} \quad (6)$$

$$\Gamma_{DFG,USC} = 0.00694 \times \rho_{df,USC2} \quad (7)$$

where

$\Gamma_{DFG,SI}$ is the drilling fluid depth gradient, expressed in kilopascals per meter;

$\Gamma_{DFG,USC}$ is the drilling fluid depth gradient, expressed in pounds per square inch, per foot.

A list of density conversions is given in Table 2.

Table 2—Density Conversion

Grams per Cubic Centimeter ^a	Kilograms per Cubic Meter	Pounds per Gallon	Pounds per Cubic Foot
g/mL	kg/m ³	lb/gal	lb/ft ³
0.70	700	5.8	43.7
0.80	800	6.7	49.9
0.90	900	7.5	56.1
1.00	1000	8.345 ^b	62.4
1.10	1100	9.2	68.7
1.20	1200	10.0	74.9
1.30	1300	10.9	81.1
1.40	1400	11.7	87.4
1.50	1500	12.5	93.6
1.60	1600	13.4	99.9
1.70	1700	14.2	106.1
1.80	1800	15.0	112.4
1.90	1900	15.9	118.6
2.00	2000	16.7	124.8
2.10	2100	17.5	131.1
2.20	2200	18.4	137.3
2.30	2300	19.2	143.6
2.40	2400	20.0	149.8
2.50	2500	20.9	156.1
2.60	2600	21.7	162.3
2.70	2700	22.5	168.5
2.80	2800	23.4	174.8
2.90	2900	24.2	181.0
^a Same value as relative density (specific gravity) in grams per cubic centimeter or kilogram per liter.			
^b Accurate conversion factor.			

6 Alternative Method for Determination of Drilling Fluid Density

6.1 Principle

The pressurized mud balance provides a more accurate method for determining the density of a drilling fluid containing entrained air or gas than does the conventional ambient pressure mud balance. The pressurized mud balance is similar in operation to the conventional mud balance, the difference being that the drilling fluid sample is placed in a fixed-volume sample cup under pressure.

The purpose of placing the sample under pressure is to minimize the effect of entrained air or gas upon drilling fluid density measurements. By pressurizing the sample cup, any entrained air or gas is decreased to a negligible volume, thus providing a more accurate drilling fluid density measurement.

6.2 Apparatus

6.2.1 Any density-measuring instrument, having an accuracy of ± 0.01 g/mL or ± 10 kg/m³ (± 0.1 lb/gal or ± 0.5 lb/ft³).

The pressurized mud balance is the pressurized density instrument generally used for drilling fluid density measurements at the rig site. It is designed such that the sample cup and screw-on lid, at one end of the beam, is balanced by a fixed counterweight at the other end, with a sliding-weight rider free to move along a graduated scale. A bubble-level is mounted on the beam to allow for accurate balancing.

The instrument should be calibrated frequently with fresh water, e.g. biweekly or weekly. Fresh water should give a reading of 1.00 g/mL or 1000 kg/m³ (8.345 lb/gal or 62.4 lb/ft³) at 21 °C (70 °F). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm, as required. A calibration of the upper density should be performed as specified by the manufacturer, and done on a less frequent basis, e.g. annually.

6.2.2 Thermometer, with a range of 0 °C to 105 °C (32 °F to 220 °F) and an accuracy of ± 1 °C (± 2 °F).

6.3 Pressurized Mud Balance Procedure

To determine drilling fluid density with a pressurized mud balance, the following procedure shall be used.

- a) Measure and record the temperature of the drilling fluid.
- b) Fill the sample cup of the pressurized mud balance to a level approximately 6.5 mm (0.25 in.) below the upper edge of the cup.
- c) Place the lid on the cup with the attached check-valve in the down (open) position. Push the lid downward into the mouth of the cup until surface contact is made between the outer skirt of the lid and the upper edge of the cup. Any excess drilling fluid will be expelled through the check-valve. When the lid has been placed on the cup, pull the check-valve up into the closed position, rinse off the cup and threads with water, and screw the threaded cap on the cup.
- d) The pressurizing plunger is similar in operation to a syringe. Fill the plunger by submersing its end in the drilling fluid with the piston rod pushed all the way down. Draw the piston rod upward, thereby filling the cylinder with drilling fluid. This volume should be expelled with the plunger action and refilled with fresh drilling fluid sample to ensure that this plunger volume is not diluted with liquid remaining from the last clean-up of the plunger mechanism.
- e) Push the nose of the plunger onto the mating O-ring surface of the cap valve. Pressurize the sample cup by maintaining a downward force on the cylinder housing in order to hold the check-valve down

(open) and at the same time force the piston rod down. A force of approximately 225 N (50 lbf) or greater should be maintained on the piston rod.

- f) The check-valve in the lid is pressure-actuated; when the inside of the cup is pressurized, the check valve is pushed upward into the closed position. To close the valve, gradually ease up on the cylinder housing while maintaining pressure on the piston rod. When the check-valve closes, release pressure on the piston rod before disconnecting the plunger.
- g) The pressurized drilling fluid sample is now ready for weighing. Rinse the exterior of the cup and wipe dry. Place the instrument on the knife edge. Move the sliding weight until the beam is balanced. The beam is balanced when the attached bubble is centered between the two black marks. Read the density from one of the four calibrated scales on the arrow side of the sliding weight. As it is considered that the density of water is 1 g/mL (see definition 3.3), the density can be read directly in units of grams per milliliter using relative density (specific gravity) scale, pounds per gallon, and pounds per cubic foot, or as a drilling fluid gradient in pounds per square inch for each 1000 ft of vertical depth.
- h) To release the pressure inside the cup, reconnect the empty plunger assembly and push downward on the cylinder housing.
- i) Clean the cup, lid, and plunger assembly.

6.4 Calculation

Report the drilling fluid density to the nearest 0.01 g/mL or 10 kg/m³ (0.1 lb/gal or 0.5 lb/ft³).

For conversions, use the equations given in 5.4.

7 Viscosity and Gel Strength

7.1 Principle

Viscosity and gel strength are measurements that relate to the flow or rheological properties of drilling fluids.

The following instruments are used to measure viscosity and gel strength of drilling fluids at temperatures from 4 °C to 65 °C (40 °F to 150 °F). Low-temperature rheology may be anticipated in the riser annulus of deepwater drilling operations. The equipment is as follows:

- a) Marsh funnel and graduated cup: a simple device for indicating viscosity on a routine basis;
- b) direct-indicating viscometer: a mechanical device for measuring viscosity at varying shear rates.
- c) a chilled rheometer cup is typically required for measuring low temperature rheology.

NOTE Information on the rheology of drilling fluids can be found in API 13D.

7.2 Determination of Funnel Viscosity Using the Marsh Funnel

7.2.1 Apparatus

7.2.1.1 Marsh funnel, calibrated to deliver 946 mL (1 qt) of fresh water at a temperature of 21 °C ±3 °C (70 °F ±5 °F) in 26 s ±0.5 s, using a graduated cup as a receiver.

