

SPECIAL NOTICE
(SEPTEMBER 1, 1991)

Specification for Materials and Testing for Well Cements

API SPECIFICATION 10 (SPEC 10)
FIFTH EDITION, JULY 1, 1990

NOTICE

The Twenty-First Edition of Specification 10A supersedes Sections 1 through 12 and Appendix O of API Specification 10, Fifth Edition, dated July 1, 1990, and represents changes adopted at the 1990 Standardization Conference as reported in Circ. 1904 and subsequently approved by letter ballot.

Spec 10A covers the performance requirements for eight classes of oil well cements as well as testing procedures.

The remaining Appendices of Spec 10 are still in effect but, will be replaced by Recommended Practice 10B that has yet to be written by Committee 10.

Copies of Spec 10A, Specification of Well Cements, Twenty-First Edition, September 1, 1991, (Order Number 811-04455) may be purchased for \$20.00 per copy from the American Petroleum Institute, Publications Distribution Section, 1220 L Street, NW, Washington, DC 20005 — telephone (202) 682-8375, fax (202) 682-8537. Prepaid orders and invoice payments should be sent to American Petroleum Institute, Lockbox, 1970 Chain Bridge Road, McLean, Virginia 22109-60000.

American Petroleum Institute
1220 L Street, Northwest
Washington, DC 20005



Specification for Materials and Testing for Well Cements

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Issued by
AMERICAN PETROLEUM INSTITUTE
Production Department

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Attention Users: Portions of this publication have been changed from the previous edition. The location of changes have been marked with a bar in the margin, as shown to the left of this paragraph. In some cases the changes are significant, while in other cases the changes reflect minor editorial adjustments. The bar notations in the margins are provided as an aid to users as to those parts of this publication that have been changed from the previous edition, but API makes no warranty as to the accuracy of such bar notations.

This edition covers changes in *API Spec 10 (Fourth Edition, August 1, 1988): Specification for Materials and Testing for Well Cements*, adopted at the 1988 and 1989 Standardization Conferences as reported in CIRC PS-1857 and PS-1884, and subsequently approved by letter ballot.

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FOREWORD

API SPECIFICATION FOR WELL CEMENTS

a. This specification is under the jurisdiction of the API Committee on Standardization of Well Cements.

b. The purpose of this specification is to provide standards for well cements, well cement additives and well cement testing procedures.

c. Conversions of U.S. Customary units* to International System (SI) metric units are provided throughout the text of this specification in parentheses, e.g., 6000 ft (1830 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 specification. Products are to be marked in the units in which ordered unless there is agreement to the contrary between the purchaser and the manufacturer. The factors used for conversion of U.S. Customary units to SI units were taken from API Publication 2564 and are listed below:

1 cubic foot (cu ft)	=	0.02831685 cubic metre (m ³)
1 cubic foot per minute (cu ft/min)	=	0.4719474 litre per second (L/sec)
1 inch (in.)	=	25.4 millimetres (mm) exactly
1 foot (ft)	=	0.3048 metre (m) exactly
1 pound mass (lb.)	=	0.4535924 kilogram (kg)
1 pound per foot (lb/ft)	=	1.488164 kilograms per metre (kg/m)
1 pound per gallon (lb/gal)	=	0.1198264 kilogram per litre (kg/L)
1 pound force per square inch (psi) fluid pressure	=	6.894757 kilopascals (kPa)

*U.S. Customary Units—Units based upon the yard and the pound commonly used in the United States of America and defined by the National Bureau of Standards. Some 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.

1 lbf (pound-force)	=	0.00448 kilonewtons (kN)
1 pound force per square inch (psi) compressive strength	=	0.006894757 megapascals (MPa)
1 bbl per US ton	=	0.1752535 m ³ /t
degrees Fahrenheit (F)	=	[1.8 x degrees Celsius (°C)] + 32

d. Related publications are:

Spec 10D: Specification for Casing Centralizers.

Provides dimensional standards and test procedures for casing centralizers.

RP 10E: Recommended Practice for Application of Cement Lining to Steel Tubular Goods, Handling, Installation and Joining.

Provides standard procedures for plant application of cement lining to oil field tubular goods and recommended methods of joining cement-lined pipe.

Spec 13A: Specification for Oil-Well Drilling Fluid Materials.

Covers specifications and test procedures for barite, bentonite and attapulgit clay.

RP 13B: Recommended Practice for Standard Procedure for Testing Drilling Fluids.

Supersedes RP 29; covers standard procedures for testing drilling fluids.

Bul 13D: The Rheology of Oil-Well Drilling Fluids.

