

Addendum 2
November 2000

Recommended Practice for Testing Well Cements

API RECOMMENDED PRACTICE 10B
TWENTY-SECOND EDITION, DECEMBER 1997



**Helping You
Get The Job
Done Right.SM**

Addendum 2 to API RP 10B, Testing Well Cements (Contains Addendum 1 to API RP 10B – October 1999)

Note: Vertical lines indicate items not contained in Addendum 1

Page 13, Section 7.6.2

The reference to Section 11 should be Section 9.

Page 16, Table 2, Schedule 10Sg, Elapsed Time 120 min, column 7, for temperature gradient of 2.7°C/100 m

Replace “(1520” with “(152)”.

Page 18, Section 9.2, metric value for Specific Heat

Replace “[2.1 – 2.4kJ/9kg x K)]” with “[2.1 – 2.4 kJ/(kg x K)]”.

Page 19, Section 9.2, 4th paragraph, first sentence

Replace “rotated as a speed” with “rotated at a speed”.

Page 20, Section 9.4.4:

Replace with the following:

During the test period, the temperature and pressure of the cement slurry in the slurry container should be increased in accordance with the appropriate well-simulation test schedule (see 9.5). Schedules may be calculated or taken from the tables. Temperature of the cement slurry shall be determined by use of an ASTM classification “special” Type J thermocouple (see Appendix B) located in the center of the sample container. The tip of the thermocouple shall be vertically positioned, within the paddle shaft, in the slurry cup in such a way that it is between 1.75 in. (4.45 cm) and 3.50 in. (8.89 cm) above the inside of the base of the sample container. As there are many models of consistometers having different dimensions, care must be taken to ensure that the thermocouple used is compatible with the consistometer and the position of the tip of the thermocouple is in the correct location specified above.

Page 22, Equation (8b)

The constant should be 9.776.

Page 87, Section 10.6.2.10

The reference to 10.6 should be “10.8”.

Page 87, Section 10.7.1.11

The reference to 10.6 should be “10.8”.

Page 89, Section 11.2.1.1, first sentence

The inside dimensions given for the bottom, 1.102 in., 27.99 mm, and top, 1.154 in., 29.31 mm are reversed. The inside dimension for the bottom should be 1.154 in. (29.31 mm) and the inside dimension for the top should be 1.102 in. (27.99 mm) as shown in Figure 9.

Page 95, Equation (17b)

Replace “4” with “2”.

Page 96, Section 12.4.2 (begins on page 95)

Remove the words “which is also transmitted to the” and add the word “or” following “cylinder”.

Page 96, Equation (19b)

Replace “32.55” with “16.28”.

Page 98, Section 12.8.1.1*First paragraph:*

The reference to Curve A should be Curve D.

Second paragraph:

The reference to Curve B should be Curve A.

Page 98, Section 12.8.1.2*First paragraph:*

The reference to Figure 11, Curve C, should be Figure 11, Curves B and C.

Second paragraph, second sentence:

The reference to Figure 11, Curve C should be Figures 11 and 12, Curve B.

Second paragraph, fourth sentence:

The reference to Figure 11, Curve D should be Figures 11 and 12, Curve C.

Second paragraph, sixth sentence:

The reference to Figure 11, Curve B should be Figures 11 and 12, Curve A.

Page 101, Figure 12

The scale for the Shear-rate axis (x-axis) should begin with 1, not 0.

Page 104, Section 13.2, first sentence

Replace “ m ” with “ μ ” and “ r ” with “ p ”.

Page 105, Section 13.3, first sentence

Replace “ r ” with “ p ”.

Page 105, Equations (62), (63), and (64)

The term K_{RePL} should be in the denominator rather than the numerator.

Page 106, Section 13.4, third paragraph

Replace “ m_p ” with “ μ_p ” and “ r ” with “ p ”.

Page 106, Equation (72)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (73)

The title should read “Annular Flow: Slot”.



Page 106, Equation (75)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (76)

The title should read “Annular Flow: Slot”.

Page 106, Section 13.4, right-hand column, first paragraph

The introductory sentence and table should read as follows:

Depending on the value of the Reynolds number the flow regime is classified as follows:

Flow Regime	Pipe Flow	Annular Flow
Laminar	$Re_{BP} \leq Re_{BP1}$	$Re_{BP} \leq Re_{BP1}$
Transitional	$Re_{BP} < Re_{BP1} < Re_{BP2}$	$Re_{BP} < Re_{BP1} < Re_{BP2}$
Turbulent	$Re_{BP} \geq Re_{BP2}$	$Re_{BP} \geq Re_{BP2}$

Page 106, Equation (78)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (79)

The title should read “Annular Flow: Slot”.

Page 107, Equation (88)

The title should read “Annular Flow: Pipe”.

Page 107, Equation (89)

The title should read “Annular Flow: Slot”.

Page 107, Equations (90), (91), (92), and (93)

The term in the denominator of each of these equations, $6Re_{BP2}$, should read “ $6Re_{BP}^2$ ”.

Page 107, Equation (91)

The title should read “Annular Flow: Pipe”.

Page 107, Equation (92)

The title should read “Annular Flow: Slot”.

Page 107, Section 13.4 (begins on page 106), right-hand column, first sentence

The expression $(\tau_o/\tau_w)^4$ should read $(\tau_o/\tau_w)^3$.

Page 108, Section 13.5.1, example calculation of Reynolds number, R_e

The correct answer is 192,000.

Page 108, Section 13.5.1, example calculation of friction factor, f

Replace 19,200 with 192,000.

Page 108, Section 13.5.1, third example problem

Replace “8 $\frac{5}{7}$ inch” with “8.5 x 7 inch”.

Page 109, Section 13.5.2, third example problem

Replace “8 $\frac{5}{7}$ inch” with “8.5 x 7 inch”.

Page 109, Section 13.5.3.1, equation for τ_o

The equation should be $\tau_o = [1.193 \times 8 - 1.611] = 7.933$

Page 110, Section 13.5.3.2, second paragraph

1.5×10^5 should be 1.575×10^5 .

Page 110, Section 13.5.3.3, Annular Flow: Slot equation for Re_{BP2}

The denominator should read 12×0.5102 .

Page 111, Section 13.5.3.4, third paragraph

1.5×10^5 should be 1.575×10^5 .

Page 111, Table 10

The U.S. Oil Field Unit for K_{RePL} should be $0.2325/12^n$.

Page 112, Table 11

Change m to μ , m_p to μ_p , r to ρ , and t_y to τ_o .

Page 113, Replace Section 15, Well Simulation Slurry Stability Tests, (including Table 13) with the following:

15 Slurry Stability Tests

15.1 INTRODUCTION

The purpose of this test is to determine the stability of a static (quiescent) cement slurry. The cement slurry is conditioned to simulate dynamic placement in a wellbore. The slurry is then left static to determine if free fluid separates from the slurry and if particle sedimentation occurs. Both the free fluid result and the sedimentation result are required to understand the static stability of the slurry under downhole conditions. Free fluid can be formed with minimal sedimentation and sedimentation can take place without free fluid being formed. Therefore, both results must be evaluated to determine slurry stability. Excessive free fluid and sedimentation are normally considered detrimental to cement sheath quality. The acceptable amount of free fluid or sedimentation will vary with the application. Table 13 can be used to record the results of these tests.

15.2 SLURRY MIXING

The cement slurry should be prepared according to Section 5. If performing the sedimentation test described in 15.7, measure the density of the slurry using a pressurized fluid density balance (see Section 6) immediately after mixing the slurry.

15.3 SLURRY CONDITIONING

15.3.1 The cement slurry should be poured immediately into the slurry cup of an atmospheric or a pressurized consistometer for conditioning. The slurry cup should be initially at ambient temperature to avoid the possibility of thermally shocking temperature sensitive slurries. The slurry may then be heated or cooled to the desired test temperature up to 176°F (80°C) in the atmospheric or pressurized consistometer, or to the desired elevated temperature [if greater than 176°F (80°C)] and pressure in a pressurized consistometer. The thickening time schedule which most closely simulates actual field conditions should be followed with either consistometer.

15.3.2 After completing the heat-up schedule, the slurry may be conditioned at the specified temperature and pressure for $30 \pm 1/2$ minutes, or other desired conditioning period, before proceeding.

15.3.3 If the conditioning temperature is greater than 194°F (90°C), safe operating practices require cooling the slurry to a minimum of 194°F (90°C) before releasing the pressure from the consistometer.

Note: The 194°F (90°C) safety temperature assumes a boiling point for water of 212°F (100°C). If the boiling point of water in your area is less than 212°F (100°C), adjust test temperatures accordingly.

Release the pressure slowly [about 200 psi/sec (1380 kPa/sec)]. Remove the slurry cup from the consistometer, keeping the container upright so oil does not mix with the slurry. Remove the top locking ring, drive bar and collar from the shaft and the diaphragm cover. Syringe and blot oil from the top of the diaphragm. Remove the diaphragm and the support ring. Syringe and blot any remaining oil from the top of the slurry. If contamination is severe, discard the slurry and begin the test again. Remove the paddle and stir the slurry briskly with a spatula for five seconds to re-disperse any solids which may have settled to the bottom of the cup.

15.3.4 After conditioning by either method, proceed with either 15.4 or 15.5 for a free fluid test. For a sedimentation test, proceed to 15.7.

15.4 FREE FLUID TEST WITH HEATED STATIC PERIOD

Pour the slurry into a clear graduated tube. The ratio of the slurry-filled length to the inside tube diameter should be greater than 6:1 and less than 8:1. The clear tube must be inert to well cements and must not deform during the test. The clear tube must be graduated such that the slurry volume placed in the tube can be visually determined with a precision of ± 2 mL. The free fluid test slurry volume must be between 100 mL and 250 mL, inclusive. Document the slurry volume placed in the tube when the tube is vertical. Document the tube dimensions as well.

A test chamber for curing the slurry during the static period should be preheated or precooled to the test temperature or 176°F (80°C), whichever is cooler. 176°F (80°C) was chosen to minimize the effects of condensation on the test results and assumes a boiling point for water of 212°F (100°C). If the boiling point of water in your area is less than 212°F (100°C), adjust the 176°F (80°C) test temperature accordingly. This chamber may be an atmospheric pressure heating or cooling bath/oven/jacket/chamber, or a suitable pressurized heating/cooling chamber that uses hydrocarbon oil to transmit heating/cooling to the slurry.

Note: Bath/oven/jacket/chamber or pressurized chamber will be designated as a chamber for the rest of this section. When hydrocarbon oil is used, the oil should have a flash point that satisfactorily meets the safety requirements of the organization performing the test.

15.4.1 Free Fluid Tests at Temperatures Less Than 176°F (80°C)

Cover the opening of the graduated tube to prevent evaporation and immediately place the graduated tube in a heating or cooling chamber that is preheated or precooled to test

temperature. The chamber must be able to heat or cool the entire slurry. The tube can be tilted to simulate wellbore deviation, if desired. Appropriate precautions should be taken to ensure the static curing is performed at essentially vibration free conditions.

The temperature is maintained at test temperature for the remainder of the test. The test duration is two hours from the time the slurry is poured into the clear tube. After the two-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the clear tube). The volume measurement should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.4.2 Free Fluid Test at Temperatures Greater Than or Equal to 176°F (80°C)

Place the graduated tube in a preheated [176°F (80°C)] oil filled heating chamber. If desired, tilt the tube to simulate wellbore deviation. Further heat the slurry to test temperature in the time required to take the slurry from a depth with 176°F (80°C) circulating temperature to test temperature. Some heating chambers may not be able to heat fast enough and in that case heat as fast as possible but minimize overshooting the test temperature. Maintain the slurry at test temperature until it is time to cool the chamber to 176°F (80°C). The time required to cool various pieces of equipment from elevated temperatures to 176°F (80°C) will vary. The pressure on the curing chamber should be maintained high enough throughout the test so the slurry cannot boil (see Table 8). The pressure applied can simulate bottom hole conditions, if desired. So as to prevent vibration, constant pump cycling should be avoided. The schedules found in Section 9 can be used to aid in selecting pressurization and heating rates. Appropriate precautions should be taken to ensure the static curing is performed at essentially vibration free conditions.

The two hour test period is initiated when the conditioned slurry is poured into the graduated tube. Slurries should be cooled to 176°F (80°C) before the free fluid is measured. This cooling time is part of the 2-hour test period. After the two-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the cylinder). Free fluid for slurries immersed in hydrocarbon oil will collect above the cement but below the oil. The volume measurement of the free fluid should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.5 FREE FLUID TEST WITH AMBIENT TEMPERATURE STATIC PERIOD

Pour 250 mL of the slurry from Section 15.3 into a 250 mL graduated glass cylinder. The zero to 250 mL graduated portion of the cylinder shall be no less than 232 mm nor more than 250 mm in length, graduated in 2 mL increments or less. The slurry should be stirred with a spatula during pouring to assure a uniform sample of the slurry. The 2-hour test period

is initiated when the conditioned slurry is poured into the cylinder. The cylinder should be sealed with plastic film wrap or equivalent material to prevent evaporation. The cylinder may be inclined at an angle to simulate wellbore deviation. Appropriate precautions should be taken to ensure that static curing is performed at essentially vibration free conditions.

After the 2-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the cylinder). The volume measurement of the free fluid should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.6 PERCENT FREE FLUID CALCULATION

The percent free fluid is calculated by the following:

$$\% \text{ Free Fluid} = \frac{(\text{mL of Free Fluid})(100)}{\text{mL of Slurry}}$$

15.7 SEDIMENTATION TEST

15.7.1 Pour the slurry from 15.3 into a sedimentation tube until it is approximately $\frac{3}{4}$ in. (20 mm) from the top. The sedimentation tube should have an inner diameter of 25 ± 5 mm and a minimum length of 100 mm (the most common length is approximately 200 mm). The tube may be split to aid in removal of the set cement. See Figure 17. The inside of the tube, and all joints, should be lightly greased to ensure that it is leak-tight and so that the set cement can be removed without damage. The tube must be inert to well cements and not deform during the course of the test. The slurry in the filled tube should be puddled to dislodge any air bubbles. The tube should then be filled completely. A top closure can be used to prevent spillage of the slurry. The top closure should allow pressure communication. The filled tube should be placed in a water-filled preheated/precooled heating/cooling chamber in a vertical position. The chamber should be preheated or precooled to the desired test temperature or 194°F (90°C), whichever is cooler (see safety note in 15.3).

15.7.2 The slurry temperature should be adjusted further to simulate temperature changes in the wellbore. Sufficient pressure must be maintained to prevent boiling of the slurry (see Table 8). The pressure applied can simulate bottom hole conditions, if desired. Constant pump cycling should be avoided to minimize vibration. The schedules in Sections 7 and 9 can be used to aid in selecting the temperature and pressure.