The Marsh funnel shall have the following characteristics:

- a) funnel cone, length 305 mm (12.0 in.), diameter 152 mm (6.0 in.), and a capacity to bottom of screen of 1500 mL (1.6 qt);
- b) orifice, length 50.8 mm (2.0 in.) and inside diameter 4.7 mm (0.185 in. = 3/16 in.);
- c) screen, with 1.6 mm (0.063 in. = 1/16 in., 12 mesh) openings, fixed at 19.0 mm (0.75 in.) below top of funnel.

7.2.1.2 Graduated cup, with a capacity of at least 946 mL (1 qt).

7.2.1.3 Timer or stopwatch.

7.2.1.4 Thermometer, with a range of 0 °C to 105 °C (32 °F to 220 °F) and an accuracy of ± 1 °C (± 2 °F).

7.2.2 Procedure

In order to determine funnel viscosity using a Marsh funnel, the following procedure shall be used.

- a) Cover the funnel orifice with a finger and pour freshly sampled drilling fluid through the screen into the clean, upright funnel. Fill until fluid reaches the bottom of the screen.
- b) Remove finger and start the stopwatch simultaneously. Measure the time for drilling fluid to fill to the 946 mL (1 qt) mark of the cup.
- c) Measure the temperature of the fluid, in degrees Celsius (degrees Fahrenheit).
- d) Report the time [7.2.2 b)] to the nearest second as the Marsh funnel viscosity. Report the temperature [7.2.2 c)] of the fluid to the nearest degree Celsius (degree Fahrenheit).

7.3 Determination of Viscosity and Gel Strengths Using a Direct-reading Viscometer

7.3.1 Apparatus

7.3.1.1 Direct-indicating viscometer, powered by an electric motor or a hand crank.

Drilling fluid is placed in the annular space between two concentric cylinders. The outer cylinder or rotor sleeve is driven at a constant rotational velocity. The rotation of the rotor sleeve in the fluid produces a torque on the inner cylinder, the bob. A torsion spring restrains the movement of the bob, and a dial attached to the bob indicates displacement of the bob. Instrument constants should be adjusted so that the plastic viscosity and yield point are obtained by using readings from rotor sleeve rotational speeds of 300 r/min and 600 r/min.

The components shall meet the following specifications:

a) Rotor sleeve—R1:

inside diameter: 36.83 mm (1.450 in.);

total length: 87.0 mm (3.425 in.);

scribed line: 58.4 mm (2.30 in.) above the bottom of sleeve, with two rows of 3.18 mm (0.125 in.) holes, spaced 2.09 rad (120°) apart, around rotor sleeve just below scribed line;

sleeve surface: surface finish (roughness) average 0.4 μm to 0.8 μm (16 $\mu\text{in.}$ to 32 $\mu\text{in.}$) RMS cross-hatched honed.

b) Bob—B1, closed, with flat base and tapered top:

diameter: 34.49 mm (1.358 in.);

cylinder length: 38.0 mm (1.496 in.);

rotor surface: surface finish (roughness) average 0.4 μm to 0.8 μm (16 $\mu\text{in.}$ to 32 $\mu\text{in.}$) RMS cross-hatched honed.

c) Torsion spring—F1.0, constant:

torsional stiffness: 10.54 N·m/rad $\equiv$ 0.184 N·m/degree of deflection (386 dyne·cm/degree deflection);

shear stress constant: 29.3 pascals per radian of deflection $\equiv$ 0.511 pascals per degree of deflection (1.067 lbf/100·ft² per degree of deflection).

d) Rotor sleeve speeds:

high speed: 600 r/min;

low speed: 300 r/min.

NOTE Other rotor speeds are available in viscometers from various manufacturers.

7.3.1.2 Timer or stopwatch.

7.3.1.3 Thermostatically controlled viscometer cup (thermocup):

- a) greater than room temperature: thermostatically controlled direct-heated viscometer cup;
- b) less than room temperature: double-walled viscometer cup connected to a thermostatically controlled refrigerated circulating bath.

7.3.1.4 Thermometer, with a range of 0 °C to 105 °C (32 °F to 220 °F) and an accuracy of ± 1 °C (± 2 °F).

7.3.2 Procedure

The following procedure shall be used.

- a) Place a sample of the drilling fluid in a thermostatically controlled viscometer cup. Leave enough empty volume (approximately 50 mL to 100 mL) in the cup for displacement of fluid due to the viscometer bob and sleeve. Immerse the rotor sleeve exactly to the scribed line. Measurements in the field should be made with minimum delay from the time of drilling fluid sampling. Testing should be carried out at either 50 °C ± 1 °C (120 °F ± 2 °F) or 65 °C ± 1 °C (150 °F ± 2 °F) for reference comparisons to historical data. Testing at a lower temperature, such as 4 °C ± 1 °C (40 °F ± 2 °F), is recommended for low temperature effects. The place of sampling should be stated in the report.

Caution—The maximum recommended operating temperature is 90 °C (190 °F). If it is necessary to test fluids above this temperature, a solid metal bob should be used. Liquid trapped inside a hollow bob can vaporize when immersed in high-temperature fluid and cause the bob to explode.

- b) Heat (or cool) the sample to the selected temperature. Use constant shear at 600 r/min or 300 r/min to stir the sample while heating (or cooling) to obtain a uniform sample temperature. After the cup temperature reaches the selected temperature, immerse the thermometer into the sample and continue stirring until the sample reaches the selected temperature. Record the temperature of the sample.

NOTE Use 300 r/min in highly weighted mud systems to minimize weighting material settling.

- c) With the sleeve rotating at 600 r/min, wait for the viscometer dial reading to reach a steady value (the time required is dependent on the drilling fluid characteristics). Record the dial reading, R_{600} .
- d) Reduce the rotor speed to 300 r/min and wait for the dial reading to reach steady value. Record the dial reading, R_{300} .

NOTE Additional dial reading values are often measured and reported, typically R_{200} , R_{100} , R_6 , and R_3 . Improved modeling accuracy can be achieved by also measuring the R_{60} and R_{30} dial readings. Measurement of dial readings should be performed stepwise from the highest to the lowest revolutions per minute (RPM) speed.

- e) With the sleeve rotating at 600 r/min, wait for the viscometer dial reading to reach a steady value.
- f) Stop the rotor and allow the drilling fluid sample to stand undisturbed for 10 s. If using a hand-crank viscometer, slowly and steadily turn the hand-wheel in the appropriate direction to produce a positive dial reading. Record the maximum reading as the initial gel strength or 10 s gel strength. For instruments having a 3 r/min speed, the maximum reading attained after starting rotation at 3 r/min is the initial gel strength. Record the initial gel strength, β_{10s} , at 10 s, in pounds-force per one hundred square feet (lbf/100·ft²).
- g) Re-stir the drilling fluid sample at 600 r/min until a steady value is achieved, stop the motor and then allow the drilling fluid to stand undisturbed for 10 min. Repeat the measurements as in 7.3.2 f) and report the maximum reading as β_{10m} , the 10 min gel strength, in pounds-force per one hundred square feet (lbf/100·ft²).

