

Recommended Practice for Testing Well Cements

API RECOMMENDED PRACTICE 10B-2
SECOND EDITION, APRIL 2013

REAFFIRMED, APRIL 2019



AMERICAN PETROLEUM INSTITUTE

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Introduction

Users of this standard should be aware that further or differing requirements may be needed for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this standard and provide details.

In this standard, where practical, U.S. customary units (USC) are included in brackets for information. The units do not necessarily represent a direct conversion of metric units (SI) to USC units, or USC to SI. 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.

In this standard, calibrating an instrument refers to assuring 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 and both. A result is valid if it is both accurate and precise.

Well cement classes and grades are defined in [API Specification 10A](#).

Warning—The tests specified in this standard require the handling of hot, pressurized equipment and materials that may be hazardous and can cause injury. Do not exceed manufacturer's safety limits. Only trained personnel should perform these tests.

Recommended Practice for Testing Well Cements

1 Scope

This standard specifies methods and gives recommendations for the testing of cement slurries and related materials under simulated well conditions.

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 Specification 10A](#), *Specification for Cements and Materials for Well Cementing*

[API Recommended Practice 13B-1](#), *Recommended Practice for Field Testing Water-based Drilling Fluids*

[API Recommended Practice 13B-2](#), *Recommended Practice for Field Testing Oil-based Drilling Fluids*

[API Recommended Practice 13J](#), *Testing of Heavy Brines*

[ASTM C109/C109M-07](#)¹, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2 in. or [50 mm] Cube Specimens)*

[ASTM C188-95](#), *Standard Test Method for Density of Hydraulic Cement*

[ASTM C618-08](#), *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*

3 Terms, Definitions, and Symbols

3.1 Terms and Definitions

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

3.1.1

absolute density

Density of a material without the fluid around the particles, similar to the relative density and can be obtained by multiplying the relative density of a material by the density of water at 4 °C, 1000 kg/m³ (8.345 lbm/gal).

3.1.2

absolute volume

The volume occupied by a material, not including the intergranular space in the case of a solid.

3.1.3

additive

Material incorporated in a cement slurry to modify or enhance some desired property.

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

3.1.4**annulus**

Space between the pipe and the wellbore wall or an outer pipe.

3.1.5**batch mix**

Process of mixing the entire volume of cement slurry prior to placement in the wellbore.

3.1.6**Bearden units of consistency**

B_c

Units used to express consistency of a cement slurry when determined using a pressurized consistometer.

3.1.7**bottomhole circulating temperature**

T_{BHC}

Pseudo-stable temperature found at the bottom of the wellbore while the well is being circulated.

3.1.8**bulk density**

Mass per unit volume of a dry material including the air between particles.

3.1.9**casing cementing**

Process of placing cement to fill or partially fill the space between a full string of casing and the wellbore.

3.1.10**cement****Portland cement**

Material formed by the grinding of clinker, generally consisting of hydraulic calcium silicates and aluminates and usually containing one or more of the forms of calcium sulfate added during grinding.

3.1.11**cement blend**

Mixture of dry cement and other dry materials.

3.1.12**cement class**

Designation of classifications of well cement according to defined specifications of [API 10A](#).

3.1.13**cement grade**

Designation for denoting the sulfate resistance of a particular cement according to specifications of [API 10A](#).

3.1.14**clinker**

Fused materials from the kiln that are interground with calcium sulfate to manufacture cement.

3.1.15**compatibility**

Capacity to form a fluid mixture that does not undergo undesirable chemical and/or physical reactions.

3.1.16**compressive strength**

Strength of a set cement sample measured by the force required to cause it to fail in compression, expressed as force per unit area.

3.1.17**consistometer**

Device used to measure the thickening time of a cement slurry under temperature and pressure.

NOTE An atmospheric consistometer can be used to condition fluids prior to testing and for determining the thickening time of arctic slurries.

3.1.18**continuous-pumping squeeze-cementing operation**

Squeeze-cementing operation that does not involve interruptions in pumping.

3.1.19**drilling fluid
mud**

Fluid, generally viscosified and possibly weighted, used to remove cuttings, cool the drill bit, and prevent formation fluids from entering the wellbore during drilling or workover operations.

3.1.20**equivalent sack**

Mass of the blend of fly ash or pozzolan and Portland cement that has the same absolute volume as a sack (1 ft³) of Portland cement.

NOTE Only used in U.S. customary (USC) measurements.

3.1.21**filtrate**

Liquid that is forced out of a cement slurry during a fluid-loss test.

3.1.22**fly ash**

Finely divided residue from the combustion of ground or powdered coal with pozzolanic properties.

NOTE See Section 14 for further description.

3.1.23**free fluid**

Colored or colorless liquid that has separated from a cement slurry when standing in a static condition.

3.1.24**freeze-thaw cycle**

A prescribed cycle of exposure of a cement sample to temperatures above and below the freezing point of water.

3.1.25**heat-up rate**

R_h

Rate of slurry temperature change from the surface slurry temperature, T_{SS} , to the predicted bottomhole circulating temperature, T_{PBHC} .

3.1.26**hesitation-squeeze-cementing operation**

Method of placement of cement during squeeze-cementing operation that involves alternate pumping and nonpumping periods.

3.1.27**liner cementing**

Annular cementing operations for which the top of the casing being cemented does not reach the surface or subsea wellhead.

3.1.28**load frame**

Frame to place a load on cement samples for determining material properties (i.e. Young's Modulus and Poisson's Ratio) or failure criteria (i.e. compressive strength and tensile strength) or both.

3.1.29**mix fluid**

Mix water containing solid or liquid (or both) additives.

3.1.30**mix water**

Fresh water or sea water without solid or liquid (or both) additives.

3.1.31**nonaqueous fluid****NAF**

NAF is a nonaqueous drilling fluid or well circulating fluid. Common NAF systems are diesel, mineral oil, or synthetic fluid based invert emulsions, or other non-water based fluids.

3.1.32**plug cementing**

Process of placing a volume of cement in a well to form a plug across the wellbore.

3.1.33**pozzolan**

Siliceous or siliceous and aluminous material that, in itself, possess little or no cementitious value but, in finely divided form and in the presence of moisture, reacts with calcium hydroxide to form a cementitious material.

NOTE See Section 14 for further description.

3.1.34**preflush**

Fluid that is not viscosified nor densified with insoluble, solid weighting agents.

3.1.35**pressure-down rate**

R_{pd}

Rate at which pressure is reduced from the bottomhole pressure, p_{BH} , to the pressure at the top-of-cement column, p_{TOC} , during a thickening-time test.

3.1.36**pressure-up rate** R_{pu}

Rate at which pressure is increased from the starting pressure, p_S , to the bottomhole pressure, p_{BH} , during a thickening-time test.

3.1.37**pressurized curing chamber**

Apparatus used for curing a sample of cement under temperature and pressure for subsequent tests such as compressive strength, sedimentation, etc.

3.1.38**pressurized fluid density balance**

Beam-type balance used to measure fluid density under pressure to minimize the effects of air entrained in the fluid.

3.1.39**relative density****specific gravity**

Ratio of the mass of a substance to the mass of an equal volume of a standard substance at a reference temperature.

NOTE The standard substance is usually water; the reference temperature is usually 4 °C.

3.1.40**sack**

A unit of measure of cement that occupies a bulk volume of one cubic foot (normally 94 lbm for Portland cement).

NOTE Only used in USC measurements.

3.1.41**sedimentation**

Separation and settling of solids in a cement slurry.

3.1.42**slurry container**

Container used to hold the slurry in a consistometer for conditioning or testing.

3.1.43**slurry stability test**

Test to determine the degree of sedimentation and/or free fluid development in a cement slurry.