15.7.3 Allow the slurry to cure for 24 hours, or until set, before removing it from the heating/cooling chamber.

15.7.4 Cool the chamber to 194°F (90°C), if required (see safety note in Section 15.3). Release pressure from the chamber, if required. Remove the tube from the heating/cooling chamber and bring the tube to $80^\circ \pm 10^\circ\text{F}$ ($27^\circ \pm 6^\circ\text{C}$) by placing it in a water bath. Once the tube has cooled remove

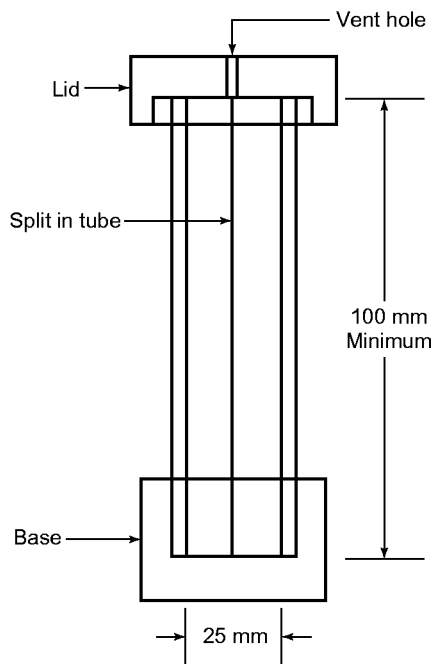


Figure 17—Typical Sedimentation Tube

the cement from the tube. Keep the cement sample immersed in water to prevent it from drying out. The length of the set cement specimen should be measured. Mark the specimen approximately $\frac{3}{4}$ in. (20 mm) from the bottom and from the top of the sample. The middle section, between the marks, should then be divided by further marks into roughly equal pieces with a minimum of 2 segments. The sample should be broken or cut at these marks. The sections must be kept in order. Keep the sections immersed in water until each is weighed.

15.7.5 The preferred way to determine the density of each section is to place a beaker containing water on the balance (a

balance with a precision of 0.01 gram is necessary; 0.001 gram is preferred) and tare the balance to zero. Remove a section to be measured from the water bath and gently dry it with a paper towel. Place this section on the balance beside the beaker. Record the weight and remove the section from the balance. Tare the balance to zero. Place a noose of thin line around the section. Pick up the section by the line and suspend the section in the water in the beaker such that the sample is totally immersed in water and does not touch the bottom or sides of the beaker. Air bubbles should not be clinging to the section. Obtain the weight of the sample suspended in water. Remove the sample from the water. Repeat the procedure for each set cement section.

15.7.6 By applying the Principle of Archimedes, calculate the specific gravity of each cement section.

$$\text{S.G.} = \frac{\text{Weight of section in air, g}}{\text{Weight of section in water, g}}$$

The results are used to construct a density profile for the entire sample.

Note: It is normal for cement slurries to experience a small density increase upon setting.

The liquid slurry density was measured prior to curing to permit the calculation of the % density difference between the liquid sample and the set sample.

% Density Difference =

$$\frac{\text{Density of Cement Segment} - \text{Density of Cement Slurry} (100)}{(\text{Density of Cement Slurry})}$$

The density difference for well cements can vary greatly and depends on many factors. The amount of density difference that is acceptable will vary with the application.

Replace Table 13 with the following:

Table 13—Free Fluid and Sedimentation Results Reporting Form

Slurry Mixing

Cement Temperature: _____
Mix Water Temperature: _____
Slurry Initial Temperature: _____
Slurry Final Temperature: _____
Time to Final Temperature: _____
Optional Additional Conditioning Period: _____
Pressure Profile:
Initial Pressure: _____
Final Pressure: _____
Time to Final Pressure: _____

Conditioning (applies to free fluid and sedimentation test)

Final Temperature: _____
Time to Final Temperature: _____ minutes
Initial Pressure: _____
Final Pressure: _____
Time to Final Pressure: _____
Conditioning Time at T & P: _____
Time to Cool the Slurry to 194°F (90°C): _____
Section 9 Schedules Employed: ☐ Yes ☐ No
If Yes, Schedule Number: _____

Free Fluid Test (Two-hour Test Period)

Length of Graduated Tube Section: _____
Graduated Tube ID: _____
Slurry Volume: _____
Test Angle: _____
Preheated or Precooled Chamber Temperature: _____
Test Temperature: _____
Time to Test Temperature: _____
Initial Test Pressure: _____
Pressure at Test Temperature: _____
Time to Pressure at Test Temperature: _____
Time at Test Temperature: _____ hours
Time to Cool the Chamber to 194°F (90°C): _____

Free Fluid Results

Measured Free Fluid Volume: _____ mL
% Free Fluid: _____

Sedimentation Test (Period after Conditioning)

Preheated or Precooled Chamber Temperature: _____
Test Temperature: _____
Time to Test Temperature: _____
Initial Test Pressure: _____
Pressure at Test Temperature: _____
Time to Pressure at Test Temperature: _____
Time at Test Temperature: _____ hours
Time to Cool the Chamber to 194°F (90°C): _____
Length of Sedimentation Tube: _____
Length of Set Specimen: _____
Section 7 Schedules Employed: ☐ Yes ☐ No
If Yes, Schedule Number: _____
Conditioning time at T & P: _____

Sedimentation Results

Measured Slurry Density: _____

Density Profile:

S₁ (top) Density: _____; % Density Diff: _____
S₂ Density: _____; % Density Diff: _____
S₃ Density: _____; % Density Diff: _____
S₄ Density: _____; % Density Diff: _____
S₅ Density: _____; % Density Diff: _____
S_x (bottom) Density: _____; % Density Diff: _____

Note: The heating/cooling, pressurizing, and cooling information that is requested in the results reporting form will allow other laboratories to reproduce the test. The information requested is sufficient only if the heating/cooling rate, pressurizing rate, and cool down rate are linear. If the rates are not linear, specify the exact heating/cooling, pressurizing, and cool down schedules.

Page 118, Section 16.1:

Replace existing “Scope” with the following:

The water-wetting capability testing procedure is intended for use in determining the degree of compatibility of wellbore fluids in cementing operations. This procedure includes testing of rheology, static gel strength, thickening time, compressive strength, fluid loss, solids suspension and water-wetting ability. By the use of this procedure, the selection of proper preflushes and/or spacers, and/or surfactant components may be made when required. User discretion should be exercised in the selection of the portion(s) of the procedure needed.

Page 118, Section 16.2.4:

Insert the following definition:

16.2.4 water-wetting capability: The capability of a fluid to alter the quality or state of being water-wetted. A fully water-wet state is considered most desirable to provide cement bonding.



Page 120, Section 16.9, Insert the following after Section 16.8:

16.9 WATER-WETTING CAPABILITY TESTING (WWCT)

16.9.1 Introduction

The WWCT procedure is specific to evaluation of water-wetting capability of spacers and/or preflushes designed to water-wet the surfaces after these surfaces have been exposed to non-aqueous fluids, specifically oil- and synthetic-based drilling fluids. The apparent water-wetting capability of various mud/spacer interface volumes and the apparent wettability of spacer systems against oil-wetted surfaces may be evaluated using this method. This procedure does not address bulk displacement issues, nor does it directly address spacer/mud compatibility issues.

The procedure is applicable to aqueous spacer systems only. This procedure is not suitable for evaluating non-aqueous or non-conductive systems or mixtures of surfactants in base oils.

16.9.2 Method and Apparatus

The apparatus provides a continuous measurement of the electrical conductivity between electrode surfaces. From the conductivity measurements, the emulsion state and apparent wettability of the fluid can be inferred if the titrating spacer fluid is conductive and the titrated drilling fluid is not. Normally, oil-external fluids are not electrically conductive. Water-based or water-external emulsion spacers are electrically conductive with the actual conductivity dependent on the solution chemistry.

16.9.3 Procedure

Observe all usual laboratory safety requirements pertaining to working with oil, synthetic, and solvent-based fluids. Note the flash points of all fluids before testing and ensure proper ventilation in the work area. All safe-handling procedures for the fluids being tested must be observed. This is an atmospheric pressure test. The maximum temperature for testing is 194°F (90°C).

16.9.3.1 Sample Preparation

16.9.3.1.1 Prepare a mud sample according to instructions from the supplier. Laboratory-prepared mud samples may require additional preparation such as static aging or hot-rolling to more fully simulate field mud properties.

16.9.3.1.2 Mix the spacers and/or preflush fluids to be evaluated according to manufacturer's procedures. A 500 ml volume is normally sufficient to run a single test.

16.9.3.1.3 Condition all spacer fluids at anticipated BHCT to ensure that fluids are stable and all chemicals have been conditioned and are in solution. Condition fluids under pressure using high-temperature, high-pressure (HTHP) equipment if conditioning at temperatures above 194°F (90°C). Fluids should be cooled below 194°F (90°C) before releasing pressure. Observe all safe handling procedures for fluids being tested. This is an atmospheric pressure test. The test should not be performed at temperatures exceeding 194°F (90°C).

16.9.3.2 Equipment Setup

16.9.3.2.1 Heat the container to testing conditions to maintain the temperature of the test fluids. Use a stirring rate sufficient to quickly homogenize added fluids and prevent static areas. Excessive shear will cause air-entrainment that may affect readings and surfactant performance.

16.9.3.2.2 Clean and dry test equipment before starting.

16.9.3.2.3 Prepare equipment according to instructions from supplier.

16.9.3.3 Test Procedure and Reporting

16.9.3.3.1 Evaluate the interaction of the spacer with the drilling fluid according to manufacturer's instructions. Observe safety precautions with respect to fluid temperatures and operator safety.

16.9.3.3.2 Record the starting volume of mud, volume of titrant (surfactant, flush, spacer), fluid conditioning procedure (time, temperature, etc.) and titration temperature. Slowly pour the titrant into the mud stirring in the test apparatus. Continue titrating until a stable, water-continuous phase, characteristic of a water-wetting state, is indicated by conductivity measurements.

16.9.3.3.3 Report test results as the volume percentage of spacer in the mud-spacer mixture that exhibits conductivity measurements indicative of complete water wetting. For example, if 150 ml of spacer must be added to a starting mud volume of 200 ml in order to obtain a full-span reading, the result should be reported as 43% (150 ml /350 ml).

American Petroleum Institute

Publications Order Form - 2000

Available through Global Engineering Documents

Phone Orders: 1-800-854-7179 (Toll-free in the U.S. and Canada) • 303-397-7956 (Local and International) • Fax Orders: 303-397-2740

Online Orders: www.global.ihs.com

Date: _____

☐ API Member (Check if Yes)

Invoice To (☐ Check here if same as "Ship To")

Name: _____

Title: _____

Company: _____

Department: _____

Address: _____

City: _____ State/Province: _____

Zip/Postal Code: _____ Country: _____

Telephone: _____

Fax: _____

E-Mail: _____

Ship To (UPS will not deliver to a P.O. Box)

Name: _____

Title: _____

Company: _____

Department: _____

Address: _____

City: _____ State/Province: _____

Zip/Postal Code: _____ Country: _____

Telephone: _____

Fax: _____

E-Mail: _____

Quantity	Product Number	Title	SO*	Unit Price	Total
	G10A22	Spec 10A, Well Cements		\$ 66.00	
	G10F02	Spec 10F, Performance of Cementing Float Equipment		\$ 50.00	
	G10TR1	10 TR 1, Cement Sheath Evaluation		\$ 83.00	
	G10TR2	10 TR 2, Shrinkage and Expansion in Oilwell Cements		\$ 83.00	
	G10TR3	10 TR 3, Temperatures for API Cement Operating Thickening Time tests		\$ 110.00	

☐ Payment Enclosed ☐ P.O. No. (Enclose Copy) _____

☐ Charge My Global Account No. _____

☐ VISA ☐ MasterCard ☐ American Express ☐ Discover

Credit Card No.: _____

Name (As It Appears on Card): _____

Expiration Date: _____

Signature: _____

Subtotal

Applicable Sales Tax (see below)

Rush Shipping Charge (see below)

Shipping and Handling (see below)

Total (in US Dollars)

*To be placed on Standing Order for future editions of this publication, place a check mark in the SO column and sign here:

Pricing and availability subject to change without notice.

Mail Orders - Payment by check or money order in U.S. dollars is required except for established accounts. State and local taxes, plus 5% for shipping and handling, must be added. Send mail orders to: **API Publications, Global Engineering Documents, 15 Inverness Way East, M/S C303B, Englewood, CO 80112-5776, USA.**

Purchase Orders - Purchase orders are accepted from established accounts. Invoice will include actual freight cost, an \$8.00 handling fee, plus state and local taxes.

Telephone Orders - If ordering by telephone, an \$8.00 handling fee and actual freight costs will be added to the order.

Sales Tax - All U.S. purchases must include applicable state and local sales tax. Customers claiming tax-exempt status must provide Global with a copy of their exemption certificate.

Shipping (U.S. Orders) - Orders shipped within the U.S. are sent via traceable means. Most orders are shipped the same day. Subscription updates are sent by First-Class Mail. Other options, including next-day service, air service, fax transmission, and electronic delivery are available at additional cost.

Shipping (International Orders) - Standard international shipping is by air express courier service. Subscription updates are sent by World Mail. Normal delivery is 3-4 days from shipping date.

Rush Shipping Fee - In addition to the carrier charges, the following charges will be added: Next Day Delivery orders placed prior to 2:00 p.m. MST - \$10.00 / Next Day Delivery orders placed after 2:00 p.m. MST - \$20.00 (if time is available for order processing)

Returns - All returns must be pre-approved by calling Global's Customer Service Department at 1-800-624-3974 for information and as is and there may be a 15% restocking fee. Special order items, electronic documents, and age-dated materials are non-returnable.

The American Petroleum Institute provides additional resources and programs to industry which are based on API Standards. For more information, contact:

- | | |
|---|---------------------------------------|
| • Training Workshops | Ph: 202-682-8564
Fax: 202-962-4797 |
| • Inspector Certification Programs | Ph: 202-682-8161
Fax: 202-962-4739 |
| • American Petroleum Institute
Quality Registrar | Ph: 202-682-8574
Fax: 202-682-8070 |
| • Monogram Licensing Program | Ph: 202-962-4791
Fax: 202-682-8070 |
| • Engine Oil Licensing and
Certification System | Ph: 202-682-8233
Fax: 202-962-4739 |

To obtain a free copy of the API Publications, Programs, and Services Catalog, call 202-682-8375 or fax your request to 202-962-4776. Or see the online interactive version of the catalog on our web site at www.api.org/cat.



Helping You
Get The Job
Done Right.™

10B-1997

Additional copies available from API Publications and Distribution:
(202) 682-8375

Information about API Publications, Programs and Services is
available on the World Wide Web at: <http://www.api.org>



**American
Petroleum
Institute**

1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

AVA Documents
Order No. G10BA2
Document Sharing Hub

Addendum 1
October 1999

Recommended Practice for Testing Well Cements

API RECOMMENDED PRACTICE 10B
TWENTY-SECOND EDITION, DECEMBER 1997



**American
Petroleum
Institute**

**Helping You
Get The Job
Done Right.SM**

Addendum 1 to API RP 10B, Testing Well Cements (Contains errata items to Twenty-Second Edition and a revised Section 15, Slurry Stability Tests)

Page 13, Section 7.6.2

The reference to Section 11 should be Section 9.