Provides information, procedures and example calculations to aid in applying rheological principles to liquid oil field drilling fluids.

e. Users of this document should be aware that the Specification portion covers Sections 1 through 12. Appendices A through R are Operating Test Procedures only.

f. Manufacturers interested in obtaining a monogram license for these materials should either write the API Dallas office at 2535 One Main Place, Dallas TX 75202-3904 for an application package or purchase a copy of the *Composite List of Manufacturers Licensed for Use of the API Monogram*, Order No. 811-00005.

SUGGESTIONS FOR ORDERING WELL CEMENTS

Order Placement. In placing orders for well cements to be manufactured in accordance with API Spec 10, the purchaser should specify the following on the purchase order:

1. Specification API Spec 10
2. Quantity
3. Class and type of well cement Section 2
4. Packages, handling and storage Section 11
5. Place of inspection Section 12

SECTION 1 SCOPE

Coverage. This specification covers requirements for manufacturing eight classes of well cements and application of the API monogram. Chemical and physical testing requirements are also included.

A well cement which has been manufactured and supplied according to this specification may be mixed and placed using water ratios or additives at the user's dis-

cretion. It is not intended that manufacturing compliance with this specification be based on such field conditions.

Appendixes A thru R cover optional testing procedures which may be used in association with specified applications.

SECTION 2 GENERAL

2.1 Classes and Types. Well cement shall be furnished in the following classes and types as specified on the purchase order:

Class A: Intended for use from surface to 6,000 ft (1830 m) depth,* when special properties are not required. Available only in ordinary type (similar to ASTM C 150, Type I).**

Class B: Intended for use from surface to 6,000 ft (1830 m) depth, when conditions require moderate to high sulfate-resistance. Available in both moderate (similar to ASTM C 150, Type II) and high sulfate-resistant types.

Class C: Intended for use from surface to 6,000 ft (1830 m) depth, when conditions require high early strength. Available in ordinary and moderate (similar to ASTM C 150, Type III) and high sulfate-resistant types.

Class D: Intended for use from 6,000 ft to 10,000 ft (1830 m to 3050 m) depth, under conditions of moderately high temperatures and pressures. Available in both moderate and high sulfate-resistant types.

Class E: Intended for use from 10,000 ft to 14,000 ft (3050 m to 4270 m) depth, under conditions of high temperatures and pressures. Avail-

able in both moderate and high sulfate-resistant types.

Class F: Intended for use from 10,000 ft to 16,000 ft (3050 m to 4880 m) depth, under conditions of extremely high temperatures and pressures. Available in both moderate and high sulfate-resistant types.

Class G: Intended for use as a basic well cement from surface to 8,000 ft (2440 m) depth as manufactured, or can be used with accelerators and retarders to cover a wide range of well depths and temperatures. No additions other than calcium sulfate or water, or both, shall be interground or blended with the clinker during manufacture of Class G well cement. Available in moderate and high sulfate-resistant types.

Class H: Intended for use as a basic well cement from surface to 8,000 ft (2440 m) depth as manufactured, or can be used with accelerators and retarders to cover a wide range of well depths and temperatures. No additions other than calcium sulfate or water, or both, shall be interground or blended with the clinker during manufacture of Class H well cement. Available in moderate and high sulfate-resistant types.

*Depth limits are based on the conditions imposed by the casing-cement specification tests (Schedules 1, 4, 5, 6, 8, 9), and should be considered as approximate values.

**ASTM C 150: Specification for Portland Cement. Copies of this specification are available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

2.2 Definitions. Cement, in the Classes A, B, C, D, E and F covered by this specification shall be defined as the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition. At the option of the manufacturer, processing additions[†] may be used in the manufacture of the cement, provided such materials in the amounts used have been shown to meet the requirements of ASTM C465. Further, at the option of the manufacturer suitable set-modifying agents[‡] may be interground or blended during manufacture of Classes D, E and F.

Cement, in the Classes G and H shall be defined as the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates to which no additions other than calcium sulfate or water, or both shall be interground or blended with clinker during manufacture.

Well cements include any class of cement defined above and may also include optional additives to obtain necessary performance. No specifications are written for blends of well cement and optional additives.

2.3 Chemical Requirements. Well cement shall conform to all of the respective chemical requirements given in Table 2.1 for the class and type of well cement ordered.

2.4 Physical Requirements. Well cement shall conform to the respective physical requirements given in Table 2.2 for the class of well cement ordered.

[†]A suitable processing addition or set-modifying agent shall be defined as one which has no deleterious effect on the durability of the hardened cement and causes no retrogression in strength.

2.5 Well Depth and Cementing Time. Fig. 2.1 shows the total cementing times for various quantities of well cement under conditions stated and for the thickening time requirements given in Table 2.2. This information is supplied for the guidance of the user in selecting the cement best suited to a particular job, giving due consideration to well conditions and estimated cementing time.