3.1.44**sonic strength**

Compressive strength of a cement sample obtained by measuring the velocity of sound through the cement and computing the strength using a correlation to compressive strength measurements.

3.1.45**spacer**

Viscosified fluid that may be densified with insoluble, solid weighting agents and are used to separate drilling fluids and cement slurries.

3.1.46**squeeze-cementing**

Remedial process in which cement slurry is forced under pressure into a specific portion of the well such as a fracture or opening.

3.1.47
starting pressure p_s

Initial pressure applied to the cement slurry at the beginning of the thickening-time test.

3.1.48
static fluid-loss test

Test to determine filtrate lost from a cement slurry when placed against a 325 mesh screen at 6900 kPa (1000 psi) differential pressure.

3.1.49
stirred fluid-loss apparatus

Apparatus specially designed to allow for conditioning of the cement slurry within the same cell used to perform a static fluid-loss test.

3.1.50
thickening time

Time elapsed from the initial application of pressure and temperature to the time at which the slurry reaches a consistency deemed sufficient to make it unpumpable (e.g. 70 B_c or 100 B_c).

NOTE The results of a thickening-time test provide an indication of the length of time a cement slurry can remain pumpable under the test conditions.

3.1.51
transit time t_T

Transit time (sometimes referred to as compressional sonic slowness) is a measurement of sonic velocity that starts when the transmitter is fired and ends when a determined amplitude peak from the waveform arrives at the receiver. Transit time is typically expressed in microseconds per inch.

NOTE Transit time is a measurement of sonic velocity and should not be confused with travel time. Some apparatus may report a travel time through the cement sample and this time should be converted into transit time by dividing it by the distance between the two sonic sensors.

3.1.52
ton

Term used to express a two thousand (2000) pound mass.

3.1.53
tonne
metric ton

Term used to express a one thousand (1000) kilogram mass.

3.1.54
weigh batch mixer
scale tank

Device or system for the weighing and blending of cement with dry additives for a cementing operation.

3.1.55
well-simulation test

Test whose parameters are designed and modified as required to simulate the conditions found in a wellbore.

3.2 Symbols

For the purposes of this document, the symbols given in Table 1 apply. This list is not exhaustive.

Table 1—Symbols

Symbol	Meaning
B_c	consistency expressed in Bearden units
$C_{ad.sol}$	solid additive concentration
d_{rel}	relative density
h_{TOCTVD}	top-of-cement true vertical depth
h_{TVD}	true vertical depth
k	consistency index
m	mass
$m_{ad.liq}$	liquid additive mass
$m_{ad.sol}$	solid additive mass
m_{air}	cement segment weight in air
m_c	cement mass
m_{lfm}	mass of loosely filled material
m_s	slurry mass
m_w	mix water mass
m_{water}	cement segment weight in water
n	flow behavior index
p_{BH}	bottomhole pressure ^a
p_{FSQ}	final bottomhole squeeze pressure
p_s	starting pressure
p_{SQ}	maximum surface squeeze pressure
p_{TOC}	top-of-cement pressure
q	pump rate
$R_{\Delta T}$	rate of temperature change (heat-up or cool-down)
R_{pd}	rate of pressure decrease
R_{pu}	rate of pressure increase
R_{PSQ}	rate of pressure increase to apply the squeeze pressure
T	torque
T_{BHC}	bottomhole circulating temperature
T_{BHS}	bottomhole static temperature
T_{PBHC}	predicted bottomhole circulating temperature
T_{PSP}	predicted bottomhole squeeze or plug temperature
T_{ss}	slurry surface temperature
T_{TOCC}	top-of-cement circulating temperature
T_{TOCS}	top-of-cement static temperature
TT	transit time (sonic slowness)

Symbol	Meaning
t	elapsed time
t_a	time to displace the leading edge of the cement slurry from bottom of the casing to the top of the annular column
t_d	time to displace the leading edge of cement slurry from the surface to the bottom of the wellbore
t_{sq}	time to apply squeeze pressure to cement slurry after bottomhole placement
V_{30}	volume of filtrate collected at 30 min
V_a	annular volume of cement
$V_{ad.liq}$	liquid additive volume
$V_{ad.sol}$	solid additive volume
V_F	volume of free fluid
V_{fp}	final packed volume
V_p	volume of the pipe
V_s	slurry yield
V_t	volume of filtrate collected at the time nitrogen blows through
V_w	mix water volume
Z	acoustic impedance
γ	shear rate
Δ_{PT}	pseudo-temperature gradient ^b
$\Delta\rho_{sc}$	density of the set cement relative to the cement slurry
μ_p	plastic viscosity
$\rho_{ad.liq}$	density of liquid additive
$\rho_{ad.sol}$	density of solid additive
ρ_{af}	density of annular fluid
ρ_{bulk}	average bulk density
ρ_c	density of cement
ρ_{df}	density of drilling fluid
ρ_{LAB}	loose apparent bulk density
ρ_{PAB}	packed apparent bulk density
ρ_s	density of slurry
ρ_{set}	density of the set cement
ρ_w	density of mix water
τ	shear stress
τ_y	yield stress
ϕ	fluid volume fraction
$v_{ad.abs}$	solid additive absolute volume
$v_{c.abs}$	cement absolute volume
^a Hydrostatic pressure at the bottom of the well, calculated using the true vertical depth and the fluid densities in the wellbore. ^b Gradient in °C/100 m (°F/100 ft), calculated from the difference between the maximum recorded bottomhole static temperature and 27 °C (80 °F).	

4 Sampling

4.1 General

Samples of the cement, cement blend, solid and liquid additives, and mixing water may be required to test a slurry in accordance with this standard. Some commonly used sampling techniques are described in this section.

4.2 Sampling Cement at a Field Location

Multiple samples should be extracted using a suitable device (Figure 1). A composite of the samples should be prepared, packaged, and labeled (see 4.7). Sample volume should be sufficient to perform the desired testing.

4.3 Sampling Cement Blends at a Blending Facility

Cement blends may be sampled from the weigh batch mixer (scale tank), bulk transport, or extracted from the flow lines during transfer. The cement and dry additives should be thoroughly blended prior to sampling. Samples from the bulk container may be extracted in accordance with 4.2. Samples extracted from a flow line during a transfer may be taken from a properly installed sample valve, diverted flow sampler, or automatic in-line sampling device [Figure 1 c), Figure 1 d), and Figure 1 e)] using a procedure designed to give a representative sample of the blend being transferred. The samples should be prepared, packaged, and labeled (4.7). Sample volume should be sufficient to perform the desired testing.

4.4 Sampling Dry Cement Additives

Dry cement additive samples may be extracted from a bulk container or sack. Multiple samples should be extracted from the center of the source using a suitable sampling device [Figure 1 a) or Figure 1 b)]. A composite of the samples from the same lot should be prepared, packaged, and labeled (4.7). The volume of each dry cement additive sample should be sufficient to perform the desired testing.

4.5 Sampling Liquid Cement Additives

Most liquid additives are solutions or suspensions of dry materials. Storage can allow separation of the active ingredients. Thus, the active ingredients may float to the top of the container, be suspended as a phase layer, or settle to the bottom. For these reasons, liquid additives should be thoroughly mixed prior to sampling. The sample should then be extracted from the center of the container using a clean, dry sampling device. A composite of the samples from the same lot should be prepared, packaged, and labeled (4.7). The volume of each liquid additive sample should be sufficient to perform the desired testing.