NOTE The gel strength value reported directly from the dial reading is an approximation of lbf/100·ft². Dial reading units are degrees of deflection (1/360 of 1 full rotation). Each 1 degree of deflection is equal to 0.511 Pa in SI units and to 1.067 lbf/100·ft² in USC units. These exact unit corrections are often neglected for simplicity in reporting. Common field practice when reporting pascals is to divide dial units by 2 for simplicity. 1 r/min of the rotor equals a shear rate of 1.7023 s⁻¹.

7.3.3 Calculation

The dimensions for the rotor R1, bob B1 and spring F1.0 constant, as described in 7.3.1.1, determine the following:

- 1° deflection of the bob equals a shear stress of 0.511 Pa and approximately 1 lbf/100·ft², or more exactly 1 degree of deflection = 1.067 lbf/100·ft²;
- 1 r/min of the rotor equals a shear rate of 1.7023 reciprocal seconds (s⁻¹).

The viscosity, defined as shear stress in millipascal divided by shear rate in reciprocal seconds, will be expressed in centipoises (which is equivalent to millipascal·seconds). At 300 r/min (shear rate of 511 s⁻¹), the degrees of deflection will correspond to viscosity expressed in millipascal·seconds (or centipoises).

The calculation for the plastic viscosity, η_{PV} , expressed in millipascal-seconds (centipoises), is given in Equation (8):

$$\eta_{PV} = R_{600} - R_{300} \quad (8)$$

where

R_{600} is the dial reading at 600 r/min, expressed in degrees of deflection;

R_{300} is the dial reading at 300 r/min, expressed in degrees of deflection.

NOTE Plastic viscosity is commonly known in the industry by the abbreviation PV.

When calculating values in USC units, the yield point, $Y_{P,USC}$, expressed in pounds-force per one hundred square feet, is given in Equation (9):

$$Y_{P,USC} = R_{300} - \eta_{PV} \quad (9)$$

where

R_{300} is the dial reading at 300 r/min, expressed in degrees of deflection;

η_{PV} is the plastic viscosity, expressed in millipascal-seconds (centipoises).

NOTE Yield point, in lbf/100-ft², is commonly known in the industry by the abbreviation YP. The yield point value calculated with Equation (10) from the dial readings is an approximation of lbf/100-ft². Dial reading units are degrees of deflection (1/360 of 1 full rotation). Each 1 degree of deflection is equal to 0.511 Pa in SI units and to 1.067 lbf/100-ft² in USC units. In Equation (10), the exact units correction is neglected for simplicity in reporting.

The calculation for yield point, $Y_{P,SI}$, expressed in pascals, is given in Equation (10):

$$Y_{P,SI} = 0.511 \times (R_{300} - \eta_{PV}) \quad (10)$$

where

R_{300} is the dial reading at 300 r/min, expressed in degrees of deflection;

η_{PV} is the plastic viscosity, expressed in millipascal-seconds (centipoises).

NOTE The conversion from lbf/100-ft² to pascals is to multiply by 0.479. However, each 1 degree of deflection is exactly equal to 0.511 Pa in SI units, so Equation (10) converts the values obtained from dial units to pascals. Common field practice when reporting pascals is to divide dial units [Equation (9)] by 2 for simplicity.

The calculation for apparent viscosity, η_{AV} , expressed in millipascal-seconds (centipoises), is given in Equation (11):

$$\eta_{AV} = \frac{R_{600}}{2} \quad (11)$$

where

R_{600} is the dial reading at 600 r/min, expressed in degrees of deflection.

NOTE Apparent viscosity is commonly known in the industry by the abbreviation AV.

Report the plastic viscosity, yield point, 10 s gel strength, 10 min gel strength, and apparent viscosity.

8 Static Filtration

8.1 General

Measurement of the filtration behavior and the filter cake characteristics of a drilling fluid are fundamental to the treatment and control of a drilling fluid, as are the characteristics of the filtrate, such as the oil, water, or emulsion concentration.

Filtration characteristics of a drilling fluid are affected by the quantity, type, and size of solid particles in the drilling fluid and by properties of the liquid phase. Interactions of these various components can be influenced by temperature and pressure.

Tests are run under static conditions at both low pressure/low temperature and high pressure/high temperature, and each requires different equipment and techniques.

8.2 Low-temperature Low-pressure Filtrate Test

8.2.1 Apparatus

8.2.1.1 Filter press, consisting mainly of a cylindrical drilling fluid cell having an inside diameter of 76.2 mm (3.0 in.) and a height of at least 64.0 mm (2.5 in.).

This cell shall be made of materials resistant to strongly alkaline solutions and is so fitted that a pressure medium can be conveniently admitted into, and bled from, the top. It shall also be fitted such that a sheet of 90 mm (3.54 in.) diameter filter paper can be placed in the bottom of the cell just above a suitable support. The filtration area is $45.8 \text{ cm}^2 \pm 0.6 \text{ cm}^2$ ($7.1 \text{ in.}^2 \pm 0.1 \text{ in.}^2$). Below the support is a drain tube for discharging the filtrate into a graduated cylinder. Sealing is accomplished with gaskets and the entire assembly supported by a stand. Pressure can be applied with any nonhazardous gas medium. The filter press is equipped with a pressure regulator that can be energized using a portable pressure cylinder, pressure cartridge or other means for applying a controllable differential pressure. To obtain correlative results, only one thickness of filter paper ¹ shall be used.

The low-temperature/low-pressure filter press should have a filter area of 45.2 cm^2 to 46.4 cm^2 (7.0 in.^2 to 7.2 in.^2) that corresponds to a diameter of 75.9 mm to 76.9 mm (2.98 in. to 3.02 in.). The inner diameter of the filter press gasket determines the dimensions of the filtration area. It is recommended that the filter press gasket to be used should be tested using a conical gauge that has the maximum 76.9 mm (3.02 in.) and the minimum 75.9 mm (2.98 in.) diameters marked on it. Any filter-press gasket found out of this range (either larger or smaller than the markings) shall not be used.

NOTE Results obtained from the use of a filter press with different filter area do not directly correlate with the results obtained when using the standard-sized press.

8.2.1.2 Filter paper, qualitative, hardened low-ash, slow filtration rate, grade 50 ¹.

8.2.1.3 Electronic or mechanical timer, with at least 30 min interval.

8.2.1.4 Graduated cylinder, with a volume of 10 mL (TC) or 25 mL (TC).

8.2.1.5 Ruler, graduated in millimeters ($1/32 \text{ in.}$), to measure filter cake thickness.

¹ This grade 50 filter paper is a thin, highly glazed, qualitative, hardened low-ash filter paper made from high-quality cotton linters, designed for slow filtration and the retention of very fine crystalline precipitates. It should have a lint-free surface and be highly resistant to acid and alkaline solutions. The filter paper has the following typical properties that may vary by manufacturer: slow filtration rate: 2685 s/100 mL (herzbergs); particle retention in liquid: 2 μm to 5 μm (at 98 % efficiency); ash content: <0.015 % by weight; basis weight: 96 g/m² (0.02 lb/ft²); and thickness: 0.115 mm (0.0045 in.).