2.6 Mandatory Sampling, Tests, and Equipment.

WELL CEMENTS

All well cements manufactured under this specification shall comply with the mandatory test requirements as indicated in Table 2.3.

These mandatory requirements are:

- a. Sampling procedure.
- b. Tests for:
 - (1) Free water
 - (2) Compressive strength
 - (3) Soundness
 - (4) Fineness
 - (5) Thickening time

Accordingly, any manufacturer who desires to produce API well cement shall be prepared to sample as prescribed and to conduct the above tests. He shall also have in his possession the equipment specified in Table 2.3.

In multi-plant manufacturing companies, the company-owned equipment need only be available at a centralized single laboratory in each country in which the cement is manufactured.

	1	2	3	4	5	6	7
				Cement Class			
		A	B	C	D,E,F	G	H
ORDINARY TYPE (O)							
Magnesium oxide (MgO), maximum, per cent.....	6.0	-----	6.0	-----	-----	-----	-----
Sulfur trioxide (SO ₃), maximum, per cent ¹	3.5	-----	4.5	-----	-----	-----	-----
Loss on ignition, maximum, per cent.....	3.0	-----	3.0	-----	-----	-----	-----
Insoluble residue, maximum, per cent.....	0.75	-----	0.75	-----	-----	-----	-----
Tricalcium aluminate (3CaO•Al ₂ O ₃), maximum, per cent ²	-----	-----	15	-----	-----	-----	-----
MODERATE SULFATE-RESISTANT TYPE (MSR)							
Magnesium oxide (MgO), maximum, per cent.....	-----	6.0	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO ₃), maximum, per cent.....	-----	3.0	3.5	3.0	3.0	3.0	3.0
Loss on ignition, maximum, per cent.....	-----	3.0	3.0	3.0	3.0	3.0	3.0
Insoluble residue, maximum, per cent.....	-----	0.75	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (3CaO•SiO ₂), { maximum, per cent ²	-----	-----	-----	-----	58	58	58
Tricalcium silicate (3CaO•SiO ₂), { minimum, per cent ²	-----	-----	-----	-----	48	48	48
Tricalcium aluminate (3CaO•Al ₂ O ₃), maximum, per cent ²	-----	8	8	8	8	8	8
Total alkali content expressed as sodium oxide (Na ₂ O) equivalent, maximum, per cent ³	-----	-----	-----	-----	0.75	0.75	0.75
HIGH SULFATE-RESISTANT TYPE (HSR)							
Magnesium oxide (MgO), maximum, per cent.....	-----	6.0	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO ₃), maximum, per cent.....	-----	3.0	3.5	3.0	3.0	3.0	3.0
Loss on ignition, maximum, per cent.....	-----	3.0	3.0	3.0	3.0	3.0	3.0
Insoluble residue, maximum, per cent.....	-----	0.75	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (3CaO•SiO ₂), { maximum, per cent ²	-----	-----	-----	-----	65	65	65
Tricalcium silicate (3CaO•SiO ₂), { minimum, per cent ²	-----	-----	-----	-----	48	48	48
Tricalcium aluminate (3CaO•Al ₂ O ₃), maximum, per cent ²	-----	3	3	3	3	3	3
Tetracalcium aluminoferrite (4CaO•Al ₂ O ₃ •Fe ₂ O ₃) plus twice the tricalcium aluminate (3CaO•Al ₂ O ₃), maximum, per cent ²	-----	24	24	24	24	24	24
Total alkali content expressed as sodium oxide (Na ₂ O) equivalent, maximum, per cent ³	-----	-----	-----	-----	0.75	0.75	0.75

²The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds. When the ratio of the percentages of Al_2O_3 to Fe_2O_3 is 0.64 or less, the C_3A content is zero. When the Al_2O_3 to Fe_2O_3 ratio is greater than 0.64, the compounds shall be calculated as follows:

$$C_3S = (4.07 \times \% \text{CaO}) - (7.60 \times \% \text{SiO}_2) - (6.72 \times \% \text{Al}_2\text{O}_3) - (1.43 \times \% \text{Fe}_2\text{O}_3) - (2.85 \times \% \text{SO}_3)$$

$$\text{ss}(\text{C}_4\text{AF} + \text{C}_2\text{F}) = (2.10 \times \% \text{Al}_2\text{O}_3) + (1.70 \times \% \text{Fe}_2\text{O}_3) \text{ and } \text{C}_5\text{S} = (4.07 \times \% \text{CaO}) - (7.60 \times \% \text{SiO}_2) - (4.48 \times \% \text{Al}_2\text{O}_3) - (2.86 \times \% \text{Fe}_2\text{O}_3) - (2.85 \times \% \text{SO}_3)$$
$$\text{Na}_2\text{O equivalent} = (0.658 \times \% \text{K}_2\text{O}) + \% \text{Na}_2\text{O}$$