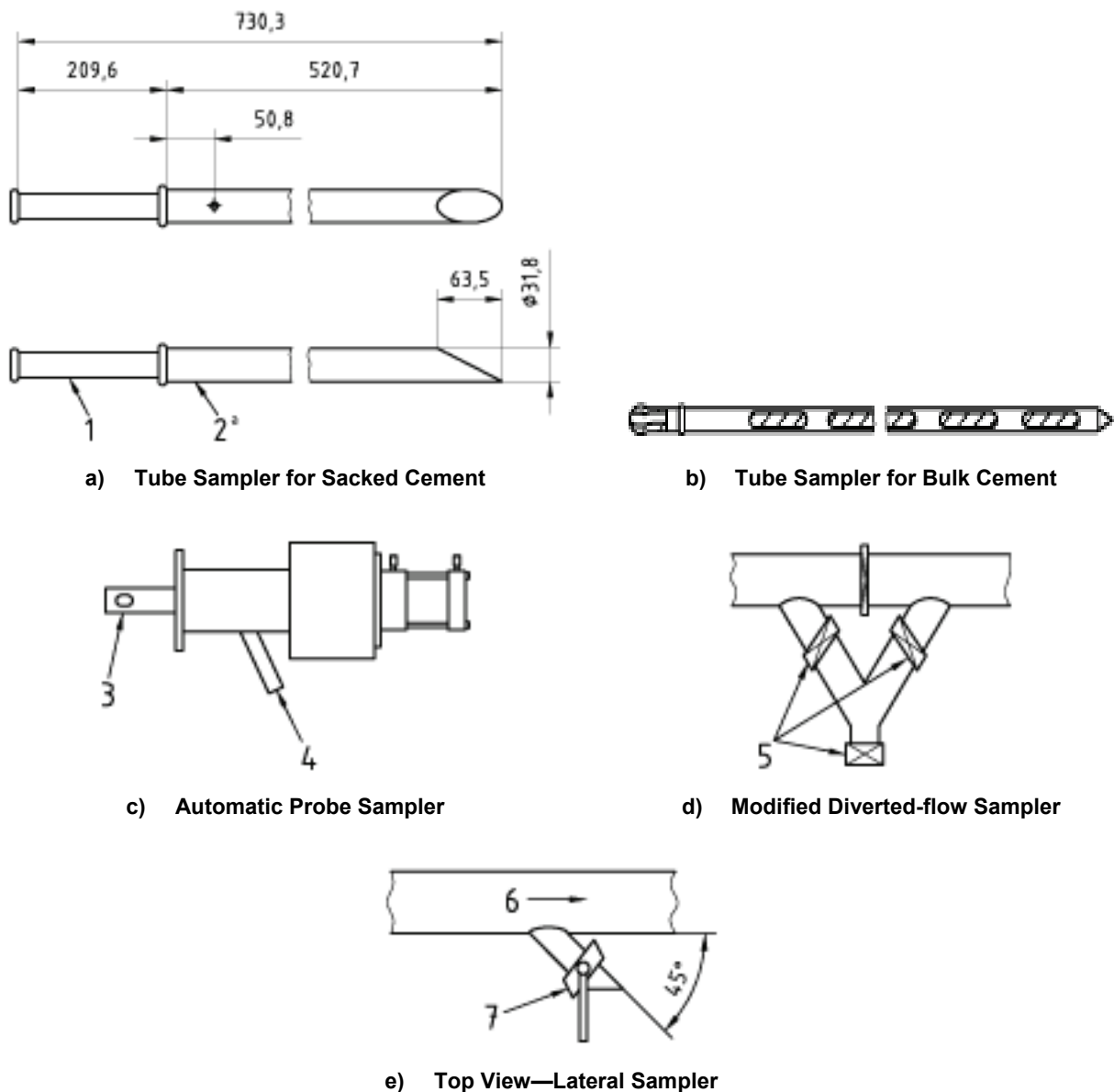
4.6 Sampling Mixing Water

The mixing water should be sampled from the source or from the tank in which it is stored just prior to mixing. The sample should be extracted in such a way as to avoid contamination. The sample should be packaged and labeled (4.7). The sample volume should be sufficient to perform the desired testing.

4.7 Shipping and Storage

Test samples should be packaged promptly in unused, clean, airtight, moisture-proof containers suitable for shipping and long-term storage. The containers should be lined metal, plastic, or other heavy-walled flexible or rigid material to assure maximum protection. Resealable plastic bags may be used provided the bag is placed in a protective container prior to shipping to prevent puncturing and to contain all material that may leak out during shipping. Ordinary cloth sacks, cans, or jars should not be used. Shipping in glass containers is not recommended.

Dimensions in millimeters

**Key**

- 1 handle
- 2 dragg tubing
- 3 sample tube, extended
- 4 product discharge
- 5 valve
- 6 flow direction
- 7 valve

a Approximate volume = 320 ml.

Figure 1—Commonly Used Sampling Devices

The body of each blend container should be clearly labeled and identified with the type of material, lot number, source, and date of sampling. Shipping containers should also be labeled. The lids of containers should not be marked, since the lids can be readily interchanged and thus lead to confusion. Any required regulatory identification or documentation should be enclosed or securely attached to the container. All hazardous material samples should be packaged and labeled in accordance with all regulatory requirements.

4.8 Sample Preparation Prior to Testing

Upon arrival at the testing location, the samples should be closely examined to ensure they have remained sealed during shipment and are not contaminated.

If the sample was not shipped in a leak-proof container, the sample should be transferred into a suitable, leak-proof container. The container should be properly labeled, dated, and stored in a dry place where room temperatures remain fairly constant. Repackaging should be indicated. At the time of testing, each sample should be examined for quality and thoroughly blended just prior to slurry preparation (see Section 5).

Optimum shelf life(s) for all samples should be determined by the supplier or manufacturer. If unknown, use of any cement additive that has been stored for longer than one year is not recommended.

4.9 Sample Disposal

Sample disposal should comply with all regulatory requirements.

5 Preparation of Slurry

5.1 General

The preparation of cement slurries varies from that of classical solid/liquid mixtures due to the reactive nature of cement. Shear rate and time at shear are important factors in the mixing of cement slurries. Varying these parameters has been shown to affect slurry performance properties.

The procedure described in this section is recommended for the laboratory preparation of slurries that require no special mixing conditions. If large slurry volumes are needed for a test series, the alternative method for slurry preparation given in Annex A may be used.

5.2 Apparatus

5.2.1 All apparatuses are calibrated as per Annex B.

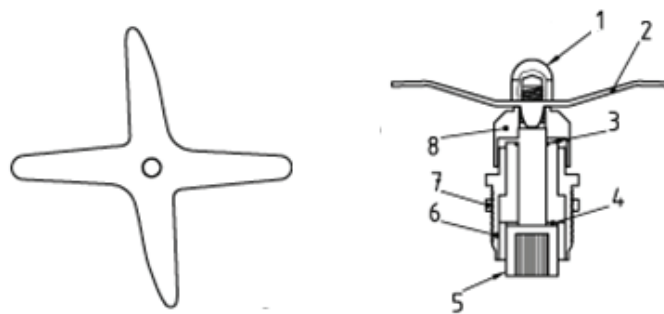
5.2.2 Electronic or mechanical balances—Balances shall be accurate to ± 0.1 % of reading for measurements made at 10 g or greater up to the full scale of the balance. Balances shall be accurate to ± 1 % of reading for measurement made less than 10 g. Balances shall have two (2) decimal place precision at a minimum.

5.2.3 Mixing device, of capacity 1 liter (1 quart), having bottom drive and a blade-type blender—An example of a mixing device in common use for preparation of slurries is shown in Figure 2. The blender container and the blender blade (Figure 3) should be constructed of corrosion-resistant material. The mixing blender assembly should be constructed so that the blade can be separated from the drive mechanism.

The mixing blender blade should be replaced with a new blade before mass loss greater than 10 % has occurred (see B.3.2.2). If the mixing device leaks at any time during the mixing procedure, the contents should be discarded, the leak repaired, and the procedure restarted.