8.2.2 Procedure

In order to conduct a low-pressure/low-temperature test on a sample of drilling fluid, the following procedure shall be used.

- a) Measure and record the initial temperature of the drilling fluid to the nearest degree Celsius (degree Fahrenheit).
- b) Inspect the cell and all components, and especially the screen, to ensure that all parts are clean and dry, and the gaskets are not cracked, distorted, or worn. Assemble the cell by placing a gasket in the base cap, place the screen on top of the gasket, place the filter paper on top of the screen, place the sealing gasket on top of the paper, then assemble the cell. Pour the drilling fluid sample into the cell to within 12 mm (0.5 in.) of the top and complete the assembly.
- c) Place a clean dry graduated cylinder under the drain tube to collect the filtrate. Close the relief valve and adjust the regulator so that a pressure of 700 kPa $\pm$ 35 kPa (100 lbf/in.² $\pm$ 5 lbf/in.²) is applied within 30 s or less. Start the 30 min timer immediately at the time of pressure application.
- d) At the end of the 30 min test period, measure and record the filtrate volume. Shut off the flow through the pressure regulator and open the relief valve carefully. The time interval, if other than 30 min, shall be reported.

NOTE Reading the meniscus correctly is extremely important for accuracy. First, always read the meniscus with the interface at eye level. Second, for the air-to-liquid meniscus, read the volume at the lowest point of the meniscus that is in the middle of the liquid receiver at the very bottom of the liquid. For opaque liquids, it might be necessary to estimate the top of the liquid in the middle of the cylinder. Third, for the water-to-oil meniscus, read the water volume at the lowest point.

- e) Report the volume of filtrate, V_f , in milliliters (to the nearest 0.1 mL) and the initial drilling fluid temperature in degrees Celsius (degrees Fahrenheit). Save the filtrate for chemical analysis.

Caution—Before attempting to open or disassemble the cell, verify that all pressure in the cell has been relieved, by following the apparatus manufacturer's recommended procedures.

- f) Remove the cell assembly from its support, open the cell and discard any fluid remaining in the cell. Disassemble the cell and remove the filter paper and deposited filter cake. During this process, use care to avoid disturbing the filter cake and any associated drilling fluid. Using a gentle, low-pressure stream of water to avoid erosion; wash the excess drilling fluid from the deposited filter cake.
- g) Measure and report the thickness of the filter cake, to the nearest millimeter (1/32 in.).

Although cake descriptions are subjective, such notations as hard, soft, tough, rubbery, firm, etc. can convey important information of cake quality.

8.3 High-temperature High-pressure Test

8.3.1 Principle

Filtration tests are performed at high temperature and under static conditions. Two filtration procedures are given: one for testing up to 150 °C (300 °F) and one for testing above 150 °C (300 °F). Use only the filtration equipment and procedure specified for the temperature required.

The 175 mL, 250 mL, or 500 mL unit may be used for static filtration testing up to and including 150 °C (300 °F).

For testing above 150 °C (300 °F), use only equipment rated by the manufacturer for these temperatures. It is suggested that the equipment be equipped with a thermocouple in direct contact with the fluid contained in the cell to more accurately measure the temperature. Do not use filter paper (including fiberglass backed filter paper) if the test temperature is above 200 °C (400 °F). A porous stainless steel

filter media up to maximum manufacturer's recommendation for the equipment may be used. Ceramic disks may also be used in equipment modified to utilize these disks.

Caution—Always follow the manufacturers' recommendations when using their equipment and media.

8.3.2 Apparatus for Testing up to 150 °C (300 °F)

8.3.2.1 High-temperature high-pressure (HTHP) filter press, consisting of:

- a) filter cell, to rated working pressure up to 9000 kPa (1300 lbf/in.²) at temperature;
- b) pressurized gas source, such as carbon dioxide or nitrogen, with regulators;
NOTE Nitrogen is the preferred gas for this application.
- c) heating system with temperature controller or thermostat, to heat to 150 °C (300 °F);
- d) high-pressure filtrate collection vessel, maintained at proper back-pressure (see Table 3) to avoid flashing or evaporation of the filtrate;
- e) filter cell with a thermometer well, fitted with a removable end, a filter-media support and with oil-resistant seals;
- f) filter cell containing a thermometer well or thermocouple in direct contact with the fluid near the center of the cell, fitted with a removable end, and a filter-media support.

Warning—Not all manufacturers' equipment can be used above 150 °C (300 °F). Failure to know the pressure/temperature rating of equipment in use can result in serious injury. Testing at high temperature and high pressure calls for added safety precautions. Strict adherence to manufacturer's recommendations as to sample volumes, equipment temperatures and pressures, O-ring material selection and inspection, and other operating instructions is essential. Using appropriate personal protective equipment and safety barriers is recommended when operating HTHP equipment. Failure to follow these precautions could result in serious injury.

Do not use nitrous oxide cartridges as pressure sources for HTHP filtration. Under temperature and pressure, nitrous oxide can detonate in the presence of grease, oil, or carbonaceous materials.

8.3.2.2 Filter paper ², qualitative, hardened low-ash, slow filtration rate, grade 50, a new paper is required for each test.

8.3.2.3 Electronic or mechanical timer, with at least a 30 min interval.

8.3.2.4 Thermometer, with a range up to 260 °C (500 °F), and with a 12.5 cm (5 in.) or longer stem, or a thermocouple with temperature read-out or controller with a range up to 260 °C (500 °F), preferred.

8.3.2.5 Graduated cylinder, with a volume of 10 mL (TC), 20 mL (TC), or 25 mL (TC), with markings having a minimum of 2 mL graduations.

8.3.2.6 Field mixer, cup type, to operate at 10,000 r/min to 15,000 r/min.

8.3.2.7 Ruler, graduated in millimeters (1/32 in.), to measure filter cake thickness.

² This grade 50 filter paper is a thin, highly glazed, qualitative, hardened low-ash filter paper made from high-quality cotton linters, designed for slow filtration and the retention of very fine crystalline precipitates. It should have a lint-free surface and be highly resistant to acid and alkaline solutions. The filter paper has the following typical properties that may vary by manufacturer: slow filtration rate: 2685 s/100 mL (herzbergs); particle retention in liquid: 2 µm to 5 µm (at 98 % efficiency); ash content: <0.015 % by weight; basis weight: 96 g/m² (0.02 lb/ft²); and thickness: 0.115 mm (0.0045 in.).