TABLE 2.2
PHYSICAL REQUIREMENTS
(Parenthetical values are in metric units)

1	2	3	4	5	6	7	8	9	10	11	12
Well Cement Class				A	B	C	D	E	F	G	H
Water, per cent by weight of well cement				46	46	56	38	38	38	44	38
Soundness (autoclave expansion), maximum, per cent (Section 4)				0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Fineness* (specific surface), minimum, m ² /kg				150	160	220	.....	.....	.....	.....	.....
Free water content, maximum, mL (Section 6)				.....	.....	.....	.....	.....	.....	3.5**	3.5**
Compressive Strength Test, Eight Hour Curing Time (Section 7)	Schedule Number, Table 7.1	Curing Temp, F (°C)	Curing Pressure, psi (kPa)	Minimum Compressive Strength, psi (MPa)							
	.....	100 (38)	Atmos.	250 (1.7)	200 (1.4)	300 (2.1)	.....	.....	.....	300 (2.1)	300 (2.1)
	.....	140 (60)	Atmos.	.....	.....	.....	.....	.....	.....	1500 (10.3)	1500 (10.3)
	6S	230 (110)	3000 (20700)	.....	.....	.....	500 (3.5)	.....	.....	.....	.....
	8S	290 (143)	3000 (20700)	.....	.....	.....	.....	500 (3.5)	.....	.....	.....
Compressive Strength Test, Twelve Hour Curing Time (Section 7)				8S	290 (143)	3000 (20700)	.....	.....	.....	.....	.....
Compressive Strength Test, Twenty-four Hour Curing Time (Section 7)	Schedule Number, Table 7.1	Curing Temp, F (°C)	Curing Pressure, psi (kPa)	Minimum Compressive Strength, psi (MPa)							
	.....	100 (38)	Atmos.	1800 (12.4)	1500 (10.3)	2000 (13.8)	.....	.....	.....	.....	.....
	4S	170 (77)	3000 (20700)	.....	.....	.....	1000 (6.9)	1000 (6.9)	.....	.....	.....
	6S	230 (110)	3000 (20700)	.....	.....	.....	2000 (13.8)	.....	1000 (6.9)	.....	.....
	8S	290 (143)	3000 (20700)	.....	.....	.....	.....	2000 (13.8)	.....	.....	.....
	9S	320 (160)	3000 (20700)	.....	.....	.....	.....	.....	1000 (6.9)	.....	.....
	10S	350 (177)	3000 (20700)	.....	.....	.....	.....	.....	.....	.....	.....
Pressure Temperature Thickening Time Test (Section 8)	Specification Test Schedule Number, Table 8.2	Maximum Consistency 15-30 Minute Stirring Period, Bc†		Minimum Thickening Time, minutes***							
	1	30	90	90	90	90	.....	.....	.....	.....	.....
	4	30	90	90	90	90	.....	.....	.....	.....	.....
	5	30	.....	.....	.....	.....	.....	.....	.....	90	90
	5	30	.....	.....	.....	.....	.....	.....	.....	120 max.†	120 max.†
	6	30	.....	.....	.....	100	.....	100	100	.....	.....
	8	30	.....	.....	.....	.....	.....	154	.....	.....	.....
	9	30	.....	.....	.....	.....	.....	.....	190	.....	.....

*Determined by Wagner turbidimeter apparatus described in ASTM C 115: *Fineness of Portland Cement by the Turbidimeter*.

**Based on 250 mL volume, percentage equivalent of 3.5 mL is 1.4%.

†Bearden units of slurry consistency (Bc).

Bc — Bearden units of consistency obtained on a pressurized consistometer as defined in Section 8 of API Spec 10 and calibrated as per the same section.

ABc — Bearden units of consistency obtained on an atmospheric pressure consistometer as defined in Section 9 of API Spec 10 and calibrated as per the same section.

The relationship between Bc and ABc is approximately $Bc \times 0.69 = ABc$. This relationship is valid only for units of consistency less than 30 Bc.

***Thickening time requirements are based on 75 percentile values of the total cementing times observed in the casing survey, plus a 25 per cent safety factor.

†Maximum thickening time requirement for Schedule 5 is 120 minutes.