Figure 2—Example of Common Mixing Device



Key

- | | |
|--|---------------------|
| 1 cap nut | 5 socket head shaft |
| 2 blade (installed with tapered edge down) | 6 bearing holder |
| 3 O-ring | 7 hexagonal nut |
| 4 thrust washer | 8 bearing cap |

Figure 3—Common Blade Assembly

5.3 Procedure

5.3.1 Determination of Relative Density (Specific Gravity) of Components

5.3.1.1 General

The relative density of different batches of cement can vary due to natural variations in the composition of the raw materials used in the manufacturing process. Cement relative density may vary from 3.10 to 3.25. This can result in variation in slurry densities by as much as 34 kg/m^3 (0.28 lbm/gal) for slurries with constant water-to-solids ratios. The relative density of mix water can also vary, depending on the source, resulting in slurry density inconsistencies. Determination of the relative density of all components of the slurry is necessary to properly calculate the required amounts for slurry preparation.

5.3.1.2 Relative Density of Cement and Dry Additives

The relative density of the cement and any dry additives can be determined by the use of a gas pycnometer (also known as stereopycnometer). Alternatively, a Le Chatelier flask as outlined in [ASTM C188-95](#) may be used for determining the relative density of these materials.

5.3.1.3 Relative Density of Mix Water and Liquid Additives

The relative density of the mix water and any liquid additives may be determined by the use of a hydrometer as outlined in [API 13J](#). Alternatively, a pycnometer may be used for determining the relative density of these materials.

5.3.1.4 Laboratory Density and Volume Calculations

5.3.1.4.1 General

For the purpose of these calculations, as a general rule one cubic centimeter is equivalent to one milliliter. Fresh water density at 23°C (73°F) is 0.9976 kg/l (8.325 lbm/gal).

A slurry volume of approximately 600 ml shall be sufficient to perform most laboratory test procedures while not overfilling the mixing container. Laboratory blend requirements may be calculated by use of the formulas based on slurry design recipes [Equations (21) to (25) in SI units or Equations (27) to (31) in USC units] under 5.3.1.4.4. Alternative, suitable equations may also be used to calculate laboratory blend requirements.

Calculations [Equations (1) to (8) in SI units or Equations (9) to (15) in USC units] are based on a slurry design that includes solid additives or liquid additives or both. Slurry composition is based on additive concentrations expressed for the solids in kilograms per tonne of cement (metric ton, 1 tonne = 1000 kg) or in percent by weight of cement (BWOC) and for the liquids in liters per tonne of cement (gallon per sack of cement). When water requirement is provided, the slurry yield (V_s) can be easily calculated based on Equation (2) (SI units) or Equation (10) (USC units). If it is not the case the first step should be to calculate water requirement and then slurry yield.

5.3.1.4.2 Slurry Design Calculation in SI Units

$$\rho_s = \frac{m_s}{V_s} \quad (1)$$

$$V_s = V_c + V_w + \sum V_{ad.liq} + \sum V_{ad.sol} \quad (2)$$

$$m_s = m_c + m_w + \sum m_{ad.liq} + \sum m_{ad.sol} \quad (3)$$

where

- ρ_s is the density of slurry, in kilograms per liter;
- V_s the slurry yield prepared with one tonne (1000 kg) of cement, in liters per tonne of cement;
- V_c is the cement volume of one tonne (1000 kg) of cement, expressed in liters;
- V_w is the mix water volume, expressed in liters per tonne of cement;
- $\sum V_{ad.liq}$ is the sum of volumes for all liquid additives, expressed in liters per tonne of cement;
- $\sum V_{ad.sol}$ is the sum of volumes for all solid additives, expressed in liters per tonne of cement;
- m_s is the slurry mass prepared with one tonne (1000 kg) of cement, expressed in kilograms per tonne of cement;
- m_c is the cement mass of one tonne (1000 kg) of cement, expressed in kilograms;
- m_w is the mix water mass, expressed in kilograms per tonne of cement;
- $\sum m_{ad.liq}$ is the sum of masses for all liquid additives, expressed in liters per tonne of cement;
- $\sum m_{ad.sol}$ is the sum of masses for all solid additives, expressed in liters per tonne of cement.

Solid additives can be also expressed by the solid additive concentration, $C_{ad.sol}$ in percent BWOC. In that case:

$$m_{ad.sol} = 10 \times C_{ad.sol} \quad (4)$$

Volumes are related to masses, and masses to volumes, for cement:

$$V_c = 1000 / \rho_c \quad (5)$$

where

ρ_c is the density of cement, expressed in kilograms per liter.

for mix water:

$$m_w = V_w \times \rho_w \quad (6)$$

where

ρ_w is the density of mix water, expressed in kilograms per liter.

and for cement additives:

$$m_{\text{ad.liq}} = V_{\text{ad.liq}} \times \rho_{\text{ad.liq}} \quad (7)$$

$$V_{\text{ad.sol}} = m_{\text{ad.sol}} / \rho_{\text{ad.sol}} = 10 \times C_{\text{ad.sol}} / \rho_{\text{ad.sol}} \quad (8)$$

where

$\rho_{\text{ad.liq}}$ is the density of a liquid additive, expressed in kilograms per liter;

$\rho_{\text{ad.sol}}$ is the density of a solid additive, expressed in kilograms per liter.

5.3.1.4.3 Slurry Design Calculation in USC Units

$$\rho_s = 0.1337 \times \frac{m_s}{V_s} \quad (9)$$

$$V_s = 0.1337 \times (V_c + V_w + \Sigma V_{\text{ad.liq}} + \Sigma V_{\text{ad.sol}}) \quad (10)$$

$$m_s = m_c + m_w + \Sigma m_{\text{ad.liq}} + \Sigma m_{\text{ad.sol}} \quad (11)$$

where

ρ_s is the density of slurry, in pounds per gallon;

V_s the slurry yield prepared with one sack of cement (94 lbm), in cubic feet per sack;

V_c is the cement volume of one sack of cement, expressed in gallons;

V_w is the mix water volume, expressed in gallons per sack of cement;

$V_{\text{ad.liq}}$ is the volume of a liquid additive, expressed in gallons per sack of cement, all liquid additives should be considered by the calculation;

$V_{\text{ad.sol}}$ is the volume of a solid additive, expressed in gallons per sack of cement, all solid additives should be considered by the calculation;

m_s is the slurry mass prepared with one sack of cement (including water and additives), expressed in pounds per sack of cement;

m_c is the cement mass of one sack of cement, taken to be 94 lbm;

m_w is the mix water mass, expressed in pounds per sack of cement;

$m_{\text{ad.liq}}$ is the mass of a liquid additive, expressed in pounds per sack of cement, all liquid additives should be considered by the calculation;

$m_{\text{ad.sol}}$ is the mass of a solid additive for one sack of cement based on its concentration, $C_{\text{ad.sol}}$, expressed in percent BWOC, all solid additives should be considered by the calculation.

where

$$m_{\text{ad.sol}} = 0.01 \times m_{\text{c}} \times C_{\text{ad.sol}} = 0.94 \times C_{\text{ad.sol}}$$

Volumes are related to masses, and masses to volumes, for cement:

$$V_{\text{c}} = 94 \times v_{\text{c.abs}} \quad (12)$$

where

$v_{\text{c.abs}}$ is the absolute volume of cement, expressed in gallons per pound;

for mix water:

$$m_{\text{w}} = V_{\text{w}} \times \rho_{\text{w}} \quad (13)$$

where

ρ_{w} is the density of mix water, expressed in pounds per gallon;

and for cement additives:

$$m_{\text{ad.liq}} = V_{\text{ad.liq}} \times \rho_{\text{ad.liq}} \quad (14)$$

$$V_{\text{sol.ad}} = 0.01 \times m_{\text{c}} \times C_{\text{ad.sol}} \times v_{\text{c.abs}} = 0.94 \times C_{\text{ad.sol}} \times v_{\text{c.abs}} \quad (15)$$

where

$\rho_{\text{ad.liq}}$ is the density of a liquid additive, expressed in pounds per gallon;

$v_{\text{ad.abs}}$ is the absolute volume of a solid additive, expressed in gallons per pound;

$C_{\text{ad.sol}}$ is the solid additive concentration expressed in percent BWOC.