Page 16, Table 2, Schedule 10Sg, Elapsed Time 120 min, column 7, for temperature gradient of 2.7°C/100 m

Replace "(1520" with "(152)".

Page 18, Section 9.2, metric value for Specific Heat

Replace "[2.1 – 2.4kJ/9kg x K)]" with "[2.1 – 2.4 kJ/(kg x K)]".

Page 19, Section 9.2, 4th paragraph, first sentence

Replace "rotated as a speed" with "rotated at a speed".

Page 22, Equation (8b)

The constant should be 9.776.

Page 87, Section 10.6.2.10

The reference to 10.6 should be "10.8".

Page 87, Section 10.7.1.11

The reference to 10.6 should be "10.8".

Page 89, Section 11.2.1.1, first sentence

The inside dimensions given for the bottom, 1.102 in., 27.99 mm, and top, 1.154 in., 29.31 mm are reversed. The inside dimension for the bottom should be 1.154 in. (29.31 mm) and the inside dimension for the top should be 1.102 in. (27.99 mm) as shown in Figure 9.

Page 95, Equation (17b)

Replace "4" with "2".

Page 96, Section 12.4.2 (begins on page 95)

Remove the words "which is also transmitted to the" and add the word "or" following "cylinder".

Page 96, Equation (19b)

Replace "32.55" with "16.28".

Page 98, Section 12.8.1.1

First paragraph:

The reference to Curve A should be Curve D.

Second paragraph:

The reference to Curve B should be Curve A.

Page 98, Section 12.8.1.2*First paragraph:*

The reference to Figure 11, Curve C, should be Figure 11, Curves B and C.

Second paragraph, second sentence:

The reference to Figure 11, Curve C should be Figures 11 and 12, Curve B.

Second paragraph, fourth sentence:

The reference to Figure 11, Curve D should be Figures 11 and 12, Curve C.

Second paragraph, sixth sentence:

The reference to Figure 11, Curve B should be Figures 11 and 12, Curve A.

Page 101, Figure 12

The scale for the Shear-rate axis (x-axis) should begin with 1, not 0.

Page 104, Section 13.2, first sentence

Replace “ m ” with “ μ ” and “ r ” with “ p ”.

Page 105, Section 13.3, first sentence

Replace “ r ” with “ p ”.

Page 105, Equations (62), (63), and (64)

The term K_{RePL} should be in the denominator rather than the numerator.

Page 106, Section 13.4, third paragraph

Replace “ m_p ” with “ μ_p ” and “ r ” with “ p ”.

Page 106, Equation (72)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (73)

The title should read “Annular Flow: Slot”.

Page 106, Equation (75)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (76)

The title should read “Annular Flow: Slot”.

Page 106, Section 13.4, right-hand column, first paragraph

The introductory sentence and table should read as follows:

Depending on the value of the Reynolds number the flow regime is classified as follows:

Flow Regime	Pipe Flow	Annular Flow
Laminar	$Re_{BP} \leq Re_{BP1}$	$Re_{BP} \leq Re_{BP1}$
Transitional	$Re_{BP} < Re_{BP1} < Re_{BP2}$	$Re_{BP} < Re_{BP1} < Re_{BP2}$
Turbulent	$Re_{BP} \geq Re_{BP2}$	$Re_{BP} \geq Re_{BP2}$

Page 106, Equation (78)

The title should read “Annular Flow: Pipe”.

Page 106, Equation (79)

The title should read “Annular Flow: Slot”.

Page 107, Equation (88)

The title should read “Annular Flow: Pipe”.

Page 107, Equation (89)

The title should read “Annular Flow: Slot”.

Page 107, Equations (90), (91), (92), and (93)

The term in the denominator of each of these equations, $6Re_{BP2}$, should read “ $6Re_{BP}^2$ ”.

Page 107, Equation (91)

The title should read “Annular Flow: Pipe”.

Page 107, Equation (92)

The title should read “Annular Flow: Slot”.

Page 107, Section 13.4 (begins on page 106), right-hand column, first sentence

The expression $(\tau_o/\tau_w)^4$ should read $(\tau_o/\tau_w)^3$.

Page 108, Section 13.5.1, example calculation of Reynolds number, R_e

The correct answer is 192,000.

Page 108, Section 13.5.1, example calculation of friction factor, f

Replace 19,200 with 192,000.

Page 108, Section 13.5.1, third example problem

Replace “8 $\frac{5}{8}$ inch” with “8.5 x 7 inch”.

Page 109, Section 13.5.2, third example problem

Replace “8 $\frac{5}{8}$ inch” with “8.5 x 7 inch”.

Page 109, Section 13.5.3.1, equation for τ_o

The equation should be $\tau_o = [1.193 \times 8 - 1.611] = 7.933$

Page 110, Section 13.5.3.2, second paragraph

1.5×10^5 should be 1.575×10^5 .

Page 110, Section 13.5.3.3, Annular Flow: Slot equation for Re_{BP2}

The denominator should read 12×0.5102 .

Page 111, Section 13.5.3.4, third paragraph

1.5×10^5 should be 1.575×10^5 .

Page 111, Table 10

The U.S. Oil Field Unit for K_{RePL} should be $0.2325/12^n$.

Page 112, Table 11

Change m to μ , m_p to μ_p , r to ρ , and t_y to τ_o .

Replace Section 15, Well Simulation Slurry Stability Tests, (including Table 13) with the following:

15 Slurry Stability Tests

15.1 INTRODUCTION

The purpose of this test is to determine the stability of a static (quiescent) cement slurry. The cement slurry is conditioned to simulate dynamic placement in a wellbore. The slurry is then left static to determine if free fluid separates from the slurry and if particle sedimentation occurs. Both the free fluid result and the sedimentation result are required to understand the static stability of the slurry under downhole conditions. Free fluid can be formed with minimal sedimentation and sedimentation can take place without free fluid being formed. Therefore, both results must be evaluated to determine slurry stability. Excessive free fluid and sedimentation are normally considered detrimental to cement sheath quality. The acceptable amount of free fluid or sedimentation will vary with the application. Table 13 can be used to record the results of these tests.

15.2 SLURRY MIXING

The cement slurry should be prepared according to Section 5. If performing the sedimentation test described in 15.7, measure the density of the slurry using a pressurized fluid density balance (see Section 6) immediately after mixing the slurry.

15.3 SLURRY CONDITIONING

15.3.1 The cement slurry should be poured immediately into the slurry cup of an atmospheric or a pressurized consistometer for conditioning. The slurry cup should be initially at ambient temperature to avoid the possibility of thermally shocking temperature sensitive slurries. The slurry may then be heated or cooled to the desired test temperature up to 176°F (80°C) in the atmospheric or pressurized consistometer, or to the desired elevated temperature [if greater than 176°F (80°C)] and pressure in a pressurized consistometer. The thickening time schedule which most closely simulates actual field conditions should be followed with either consistometer.

15.3.2 After completing the heat-up schedule, the slurry may be conditioned at the specified temperature and pressure for $30 \pm 1/2$ minutes, or other desired conditioning period, before proceeding.

15.3.3 If the conditioning temperature is greater than 194°F (90°C), safe operating practices require cooling the slurry to a minimum of 194°F (90°C) before releasing the pressure from the consistometer.

Note: The 194°F (90°C) safety temperature assumes a boiling point for water of 212°F (100°C). If the boiling point of water in your area is less than 212°F (100°C), adjust test temperatures accordingly.

Release the pressure slowly [about 200 psi/sec (1380 kPa/sec)]. Remove the slurry cup from the consistometer, keeping the container upright so oil does not mix with the slurry. Remove the top locking ring, drive bar and collar from the shaft and the diaphragm cover. Syringe and blot oil from the top of the diaphragm. Remove the diaphragm and the support ring. Syringe and blot any remaining oil from the top of the slurry. If contamination is severe, discard the slurry and begin the test again. Remove the paddle and stir the slurry briskly with a spatula for five seconds to re-disperse any solids which may have settled to the bottom of the cup.

15.3.4 After conditioning by either method, proceed with either 15.4 or 15.5 for a free fluid test. For a sedimentation test, proceed to 15.7.

15.4 FREE FLUID TEST WITH HEATED STATIC PERIOD

Pour the slurry into a clear graduated tube. The ratio of the slurry-filled length to the inside tube diameter should be greater than 6:1 and less than 8:1. The clear tube must be inert to well cements and must not deform during the test. The clear tube must be graduated such that the slurry volume placed in the tube can be visually determined with a precision of ± 2 mL. The free fluid test slurry volume must be between 100 mL and 250 mL, inclusive. Document the slurry volume placed in the tube when the tube is vertical. Document the tube dimensions as well.

A test chamber for curing the slurry during the static period should be preheated or precooled to the test temperature or 176°F (80°C), whichever is cooler. 176°F (80°C) was chosen to minimize the effects of condensation on the test results and assumes a boiling point for water of 212°F (100°C). If the boiling point of water in your area is less than 212°F (100°C), adjust the 176°F (80°C) test temperature accordingly. This chamber may be an atmospheric pressure heating or cooling bath/oven/jacket/chamber, or a suitable pressurized heating/cooling chamber that uses hydrocarbon oil to transmit heating/cooling to the slurry.

Note: Bath/oven/jacket/chamber or pressurized chamber will be designated as a chamber for the rest of this section. When hydrocarbon oil is used, the oil should have a flash point that satisfactorily meets the safety requirements of the organization performing the test.

15.4.1 Free Fluid Tests at Temperatures Less Than 176°F (80°C)

Cover the opening of the graduated tube to prevent evaporation and immediately place the graduated tube in a heating or cooling chamber that is preheated or pre-cooled to test

temperature. The chamber must be able to heat or cool the entire slurry. The tube can be tilted to simulate wellbore deviation, if desired. Appropriate precautions should be taken to ensure the static curing is performed at essentially vibration free conditions.

The temperature is maintained at test temperature for the remainder of the test. The test duration is two hours from the time the slurry is poured into the clear tube. After the two-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the clear tube). The volume measurement should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.4.2 Free Fluid Test at Temperatures Greater Than or Equal to 176°F (80°C)

Place the graduated tube in a preheated [176°F (80°C)] oil filled heating chamber. If desired, tilt the tube to simulate wellbore deviation. Further heat the slurry to test temperature in the time required to take the slurry from a depth with 176°F (80°C) circulating temperature to test temperature. Some heating chambers may not be able to heat fast enough and in that case heat as fast as possible but minimize overshooting the test temperature. Maintain the slurry at test temperature until it is time to cool the chamber to 176°F (80°C). The time required to cool various pieces of equipment from elevated temperatures to 176°F (80°C) will vary. The pressure on the curing chamber should be maintained high enough throughout the test so the slurry cannot boil (see Table 8). The pressure applied can simulate bottom hole conditions, if desired. So as to prevent vibration, constant pump cycling should be avoided. The schedules found in Section 9 can be used to aid in selecting pressurization and heating rates. Appropriate precautions should be taken to ensure the static curing is performed at essentially vibration free conditions.

The two hour test period is initiated when the conditioned slurry is poured into the graduated tube. Slurries should be cooled to 176°F (80°C) before the free fluid is measured. This cooling time is part of the two-hour test period. After the two-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the cylinder). Free fluid for slurries immersed in hydrocarbon oil will collect above the cement but below the oil. The volume measurement of the free fluid should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.5 FREE FLUID TEST WITH AMBIENT TEMPERATURE STATIC PERIOD

Pour 250 mL of the slurry from Section 15.3 into a 250 mL graduated glass cylinder. The zero to 250 mL graduated portion of the cylinder shall be no less than 232 mm nor more than 250 mm in length, graduated in 2 mL increments or less. The slurry should be stirred with a spatula during pouring to assure a uniform sample of the slurry. The two-hour test

period is initiated when the conditioned slurry is poured into the cylinder. The cylinder should be sealed with plastic film wrap or equivalent material to prevent evaporation. The cylinder may be inclined at an angle to simulate wellbore deviation. Appropriate precautions should be taken to ensure that static curing is performed at essentially vibration free conditions.

After the 2-hour test period, measure the free fluid (clear or colored fluid on top of the cement slurry inside the cylinder). The volume measurement of the free fluid should be made with a precision of ± 0.2 mL.

Calculate the free fluid according to 15.6.

15.6 PERCENT FREE FLUID CALCULATION

The percent free fluid is calculated by the following:

$$\% \text{ Free Fluid} = \frac{(\text{mL of Free Fluid})(100)}{\text{mL of Slurry}}$$

15.7 SEDIMENTATION TEST

15.7.1 Pour the slurry from 15.3 into a sedimentation tube until it is approximately $\frac{3}{4}$ inch (20 mm) from the top. The sedimentation tube should have an inner diameter of 25 ± 5 mm and a minimum length of 100 mm (the most common length is approximately 200 mm). The tube may be split to aid in removal of the set cement. See Figure 17. The inside of the tube, and all joints, should be lightly greased to ensure that it is leak-tight and so that the set cement can be removed without damage. The tube must be inert to well cements and not deform during the course of the test. The slurry in the filled tube should be puddled to dislodge any air bubbles. The tube should then be filled completely. A top closure can be used to prevent spillage of the slurry. The top closure should allow pressure communication. The filled tube should be placed in a water-filled preheated/precooled heating/cooling chamber in a vertical position. The chamber should be preheated or precooled to the desired test temperature or 194°F (90°C), whichever is cooler (see safety note in 15.3).

15.7.2 The slurry temperature should be adjusted further to simulate temperature changes in the wellbore. Sufficient pressure must be maintained to prevent boiling of the slurry (see Table 8). The pressure applied can simulate bottom hole conditions, if desired. Constant pump cycling should be avoided to minimize vibration. The schedules in Sections 7 and 9 can be used to aid in selecting the temperature and pressure.

15.7.3 Allow the slurry to cure for 24 hours, or until set, before removing it from the heating/cooling chamber.

15.7.4 Cool the chamber to 194°F (90°C), if required (see safety note in Section 15.3). Release pressure from the chamber, if required. Remove the tube from the heating/cooling chamber and bring the tube to $80^\circ \pm 10^\circ\text{F}$ ($27^\circ \pm 6^\circ\text{C}$) by plac-

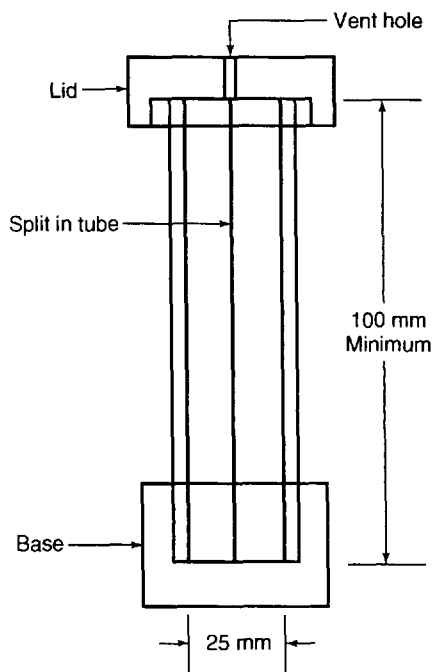


Figure 17—Typical Sedimentation Tube

ing it in a water bath. Once the tube has cooled remove the cement from the tube. Keep the cement sample immersed in water to prevent it from drying out. The length of the set cement specimen should be measured. Mark the specimen approximately $\frac{3}{4}$ inch (20 mm) from the bottom and from the top of the sample. The middle section, between the marks, should then be divided by further marks into roughly equal pieces with a minimum of 2 segments. The sample should be broken or cut at these marks. The sections must be kept in order. Keep the sections immersed in water until each is weighed.