TABLE 2.3
MANDATORY TEST EQUIPMENT FOR WELL CEMENT MANUFACTURERS
 (See Par. 2.6)

1	2	3	4
Test or Preparation	Well Cement Classes	Reference	Required Equipment
Sampling	All	Sect. 3	Apparatus specified in Par. 3.2
Soundness	A,B,C,D,E, F,G,H	Sect. 4	Autoclave and auxiliary equipment as specified in the latest edition of ASTM C 151: <i>Autoclave Expansion of Portland Cement</i> .*
Fineness	A,B,C	Sect. 4	Wagner Turbidimeter and auxiliary equipment as specified in the latest edition of ASTM C 115: <i>Fineness of Portland Cement by the Turbidimeter</i> .*
Slurry Preparation**	All	Sect. 5	Apparatus specified in Par. 5.3, 5.4, and 5.5.
Free Water	G,H	Sect. 6	Apparatus specified in Par. 6.1
Compressive Strength	A,B,C,G,H	Sect. 7	Apparatus specified in Par. 7.1, except pressure vessel and pyrometer of Par. 7.1.d.2 and 7.1.f.2, respectively.
Compressive Strength	D,E,F,G,H	Sect. 7	Apparatus specified in Par. 7.1.
Thickening Time	All	Sect. 8	Pressurized consistometer specified in Par. 8.1.

*ASTM Standards.

**Equipment necessary to prepare slurry for free water, compressive strength and thickening time tests.

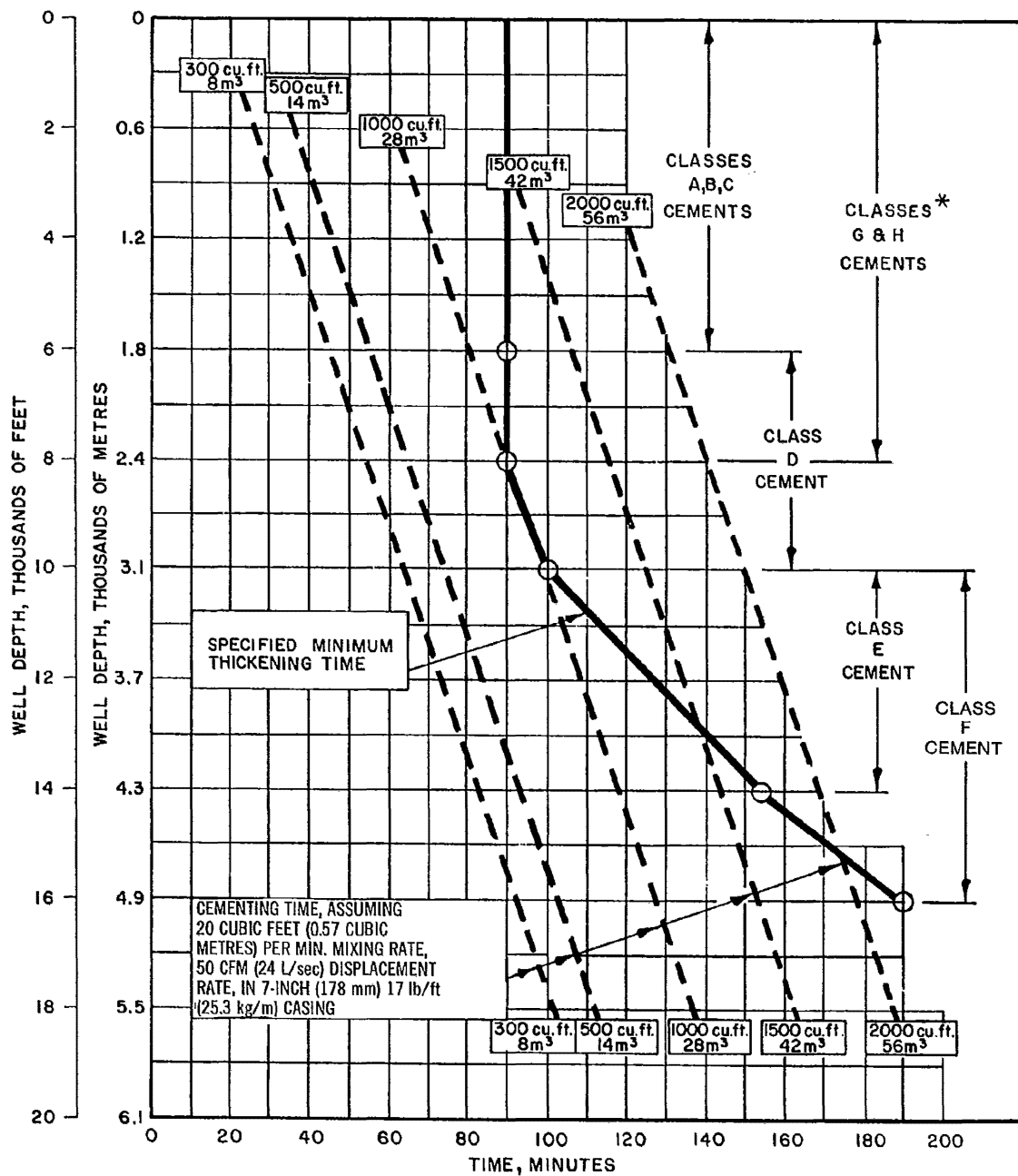


FIG. 2.1
WELL DEPTH AND CEMENTING TIME RELATIONSHIPS
(See Par. 2.5)

*Specified maximum thickening time—120 minutes.