Remarks:

- a) USC equations are based on a sack of cement. If a sack is defined as one bulk cubic foot (3.140), a cement sack weight would be 94 lb. For a cement blend, sack weight should be defined by the user and in that case, Equation (12) shall be modified accordingly.
- b) Salt as an additive is defined in percent by weight of water (BWOW). For testing purposes, it is recommended to consider mixing water as brine and to calculate m_{w} from brine density and brine volume requirements. An alternate method to calculate the salt in the slurry is to use a graph or table containing an equivalent specific gravity for the actual salt when it is in solution. Using this method, salt can be treated as any other additive as long as the concentration is BWOW.

5.3.1.4.4 Water Requirement Calculations

In SI units, mix water requirement is calculated by solving Equation (1) using Equations (2) to (8), mix water requirement is calculated by Equation (16).

$$V_w = \frac{1000 \left(1 - \frac{\rho_s}{\rho_c} \right) - \Sigma \left[V_{ad.liq} (\rho_s - \rho_{ad.liq}) \right] + \Sigma \left[m_{ad.sol} \left(1 - \frac{\rho_s}{\rho_{ad.sol}} \right) \right]}{(\rho_s - \rho_w)} \quad (16)$$

which is resumed with fresh water at 23 °C (73 °F) to:

$$V_w = \frac{1000 \left(1 - \frac{\rho_s}{\rho_c} \right) - \Sigma \left[V_{ad.liq} (\rho_s - \rho_{ad.liq}) \right] + \Sigma \left[m_{ad.sol} \left(1 - \frac{\rho_s}{\rho_{ad.sol}} \right) \right]}{(\rho_s - 0.9976)} \quad (17)$$

where

- V_w is the mix water volume, expressed in liters per tonne of cement (1000 kg);
- $V_{ad.liq}$ is the volume of a liquid additive, expressed in liters per tonne of cement (1000 kg); all liquid additives should be considered by the calculation;
- $m_{ad.sol}$ is the mass of a solid additive, expressed in liters per tonne of cement (1000 kg) or calculated by Equation (4) and solid additive concentration, $C_{ad.sol}$; all solid additives should be considered by the calculation;
- ρ_s is the density of slurry, expressed in kilograms per liter;
- ρ_c is the density of cement, expressed in kilograms per liter;
- ρ_w is the density of mix water, expressed in kilograms per liter;
- $\rho_{ad.liq}$ is the density of liquid additive, expressed in kilograms per liter;
- $\rho_{ad.sol}$ is the density of solid additive, expressed in kilograms per liter.

In USC units, mix water requirement is calculated solving Equation (9) using Equations (10) to (15), by Equation (18).

$$V_w = \frac{94 \left(1 - \rho_s \times v_{c.abs} \right) - \Sigma \left[V_{ad.liq} (\rho_s - \rho_{ad.liq}) \right] + 0.94 \times \Sigma \left[C_{ad.sol} \left(1 - \rho_s \times v_{ad.abs} \right) \right]}{(\rho_s - \rho_w)} \quad (18)$$

which is resumed with fresh water to:

$$V_w = \frac{94 \left(1 - \rho_s \times v_{c.abs} \right) - \Sigma \left[V_{ad.liq} (\rho_s - \rho_{ad.liq}) \right] + 0.94 \times \Sigma \left[C_{ad.sol} \left(1 - \rho_s \times v_{ad.abs} \right) \right]}{(\rho_s - 8.325)} \quad (19)$$

where

- V_w is the mix water volume, expressed in gallons per sack of cement;
- ρ_s is the density of slurry, expressed in pounds per gallon;

- $V_{c.abs}$ is the absolute volume of cement, expressed in gallons per pound;
- $V_{ad.liq}$ is the volume of liquid additive, expressed in gallons per sack of cement, all liquid additives should be considered by the calculation;
- $\rho_{ad.liq}$ is the density of liquid additive, expressed in pounds per gallon;
- $C_{ad.sol}$ is the concentration of solid additive, expressed in percent BWOC, all solid additives should be considered by the calculation;
- $V_{ad.abs}$ is the absolute volume of solid additive, expressed in gallon per pounds;
- ρ_w is the density of mix water, expressed in pounds per gallon.

5.3.1.4.5 Slurry Yield Calculations

Slurry yield (V_s) expressed in liters per tonne of cement (cubic feet per sack) are calculated with Equation (2) and Equation (10) in USC units.

5.3.1.4.6 Laboratory Mass Calculations

A slurry volume of 600 ml should be mixed based on mix water, cement, and additives mass requirements expressed in grams. Mass requirements for 600 ml are calculated based on Equations (20), (1), and (3):

$$m_{s,600} = m_{c,600} + m_{w,600} + \sum m_{ad.liq,600} + \sum m_{ad.sol,600} \quad (20)$$

where

- $m_{s,600}$ is the mass of 600 ml of slurry to be mixed, expressed in grams
- $m_{c,600}$ is the cement mass to be mixed for 600 ml of slurry, expressed in grams;
- $m_{w,600}$ is the mix water mass to be mixed for 600 ml of slurry, expressed in grams;
- $\sum m_{ad.liq,600}$ is the sum of masses for all liquid additives to be mixed for 600 ml of slurry, expressed in grams;
- $\sum m_{ad.sol,600}$ is the sum of masses for all solid additives masses to be mixed for 600 ml of slurry, expressed in grams.

For SI units as per slurry composition and yield calculation mass requirements are:

Mass of cement ($m_{c,600}$) to be mixed:

$$m_{c,600} = \frac{600}{V_s} \times 1000 \quad (21)$$

into the mass of mix water ($m_{w,600}$)

$$m_{w,600} = \frac{600}{V_s} \times V_w \times \rho_w \quad (22)$$

with fresh water at 23 °C (density 0.9976 kg/l):

$$m_{w,600} = \frac{598.56}{V_s} \times V_w \quad (23)$$

and with the masses of liquid additives ($m_{ad.liq,600}$) and solids additives ($m_{ad.sol,600}$):

$$m_{ad.liq,600} = \frac{600}{V_s} \times V_{ad.liq} \times \rho_{ad.liq} \quad (24)$$

$$m_{ad.sol,600} = \frac{600}{V_s} \times m_{ad.sol} \quad (25)$$

where

V_s is the slurry yield prepared with one tonne of cement (1000 kg), expressed in liters per tonne of cement;

V_w is the mix water volume per one tonne of cement (1000 kg), expressed in liters per tonne of cement;

ρ_w is the density of mix water, expressed in kilograms per liter;

$V_{ad.liq}$ is the volume for a liquid additive per one tonne of cement (1000 kg), expressed in liters per tonne of cement;

$\rho_{ad.liq}$ is the density of a liquid additive, expressed in kilograms per liter;

$m_{ad.sol}$ is the mass for a solid additive per one tonne of cement (1000 kg), expressed in kilograms per tonne of cement.

or with

$$m_{ad.sol} = 10 \times C_{ad.sol} \quad (4)$$

where

$C_{ad.sol}$ is the concentration of the solid additive, expressed in percent BWOC.

For USC units as per slurry composition and yield calculation, to mix a 600 ml sample, the mass requirements expressed in grams are calculated by the following equations (based on a 94 lbm sack of cement).