15.7.5 The preferred way to determine the density of each section is to place a beaker containing water on the balance (a balance with a precision of 0.01 gram is necessary; 0.001 gram is preferred) and tare the balance to zero. Remove a section to be measured from the water bath and gently dry it with a paper towel. Place this section on the balance beside the beaker. Record the weight and remove the section from the balance. Tare the balance to zero. Place a noose of thin line around the section. Pick up the section by the line and suspend the section in the water in the beaker such that the sample is totally immersed in water and does not touch the bottom or sides of the beaker. Air bubbles should not be clinging to the section. Obtain the weight of the sample suspended in water. Remove the sample from the water. Repeat the procedure for each set cement section.

15.7.6 By applying the Principle of Archimedes, calculate the specific gravity of each cement section.

$$\text{S.G.} = \frac{\text{Weight of section in air, g}}{\text{Weight of section in water, g}}$$

The results are used to construct a density profile for the entire sample.

Note: It is normal for cement slurries to experience a small density increase upon setting.

The liquid slurry density was measured prior to curing to permit the calculation of the % density difference between the liquid sample and the set sample.

% Density Difference =

$$\frac{\text{Density of Cement Segment} - \text{Density of Cement Slurry (100)}}{(\text{Density of Cement Slurry})}$$

The density difference for well cements can vary greatly and depends on many factors. The amount of density difference that is acceptable will vary with the application.

Table 13—Free Fluid and Sedimentation Results Reporting Form

Replace Table 13 with the following:

Slurry Mixing

Cement Temperature: _____
 Mix Water Temperature: _____
 Slurry Initial Temperature: _____
 Slurry Final Temperature: _____
 Time to Final Temperature: _____
 Optional Additional Conditioning Period: _____
 Pressure Profile: _____
 Initial Pressure: _____
 Final Pressure: _____
 Time to Final Pressure: _____

Conditioning (applies to free fluid and sedimentation test)

Final Temperature: _____
 Time to Final Temperature: _____ minutes
 Initial Pressure: _____
 Final Pressure: _____
 Time to Final Pressure: _____
 Conditioning Time at T & P: _____
 Time to Cool the Slurry to 194°F (90°C): _____
 Section 9 Schedules Employed: ☐ Yes ☐ No
 If Yes, Schedule Number: _____

Free Fluid Test (Two-hour Test Period)

Length of Graduated Tube Section: _____
 Graduated Tube ID: _____
 Slurry Volume: _____
 Test Angle: _____
 Preheated or Precooled Chamber Temperature: _____
 Test Temperature: _____
 Time to Test Temperature: _____
 Initial Test Pressure: _____
 Pressure at Test Temperature: _____
 Time to Pressure at Test Temperature: _____
 Time at Test Temperature: _____ hours
 Time to Cool the Chamber to 194°F (90°C): _____

Free Fluid Results

Measured Free Fluid Volume: _____ mL
 % Free Fluid: _____

Sedimentation Test (Period after Conditioning)

Preheated or Precooled Chamber Temperature: _____
 Test Temperature: _____
 Time to Test Temperature: _____
 Initial Test Pressure: _____
 Pressure at Test Temperature: _____
 Time to Pressure at Test Temperature: _____
 Time at Test Temperature: _____ hours
 Time to Cool the Chamber to 194°F (90°C): _____
 Length of Sedimentation Tube: _____
 Length of Set Specimen: _____
 Section 7 Schedules Employed: ☐ Yes ☐ No
 If Yes, Schedule Number: _____
 Conditioning time at T & P: _____

Sedimentation Results

Measured Slurry Density: _____
 Density Profile:
 S₁ (top) Density: _____; % Density Diff: _____
 S₂ Density: _____; % Density Diff: _____
 S₃ Density: _____; % Density Diff: _____
 S₄ Density: _____; % Density Diff: _____
 S₅ Density: _____; % Density Diff: _____
 S_x (bottom) Density: _____; % Density Diff: _____

Note: The heating/cooling, pressurizing, and cooling information that is requested in the results reporting form will allow other laboratories to reproduce the test. The information requested is sufficient only if the heating/cooling rate, pressurizing rate, and cool down rate are linear. If the rates are not linear, specify the exact heating/cooling, pressurizing, and cool down schedules.

Additional copies available from API Publications and Distribution:
(202) 682-8375

Information about API Publications, Programs and Services is
available on the World Wide Web at: <http://www.api.org>



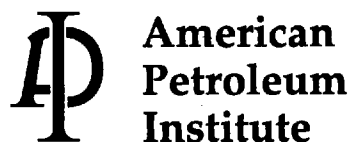
**American
Petroleum
Institute**

1220 L Street, Northwest
Washington, D.C. 20005-4070
202-682-8000

AVA **Documents**
Order No. G10BA1
Document Sharing Hub

Recommended Practice for Testing Well Cements

API RECOMMENDED PRACTICE 10B
TWENTY-SECOND EDITION, DECEMBER 1997

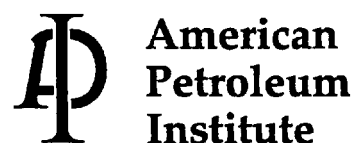


Documents
Document Sharing Hub

Recommended Practice for Testing Well Cements

Exploration and Production Department

API RECOMMENDED PRACTICE 10B
TWENTY-SECOND EDITION, DECEMBER 1997



SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Authoring Department [telephone (202) 682-8000]. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the director of the Authoring Department (shown on the title page of this document), American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, N.W., Washington, D.C. 20005.

Copyright © 1997 American Petroleum Institute

FOREWORD

This recommended practice is under the jurisdiction of the API Subcommittee on Standardization of Well Cements.

The purpose of this recommended practice is to provide guidance for the testing of cement slurries and related materials under simulated well conditions.

Conversions of U.S. customary units^a to International System (SI) metric units are provided throughout the text of this document in parentheses, e.g., 6,000 ft (1,830 m). SI equivalents have also been included in all tables. U.S. customary units, where stated, are preferential and shall be the standard in this recommended practice. U.S. customary units are based on the foot, the pound, the gallon and the degree Fahrenheit commonly used in the United States of America and defined by the National Institute of Standards and Technology. The factors used for conversion of U.S. customary units to SI units are listed below:

- 1 cubic foot (ft³) = 0.02831685 cubic meter (m³)
- 1 cubic foot per minute = 0.4719474 liter per second (L/s)
- 1 inch = 25.4 millimeters (mm) exactly
- 1 foot (ft) = 0.3048 meter (m) exactly
- 1 pound mass (lb) = 0.4535924 kilogram (kg)
- 1 pound per foot (lb/ft) = 1.488164 kilograms per meter (kg/m)
- 1 pound force (lbf) = 4.448222 Newton (N)
- 1 pound force per square inch (psi) = 0.006894757 megapascals (MPa)
- degrees Fahrenheit (°F) = [(°Celsius)(1.8)]+32
- 1 U.S. gallon = 3.785412 liter (L)

API Recommended Practice for Testing Well Cements (API RP10B) is published as an aid to the laboratory testing of well cements. By the use of this recommended practice, well cement test data produced by different laboratories can be compared. Well cement specification testing is covered in API Specification 10A (Spec 10A), *Specification for Well Cements*.

This recommended practice shall become effective on the date printed on the cover but may be used voluntarily from the date of distribution.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the director of the Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

^aSome of these units have the same name as similar units in the United Kingdom (British, English, or U.K. Units) but are not necessarily equal to them

CONTENTS

	Page
1 SCOPE	1
1.1 Well Cements	1
1.2 API Cement Classes	1
2 REFERENCED PUBLICATIONS	2
3 DEFINITIONS	2
4 SAMPLING	5
4.1 General	5
4.2 Sampling Cement at Field Location	5
4.3 Sampling Cement Blends at Field Location	5
4.4 Sampling Dry Cement Additives at Field Location	5
4.5 Sampling Liquid Cement Additives at Field Location	5
4.6 Sampling Mixing Water	5
4.7 Shipping and Storage	5
4.8 Sample Preparation Prior to Testing	7
4.9 Sample Disposal	7
5 PREPARATION OF SLURRY	7
5.1 General	7
5.2 Apparatus	7
5.3 Procedure	7
6 DETERMINATION OF SLURRY DENSITY	9
6.1 Preferred Apparatus	9
6.2 Calibration	9
6.3 Procedure	10
6.4 Alternate Apparatus and Calibration	10
6.5 Alternate Procedure	10
7 WELL-SIMULATION COMPRESSIVE STRENGTH TESTS	10
7.1 General	10
7.2 Sampling	11
7.3 Preparation of Slurry	11
7.4 Apparatus	11
7.5 Procedure	11
7.6 Procedure of Determining Cement Compressive Strength at the Top of Long Cement Columns	13
7.7 Well Simulation Compressive Strength Tests (See Table 2)	14
8 NON-DESTRUCTIVE SONIC TESTING OF CEMENT	18
8.1 General	18
8.2 Apparatus	18
8.3 Sampling	18
8.4 Preparation of Slurry	18
8.5 Procedure	18
8.6 Curing Time	18
8.7 Curing Schedules	18
8.8 Data Reporting	18

	Page
9 WELL SIMULATION THICKENING TIME TESTS	18
9.1 General	18
9.2 Apparatus	18
9.3 Calibration	19
9.4 Test Procedure	20
9.5 Determination of Test Schedule	21
10 STATIC FLUID LOSS TEST	86
10.1 General	86
10.2 Apparatus	86
10.3 Safety	86
10.4 Mixing Procedure	86
10.5 Conditioning Procedures	86
10.6 Procedures for Testing at Temperatures Less Than 194°F (90°C)	86
10.7 Procedures for Testing at Temperatures Greater Than 193°F (89.4°C)	87
10.8 Filling the Static Fluid Loss Cell	88
10.9 Heating (Non-stirred Cell)	88
10.10 Equipment Setup	88
10.11 Fluid Loss Test	89
10.12 Test Completion and Clean Up	89
11 PERMEABILITY TESTS	89
11.1 Scope	89
11.2 Apparatus	89
11.3 Sample Preparation	91
11.4 Liquid Permeability (Cement Permeameter—Figure 9)	91
11.5 Liquid Permeability Alternate Procedure (Core Permeameter—Figure 10)	92
11.6 Calculating Liquid Permeability	94
11.7 Gas Permeability (Core Permeameter—Figure 10)	94
11.8 Calculating Gas Permeability	94
12 DETERMINATION OF RHEOLOGICAL PROPERTIES AND GEL STRENGTH USING A ROTATIONAL VISCOMETER	95
12.1 Scope	95
12.2 Procedure	95
12.3 Units	95
12.4 Apparatus	95
12.5 Calibration	96
12.6 Procedure for the Determination of Rheological Properties	96
12.7 Procedure for Determination of Gel Strength	97
12.8 Modeling of the Rheological Behavior	98
12.9 Examples	100
13 PROCEDURE FOR CALCULATING PRESSURE DROP AND FLOW REGIME FOR CEMENT SLURRIES IN PIPES AND ANNULI	104
13.1 General	104
13.2 Newtonian Fluids	104
13.3 Power Law Fluids	105
13.4 Bingham Plastic Fluids	106
13.5 Example of Calculations	108

	Page
14 ARCTIC CEMENTING TEST PROCEDURE	113
14.1 Scope	113
14.2 Preparation of Cement Slurry	113
14.3 Fluid Fraction	113
14.4 Thickening Time	113
14.5 Compressive Strength	113
14.6 Freeze-Thaw Cycling at Atmospheric Pressure	113
14.7 Compressive Strength Cyclic Testing	113
15 WELL SIMULATION SLURRY STABILITY TESTS	113
15.1 Introduction	113
15.2 Slurry Mixing	113
15.3 Slurry Conditioning	114
15.4 Free Fluid Test with Heated Static Period	114
15.5 Free Fluid Test with Ambient Temperature Static Period	115
15.6 Sedimentation Test	115
16 COMPATIBILITY OF WELLBORE FLUIDS	118
16.1 Scope	118
16.2 Definitions	118
16.3 Preparation of Test Fluids	118
16.4 Rheology	118
16.5 Thickening Time	118
16.6 Compressive Strength	118
16.7 Solids Suspension and Static Gel Strength	118
16.8 Fluid Loss	120
17 POZZOLANS	120
17.1 General	120
17.2 Definitions	120
17.3 Physical and Chemical Properties	120
17.4 Slurry Calculations	121
17.5 Bulk Volume of a Blend	122
APPENDIX A PROCEDURE FOR PREPARATION OF LARGE SLURRY VOLUMES	123
APPENDIX B CALIBRATION PROCEDURES FOR THERMOCOUPLES, TEMPERATURE MEASURING SYSTEMS, AND CONTROLLERS	125
APPENDIX C ADDITIONAL INFORMATION RELATING TO TEMPERATURE DETERMINATION	127
APPENDIX D ALTERNATE APPARATUS FOR WELL SIMULATION THICKENING TIME TESTS	133
 Figures	
1 Commonly Used Sampling Devices	6
2 Examples of Mixing Devices	7
3 Blade Assembly	8
4 Fluid Density Balance Diagram	10

	Page
5 Diagram of Mold Preparation	12
6 Typical Pressurized Consistometer	19
7 Typical Calibrating Device for Pressurized Consistometer	19
8 Fluid Loss Results Reporting Form	90
9 Cement Permeameter	92
10 Liquid/Gas Core Permeameter	93
11 An Illustration of Shear-Stress Shear-Rate Behavior of Various Fluids on a Linear Plot	101
12 An Illustration of Shear-Stress Shear-Rate Behavior of Various Fluids on a Log-Log Plot	101
13 A Linear Plot of Shear-Stress vs. Shear-Rate for Example 1	102
14 A Logarithmic Plot of Shear-Stress vs. Shear-Rate for Example 1	102
15 A Linear Plot of Shear-Stress vs. Shear-Rate for Example 2	103
16 A Logarithmic Plot of Shear-Stress vs. Shear-Rate for Example 2	103
17 Typical Sedimentation Tube	115
A-1 Examples of Typical Cement Mixing Devices	123
C-1 Error Range of Predicted Versus Measured Bottom-hole Temperatures for 66 Data Points Used to Develop PBHCT Correlation	129
C-2 Error Range of Predicted Versus Measured Squeeze Temperatures for the 40 Data Points Used to Develop the PSqT Correlation	129
D-1 Alternate Consistometer Design for Well Simulation Thickening Time, Example 1	133
D-2 Alternate Consistometer Design for Well Simulation Thickening Time, Example 2	134

Tables

1 Grades of API Classes of Well Cements	1
2 Well-Simulation Test Schedules for Curing Compressive Strength Specimens	14
3 Slurry Consistency Versus Equivalent Torque	20
4 Casing Well-Simulation Tests	24
5 Liner Well-Simulation Tests	36
6 Continuous Pumping Squeeze Well-Simulation Tests	46
7 Hesitation Squeeze Well-Simulation Tests	64
8 Vapor Pressure and Volume Expansion of Water at Temperatures between 212°F (100°C) and 600°F (316°C)	88
9 Example of a Rheological Properties Test	97
10 Value of Constant K	111
11 Nomenclature	112
12 Conversion Factors	112
13 Free Fluid and Sedimentation Results Data Sheet	117
14 Compatibility Mixing Ratios	118
15 Rheological Compatibility of Mud Cement and Spacer Data Sheet	119
A-1 Slurry Mixing Time	123

Recommended Practice for Testing Well Cements

1 Scope

1.1 WELL CEMENTS

Well cement slurries can be based on (but are not limited to) one of the API classes and grades of cement identified in this section and shown in Table 1. API well cements are produced by grinding Portland cement clinker, generally consisting of hydraulic calcium silicates and aluminates and usually containing one or more of the forms of calcium sulfate as an interground addition.