Table 3—Recommended Minimum Back-pressure

Test Temperature		Vapor Pressure		Minimum Back-pressure	
°C	°F	kPa	lbf/in. ²	kPa	lbf/in. ²
95–149	200–299	84–462	12.1–67	700	100
150–189	300–374	462–1269	67–184	1400	200
190–199	375–399	1269–1704	184–247	1900	275
200–219	400–424	1704–2245	247–326	2500	350
220–230	425–450	2245–2912	326–422	3100	450

8.3.3 Procedure

In order to conduct an HTHP filtration test on a sample of drilling fluid up to 150 °C (300 °F) using a differential pressure of 3450 kPa (500 lbf/in.²), the following procedure shall be used.

- a) Place the thermometer in the well of the heating jacket. Preheat the jacket to approximately 6 °C (10 °F) above the desired test temperature. Adjust the thermostat to maintain this temperature.

Warning—The outside of the jacket can get hot enough to cause burns.

If the filtration unit is equipped with a thermocouple in direct contact with the drilling fluid, then that temperature should be monitored and reported during the filtration test. Under the “Comments” section, record if the results were based on fluid temperature measured with a direct contact thermocouple or using the 30 min heat-up time (after the cell wall reaches test temperature).

- b) Stir the drilling fluid sample for 10 min using the field mixer set at the 10,000 r/min speed. Install and close the upper valve stem on the test cell. Pour the fluid sample into the filter cell, leaving at least a 2.5 cm (1 in.) space in the cell to allow for fluid expansion. Install the filtration media.
- c) Ensuring that all O-rings are in place, install the lower end cap, with the valve stem open, above the filtration media and secure. Close the lower valve stem.
- d) Complete the assembly of the filter cell and place it in the preheated heating jacket with the filter media on the bottom. Rotate the cell to lock it in place with the pin inside the heating jacket. If the filtration unit is not equipped with a thermocouple in direct contact with the drilling fluid, insert a thermometer into the well of the filter cell wall.
- e) Ensure that the filtrate collection vessel is completely free of water or oil. Connect the regulated-pressure filtrate collection vessel assembly onto the lower valve stem and lock it in place. Connect the regulated-pressure assembly to the upper valve and lock it in place.
- f) Keeping the two valve stems closed, adjust the pressure on the upper and lower pressure regulators to 700 kPa (100 lbf/in.²). Open the upper valve stem and readjust the upper pressure regulator to 700 kPa (100 lbf/in.²). Maintain these pressures during the heat-up time. If the filtration unit is equipped with a thermocouple in direct contact with the drilling fluid, proceed to step g) when the thermocouple temperature reaches the test temperature. If the filtration unit is not equipped with a thermocouple in direct contact with the drilling fluid, wait 30 min after the filter cell wall reaches the test temperature before proceeding to step g).

NOTE If the total time required to begin the test exceeds 1 h, the heater might be defective, and the validity of the test is questionable.

- g) When the sample reaches the selected test temperature, as indicated by the thermocouple or after the 30 min heat-up time, ensure that the lower pressure regulator is at 700 kPa (100 lbf/in.²). Open the lower valve stem and immediately increase the pressure on the upper regulator to 4150 kPa (600 lbf/in.²). This will start the filtration process. Start the timer. Maintain the test temperature to within ± 3 °C (± 5 °F) during the test, as indicated by the thermocouple or thermometer in the filter cell wall. Maintain these pressures during the test, if the back-pressure rises above the selected back-pressure, cautiously draw off and collect a portion of the filtrate to reduce the back-pressure.

Caution—Filtrate will be hot and steam may escape if the valve is left open too long.

- h) Collect the filtrate in the graduated cylinder. Record the total volume of filtrate collected during the 30 min test, in milliliters. Correct the filtrate volume, V_f , to a filter area of 45.8 cm² (7.1 in.²). For example, if the filter area is 22.6 cm² (3.5 in.²), double the filtrate volume reported. Also note the presence of, or volumes of, any solids, oil, or emulsions, if present.
- i) Immediately after collecting the 30 min filtrate, close the lower, then the upper valve stem. Switch off the heating jacket and unplug from the electrical power source. Following the manufacturer's detailed instructions, bleed pressure off the regulators and hoses, and then carefully disconnect the pressurization system.

Caution—Cell and heating jacket are still hot!

- j) Using appropriate personal protective equipment, carefully remove the cell from the heating jacket and allow cell to cool to below 50 °C (125 °F). Keep the cell upright during cooling, depressurization, and disassembly.

Warning—The filter cell may still be pressurized even after the cell is cooled. To avoid possible serious injury, keep cell upright and cool to room temperature, and then bleed pressure from cell before disassembling.

- k) After cooling the cell, bleed pressure from the filter cell by slowly opening the upper valve stem. Avoid spraying drilling fluid as gas exits the stem. Ensure that pressure is fully released before removing the cap. Carefully disassemble the cell.

NOTE If there is resistance when loosening the cap, pressure may still be inside the cell. Ensure that all pressure is released before attempting to remove the end cap.

- l) Pour the liquid from the cell.
- m) Remove the filter cake with the filtration medium. Measure the filter cake thickness, at its center, to the nearest millimeter (1/32 in.).
- n) Settling of solids onto the filter cake may have occurred during the test. Observe indications of this, such as an abnormally thick cake or coarse texture. Record these cake characteristics under the "Comments" on the Mud Report Form. To minimize settling, the times for heat-up and cool-down should be minimized and the cake should be recovered and examined promptly.

8.3.4 Calculation

The filtrate volume should be corrected to a filter area of 45.8 cm² (7.1 in.²). HTHP filter cells usually have half the standard filter area 22.6 cm² (3.5 in.²), thus double the observed volume before reporting V_f .

Report the cake thickness to the nearest millimeter (1/32 in.), its texture, and the presence of any emulsion or oil in the filtrate.

8.4 High-temperature High-pressure Test at 150 °C (300 °F) up to and Including 230 °C (450 °F)

8.4.1 Principle

For testing above 150 °C (300 °F), use only equipment rated by the manufacturer for these temperatures. It is suggested that the equipment be equipped with a thermocouple in direct contact with the fluid contained in the cell to more accurately measure the temperature. Do not use filter paper (including fiberglass backed filter paper) if the test temperature is above 200 °C (400 °F). A porous stainless-steel filter media up to maximum manufacturer's recommendation for the equipment may be used. Ceramic disks may also be used in equipment modified to utilize these disks.

8.4.2 Apparatus

8.4.2.1 HTHP filter press, consisting of the following components:

- only use cells and equipment rated to safely operate at the intended test temperature and pressures; see manufacturers' recommendations;
- filter cell, with a rated working pressure up to 13,800 kPa (2000 lbf/in.²) at a temperature of 230 °C (450 °F); filter cell fitted with a removable end, a filter-media support, with oil-resistant seals, and with a thermometer well;
- pressure regulated gas source, nitrogen (preferred);
- heating system with temperature controller or thermostat, capable of heating to 260 °C (500 °F);
- high-pressure filtrate collection vessel, maintained at proper back-pressure (see Table 3), to avoid flashing or evaporation of the filtrate;

NOTE For temperatures >190 °C (>375 °F), the back-pressure gauge of the high-pressure filtrate collection vessel will need to be capable of measuring pressures above 1400 kPa (200 lbf/in.²).