Mass of cement ($m_{c,600}$) to be mixed:

$$m_{c,600} = \frac{9.611}{V_s} \times 94 = \frac{903.4}{V_s} \quad (26)$$

into the mass of mix water ($m_{w,600}$)

$$m_{w,600} = \frac{9.611}{V_s} \times V_w \times \rho_w \quad (27)$$

with fresh water at 73 °F (density 8.325 lb/gal):

$$m_{w,600} = \frac{80.01}{V_s} \times V_w \quad (28)$$

and with the masses of liquid additives ($m_{ad.liq,600}$) and solids additives ($m_{ad.sol,600}$):

$$m_{ad.liq,600} = \frac{9.611}{V_s} \times V_{ad.liq} \times \rho_{ad.liq} \quad (29)$$

$$m_{ad.sol,600} = \frac{0.09611}{V_s} \times 94 \times C_{ad.sol} = \frac{9.034}{V_s} \times c_{ad.sol} \quad (30)$$

where

V_s is the slurry yield prepared with one sack of cement (94 lbm), expressed in cubic feet per one sack of cement;

V_w is the mix water volume, expressed in gallons per one sack of cement;

ρ_w is the density of mix water, expressed in pounds per gallon;

$V_{ad.liq}$ is the volume for a liquid additive per one sack of cement, expressed in gallons per one sack of cement;

$\rho_{ad.liq}$ is the density of a liquid additive, expressed in pounds per gallon;

$C_{ad.sol}$ is the concentration of the solid additive, expressed in percent BWOC.

5.3.2 Temperature of Water and Cement

The temperature of the mix water, dry cement or cement blend, and mixing and blending devices should be representative of field mixing conditions. If field conditions are unknown, the temperature of the mix water (including any premixed additives) and dry cement should be $23\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ ($73\text{ }^{\circ}\text{F} \pm 2\text{ }^{\circ}\text{F}$) immediately prior to mixing. In all cases, the temperatures of the mix water and dry cement should be measured and documented.

5.3.3 Mix Water and Mix Fluid

Water composition can affect slurry performance. Water from the field source should be used. If field mix water is unavailable, water of similar composition should be used. If field mix water composition is unknown, deionized, distilled, or tap water may be used. The type of mix water should be documented in the lab report. The mix water should be weighed into a clean, dry, blender container. If used, additives may be weighted into the water in the blender container or may be weighed separately and added to the water while agitating at low speed. No excess water should be added to compensate for evaporation or wetting.

5.3.4 Mixing of Cement and Water

A slurry volume of approximately 600 ml is sufficient to perform most laboratory test procedures while not overfilling the blender container. Weigh dry materials and then blend thoroughly and uniformly prior to adding them to the mix fluid. Place the blender container with the required mass of mix water and liquid additives (if previously added) on the blender base. Turn on the motor and maintain at $4000 \text{ r/min} \pm 250 \text{ r/min}$. If additives are present in the mix water, stir at the above rotational speed to thoroughly disperse them prior to the addition of cement. In some cases, additives (dry or liquid) may be added to the mix water in the field. In such cases, the additives should be added to the mix water while mixing at low speed. In certain cases, the order of addition of the additives to the mix water can be critical, in which case, the additives should be mixed in the order that they will be mixed in the field. Document any special mixing procedures and mixing time.

While mixing at $4000 \text{ r/min} \pm 250 \text{ r/min}$, add the cement or cement/dry additive blend at a uniform rate in not more than 15 s, if possible. Some slurry designs may take longer to completely wet the cement blend; however, the time used to add the blend should be kept to a minimum. If more than 15 s were required to add the cement blend to the water, document that time. After 15 s or when all the dry materials have been added to the mix water, if longer than 15 s, place the cover on the mixing container and continue mixing at $12,000 \text{ r/min} \pm 250 \text{ r/min}$ for $35 \text{ s} \pm 1 \text{ s}$. Measure and document the rotational speed under load.

5.4 Test Fluid Conditioning

5.4.1 General

Conditioning simulates the conditions the test fluid will encounter during placement into the wellbore. Conditioning should be done according to a schedule that reflects the expected conditions under which the test fluid will be exposed during placement. If possible, the schedule should use the temperatures and pressures of the well. Alternatively, the conditioning can be done at atmospheric pressure.

5.4.2 Procedure: Pressurized Conditioning

Any consistometer referenced in Section 9 or Annex C may be used.

- a) Within 1 min after mixing according to 5.3.4, pour the test fluid into the slurry container of a pressurized consistometer. Start test within 5 min after placing test fluid in the pressurized consistometer.
- b) Heat to T_{PBHC} in accordance with the pressure/temperature schedule designed to simulate conditions in the well. Hold test temperature and pressure for $30 \text{ min} \pm 30 \text{ s}$ to allow the test fluid temperature to reach equilibrium. This hold time may be modified to simulate cementing operations. Proper note should be made of this in the test report.
- c) If the temperature is greater than 88°C (190°F), cool the test fluid as quickly as possible to 88°C (190°F). If the boiling point of water at the test location is less than 100°C (212°F), adjust temperatures accordingly. Maintain test pressure while decreasing the temperature. When 88°C (190°F) is reached, release the pressure slowly [about 1400 kPa/s (200 psi/s)].
- d) Remove the slurry container from the consistometer, keeping the container upright so that the oil does not mix with the test fluid. Do not cool the slurry container further after removal from the pressurized consistometer.
- e) Remove the flange ring and the backup plate and syringe or blot oil from the top of the slurry container.

- f) Remove the diaphragm and the support ring. Syringe or blot the top of the test fluid with an absorbent cloth or paper towel to remove any visible oil. If the contamination is severe, discard the test fluid and condition a fresh test fluid.
- g) Remove the paddle and stir the test fluid briskly with a spatula to ensure it is uniform.
- h) Continue with the desired test.

5.4.3 Procedure: Atmospheric-pressure Conditioning

This procedure is limited to a maximum temperature of 88 °C (190 °F). If the boiling point of water at the test location is less than 100 °C (212 °F), adjust conditioning temperatures accordingly.

- a) Within 1 min after mixing according to 5.3.4 using test fluid, fill the slurry container of the atmospheric-pressure consistometer to the fill line.
- b) Heat the test fluid from ambient temperature or a temperature that simulates field surface mixing temperature to T_{PBHC} in accordance with the thickening-time schedule that most closely simulates actual field conditions. If the atmospheric consistometer is not capable of heating on a controlled temperature ramp, heat as rapidly as the instrument is capable and record the time to T_{PBHC} . If the atmospheric-pressure consistometer is not equipped to measure test fluid temperature, the bath should be heated in accordance with the appropriate schedule.
- c) With test fluids containing additives that are not affected by sudden temperature increases, the slurry container may be placed in the heating bath preheated to the test temperature [± 3 °C (± 5 °F)] or other initial temperature that is appropriate. Care should be taken to prevent unusual behavior such as gelation, increase in free fluid, or poor response to additives such as retarders and fluid-loss control agents, when conditioning the fluid.
- d) After the slurry reaches test temperature (the temperature must be verified by measurement), hold the test temperature for 30 min $\pm$ 30 s to allow the test fluid temperature to reach equilibrium. This hold time may be modified to simulate cementing operations. However, proper note should be made of this in the test report.
- e) Remove the paddle and stir the test fluid briskly with a spatula to ensure it is uniform.
- f) Continue with the desired test.

6 Determination of Slurry Density

6.1 Apparatus

The preferred apparatus for measuring the density of a cement slurry is the pressurized fluid density balance. By pressurizing the sample cup, any entrained air is decreased to a negligible volume, thus providing a slurry density measurement more representative of the true slurry density. The apparatus is calibrated according to the requirements found in Annex B. The apparatus should be clean and dry.