SECTION 3 SAMPLING (Specification Requirement)

3.1 Sampling. In order to secure a sample of well cement which is truly representative of the lot in question, the following well cement-sampling equipment and methods are recommended.

3.2 Apparatus.

- a. **Sacked Cement.** A tube sampler, as shown in Fig. 3.1, shall be used for sampling sacked cement.
- b. **Bulk Cement.** Either of the following samplers shall be used:
 - (1) A tube sampler, similar to that shown in Fig. 3.2, consisting of two polished brass telescopic tubes. Registering slots are opened or closed by rotation of the inner tube. The outer tube is provided with a sharp point to facilitate penetration. The length shall be appropriate to the vessel being sampled.
 - (2) A small grocers scoop for sampling during loading or unloading operations.

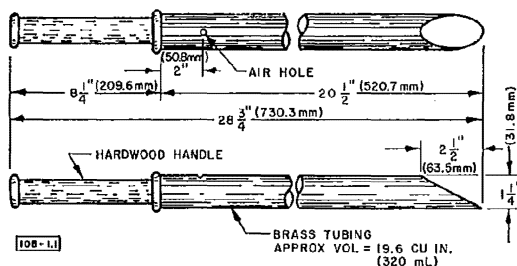


FIG. 3.1
TUBE SAMPLER FOR SACKED CEMENT

3.3 Procedure.

- a. **Sacked Cement.** Test samples must be forwarded to the laboratory promptly in clean air-tight,

moisture-proof containers. This container should be made of metal or some other rigid material and should have a poly-olefin liner to assure maximum protection. Ordinary paper or cloth sacks must not be used. Each sample should be marked plainly and identified completely on the outside of the body of the container as to source and date of sampling. Do not mark the lids of containers, since the lids may be readily interchanged and lead to confusion. Also, complete identification should be enclosed in the container. As it is important to keep variable influences at a minimum, the sample should be kept in airtight, moisture-proof containers from the time it is taken until it is tested or made into specimens. Reserve portions of samples should be likewise protected as long as they are kept.

Prior to testing, a sample should be thoroughly mixed and passed through the No. 20 (850 μ m) sieve, and brought to room temperature. All foreign matter and lumps that do not pulverize easily in the fingers must be discarded. Make a note of type of material if other than cement.

- b. **Bulk Cement.** The various procedures given in ASTM C 188: *Sampling and Acceptance of Hydraulic Cement*, shall be used for sampling bulk cement.

3.4 Sample Size. The sample size of cement required to conduct all specification tests is about 25 pounds.

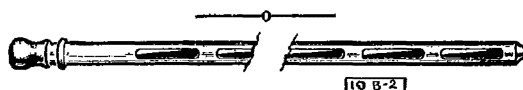


FIG. 3.2
TUBE SAMPLER FOR BULK CEMENT

SECTION 4 SOUNDNESS AND FINENESS TESTS (Specification Test)

4.1 Soundness Test. Test for soundness of well cement shall be made in accordance with the testing procedure in the latest edition of ASTM C 151: *Autoclave Expansion of Portland Cement*.

Acceptance requirements for the soundness test (autoclave expansion) are 0.80 percent.

4.2 Fineness Tests. Tests for fineness of well cement shall be made in accordance with the testing procedure in the latest edition of ASTM C 115: *Fineness of Portland Cement by the Turbidimeter*.

Acceptance requirements for the fineness test are given in Table 4.2.

**TABLE 4.2
ACCEPTANCE PARAMETERS FOR
FINENESS TEST**

Cement Class	Fineness (Specific Surface) Minimum m ² /kg
A	150
B	160
C	220
D,E,F,G,H	Not Required

SECTION 5

PREPARATION OF SLURRY

(Specification Requirement)

Apparatus

5.1 Scales. The indicated load on scales shall be accurate within a tolerance of 2 g for loads of 2000 g or more, and within 0.1 percent of the indicated load for loads smaller than 2000 g, except that for new scales the tolerances on accuracy shall be one-half of these values. The sensibility reciprocal* shall not be greater than twice the permissible tolerance on scale accuracy.