- filter cell containing a thermometer well or thermocouple in direct contact with the fluid near the center of the cell, fitted with a removable end, and a filter-media support.

NOTE Valve stems on each end of the cell can be opened or closed during a test.

Warning—Not all manufacturers' equipment can be used above 150 °C (300 °F). Failure to know the pressure/temperature rating of equipment in use can result in serious injury. Testing at high temperature and high pressure calls for added safety precautions. The 175 mL and 250 mL filtration cells are not recommended for use at these higher temperatures and pressures. Strict adherence to manufacturer's recommendations as to sample volumes, equipment temperatures and pressures, O-ring material selection and inspection, and other operating instructions is essential. High temperature O-rings and elastomer seals are required for high temperatures. Equipment manufacturers often recommend replacement or inspection after every test. Inspection should include making sure the O-rings and elastomer seals are pliable with no permanent deformations, nicks, or cuts, etc. A loss of pressure during a test may be an indication of an O-ring or elastomer seal failure and should be corrected. Using appropriate personal protective equipment and safety barriers is recommended when operating HTHP equipment. Failure to follow these precautions could result in serious injury.

Caution—Do not use nitrous oxide cartridges as pressure sources for HTHP filtration. Under temperature and pressure, nitrous oxide can detonate in the presence of grease, oil, or carbonaceous materials. Nitrous oxide cartridges shall be used only for Garrett gas train carbonate analysis, in accordance with A.5.

8.4.2.2 Filter media:

- Filter paper, qualitative, hardened low-ash, slow filtration rate, grade 50 ² (see 8.3.2.2).
- Filter paper, qualitative, hardened low-ash, slow filtration rate, grade 50 ² (see 8.3.2.2), backed with a fiberglass disk for temperatures above 175 °C (350 °F) up to temperatures of 200 °C (400 °F).

- c) Sintered metal fiber porous disc should be used for temperatures above 200 °C (400 °F); a new disc is required for each test. Disk is comprised of sintered stainless steel metal fibers with a particle retention rating in liquid of 5 µm nominal and 10 µm absolute for temperatures above 200 °C (400 °F). A new disc is required for each test (for example, Dynalloy X-5 sintered metal fiber media).

8.4.2.3 Electronic or mechanical timer, with at least 30 min interval.

8.4.2.4 Thermometer, with a range up to 260 °C (500 °F), and with a 12.5 cm (5 in.) or longer stem, or a thermocouple with a range up to 260 °C (500 °F), preferred.

8.4.2.5 Graduated cylinder (TC), long, slender with a volume of 10 mL or 20 mL.

8.4.2.6 Graduated cylinder (TC), optional, with a volume of 25 mL.

8.4.2.7 Field mixer, cup type, to operate at 10,000 r/min to 15,000 r/min.

8.4.2.8 Ruler, graduated in millimeters (1/32 in.), to measure filter cake thickness.

8.4.3 Procedure

In order to conduct an HTHP test at 150 °C (300 °F) up to and including 230 °C (450 °F) test using a differential pressure of 3450 kPa (500 lbf/in.²), the following procedure shall be used.

- a) Place the thermometer in the well of the heating jacket. Preheat the jacket to approximately 6 °C (10 °F) above the desired test temperature. Adjust the thermostat to maintain this temperature.

Warning—The outside of the jacket can get hot enough to cause burns.

If the filtration unit is equipped with a thermocouple in direct contact with the drilling fluid, then that temperature should be monitored and reported during the filtration test. Under the “Comments” section, record if the results were based on fluid temperature measured with a direct contact thermocouple or using the 30 min of heat-up time (after the cell wall reaches test temperature).

- b) Stir the drilling fluid sample for 10 min using the field mixer set at the 10,000 r/min speed. Install and close the upper valve stem on the test cell. Pour the fluid sample into the filter cell, leaving at least a 5 cm (2 in.) space in the cell to allow for fluid expansion. Install the filtration media.
- c) Ensuring that all O-rings are in place, install the lower end cap, with the valve stem open, above the filtration media and secure. Close the lower valve stem.
- d) Complete the assembly of the filter cell and place it in the preheated heating jacket with the filter media on the bottom. Rotate the cell to lock it in place with the pin inside the heating jacket. If the filtration unit is not equipped with a thermocouple in direct contact with the drilling fluid, insert a thermometer into the well of the filter cell wall.
- e) Ensure that the filtrate collection vessel is completely free of water or oil. Connect the regulated pressure filtrate collection vessel assembly onto the lower valve stem and lock it in place. Connect the regulated pressurized gas source to the upper valve and lock in place.
- f) Keeping the two valve stems closed, adjust the pressure on the upper and lower pressure regulators to the minimum back-pressure for the test temperature as shown in Table 3. Open the upper valve stem and readjust the upper pressure regulator to the minimum back-pressure temperature. Maintain these pressures during the heat-up time. If the filtration unit is equipped with a thermocouple in direct contact with the drilling fluid, proceed to step g) when the thermocouple temperature reaches the test temperature. If the filtration unit is not equipped with a thermocouple in direct contact with the drilling fluid, wait 30 min after the filter cell wall reaches the test temperature before proceeding to step g).

NOTE If the total time required to begin the test exceeds 1 h, the heater might be defective, and the validity of the test is questionable.

- g) When the sample reaches the selected test temperature, as indicated by the thermocouple or after the 30 min heat-up time, ensure that the lower pressure regulator is at the minimum back-pressure for the test temperature as shown in Table 3. Open the lower valve stem and immediately increase the pressure on the upper regulator to a pressure 3450 kPa (500 lbf/in.²) higher than the back-pressure. This will start the filtration process. Start the timer. Maintain the test temperature to within ± 3 °C (± 5 °F) during the test, as indicated by the thermocouple or thermometer in the filter cell wall. Maintain these pressures during the test, if the back-pressure rises above the selected back-pressure, cautiously draw off and collect a portion of the filtrate to reduce the back-pressure.

Caution—Filtrate will be hot and steam may escape if the valve is left open too long.

- h) Collect the filtrate in the graduated cylinder. Record the total volume of filtrate collected during the 30 min test, in milliliters. Correct the filtrate volume, V_f , to a filter area of 45.8 cm² (7.1 in.²). For example, if the filter area is 22.6 cm² (3.5 in.²), double the filtrate volume reported. Also note the presence of, or volumes of, any solids, oil, or emulsions, if present.
- i) Immediately after collecting the 30 min filtrate, close the lower, then the upper valve stem. Switch off the heating jacket and unplug from the electrical power source. Following the manufacturer's detailed instructions, bleed pressure off the regulators and hoses, and then carefully disconnect the pressurization system.

Caution—Cell and heating jacket are still hot!

- j) Using appropriate personal protective equipment, carefully remove the cell from the heating jacket and allow cell to cool to below 50 °C (125 °F). Keep the cell upright during cooling, depressurization, and disassembly.