6.2 Procedure

6.2.1 The sample cup should be filled to a level slightly below the upper edge of the cup.

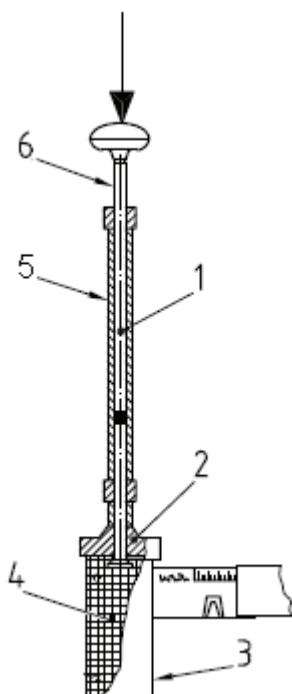
6.2.2 Place the lid on the cup with the check valve in the down (open) position. Push the lid downward into the mouth of the cup until surface contact is made between the outer skirt of the lid and the upper edge of the cup. Expel excess slurry through the check valve.

Caution—Slurry can be expelled forcibly.

After 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 ring on the cup.

6.2.3 The pressurizing pump is similar in operation to a syringe. Fill the pump by submerging the nose of the pump assembly in the slurry with the piston rod in the completely downward position. Then draw the piston rod upward, thereby filling the pump cylinder with slurry. Return the piston to the downward position to expel air from the piston and then draw the rod upward to refill the pump cylinder with slurry.

6.2.4 Push the nose of the pump onto the mating O-ring surface of the check valve. Pressurize the sample cup by applying a downward force on the pump cylinder housing in order to hold the check valve down (open) and at the same time push the piston rod downward, forcing the slurry into the cup. Maintain approximately 230 N (50 lbf) force or greater on the piston rod (Figure 4).

**Key**

- 1 pressurizing pump
- 2 pressurizing valve
- 3 sample cup
- 4 slurry sample with entrained air
- 5 cylinder housing
- 6 piston rod

Figure 4—Common Pressurized Fluid Density Balance

6.2.5 The check valve in the lid is pressure-actuated, which means the pressure in the cup closes the valve and keeps it closed. Close the valve by gradually lifting the cylinder housing of the pressurizing pump while maintaining pressure on the piston rod. When the check valve closes, release pressure on the piston rod before disconnecting the pump. Check to ensure the valve has closed. Fluid leaking out of the check valve indicates it is not fully closed or the interior O-ring is defective. Correct the problem and restart the test.

6.2.6 Rinse off the exterior of the cup and wipe dry. Then place the instrument on the knife edge as illustrated in Figure 5. Move the sliding weight right or left until the beam is balanced. The beam is balanced when the bubble is centered in the sight glass. Obtain the density by reading one of the four calibrated scales on the arrow side of the sliding weight.

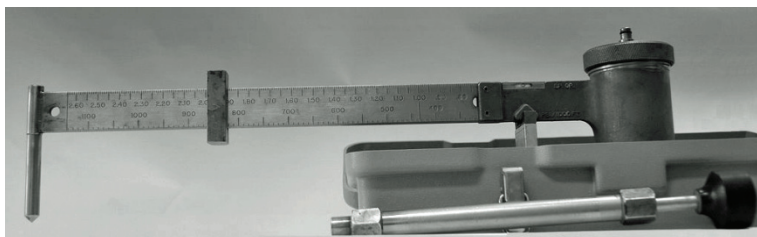


Figure 5—Common Pressurized Fluid Density Balance

6.2.7 After the measurement, reconnect the pump assembly and push downward on the pump cylinder housing to release the pressure. Empty the cup and pump assembly and thoroughly clean all components.

7 Well-simulation Compressive-strength Tests

7.1 General

This section presents procedures for well-simulation compressive-strength testing.

7.2 Sampling

Obtain samples of the cement, additives, and mix water in accordance with Section 4.

7.3 Apparatus

7.3.1 Cube molds and compressive-strength testing load frame should conform with [ASTM C109/C109M-07](#), except for: (1) the bearing block surface dimension requirement, (2) the bearing block Rockwell hardness requirement, and (3) that molds can be separable into more than two parts.

The testing load frame block should be free to tilt in any direction. The center of the block should align with the center of the surface of the specimen, to assure even loading across the sample surfaces. A hardened metal bearing block should be used beneath or above the specimen, depending on how the swivel bearing is tilting to minimize wear on the lower platen. The platen should be inscribed to assist in the placement of the specimen in the center of the platen surface. The apparatus is calibrated according to the requirements found in Annex B.

The molds should be made of hard metal and mold tolerance should be verified at least once every two years. The cube mold base plate should be of corrosion-resistant metal; the cover plate should have a minimum thickness of 6 mm (0.25 in.) and be made of corrosion-resistant material. Grooves may be incorporated into the surface of the cover plate contacting the surface of the cement. Glass plates may be used but are not recommended for tests above 110 °C (230 °F) because of the risk of silica replacement.

7.3.2 Water curing bath or tank, having dimensions permitting the complete immersion of molds for compressive-strength test samples in water, and capable of maintaining the specified test temperatures within ± 2 °C (± 3 °F).

The two types of water curing baths are:

- a) **atmospheric-pressure curing bath** (unpressurized), having an agitator or circulating system. Atmospheric-pressure curing baths at or below 66 °C (150 °F) may be used for curing samples for compressive-strength testing when higher pressure is not required.
- b) **pressurized curing chamber**, suitable for curing samples at the appropriate final test temperature and a pressure of at least 21 MPa (3000 psi). The vessel should be capable of being heated at the desired rate.

7.3.3 Cooling bath, designed so that the specimen to be cooled from the curing temperature can be completely submerged in water maintained at 27 °C ± 3 °C (80 °F ± 5 °F).

7.3.4 Temperature-measuring system, three commonly used temperature-measuring systems are as follows:

- a) A thermometer, of range – 18 °C to 104 °C (0 °F to 220 °F), with minimum scale divisions not to exceed 1 °C (2 °F) may be used in a nonpressurized bath.
- b) A thermocouple, of range – 18 °C to 104 °C (0 °F to 220 °F), accurate to ± 2 °C (± 3 °F) is preferred in a nonpressurized bath.
- c) A thermocouple, of range – 18 °C to at least 204 °C (0 °F to at least 400 °F), accurate to ± 2 °C (± 3 °F), should be used in a pressurized curing chamber.

7.3.5 Puddling rod, corrosion-resistant, typically with a diameter of 6 mm (0.25 in.).

7.3.6 Mold-sealing grease, possessing the following properties when subjected to anticipated test temperatures and pressures is suitable for use:

- a) a consistency to permit ease of application,
- b) good sealing properties to prevent leakage,
- c) water resistance,
- d) inert to the cement, and
- e) noncorrosive in the temperature range of the test.

7.3.7 Mold-release agent (optional)—A thin layer of mold-release agent may be applied to the interior surfaces of the mold to prevent the sample from being damaged when removed from the mold. The mold-release agent should comply with 7.3.6.

7.4 Procedure

7.4.1 General

Apparatuses are calibrated according to the requirements in Annex B.

7.4.2 Preparation of Molds

The interior faces of the molds and the contact surfaces of the plates are commonly coated with mold release agent, but may be clean and dry. Care should be taken to ensure there is no bead of sealant on the interior of the mold. See Figure 6.

7.4.3 Preparation of Slurry and Filling of Molds

7.4.3.1 Preparation

Prepare the cement slurry in accordance with 5.3. If preconditioning is required, then either 5.4 or 7.5 should be followed. Section 7.5 is particularly useful to determine the compressive strength at the top of long cement columns.

7.4.3.2 Mold Filling

Pour the cement slurry into each chamber of the prepared molds to approximately one-half of the mold depth. Puddle each sample sufficiently with a puddling rod to remove air bubbles. Stir the remaining slurry with a spatula to ensure the slurry is uniform. Fill each mold chamber to overflowing with slurry and puddle the same as the first layer. After puddling, strike off the excess slurry even with the top of the mold using a straight edge. Discard specimens in molds that leak. Place the cover plate on top of the molds. For each test, prepare at least three specimens.