API cements are graded according to sulfate resistance. Three grades are defined: ordinary (O), moderate sulfate-resistant (MSR), and high sulfate-resistant (HSR).

1.2 API CEMENT CLASSES

The following is a brief discussion of the differences and similarities among API classes of cement.

1.2.1 Class A

This product is intended for use when special properties are not required. It is available only in ordinary (O) grade. Class A cement is similar to ASTM C 150, Type I with regard to both chemistry and fineness. Processing additions may be used in the manufacture of Class A cement provided such materials in the amounts used have been shown to meet the requirements of ASTM C 465. Specification testing of Class A cement slurries requires 46 percent water (100 parts dry cement by weight to 46 parts mixing water by weight) according to API Specification 10A.

1.2.2 Class B

This product is intended for use when conditions require moderate or high sulfate-resistance. Class B cement is similar to Class A cement except that it is available in both moderate (MSR) and high sulfate-resistant (HSR) grades. The MSR grade is similar to ASTM C 150, Type II with regard to both chemistry and fineness. The HSR grade is similar to ASTM C 150 Type V with regard to both chemistry and fineness. Specification testing of Class B cement slurries requires 46 percent water (100 parts dry cement by weight to 46 parts mixing water by weight) according to API Specification 10A.

1.2.3 Class C

This product is intended for use when conditions require high early strength; it is typically the most finely ground of all API classes of well cement. It is available in ordinary (O),

Table 1—Grades of API Classes of Well Cements*

Class	Ordinary (O) (C ₃ A Not Specified)	Moderate Sulfate Resistant (MSR) (3–8% C ₃ A)	High Sulfate Resistant (HSR) (<3% C ₃ A)
A	X		
B		X	X
C	X	X	X
D		X	X
E		X	X
F		X	X
G		X	X
H		X	X

*From API Specification 10A.

moderate sulfate-resistant (MSR), and high sulfate-resistant (HSR) grades. Class C (O) cement is similar to ASTM C 150, Type III. Processing additions may be used in the manufacture of Class C cement provided such materials in the amounts used have been shown to meet the requirements of ASTM C 465. Specification testing of Class C cement slurries requires 56 percent water (100 parts dry cement by weight to 56 parts mixing water by weight) according to API Specification 10A.

1.2.4 Class D

This product is intended for use under conditions of moderately high temperatures. Specifications for Class D cement cover moderate sulfate-resistant (MSR) and high sulfate-resistant (HSR) grades. Processing additions may be used in the manufacture of the cement provided such materials in the amount used have been shown to meet the requirements of ASTM C 465. Suitable set-modifying agents are typically interground or blended during manufacture. Specification testing of Class D cement slurries requires 38 percent water (100 parts dry cement by weight to 38 parts mixing water by weight) according to API Specification 10A.

1.2.5 Class E

This product is similar to Class D cement. It is intended for use under conditions of high temperature. Specification testing of Class E cement slurries requires 38 percent water (100 parts dry cement by weight to 38 parts mixing water by weight) according to API Specification 10A.

1.2.6 Class F

This product is similar to Class D cement. It is intended for use under conditions of extremely high temperatures. Specification testing of Class F cement slurries requires 38 percent water (100 parts dry cement by weight to 38 parts mixing water by weight) according to API Specification 10A.

1.2.7 Class G

This product is intended for use as a basic well cement. No additions other than calcium sulfate or water, or both, shall be interground or blended with clinker during manufacture. It is available in moderate sulfate-resistant (MSR) and high sulfate-resistant (HSR) grades. Specification testing of Class G cement slurries requires 44 percent water (100 parts dry cement by weight to 44 parts mixing water by weight) according to API Specification 10A.

1.2.8 Class H

This product is intended for use as a basic well cement. Class H cement is similar to Class G cement. Class H cement is typically more coarsely ground than Class G cement. Specification testing of Class H cement slurries requires 38 percent water (100 parts dry cement by weight to 38 parts mixing water by weight) according to API Specification 10A.

2 Referenced Publications

Unless otherwise specified, the most recent editions or revisions of the following standards, codes, and specifications shall, to the extent specified herein, form a part of this standard:

API

Spec 10A	<i>Specification for Well Cements</i>
Spec 10D	<i>Specification for Bow-Spring Casing Centralizers</i>
RP 10E	<i>Recommended Practice for Application of Cement Lining to Steel Tubular Goods, Handling, Installation and Joining</i>
Spec 13A	<i>Specification for Drilling-Fluid Materials</i>
RP 13B-1	<i>Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids</i>
Bul 13D	<i>Bulletin on the Rheology of Oil-Well Drilling Fluids</i>
RP13J	<i>Recommended Practice for Testing Heavy Brines</i>
Bul D17	<i>Running and Cementing Liners in the Delaware Basin, Texas</i>
GOT	<i>Glossary of Oilfield Production Terminology</i>

ASTM¹

C 109	<i>Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)</i>
C 150	<i>Standard Specification for Portland Cement</i>
C 183	<i>Standard Practice for Sampling and the Amount of Testing of Hydraulic Cement</i>
C 188	<i>Standard Test Method for Density of Hydraulic Cement</i>
C 465	<i>Standard Specification for Processing Additions for Use in the Manufacture of Hydraulic Cements</i>

3 Definitions

The following is a listing of terms found in the API Recommended Practice 10B. The bold numbers in parenthesis following the definitions are the location in the document from which the term was taken. These definitions are only valid within the context of the Recommended Practice 10B. The terms, mathematical abbreviations and expressions found in Sections 12 and 13 of Recommended Practice 10B are defined in each respective section and are not part of this listing.

3.1 absolute volume: The volume per unit mass. The reciprocal of absolute density expressed as volume per unit mass. (17.3)

3.2 additives: Materials added to a cement slurry to modify or enhance some desired property. Common properties that are modified include: modification of the setting time by use of retarders or accelerators, fluid loss control, viscosity modification, etc. (4.1)

3.3 annulus: Space surrounding the pipe in the wellbore. The outer wall of the annular space may be either formation or casing.

3.4 API: Abbreviation for the American Petroleum Institute, headquartered in Washington, D.C. This is the trade association for the petroleum industry.

3.5 API specification: A document which describes the approved specification for a product. The conditions of a specification test are applicable only to the product for which the specification is intended and the test procedure shall not be modified in any manner.

3.6 API recommended practice: A document which describes the approved recommended inspection or test procedure for a product. The testing procedure may be readily modified to simulate specific well conditions.

¹American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

- 3.7 AST (assumed surface temperature):** The assumed temperature at surface used for calculating a Pseudo-Temperature Gradient. (C.9)
- 3.8 batch mixing:** The process of mixing and holding a volume of cement slurry prior to placement in the wellbore. (9.5.3.1)
- 3.9 B_c (Bearden units of consistency):** The consistency of a cement slurry when determined on a pressurized consistometer. (9.3.1.1)
- 3.10 BHCT:** Bottom hole circulating temperature. (7.6.1)
- 3.11 BHP (bottom hole pressure):** The hydrostatic pressure at the bottom of the well calculated from the true vertical depth and the fluid densities in the wellbore. (9.5.3.5)
- 3.12 BHST (bottom hole static temperature):** The static temperature at the bottom of the wellbore. (Table 2)
- 3.13 blow out:** The point in time at which nitrogen flows through the sample in a fluid loss test. (10.9.4)
- 3.14 bottom hole circulating temperature (BHCT):** The circulating temperature at the bottom of the wellbore. (7.6.1) The temperature at the bottom of a well with a fluid circulating in the well. The BHCT can vary with time, fluid being circulated, pump rate, pipe size, etc.
- 3.15 bottom hole static temperature (BHST):** The undisturbed temperature at the bottom of the well. (Table 2)
- 3.16 bulk density:** The weight per unit volume of a dry material containing entrained air. (17.2.2)
- 3.17 casing cementing:** The complete or partial annular cementing of a full casing string. (9.5.1)
- 3.18 cement (Portland):** Ground clinker generally consisting of hydraulic calcium silicates and aluminates and usually containing one or more of the forms of calcium sulfate as an interground addition. (1.1)
- 3.19 cement class:** The designation by API to denote the various classification of API cement according to its intended use. (1.2)
- 3.20 cement grade:** The designation by API to denote the sulfate resistance of a particular cement. (1.2)
- 3.21 cement type:** The designation used by ASTM to denote the various classifications of ASTM cement according to its intended use.
- 3.22 cement blend:** A mixture of dry cement and other dry materials.
- 3.23 clinker:** The fused materials from the kiln in cement manufacturing that are interground with calcium sulfate to make cement. (1.1)
- 3.24 compatibility:** Capacity of forming a fluid mixture that does not undergo undesirable chemical and/or physical reactions. (16.2)
- 3.25 compressive strength:** The force per unit area required to crush a set cement sample. (7.1)
- 3.26 consistometer:** A device used to measure the thickening time of a cement slurry under temperature and pressure. (9.2)
- 3.27 continuous pumping squeeze cementing operations:** A squeeze cementing operation that does not involve cessation of pumping. (9.5.4.1)
- 3.28 density:** Mass per unit volume. (6.1)
- 3.29 equivalent sack:** The weight in pounds of the blend of Portland cement and fly ash or pozzolan that has the same absolute volume as 94 lbs of Portland cement. (17.3)
- 3.30 filtrate:** The liquid that is forced out of a cement slurry during a fluid loss test. (10.9.2)
- 3.31 fly ash:** The powdered residue from the combustion of coal having pozzolanic properties. (17.1.3)
- 3.32 free fluid:** The colored or colorless liquid which has separated from a cement slurry. (15.4.1)
- 3.33 freeze thaw cycle:** Test involving a cement sample that is alternately exposed to temperatures from 20°F (−7°C) to 170°F (77°C). (14.6)
- 3.34 hesitation pumping squeeze cementing operations:** A squeeze cementing operation that incorporates discontinuous pumping of the cement slurry. The slurry is placed into the well, the pumps are stopped for some period of time, then a volume of slurry is again pumped. The process is repeated until a predetermined pressure is reached or the volume of cement slurry has been completely pumped. (9.5.4.2)
- 3.35 H_{ur} [heat up rate in °F/min (°C/min)]:** The rate of temperature change from the SST to the PBHCT. (9.5.3.4)
- 3.36 liner cementing:** Annular cementing operations for which the top of the casing being cemented is not at the top of the wellbore. (9.5.2)
- 3.37 MaxRBHST:** The maximum recorded bottom hole static temperature at the bottom of the wellbore after a static period. (C.9)
- 3.38 MinRBHCT:** The minimum recorded bottom hole circulating temperature after sufficient circulation in the well to obtain a stabilized or steady-state temperature. (C.9)
- 3.39 mud:** The fluid that is circulated through the wellbore during drilling or workover operations. (16.3.2)
- 3.40 mud balance:** A beam type balance used to measure fluid density at atmospheric pressure. (6.1)

3.41 neat cement slurry: A cement slurry consisting of only cement and water.

3.42 PBHCT: Predicted bottom hole circulating temperature. (9.5.3.3) (See also C.9.)

3.43 P_{dr} (pressure down rate): The rate at which pressure is reduced from BHP to TOCP during a thickening time test. (9.5.3.12)

3.44 permeability: The measure of the capacity of a porous medium to allow flow of fluids or gasses. The unit of measure is normally millidarcy, mD. (Section 11)

3.45 plug cementing: The process of placing a volume of cement in a well to form a plug across the wellbore. (9.5.6)

3.46 pozzolan: A siliceous or siliceous and aluminous material which in finely divided form will react with calcium hydroxide to form a cementitious material. (17.1.1)

3.47 preflush: A fluid containing no insoluble weighting agents used to separate drilling fluids and cementing slurries. (16.2)

3.48 pressure vessel: The vessel in a consistometer used for thickening time testing into which the slurry container is placed for testing. (9.4.3)

3.49 pressurized curing vessel: A vessel used for curing a sample of cement under temperature and pressure for compressive strength testing. (7.4.3.2, 7.5.4)

3.50 $PSqT$ (predicted squeeze temperature in degrees F): A squeeze temperature based on a mathematical correlation. (9.5.5.1).

3.51 $PsTG$: Pseudo temperature gradient in °F/100 feet calculated from the difference between the MaxPBHST and the AST. (9.5.3.3) (See also C.2.)

3.52 $PsUT$ (pseudo undisturbed temperature): The calculated value for formation temperature based on field data and associated correlation techniques. (C.9)

3.53 P_{ur} (pressure up rate): The rate at which pressure is increased from the starting pressure to the bottom hole pressure during a thickening time test. (9.5.3.7)

3.54 $RSqT$: Recorded Squeeze Temperature. (C.5)

3.55 sedimentation: The separation and settling of solids in a cement slurry. (10.10.4 Note 1 and 15.1)

3.56 slurry container/cup: The container in a pressurized consistometer used to hold the slurry for conditioning the sample or for thickening time testing. (7.6.2)

3.57 sonic strength: The extent of strength development of a cement sample calculated by measuring the sonic velocity. The calculation is based on specific mathematical correlations and not direct measurements of strength. (Section 8)

3.58 SP: Starting pressure in a thickening time test. The initial pressure applied to the test sample at the beginning of the thickening time test. Also used to determine the pressure up rate. (9.5.3.7)

3.59 spacer: A fluid with insoluble weighting materials that is used to separate drilling fluids and cementing slurries. (16.2)

3.60 specific gravity: The ratio of the mass of a substance to the weight of an equal volume of a standard substance (water) at a reference temperature (4°C). (5.3)

3.61 squeeze cementing: The remedial process of forcing cementing material under pressure into a specific portion of the well such as fractures or openings. (9.5.4)

3.62 SST (slurry surface temperature): The temperature of the cement slurry at surface prior to placement in the wellbore. (9.5.3.4)

3.63 static fluid loss: Fluid lost from a cement slurry when tested against a 325 mesh screen and 1,000 psi differential pressure according to Section 10. (10.1)

3.64 static stability: A test for determination of the degree of sedimentation and free fluid development in a cement slurry. (Section 15)

3.65 stirred fluid loss cell: A specially designed cell that allows for conditioning of the cement slurry within the same cell used to perform a static fluid loss test. (10.1)

3.66 strength retrogression: The reduction in compressive strength and the increase in permeability of a cement brought on by exposure to temperatures exceeding 230°F (110°C). (7.7)

3.67 t_s : Time to displace the leading edge of the cement slurry from bottom of the casing to the top of the annular cement column. (9.5.3.9)

3.68 TCCT (top of cement circulating temperature): The circulating temperature at the top of the cement column. (7.6.2.1)

3.69 TCST (top of cement static temperature): The static temperature at the top of the cement column. (7.6.1)

3.70 TCTVD (top of cement true vertical depth): The true vertical depth at the top of the cement column. (9.5.3.11)

3.71 t_{disp} : Time to displace leading edge of cement slurry to the bottom of the wellbore or other predetermined location in the well. (9.5.3.2)

3.72 thickening time: The time for a cement slurry to develop a selected B_c . (9.1) The results of a thickening time test provide an indication of the length of time a cement

slurry will remain pumpable under the test conditions. (See also 9.4.5.)