Warning—The filter cell may still be pressurized even after the cell is cooled. To avoid possible serious injury, keep cell upright and cool to room temperature, and then bleed pressure from cell before disassembling.

- k) After cooling the cell, bleed pressure from the filter cell by slowly opening the upper valve stem. Avoid spraying drilling fluid as gas exits the stem. Ensure that pressure is fully released before removing the cap. Carefully disassemble the cell.

NOTE If there is resistance to loosening the cap, pressure may still be inside the cell. Ensure that all pressure is released before attempting to remove the end cap.

- l) Pour the liquid from the cell.
- m) Remove the filter cake with the filtration medium. Measure the filter cake thickness, at its center, to the nearest millimeter (1/32 in.).
- n) Settling of solids onto the filter cake may have occurred during the test. Observe indications of this, such as an abnormally thick cake or coarse texture. Record these cake characteristics under the "Comments" on the Mud Report Form. To minimize settling, the times for heat-up and cool-down should be minimized and the cake should be recovered and examined promptly.

8.4.4 Calculation

The filtrate volume should be corrected to a filter area of 45.8 cm² (7.1 in.²). HTHP filter cells usually have half the standard filter area 22.6 cm² (3.5 in.²), thus double the observed volume before reporting V_f .

Report the cake thickness to the nearest millimeter (1/32 in.), its texture, and the presence of any emulsion or oil in the filtrate.

9 Retort Test for Water, Oil, and Solids Concentrations

9.1 Principle

The retort instrument provides a means for separating and measuring the volumes of water, oil, and solids contained in a sample of drilling fluid. In the retort, a known volume of a whole drilling fluid sample

is heated to vaporize the liquid components that are subsequently condensed and collected in a graduated cylinder for standard accuracy measurements or in a special liquid receiver for more precise measurements. Liquid volumes are determined directly from reading the water and oil phases in the receiver. The total volume of solids (suspended and dissolved) is obtained by difference (retort sample volume minus all condensed liquid volumes). Calculations are necessary to determine the volume of dissolved and suspended solids, since both soluble (salts) and insoluble solids are retained in the retort. The relative volumes of low-gravity solids and weighting material can also be calculated. Knowledge of water, oil, and solids concentrations is fundamental to proper control of drilling fluid properties such as rheology, density, filtration, and salinity of the aqueous (water) phase. Given that knowledge of solids in a drilling fluid is essential to the evaluation of solids control equipment, reference shall be made to API 13C.

Warning—Formate-based or nitrate-based drilling fluids should not be retorted. This can lead to an explosion.

9.2 Apparatus

9.2.1 Retort instrument, consisting of:

- a) Retort assembly, including a retort body, cup, and lid constructed of 303 stainless steel, or equivalent.

Standard cup sizes are 10 mL (precision ± 0.05 mL), 20 mL (precision ± 0.1 mL), and 50 mL (precision ± 0.25 mL). The retort cup volume with lid shall be verified gravimetrically in accordance with the procedure and calculations given in Annex I.

- b) Condenser, capable of cooling the oil and water vapors below their vaporization temperature.
- c) Heating jacket, nominal power 350 W and of sufficient power to raise the temperature of the sample above the vaporization point of the liquid components within 15 min without causing solids boil-over.
- d) Temperature controller, capable of limiting the temperature of the retort to $500\text{ }^{\circ}\text{C} \pm 40\text{ }^{\circ}\text{C}$ ($930\text{ }^{\circ}\text{F} \pm 70\text{ }^{\circ}\text{F}$).

9.2.2 Graduated cylinder (TC) or special liquid receiver (TC): Graduated cylinders are used for standard accuracy retort measurements or a special liquid receiver may be used for more precise retort measurements. The special liquid receivers are a specially designed cylindrical glassware with a rounded bottom, to facilitate cleaning, and a funnel-shaped top to catch falling drops and are often referred to in industry as JP-tubes. The two types and three sizes of receivers shall meet the following specifications:

- material: transparent and inert to oil, water, and salt solutions at temperatures up to $32\text{ }^{\circ}\text{C}$ ($90\text{ }^{\circ}\text{F}$);
- calibration (TC): at $20\text{ }^{\circ}\text{C}$ ($68\text{ }^{\circ}\text{F}$);
- frequency of graduations: milliliter or volume fraction (as a percentage), see Table 4;
- tolerance (milliliter): see Table 4;
- the receiver volume shall be verified gravimetrically in accordance with the procedure and calculations in I.6.

9.2.3 Fine steel wool, oil-free.

Liquid steel wool or coated steel wool substitutes should not be used for this application.

9.2.4 High temperature-resistant silicone grease, to be used as a thread seal and lubricant.

9.2.5 Pipe cleaners and/or **T-drill**.

9.2.6 Putty knife or **spatula**, with blade shaped to fit the inside dimensions of the sample cup of the retort.

9.2.7 Corkscrew.

9.2.8 Syringe, of capacity 10 mL, 20 mL, or 50 mL, to fill retort cup.

9.2.9 Marsh funnel (see 7.2.1.1).

9.2.10 Defoaming agent.

9.2.11 Mud balance (see 5.2.1).

Table 4—Precision of Retort Liquid Receivers

	Tolerance	Frequency of Graduations
Graduated cylinder 10 mL (TC)	± 0.10 mL *	0.10 mL and/or 1 %
Graduated cylinder 20 mL (TC)	± 0.15 mL	0.20 mL and/or 1 %
Graduated cylinder 50 mL (TC)	± 0.25 mL *	≤ 1.0 mL and/or ≤ 2 %
	* Meets ASTM E1272 Class A standards.	
	Tolerance	Frequency of Graduations
Special liquid receiver 10 mL (TC)	± 0.05 mL	0.10 mL and/or 1 %
Special liquid receiver 20 mL (TC)	± 0.05 mL	0.10 mL and/or 0.5 %
Special liquid receiver 50 mL (TC)	± 0.15 mL	≤ 0.25 mL and/or ≤ 0.5 %

9.3 Procedure

In order to perform a retort test for a sample of drilling fluid using the volumetric method, the following procedure shall be used.

- a) Ensure that the 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 should also be cleaned and dried before each test using pipe cleaners and/or T-drill. A build-up of material in the condenser passage can decrease condensation efficiency that can cause erroneous liquid readings in the test and, for some types of equipment, may present a safety hazard.

Caution—A partially clogged condenser passage is a safety hazard.

- b) The heating jacket should be cooled to less than 93 °C (200 °F).
- c) Pack the retort body with steel wool.

- d) Collect a representative sample of the drilling fluid and allow it to cool to approximately 27 °C (80 °F). Screen the test sample through the screen of the Marsh funnel to remove lost circulation material, large cuttings, or debris.
- e) Ensure that the drilling fluid sample is homogeneous. If mixing is required, be careful not to entrain any air, and ensure that no solids remain on the bottom of the container.