7.4.4 Curing at Atmospheric Pressure

After the molds have been filled and covered and within 5 min after mixing, place them in a curing bath maintained at the desired curing temperature. Raise the molds off the bottom of the bath using a perforated baffle plate, wire rack, or suitable spacers to allow water to completely circulate around the samples during the curing period. At 45 min (± 5 min) prior to the age at which the samples are to be tested, remove the molds from the water bath and remove the cured samples from the molds. Immediately immerse the samples in a water cooling bath at $27\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($80\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$) until the samples are tested.

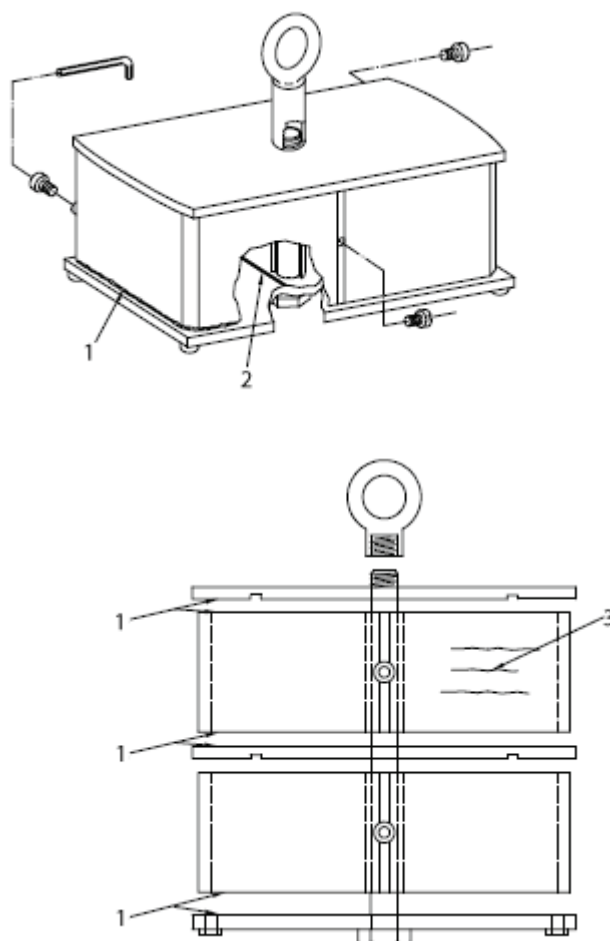
7.4.5 Curing at Pressures Above Atmospheric

Within 5 min after the last slurry mixing, the molds have been filled and covered with the top plate, and immediately placed in a curing vessel at the desired test initiation temperature [normally $27\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($80\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$)], heat and pressure in accordance with the test schedule is applied. Cement samples may be cured in accordance with pressure/temperature schedules provided in Table 2 and Table 3 (see below) or by a schedule designed to simulate conditions in a specific well. For depths greater than 6600 m or 22,000 ft, user defined schedules must be used. Schedules should be interpolated to arrive at the correct depth/static temperature of the well for which the test is performed.

For samples cured at or below $88\text{ }^{\circ}\text{C}$ ($190\text{ }^{\circ}\text{F}$), maintain test temperature and pressure until 45 min (± 5 min) prior to testing. For test temperatures above $90\text{ }^{\circ}\text{C}$ ($194\text{ }^{\circ}\text{F}$), discontinue heating and allow samples to cool at such a rate that the sample temperature is $90\text{ }^{\circ}\text{C}$ ($194\text{ }^{\circ}\text{F}$) or less 45 min prior to testing. Maintain test pressure on the curing vessel during the cooling process. Release the pressure gradually and remove the molds from the curing vessel. Immediately remove the samples from the molds and immerse them in a water cooling bath at $27\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($80\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$) for 45 min (± 5 min) until the samples are tested.

7.4.6 Test Period

The test period is the time elapsed from subjecting the specimen to heat in the curing vessel to testing the sample for strength. The test should be performed within 45 min of the desired test duration.



Key

- 1 grease lightly here
- 2 remove extruded grease
- 3 apply mold release agent inside sample cavity

Figure 6—Diagram of Mold Preparation

7.4.7 Strength Testing

Test specimens immediately after removal from the cooling bath. Measure the specimen height and calculate the minimum surface area in contact with the platen. Place the specimen on the platen with a side of the specimen in contact with the platen (i.e. the top surface during curing should not be in contact with the platen). The test procedure should be in accordance with [ASTM C109/C109M-07](#), except for the following.

- a) A compressive-strength testing load frame should be used, and the rate of loading for samples with expected strength greater than 3.5 MPa (500 psi) should be $72 \text{ kN} \pm 7 \text{ kN}$ (16,000 lbf $\pm$ 1600 lbf) per minute. For a nominal 25.8 cm^2 (4 in.²) sample surface, this rate can be achieved by adjusting the load rate to obtain a gauge indicator change of 18 kN (4000 lbf) in gauge reading in 15 s. For samples with expected strength of 3.5 MPa (500 psi) or less, a loading rate of $18 \text{ kN} \pm 2 \text{ kN}$ (4000 lbf $\pm$ 400 lbf) per minute should be used. For a nominal 25.8 cm^2 (4 in.²) sample surface, this rate can be achieved by adjusting the load rate to obtain a change of 18 kN (4000 lbf) in gauge reading in 1 min. Depending on the type of compressive strength load frame employed, it may

require some time for the load frame to build up the required load rate after initial contact with the cement sample.

NOTE If the cube height is less than 48 mm (1.9 in.), the cube should be discarded.

- b) Report compressive strength as the force required to break the sample divided by the smallest measured cross-sectional area in contact with the load-bearing plates of the load frame. Average the compressive strength of all acceptable test samples (see [ASTM C109/C109M-07](#)) made from the same slurry and tested at the same time. Report compressive strength results to the nearest 0.3 MPa (50 psi) and include the test conditions used.

7.5 Determination of Cement Compressive Strength at the Top of a Long Cement Column

7.5.1 Guidelines for Use

This procedure is especially useful if the predicted bottomhole circulating temperature (T_{PBHC}) is higher than the static temperature at the top of the cement column (T_{TOCS}).

7.5.2 Procedure

7.5.2.1 Prepare a cement slurry in accordance with Section 5. Pour the slurry into the slurry container of a pressurized consistometer, and heat to T_{PBHC} . Apply pressure in accordance with the Table 2, Table 3, or 9.4. Hold at T_{PBHC} and pressure for 60 min to allow the cement temperature to reach equilibrium.

7.5.2.2 Upon completion of the appropriate test schedule, plus 60 min at temperature, change the temperature of the slurry to the top-of-cement circulating temperature (T_{TOCC}) or 88 °C (190 °F), whichever is lower, at a rate of 1.0 °C/min (2.0 °F/min). Use one of the following equations to determine the cool-down time (t), in minutes.

In SI units:

$$t = \frac{T_{PBHC} - T_{TOCC}}{1.0\text{ °C}} \quad (31)$$

In USC units:

$$t = \frac{T_{PBHC} - T_{TOCC}}{2.0\text{ °F}} \quad (32)$$

where

t is the elapsed cool-down time, expressed in minutes;

T_{PBHC} is the predicted bottomhole circulating temperature, expressed in °C or °F;

T_{TOCC} is the top-of-cement circulating temperature or 88 °C (190 °F), whichever is lower, expressed in °C or °F.

Maintain test pressure while decreasing the temperature. When the T_{TOCC} or 88 °C (190 °F) (whichever is lower) is reached, release the pressure slowly and remove the slurry container.