3.73 TOCP: Top of cement pressure. (9.5.3.8 and 9.5.3.11)

3.74 TOCT (top of cement column temperature):

The circulating temperature at the top of the cement column. (9.5.3.8 and 9.5.3.10)

3.75 UFT: Undisturbed formation temperature. (C.2)

3.76 weigh batch mixer: Device or system for the weighing and blending of cement with dry additives. Also called a scale tank. (4.3)

3.77 well simulation test: A test whose parameters are designed and modified as required to simulate the conditions found in a wellbore. (7.1)

4 Sampling

4.1 GENERAL

Past API documents have dealt only with sampling unblended cement according to the procedure outlined in ASTM C 183. For cement blends, the purpose for which samples are taken must be considered. In many cases, samples of the cement, cement blend, solid and liquid additives, and mixing water may be required to test a slurry according to API Recommended Practice 10B. The best available sampling technology should be employed to ensure accurate samples are taken. Some commonly-used sampling techniques are contained in this section.

4.2 SAMPLING CEMENT AT FIELD LOCATION

When sampling from bulk tanks, transports or sacks, the cement should be dry and uniform. Multiple samples should be extracted using a suitable device (see Figure 1). A composite of the samples should be prepared, packaged and labeled (see 4.7). Average sample size should be 2 to 5 gallons. Sampling procedures are also outlined in ASTM C 183.

4.3 SAMPLING CEMENT BLENDS AT FIELD LOCATION

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. This can be done by transferring the cement (air blowing) from the weigh batch mixer to some other container three (3) to six (6) times. Samples from the bulk container may be extracted according to 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 (see Figure 1). The samples should be prepared, packaged,

and labeled (see 4.7). Sample size should be sufficient to perform the desired testing.

4.4 SAMPLING DRY CEMENT ADDITIVES AT FIELD LOCATION

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

4.5 SAMPLING LIQUID CEMENT ADDITIVES AT FIELD LOCATION

Most liquid additives are solutions or suspensions of dry materials. Prolonged storage may cause 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 (see 4.7). The sample size of each liquid additive should be sufficient to perform the desired testing.

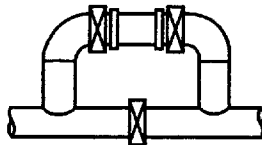
4.6 SAMPLING MIXING WATER

The mixing water should be sampled from the source. The sample should be extracted in such a way as to avoid contamination. The sample should be packaged and labeled (see 4.7). The sample size should be sufficient to perform the desired testing.

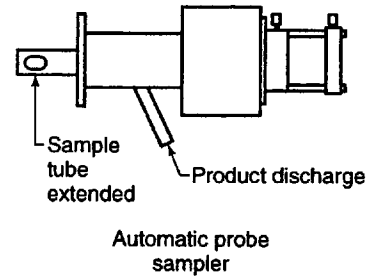
4.7 SHIPPING AND STORAGE

Test samples must be packaged promptly in clean, airtight, moisture-proof containers suitable for shipping and long-term storage. The containers should be lined metal, plastic, or some other heavy-walled flexible or rigid material to assure maximum protection. Re-sealable 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.

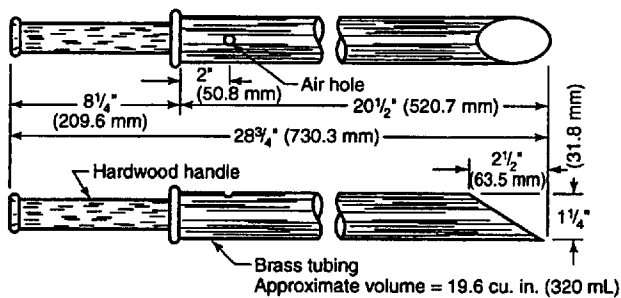
Each sample container should be clearly labeled and identified with the type of material, lot number, source, and date of sampling. Shipping containers should also be labeled. Do not mark the lids of containers, since the lids may be readily interchanged and lead to confusion. Any required regulatory identification or documentation should be enclosed or



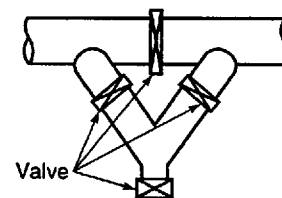
Top view—diverted flow sampler



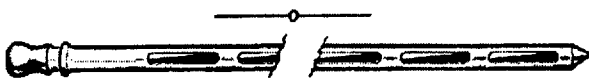
Automatic probe sampler



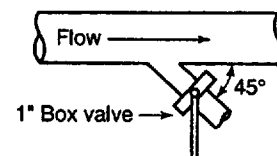
Tube sampler for sacked cement



Modified diverted flow sampler



Tube sampler for bulk cement



Top view—lateral sampler

Figure 1—Commonly Used Sampling Devices

securely attached to the container. All hazardous material samples should be packaged and labeled according to 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. Each sample should be thoroughly blended just prior to slurry preparation (see Section 5).

For storage, each sample should be transferred into a suitable, leak-proof container (if one has not been used in shipping), properly labeled and dated, and stored in a dry place where room temperatures remain fairly constant. At time of testing, each sample should be examined for quality, and thoroughly blended just prior to slurry preparation.

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, an alternate method for slurry preparation is found in Appendix A.

5.2 APPARATUS

5.2.1 Electronic Balances

The indicated load on balances should be accurate within ± 0.1 percent of the indicated load. Balances should be calibrated frequently enough to ensure accuracy, and at least annually.

5.2.2 Mechanical Balances

Free or sliding-beam weights used on mechanical balances should be accurate within ± 0.1 percent of the weight indicated.

5.2.3 Mixing Device

The mixing device for preparation of slurries should be a one quart size, bottom drive, blade type mixer. Examples of mixing devices in common use are shown in Figure 2. The mixing container and the mixing blade should be constructed of corrosion-resistant material (see Figure 3). The mixing assembly should be constructed so that the blade can be separated from the drive mechanism. The mixing blade should be separated from the mixing assembly and weighed prior to use and replaced with a new blade when 10 percent weight loss has occurred. The blade should also be visually inspected for damage prior to each use and replaced as necessary. Should the mixing device leak at any time during the mixing procedure, the contents should be discarded, the leak repaired and the procedure restarted.

5.3 PROCEDURE

5.3.1 Determination of Specific Gravity of Components

The specific gravity of different batches of cement may vary due to natural changes in the composition of the raw materials used in the manufacturing process. Studies have shown that cement specific gravity may vary from 3.10 to 3.25. This variability could result in deviation of slurry densities by as much as 0.4 lb/gal for slurries with constant water-to-solids ratio. The specific gravity of mix water may also vary, depending on the source, resulting in slurry density inconsistencies. Determination of the specific gravity of all components of the slurry is necessary to properly calculate the required amounts for slurry preparation.

5.3.1.1 Specific Gravity of Cement and Dry Additives

The specific gravity of the cement and any dry additives may be determined by the use of a Le Chatelier flask as outlined in ASTM C 188. Alternately, a pycnometer may be used for determining the specific gravity of these materials.

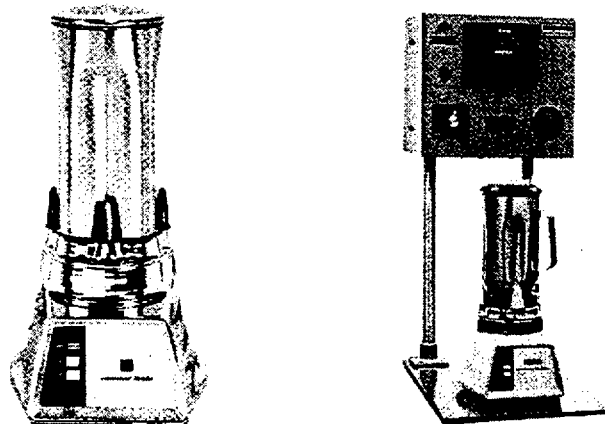
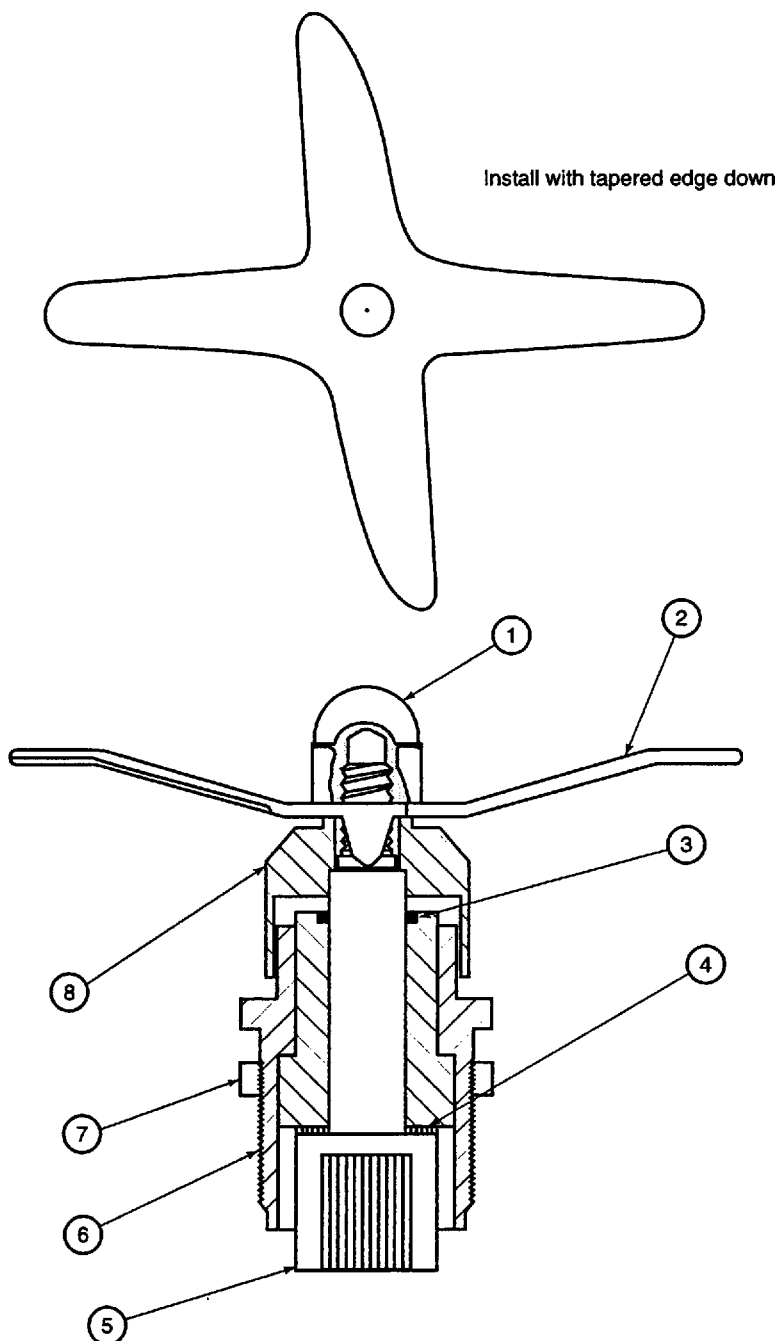


Figure 2—Examples of Mixing Devices



8	1		Bearing cup
7	1		Hex nut
6	1		Bearing holder
5	1		Socket head shaft
4	1		Thrust washer
3	1		O-ring
2	1		Hardened blade
1	1		Cap nut
Item no.	Qty. Reqd.	Part number	Description
Parts list			

Figure 3—Blade Assembly

5.3.1.2 Specific Gravity of Mix Water and Liquid Additives

The specific gravity of the mix water and any liquid additives should be determined by the use of a hydrometer as outlined in API Recommended Practice 13J. Alternately, a pycnometer may be used for determining the specific gravity of these materials.

5.3.2 Laboratory Density and Volume Calculations

A slurry volume of approximately 600 mL should be sufficient to perform most laboratory test procedures while not overfilling the mixing container. Laboratory blend requirements may be calculated by use of the following formulas. Alternate, suitable equations may also be used to calculate laboratory blend requirements.

For the purpose of these calculations, assume that specific gravity is equal to density in g/mL.

$$\begin{aligned}V_s &= V_c + V_w + V_a \\M_s &= M_c + M_w + M_a \\D_s &= \frac{M_s}{V_s}\end{aligned}$$

Where:

- V_s = slurry volume (mL).
- V_c = cement volume (mL).
- V_w = water volume (mL).
- V_a = additive volume (mL).
- D_s = density of slurry (g/mL).
- M_s = slurry mass (g).
- M_c = cement mass (g).
- M_w = water mass (g).
- M_a = additive mass (g).
- $V_c = M_c/D_c$
- $V_w = M_w/D_w$
- $V_a = M_a/D_a$

5.3.3 Temperature of Water and Cement

The temperature of the mix water, dry cement or cement blend, mixing and blending devices should be representative of field mixing conditions. If field conditions are unknown, the temperature of the mix water and dry cement should be 73, $\pm 2^\circ\text{F}$ (22.8, $\pm 1.1^\circ\text{C}$) immediately prior to mixing. In all cases, the temperatures of the mix water and dry cement should be measured and documented.

5.3.4 Mix Water

Water composition may affect slurry performance. Water from the field source should be used. If field mix water is unavailable, a water of similar composition should be used. If

field mix water composition is unknown, deionized, distilled, or tap water may be used. The mix water and any liquid additives should be weighed into a clean, dry, mixing container. No excess water should be added to compensate for evaporation or wetting.