NOTE Air or gas entrapment in the retort sample will result in erroneously high retort solids, due to a reduced volume of drilling fluid sample. If drilling fluid sample contains gas or air, add 2 drops to 3 drops of defoaming agent to about 300 mL of drilling fluid and stir slowly for 2 min to 3 min to release gases. Alternatively the procedure described in Annex E can be used for severe cases of foaming or air/gas entrapment.

- f) Fill the retort sample cup slowly to avoid air entrapment. Lightly tap the side of the cup to expel air. Place the lid on the cup. Rotate the lid to obtain a proper fit, ensuring that a small excess of drilling fluid flows out of the hole in the lid. Wipe the excess drilling fluid from the lid; avoid wicking out the drilling fluid through the hole.
- g) Apply lubricant/sealant sparingly to the threads of the retort sample cup. With lid in place, hand tighten the retort sample cup onto the body.
- h) Apply lubricant/sealant sparingly to the threads on the condenser passage stem and attach to the condenser body. Place the retort assembly into the heating jacket. Close the insulating lid.
- i) Place the clean, dry liquid receiver below the condenser passage outlet.

NOTE If using the special liquid receiver (JP-tube), due to the rounded bottom and length, it normally must be angled out from the retort condenser passage/retort assembly and off the edge of the worktable such that a condenser tube clip or other special support is needed.

- j) Turn on the heating jacket and allow the retort assembly to run a minimum of 1 h or longer. Continue heating for 10 min after the last condensate is collected. Collect the condensate into the glass liquid receiver. If the drilling fluid boils over into the liquid receiver, cool and clean the equipment and rerun the test using a larger amount of steel wool in the retort body.
- k) After the completed retort test, remove the liquid receiver and allow the retort assembly to cool.

Warning—The retort body is still extremely hot and will cause severe burns if contacted.

NOTE If an emulsion interface is present in the receiver tube, between the oil and water phases, heating the interface might break the emulsion. As a suggestion, remove the retort assembly from the heating jacket by grasping the condenser. Carefully heat the glass liquid receiver along the emulsion band by gently touching the receiver for short intervals with the hot retort assembly. Avoid boiling the liquid. After the emulsion interface is broken, allow the liquid receiver to cool. Do not use this procedure when using a plastic or polycarbonate receiving tube.

- l) Record the total liquid volume, V_L (oil and water) and water volume, V_W , collected in the liquid receiver.

NOTE Reading the meniscus correctly is extremely important for accuracy. First, always read the meniscus with the interface at eye level. Second, for the air-to-liquid meniscus, read the volume at the lowest point of the meniscus that is in the middle of the liquid receiver at the very bottom of the liquid. For opaque retort assembly to cool it might be necessary to estimate the top of the liquid in the middle of the cylinder. Third, for the water-to-oil meniscus, read the water volume at the lowest point.

- m) After the retort assembly has cooled carefully remove the retort assembly and condenser from the heating jacket and allow them to cool. After the retort cell has cooled, remove the condenser. Clean the retort assembly and condenser.

9.4 Calculation

9.4.1 Drilling Fluid Volume Fractions (Oil, Water, and Dried Solids)

Using the measured volumes of oil and water, and the volume of the original whole drilling fluid sample (10 mL, 20 mL, or 50 mL), calculate, as percentages, the volume fractions of water, oil, and dried solids in the drilling fluid (dried or total solids from the retort includes both soluble and insoluble solids).

Calculate the volume of oil, V_O , in the condensed sample, expressed in milliliters, as given in Equation (12):

$$V_O = V_L - V_W \quad (12)$$

where

V_L is the total volume of condensed liquids (oil and water), expressed in milliliters;

V_W is the condensed water volume, expressed in milliliters, or condensed water mass, expressed in grams (1 mL $\equiv$ 1 g).

Calculate the volume fraction of oil, ϕ_O , in the total drilling fluid sample, expressed as a percentage, as given in Equation (13):

$$\phi_O = 100 \times \frac{V_O}{V_{df}} \quad (13)$$

where

V_O is the volume of oil, expressed in milliliters;

V_{df} is the whole drilling fluid sample volume, expressed in milliliters.

Calculate the volume fraction of water, ϕ_W , in the total drilling fluid sample, expressed as a percentage, as given in Equation (14):

$$\phi_W = 100 \times \frac{V_W}{V_{df}} \quad (14)$$

where

V_W is the condensed water volume, expressed in milliliters, or condensed water mass, expressed in grams (1 mL $\equiv$ 1 g);

V_{df} is the whole drilling fluid sample volume, expressed in milliliters.

Calculate the volume fraction of dried solids from retort, ϕ_{ds} , which includes both soluble and insoluble solids, expressed as a percentage of the drilling fluid volume, as given in Equation (15):

$$\varphi_{ds} = 100 - (\varphi_W + \varphi_O) \quad (15)$$

where

φ_W is the volume fraction of water, expressed as a percentage of the drilling fluid volume;

φ_O is the volume fraction of oil, expressed as a percentage of the drilling fluid volume.

NOTE The calculated dried solids fraction from the retort, φ_{ds} , Equation (15), includes both dissolved soluble materials (e.g. salt) and insoluble suspended solids (weighting material, drilling fluid additives, and drill solids). The quantity of insoluble suspended solids can be determined by correcting for the volume of soluble solids from salts using the chloride concentration, c_{Cl} (see Section 14), using known volume factors for salt solutions.

9.4.2 Drilling Fluid Solids Volume Fractions (Suspended, Low-gravity, Weighting Material)

Additional calculations are required to find the percentage (volume fraction) of suspended solids and relate them to the relative volumes of low-gravity solids and weighting material. To make these calculations, an accurate drilling fluid density and chloride concentration are needed.

The volume fraction of suspended solids, φ_{SS} , expressed as a percentage of the drilling fluid volume, is given in Equation (16):

$$\varphi_{SS} = \varphi_{ds} - \left[\frac{\varphi_W \times c_{Cl}}{(1.68 \times 10^6) - 1.21 \times c_{Cl}} \right] \quad (16)$$

where

φ_{ds} is the volume fraction of dried solids from retort, expressed as a percentage of the drilling fluid volume;

φ_W is the volume fraction of water, expressed as a percentage of the drilling fluid volume;

c_{Cl} is the chloride ion concentration, expressed in milligrams per liter [see Equation (33)].

The volume fraction of low-gravity solids, φ_{LG} , expressed as a percentage of the drilling fluid volume, is given in Equation (17):

$$\varphi_{LG} = \frac{1}{\rho_{WM} - \rho_{LG}} \left[100\rho_f + (\rho_{WM} - \rho_f) \times \varphi_{SS} - 100\rho_{df} - (\rho_f - \rho_O) \times \varphi_O \right] \quad (17)$$

where

φ_{SS} is the volume fraction of suspended solids, expressed as a percentage of the drilling fluid volume;

φ_O is the volume fraction of oil, expressed as a percentage of the drilling fluid volume;

ρ_{df} is the drilling fluid density, expressed in grams per milliliter;