5.2 Weights. Weights shall be accurate within the tolerance shown in Table 5.1, except that new weights shall be accurate within one-half of such tolerances. On beam-type scales where the weights are on the beam, the indicated weights shall conform to the requirements given in Par. 5.1.

TABLE 5.1
PERMISSIBLE VARIATION IN WEIGHTS

1	2
Weight, Grams	Variation, Plus or Minus, Grams
1000	0.50
500	0.35
300	0.30
200	0.20
100	0.15
50	0.10

5.3 Graduate Glass Cylinder. Graduated glass cylinders shall be large enough to measure and deliver, in a single operation, the required volume of mixing water at 68 F (20 °C). The variations in volume shall not exceed ± 0.2 percent. The graduations shall be subdivided to at least 5 mL. The main graduation lines shall be complete circles, and shall be numbered. The intermediate graduations shall extend around a minimum of one-fifth of the circumference, and the smallest graduations shall extend around a minimum of one-seventh of the circumference of the cylinder.

5.4 Mixing Devices. The mixing device¹ for preparation of well cement slurries shall be a 1 qt size (approximately 1 L), two speed propeller-type mixer capable of rotating 4000 rpm (66.7 r/s) or greater under no load on "slow" speed and 12,000 rpm (200 r/s) or greater under no load on "high" speed. Examples of mixing devices in common use are shown in Figure 5.1. The propeller blade shall be constructed of corrosion-resistant metal. The mixing container shall be constructed of either corrosion-resistant metal or glass.

*The sensibility reciprocal is obtained by determining the amount of weight required to move the position of equilibrium (rest point) of the balance pointer one division of the scale.

A ten percent (10%) or greater weight loss due to wear of a corrosion-resistant non-treated metal propeller blade may result in a thickening time change of ten percent (10%) or greater. It is recommended that the non-treated blade be replaced with a new blade when a ten percent (10%) or greater weight loss is observed.

An alternate 1 qt size (approximately 1 L) mixer¹ shall consist of an electric motor capable of rotating at 20,000 rpm (333 r/s) or greater with no load. The power to the motor is routed through a regulating device capable of controlling the speed of the mixer as required.

The power to the regulating device is controlled by a timer which can either supply power continuously or when activated, can turn off power to the regulating device after 35 seconds. A tachometer is permanently attached which is capable of displaying the rotational speed of the electric motor during operation to an accuracy of ± 100 rpm (± 1.7 r/s).

Procedure

5.5 Screening. The sample of cement to be tested shall be passed through an 850 micrometre (No. 20) sieve, meeting the requirements given in ASTM E 11: *Wire-Cloth Sieves for Testing Purposes*, in order to break up lumps and remove foreign materials. The materials retained on the screen shall be weighed, the weight recorded as a percent of the total cement sieved, and a notation made as to its characteristics. These materials shall then be discarded.

5.6 Mixing Water. For reference tests, freshly distilled water or distilled water essentially free of carbon dioxide shall be used. For routine tests, any potable water may be employed. The mixing water shall be measured in a graduated glass cylinder (see Par. 5.3) or weighed by means of scales and weights (see Par. 5.1 and 5.2).

5.7 Temperature of Water and Cement. The temperature of the water prior to mixing shall be 73 ± 2 F (22.8 ± 1.1 °C) and that of the cement shall be 73 ± 2 F (22.8 ± 1.1 °C).

5.8 Water Percentage. The water percentage by weight to be added for each class of well cement shall conform to the values given in Table 5.2. No water shall be added to compensate for evaporation, wetting, etc.

¹Information on testing devices in common use is available from The American Petroleum Institute, 2535 One Main Place, Dallas TX 75202-3904.

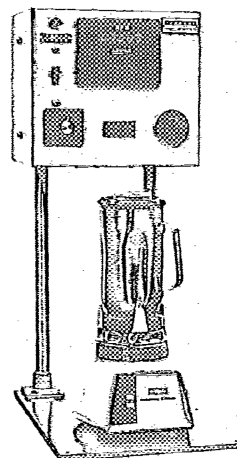
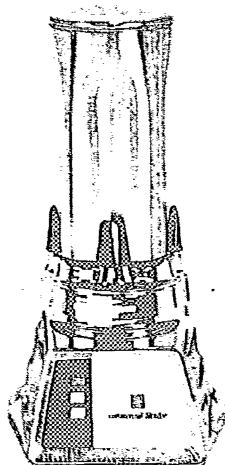


FIG. 5.1
EXAMPLES OF TYPICAL CEMENT MIXING DEVICES

TABLE 5.2
CEMENT SLURRY COMPOSITION

1 API CLASS Cement	2 Water Per cent By Weight of Cement	3 Water,	
		Gallons per Sack	(Litres per Sack)
A & B	46	5.19	(19.6)
C	56	6.32	(23.9)
D, E, F, & H	38	4.29	(16.2)
G	44	4.97	(18.8)

5.9 Mixing Cement and Water. Mixing of the cement and the requisite percentage of water at the given temperature shall conform to the following mixing procedure:

The required quantity of water shall be placed in the mixing container, the mixer turned on "slow" speed [4000 ± 200 rpm (66.7 ± 3.3 r/s)¹], and the cement sample added in not more than 15 s.