5.3.5 Mixing Cement and Water

Dry materials should be weighed and then thoroughly and uniformly blended prior to being added to the mixing fluid. The mixing container with the required weight of mix water and any liquid additives should be placed on the mixer base. The motor should be turned on and maintained at 4,000, ± 200 rpm (66.7, ± 3.3 rev/sec). 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 certain cases, the order of addition of the additives to the mixing water may be critical. Special mixing procedures and mixing time should be documented. The cement or cement/dry additive blend should be added at a uniform rate, in not more than 15 seconds 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 at a minimum. When all the dry materials have been added to the mix water, the cover should be placed on the mixing container and mixing should be continued at 12,000, ± 500 rpm (200, ± 8.3 rev/sec) for 35, ± 1 seconds. Rotational speed under load should be measured and documented.

6 Determination of Slurry Density

6.1 PREFERRED APPARATUS

The preferred method for measuring the density of a cement slurry is by using the pressurized fluid density balance. The pressurized fluid density balance is similar in operation to the conventional mud balance, the difference being that the slurry can be 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 upon slurry density measurements. A major problem found in the density measurement of cement slurries is that oftentimes these fluids have a considerable amount of air entrained when initially mixed. By pressurizing the sample cup, any entrained air will be decreased to a negligible volume, thus providing a slurry density measurement more closely in agreement with that which will be realized under downhole conditions.

6.2 CALIBRATION

The apparatus should be checked for calibration by placing water or heavier fluids of known density in the sample cup or by using manufacturer-specified weights for equivalent densities placed in the sample cup.

6.3 PROCEDURE

6.3.1 The sample cup should be filled to a level slightly below the upper edge of the cup [approximately $\frac{1}{4}$ inch (6 mm)].

6.3.2 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. Excess slurry must be expelled through the check valve. (Note: slurry may be expelled forcibly.) When the lid has been placed on the cup, pull the check valve up in the closed position, rinse off the cup and threads with water, and screw the threaded cap on the cup.

6.3.3 The pressurizing pump is similar in operation to a syringe. The pump is filled by submersing the nose of the pump assembly in the slurry with the piston rod in the completely inward position. The piston rod is then drawn upward, thereby filling the pump cylinder with slurry.

6.3.4 The nose of the pump is pushed onto the mating O-ring surface of the check valve. The sample cup is pressurized by maintaining a downward force on the pump cylinder housing in order to hold the check valve down (open) and at the same time forcing the piston rod inward. Approximately 50 pounds (255 N) force or greater should be maintained on the piston rod (see Figure 4).

6.3.5 The check valve in the lid is pressure actuated, which means the pressure in the cup keeps the valve closed. The valve is initially closed by gradually lifting the cylinder housing of the pressurizing pump while pressure is being applied to the piston rod. When the check valve closes, release pressure on piston rod before disconnecting the pump.

6.3.6 The exterior of the cup should be rinsed off and wiped dry. The instrument should then be placed on the knife edge as

illustrated (see Figure 4). The sliding weight should be moved right or left until the beam is balanced. The beam is balanced when the attached bubble is centered between the two scribed marks. The density is obtained by reading one of the four calibrated scales on the arrow side of the sliding weight.

6.3.7 The pressure is released by pushing the valve downward. This is done by reconnecting the pump assembly and pushing downward on the pump cylinder housing.

The cup and pump assembly should then be emptied of its contents and all components should be thoroughly cleaned.

For best operation the valve, lid and cylinder should be lightly greased.

6.4 ALTERNATE APPARATUS AND CALIBRATION

Cement slurry density may be determined by use of the mud balance described in API Recommended Practice 13B-1, *Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids*.

6.5 ALTERNATE PROCEDURE

The recommended procedure for using a mud balance should be in accordance with the latest edition of API 13B-1 except that the slurry, after being poured into the mud balance cup, should be puddled 25 times to eliminate entrapped air.

7 Well-Simulation Compressive Strength Tests

7.1 GENERAL

This section presents procedures for well-simulation compressive strength testing. Well-simulation compressive strength tests are not required for compliance with Specification 10A.

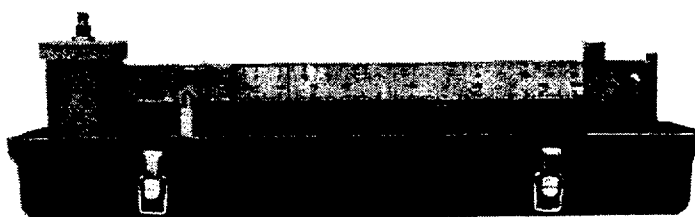
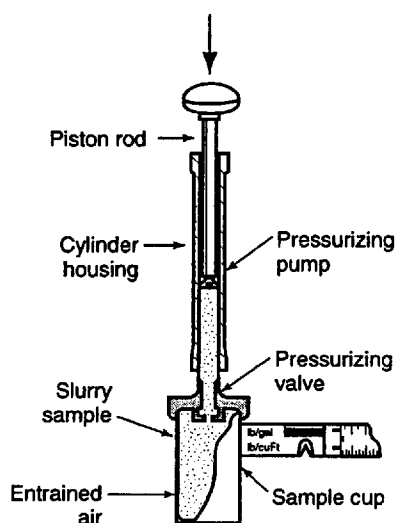


Figure 4—Fluid Density Balance Diagram

7.2 SAMPLING

Samples of the cement, additives, and mix water should be obtained according to Section 4 of API Recommended Practice 10B.

7.3 PREPARATION OF SLURRY

The slurry should be prepared according to Section 5 of API Recommended Practice 10B.

7.4 APPARATUS

7.4.1 Two-Inch Cube Molds and Compressive Strength-Testing Device

Molds and the testing device for compressive strength tests should conform to the requirements of ASTM C 109, except that the molds may be separable into more than two parts. Calibrate the testing device to be accurate to ± 1 percent throughout the expected load range. The molds and testing device should be calibrated at least every two years.

7.4.2 Base and Cover Plates

Use corrosion-resistant plates having a minimum thickness of $\frac{1}{4}$ inch (6 mm) for the cover plate. Grooves may be incorporated into the surface of the cover plate contacting the surface of the cement. Use only corrosion-resistant metal plates for the base plates. Glass plates are not recommended for tests above 230°F (110°C) because of silica replacement.

7.4.3 Water Curing Bath

Utilize a curing bath or tank having dimensions suitable for the complete immersion of compressive strength molds in water and operable within $\pm 3^\circ\text{F}$ ($\pm 1.7^\circ\text{C}$) of the test temperature. The two types of water curing baths are:

7.4.3.1 Atmospheric Pressure

An atmospheric pressure vessel for curing samples should have an agitator or circulating system. Atmospheric curing baths may be used for curing compressive strength samples at or below 150°F (65.6°C) when pressure is not required.

7.4.3.2 Pressurized

A pressure vessel suitable for curing samples at the appropriate final test temperature and capable of maintaining a pressure of at least 3,000 psig (20,700 kPa) is recommended. The vessel should be capable of being heated at the desired heating rate.

7.4.4 Cooling Bath

The cooling bath should be designed so that the sample to be cooled from the curing temperature can be completely submerged in water maintained at 80, $\pm 5^\circ\text{F}$ (27, $\pm 3^\circ\text{C}$).

7.4.5 Temperature Measuring System

7.4.5.1 Thermocouple, range 0°F to 220°F (-18°C to 104°C), calibrated to an accuracy of $\pm 3^\circ\text{F}$ (1.7°C) is preferred in a non-pressure vessel.

7.4.5.2 Thermometer, range 0°F to 220°F (-18°C to 104°C), with minimum scale divisions not to exceed 2°F (1°C) may be used in a non-pressure vessel.

7.4.5.3 Thermocouple, range 0°F to at least 400°F (-18°C to at least 204°C), calibrated to an accuracy of $\pm 3^\circ\text{F}$ (1.7°C), should be used in pressure vessels.

7.4.6 Puddling Rod

A corrosion-resistant rod with a width of approximately $\frac{1}{4}$ inch (6mm) is recommended.

7.4.7 Mold Sealing Grease

Any grease that possesses the following properties when subjected to anticipated test temperatures and pressures is suitable for use: 1) a consistency to permit ease of application, 2) good sealing properties to prevent leakage, 3) water resistance, and 4) inert to the cement. The grease will be non-corrosive in the temperature range of 0°F to at least 400°F (-18°C to at least 204°C).

7.4.8 Mold Release Agent

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.

7.5 PROCEDURE

7.5.1 Preparation of Molds

The interior faces of the molds and the contact surfaces of the plates may be coated with mold release agent. The assembled molds should be water tight. Care should be taken to ensure there is no bead of sealant on the interior of the mold (see Figure 5).

7.5.2 Preparation and Placement of Cement Slurry

7.5.2.1 Preparation

Prepare the slurry in accordance with Section 5, API Recommended Practice 10B.

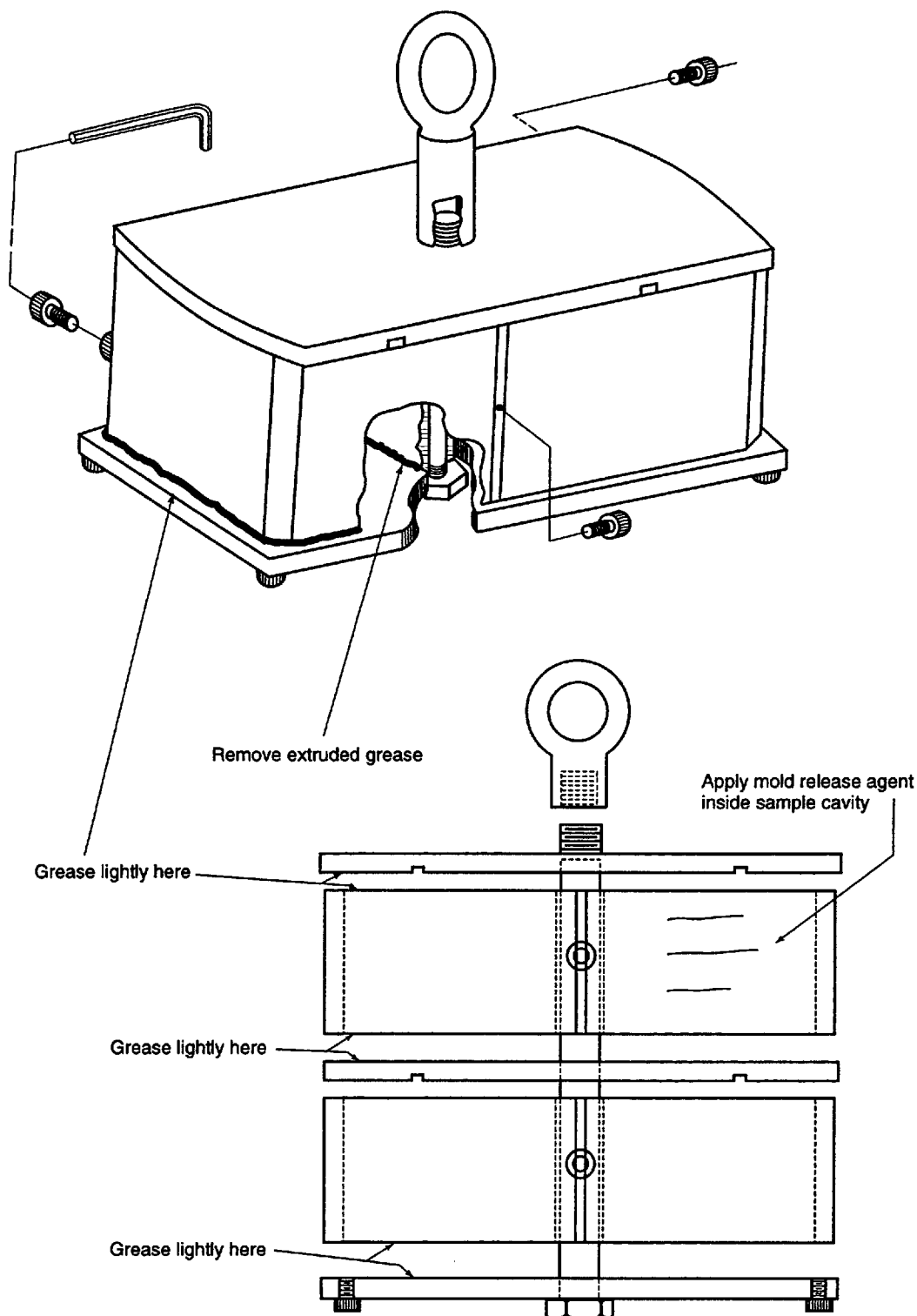


Figure 5—Diagram of Mold Preparation

7.5.2.2 Placement

Pour the cement slurry into the prepared molds to $\frac{1}{2}$ (one half) of the mold depth. Puddle each sample approximately 30 times with a puddling rod after all chambers have received slurry. Stir the remaining slurry by hand to re-suspend the components. Completely fill each sample mold with slurry and puddle as before. After the chambers are completely filled, place the cover plate on top of the molds. Samples that leak should be discarded.

7.5.3 Curing at Atmospheric Pressure

After the molds have been filled and covered with the top plate, immediately place them in a water curing bath maintained at the desired curing temperature. Elevate the molds off the bottom of the bath using a perforated baffle plate or suitable spacers to allow water to completely circulate around the samples during the curing period. At approximately 45 minutes 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 bath at $80, \pm 5^{\circ}\text{F}$ ($27, \pm 3^{\circ}\text{C}$) until the samples are tested.

7.5.4 Curing at Pressures Above Atmospheric

After the molds have been filled and covered with the top plate, immediately place them in a pressurized curing vessel at the desired test initiation temperature [normally $80, \pm 5^{\circ}\text{F}$ ($27, \pm 3^{\circ}\text{C}$)]. Apply heat and pressure according to the test schedule. Cement samples may be cured according to pressure/temperature schedules provided in Section 7 or a schedule designed to simulate a specific well's conditions.

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

7.5.5 Test Period

The test period is the elapsed time from subjecting the sample to temperature in the curing vessel to testing the sample for strength.

7.5.6 Sample Testing

Test samples immediately after removal from the cooling bath. The test procedure will be in accordance with ASTM C

109, *Compressive Strength of Hydraulic Cement Mortars*, except:

7.5.6.1 A compressive strength testing device shall be used and the rate of loading for samples with strength greater than 500 psi (3.5 MPa) will be 4,000, ± 400 psi (16,000, $\pm 1,600$ lbf) (71.7, ± 7.2 kN) per minute. For a nominal four square inch sample surface, this rate can be achieved by adjusting the load rate to obtain a gauge indicator travel between 2,000 and 6,000 lbf (gauge reading) in 15 seconds. For samples with strength of 500 psi (3.5 MPa) or less, a 1,000, ± 100 psi (4,000, ± 400 lbf) (17.9, ± 1.8 kN) per minute shall be used. For a nominal four square inch sample surface, this rate can be achieved by adjusting the load rate to obtain a gauge indicator travel between 2,000 and 6,000 lbf (gauge reading) in one minute. Make no adjustment in the controls of the testing machine while a sample is yielding before failure.

7.5.6.2 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 compression tester. Average the compressive strength of all acceptable test samples (see ASTM C 109) made from the same slurry and tested at the same time. Report compressive strength results to the nearest 10 psi (0.1 MPa) and test schedule used.

7.6 PROCEDURE OF DETERMINING CEMENT COMPRESSIVE STRENGTH AT THE TOP OF LONG CEMENT COLUMNS

7.6.1 Guidelines for Use

Use this procedure if the bottomhole circulating temperature (BHCT) is higher than the static temperature at the top of the cement column (TCST).

7.6.2 Procedure

Prepare a cement slurry in accordance with Section 5, API Recommended Practice 10B. Pour the slurry into the slurry cup of a pressurized consistometer and heat to BHCT according to pressure/temperature schedules provided in Section 11 or a schedule designed to simulate a specific well's conditions. Hold test temperature and pressure for 60 minutes to allow the cement temperature to reach equilibrium.

7.6.2.1 Upon completion of the appropriate test schedule, plus the 60 minutes to reach equilibrium, cool to the top of the cement column's circulating temperature (TCCT) or 194°F (90°C), whichever is lower at 2.0°F (1.1°C)/minute. Use the following equation to determine the cool down time (T) in minutes:

$$T = \frac{\text{BHCT} - \text{TCCT}}{2.0^{\circ}\text{F} (1.1^{\circ}\text{C})}$$



Decrease the temperature while maintaining test pressure. When the TCCT or 194°F (90°C) (whichever is lower) is reached, release the pressure slowly and remove the slurry cup.

7.6.2.2 Take care to minimize oil contamination of the slurry. Open the slurry container from the top (while leaving the paddle in place). This will eliminate the need for inverting the slurry cup and reduce contamination that could be caused by oil migrating through the slurry. Blot the top of the slurry with an absorbent cloth or paper towel to remove any visible oil. Transfer the slurry three (3) times between the slurry cup and a beaker to re-suspend any solids that may have settled.

7.6.2.3 Pour the slurry into a prepared mold as specified in 7.5.2.2. and place molds into a preheated curing vessel [preheated to TCCT or 194°F (90°C), whichever is lower]. A non-destructive sonic test device as described in Section 8 may also be used. No longer than 15 minutes after removing the slurry from the consistometer, apply 3,000, ±500 psi (20,700, ±3,400 kPa) curing pressure. Adjust to the final curing temperature.

7.6.2.4 Adjust sample temperature TCST over a period appropriate to well conditions while maintaining curing pres-

sure. If a time to reach final conditions is not known or specified, use 6 hours.

7.6.2.5 Remove samples as prescribed in 7.5.4.

7.6.2.6 Test the samples for strength in accordance with procedure in 7.5.6 or Section 8.

7.7 WELL SIMULATION COMPRESSIVE STRENGTH TESTS (SEE TABLE 2)

The well-simulation compressive strength tests described in the section may be used to test cements or cement blends for resistance to thermally-induced strength retrogression. To do this, the cement or cement blend is exposed to temperature and pressure for varying periods of time and observed for changes in compressive strength. The procedure involves comparing the compressive strength observed after some initial period (such as 24, 48, or 72 hours) with the compressive strength observed after some extended period or periods (such as 28 days). Cements or cement blends that exhibit lower compressive strength after extended aging may be considered to exhibit strength retrogression. The commonly-cited threshold for thermally induced strength retrogression is 230°F (110°C) although deviation from this value has been reported.

Table 2—Well-Simulation Test Schedules for Curing Compressive Strength Specimens

Schedule	Elapsed Time (min)	Temperature Gradient, °F/100 ft depth (°C/100 m depth) ^a													
		Pressure		°F		°F		°F		°F		°F		°F	
		psi	(kPa)	0.9	(1.6)	1.1	(2)	1.3	(2.4)	1.5	(2.7)	1.7	(3.1)	1.9	(3.5)
1Sg	15 ^a	800	(5,500)	80	(27)	80	(27)	80	(27)	80	(27)	80	(27)	80	(27)
1,000 ft	30 ^b			81	(27)	81	(27)	81	(27)	81	(27)	81	(27)	81	(27)
(305 m)	60 ^b			82	(28)	82	(28)	83	(28)	83	(28)	84	(29)	84	(29)
	90 ^b			83	(28)	84	(29)	84	(29)	85	(29)	86	(30)	86	(30)
	120 ^b			84	(29)	85	(29)	86	(30)	87	(31)	88	(31)	89	(32)
	150 ^b			85	(29)	87	(31)	88	(31)	89	(32)	90	(32)	91	(33)
	180 ^b			87	(31)	88	(31)	90	(32)	91	(33)	93	(34)	94	(34)
	210 ^b			88	(31)	90	(32)	91	(33)	93	(34)	95	(35)	96	(36)
	240			89	(32)	91	(33)	93	(34)	95	(35)	97	(36)	99	(37)
2Sg	15	1,600	(11,000)	88	(31)	88	(31)	89	(32)	89	(32)	90	(32)	90	(32)
2,000 ft	30 ^b			90	(32)	90	(32)	91	(33)	91	(33)	92	(33)	93	(34)
(610 m)	60 ^b			91	(33)	92	(33)	93	(34)	94	(34)	95	(35)	96	(36)
	90 ^b			92	(33)	93	(34)	95	(35)	97	(36)	99	(37)	100	(38)
	120 ^b			93	(34)	95	(35)	97	(36)	99	(37)	102	(39)	103	(39)
	150 ^b			94	(34)	97	(36)	100	(38)	102	(39)	105	(41)	107	(42)
	180 ^b			96	(36)	99	(37)	102	(39)	105	(41)	108	(42)	111	(44)
	210 ^b			97	(36)	100	(38)	104	(40)	107	(42)	111	(44)	114	(46)
	240			98	(37)	102	(39)	106	(41)	110	(43)	114	(46)	118	(48)



Documents

Document Sharing Hub

Table 2—Well-Simulation Test Schedules for Curing Compressive Strength Specimens (Continued)

1	2	3	4	5	6	7	8	9							
Schedule	Elapsed Time (min)	Temperature Gradient, °F/100 ft depth (°C/100 m depth) ^a													
		Pressure		°F (°C)		°F (°C)		°F (°C)		°F (°C)		°F (°C)			
		psi	(kPa)	0.9	(1.6)	1.1	(2)	1.3	(2.4)	1.5	(2.7)	1.7	(3.1)	1.9	(3.5)
3Sg	15	3,000	(20,700)	91	(33)	92	(33)	93	(34)	93	(34)	94	(34)	94	(34)
4,000 ft	30 ^b			99	(37)	101	(38)	102	(39)	103	(39)	104	(40)	105	(41)
(1,220 m)	60 ^b			102	(99)	104	(40)	106	(41)	108	(42)	110	(43)	112	(44)
	90 ^b			104	(40)	107	(42)	110	(43)	113	(45)	117	(47)	120	(49)
	120 ^b			107	(42)	111	(44)	115	(46)	119	(48)	123	(51)	127	(53)
	150 ^b			109	(43)	114	(46)	119	(48)	124	(51)	129	(54)	134	(57)
	180 ^b			111	(44)	117	(47)	123	(51)	129	(54)	135	(57)	141	(61)
	210 ^b			114	(46)	121	(49)	128	(53)	135	(57)	142	(61)	149	(65)
	240			116	(47)	124	(51)	132	(56)	140	(60)	148	(64)	156	(69)
4Sg	15	3,000	(20,700)	95	(35)	95	(35)	96	(36)	97	(36)	98	(37)	101	(38)
6,000 ft	30			109	(43)	111	(44)	113	(45)	115	(46)	116	(47)	122	(50)
(1,830 m)	45 ^b			113	(45)	116	(47)	118	(48)	121	(49)	124	(51)	130	(54)
	60 ^b			115	(46)	118	(48)	121	(49)	125	(52)	128	(53)	135	(57)
	90 ^b			118	(48)	123	(51)	128	(53)	132	(56)	137	(58)	145	(63)
	120 ^b			121	(49)	127	(53)	134	(57)	140	(60)	146	(63)	155	(68)
	150 ^b			124	(51)	132	(56)	140	(60)	147	(64)	155	(68)	164	(73)
	180 ^b			128	(53)	137	(58)	146	(63)	155	(68)	164	(73)	174	(79)
	210 ^b			131	(55)	141	(61)	152	(67)	162	(72)	173	(78)	184	(84)
	240			134	(57)	146	(63)	158	(70)	170	(77)	182	(83)	194	(90)
5Sg	15	3,000	(20,700)	97	(36)	98	(37)	100	(38)	102	(39)	104	(40)	109	(43)
8,000 ft	30			114	(46)	116	(47)	120	(49)	124	(51)	128	(53)	139	(59)
(2,440 m)	45 ^b			127	(53)	130	(54)	136	(58)	141	(61)	147	(64)	161	(72)
	60 ^b			128	(53)	133	(56)	140	(60)	146	(63)	153	(67)	167	(75)
	90 ^b			132	(56)	139	(59)	147	(64)	155	(68)	163	(73)	178	(81)
	120 ^b			136	(58)	144	(62)	154	(68)	164	(73)	174	(79)	189	(87)
	150 ^b			140	(60)	150	(66)	162	(72)	173	(78)	184	(84)	199	(93)
	180 ^b			144	(62)	156	(69)	169	(76)	182	(83)	195	(91)	210	(99)
	210 ^b			148	(64)	162	(72)	177	(81)	191	(88)	205	(96)	221	(105)
	240			152	(67)	168	(76)	184	(84)	200	(93)	216	(102)	232	(111)
6Sg	15	3,000	(20,700)	98	(37)	100	(38)	103	(39)	106	(41)	110	(43)	116	(47)
10,000 ft	30			116	(47)	120	(49)	127	(53)	132	(56)	140	(60)	152	(67)
(3,050 m)	45			134	(57)	139	(59)	150	(66)	158	(70)	170	(77)	188	(87)
	60 ^b			142	(61)	148	(64)	161	(72)	170	(77)	184	(84)	204	(96)
	90 ^b			146	(63)	155	(68)	169	(76)	180	(82)	195	(91)	215	(102)
	120 ^b			151	(66)	162	(72)	177	(81)	190	(88)	206	(97)	226	(108)
	150 ^b			156	(69)	169	(76)	185	(85)	200	(93)	217	(103)	237	(114)
	180 ^b			161	(72)	176	(80)	194	(90)	210	(99)	228	(109)	248	(120)
	210 ^b			165	(74)	183	(84)	202	(94)	220	(104)	239	(115)	259	(126)
	240			170	(77)	190	(88)	210	(99)	230	(110)	250	(121)	270	(132)

Table 2—Well-Simulation Test Schedules for Curing Compressive Strength Specimens (Continued)

Schedule	Elapsed Time (min)	Pressure		Temperature Gradient, °F/100 ft depth (°C/100 m depth) ^a											
				Temperature, °F (°C)											
				°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)	°F (°C)
		psi	(kPa)	0.9 (1.6)	1.1 (2)	1.3 (2.4)	1.5 (2.7)	1.7 (3.1)	1.9 (3.5)						
7Sg	15	3,000	(20,700)	98 (37)	102 (39)	107 (42)	111 (44)	116 (47)	120 (49)						
12,000 ft	30			115 (46)	124 (51)	133 (56)	143 (62)	152 (67)	161 (72)						
(3,660 m)	45			133 (56)	146 (63)	160 (71)	174 (79)	188 (87)	201 (94)						
	60 ^b			148 (64)	166 (74)	184 (84)	202 (94)	220 (104)	237 (114)						
	90 ^b			155 (68)	173 (78)	192 (89)	211 (99)	230 (110)	249 (121)						
	120 ^b			162 (72)	181 (83)	201 (94)	221 (105)	241 (116)	261 (127)						
	150 ^b			168 (76)	189 (87)	210 (99)	231 (111)	252 (122)	272 (133)						
	180 ^b			175 (79)	197 (92)	219 (104)	241 (116)	263 (128)	284 (140)						
	210 ^b			181 (83)	204 (96)	227 (108)	250 (121)	273 (134)	296 (147)						
	240			188 (87)	212 (100)	236 (113)	260 (127)	284 (140)	308 (153)						
8Sg	15	3,000	(20,700)	99 (37)	104 (40)	109 (43)	114 (46)	119 (48)	123 (51)						
14,000 ft	30			118 (48)	128 (53)	138 (59)	147 (64)	157 (69)	167 (75)						
(4,270 m)	45			137 (58)	152 (67)	167 (75)	181 (83)	196 (91)	210 (99)						
	60			156 (69)	175 (79)	195 (91)	215 (102)	235 (113)	254 (123)						
	75 ^b			166 (74)	188 (87)	210 (99)	231 (111)	254 (123)	275 (135)						
	90 ^b			170 (77)	192 (89)	215 (102)	237 (114)	259 (126)	281 (138)						
	120 ^b			177 (81)	200 (93)	224 (107)	247 (119)	271 (133)	294 (146)						
	150 ^b			184 (84)	209 (98)	234 (112)	258 (126)	283 (139)	307 (153)						
	180 ^b			192 (89)	217 (103)	243 (117)	269 (132)	295 (146)	320 (160)						
	210 ^b			199 (93)	226 (108)	253 (123)	279 (137)	306 (152)	333 (167)						
	240			206 (97)	234 (112)	262 (128)	290 (143)	318 (159)	346 (174)						
9Sg	15	3,000	(20,700)	101 (38)	106 (41)	111 (44)	116 (47)	121 (49)	126 (52)						
16,000 ft	30			121 (49)	131 (55)	142 (61)	152 (67)	163 (73)	173 (78)						
(4,880 m)	45			142 (61)	157 (69)	173 (78)	188 (87)	204 (96)	219 (104)						
	60			163 (73)	183 (84)	204 (96)	224 (107)	245 (118)	266 (130)						
	75 ^b			182 (83)	207 (97)	233 (112)	258 (126)	284 (140)	309 (154)						
	90 ^b			186 (86)	212 (100)	238 (114)	264 (129)	291 (144)	316 (158)						
	120 ^b			194 (90)	221 (105)	248 (120)	275 (135)	303 (151)	330 (166)						
	150 ^b			201 (94)	229 (109)	258 (126)	286 (141)	315 (157)	343 (173)						
	180 ^b			209 (98)	238 (114)	268 (131)	298 (148)	327 (164)	357 (181)						
	210 ^b			216 (102)	247 (119)	278 (137)	309 (154)	340 (171)	370 (188)						
	240			224 (107)	256 (124)	288 (142)	320 (160)	352 (178)	384 (196)						
10Sg	15	3,000	(20,700)	102 (39)	108 (42)	113 (45)	119 (48)	124 (51)	129 (54)						
18,000 ft	30			124 (51)	135 (57)	146 (63)	157 (69)	168 (76)	179 (82)						
(5,490 m)	45			146 (63)	163 (73)	179 (82)	196 (91)	212 (100)	228 (109)						
	60			169 (76)	190 (88)	212 (100)	234 (112)	256 (124)	278 (137)						
	75			191 (88)	218 (103)	246 (119)	273 (134)	300 (149)	327 (164)						
	90 ^b			203 (95)	233 (112)	264 (129)	294 (146)	324 (162)	354 (179)						
	120 ^b			211 (99)	242 (117)	274 (134)	305 (152)	337 (169)	367 (186)						