After all of the cement has been added to the water, the cover shall be placed on the mixing container and mixing shall be continued under "high" speed [12000 ± 500 rpm (200 ± 8.3 r/s)¹] for 35 s.

¹Rotational speed under load is measured using either a resonant reed or a photoelectric tachometer.

5.10 Volume of Slurry. The volume of slurry in the mixer shall be 600 mL.

TABLE 5.3
SLURRY VOLUME REQUIREMENTS

1 Slurry, Volume, mL	2 Com- po- nents	3 API Class of Cement			
		A & B, grams	C, grams	D, E, F & H, grams	G, grams
600	Water	355	383	327	349
	Cement	772	684	860	792

SECTION 6 DETERMINATION OF FREE WATER CONTENT OF SLURRY

(Specification Test)

6.1 Free Water Content Procedure. Cement slurry, prepared according to Sect. 5, shall be poured immediately into an atmospheric pressure consistometer* and stirred at 80 F (27 °C) for a period of 20 minutes.† The slurry shall then be remixed for an additional 35 s at high speed in a 1 qt Waring Blendor or equivalent mixing device. The slurry shall then be used to fill a clean, dry 250 mL graduated glass cylinder and sealed to prevent evaporation. The temperature to which the graduated cylinder is exposed shall be 73 ± 2 F (22.8 ± 1.1 °C). The 0-250 mL graduated portion of the cylinder shall not be less than 232 mm nor more than 248 mm in length. The cylinder shall be set on a $\frac{1}{4}$ in. (6.4 mm) steel plate which is supported by a 1 in. (25.4 mm) foam rubber pad.** The steel plate and pad shall be approximately 8 in. by 12 in. (approximately 200 mm by 300

mm). The supernatant water developed after standing quiescent for 2 hr shall be removed by either pipetting or decanting and measured in a graduated glass cylinder of proper size. It shall be expressed in millilitres (mL) and designated the *Free Water Content*.

6.2 Acceptance Requirements. Classes G & H cements shall not exceed 3.5 mL (1.4%) of free water (testing is not required for Classes A, B, C, D, E or F cements).

*Refer to Section 9 of this publication for test procedure.

**Upholsterer's medium density flat stock foam rubber 1 in. (approximately 25 mm) thickness.

†Refer to Par. L.5, Appendix L of this publication.

SECTION 7

COMPRESSIVE STRENGTH TESTS

(Specification Test)

NOTE: Reliable compressive strength test results depend upon careful observance of all specified requirements and procedures. Improper centering of specimens resulting in oblique fractures will often cause lower strength results. A specimen so broken shall be considered as manifestly faulty if there is a strength difference of more than 10 percent from the average of all test specimens made from the same sample and tested in the same period.

7.1. Apparatus.*

- a. **Sieve:** The sieve shall be 850 micrometre (No. 20) U.S. Standard Sieve Series, meeting requirements given in ASTM E 11: *Wire-Cloth Sieves for Testing Purposes*.
- b. **Specimen Molds and Compressive Strength-Testing Machine:** Molds and testing machine for the compressive strength shall conform to the requirements in ASTM C 109: *Compressive Strength of Hydraulic Cement Mortars*, except that the testing machine shall be a hydraulic type machine (Par. 7.9a). The molds shall be checked for tolerances and the testing machine shall be calibrated at least once every two years or more frequently if an error is suspected.
- c. **Base and Cover Plates:** Plate glass or noncorroding metal plates having a minimum thickness of $\frac{1}{4}$ in. (approximately 6 mm) shall be used.
- d. **Water Curing Bath:** A curing bath or tank having dimensions suitable for the complete immersion of compressive strength molds in water and operable within ± 3 F (± 2 °C) of the prescribed test temperatures shall be employed. The two types of water curing baths are:
 - (1) A non-pressure vessel suitable for curing specimens at temperatures of 180 F (82 °C) or less shall have a suitable agitator or circulating system to insure a uniform vessel temperature.
 - (2) A pressure vessel suitable for curing specimens at temperatures up to and including 380 F (193 °C) and at pressures that can be controlled between 0 and 3000 psi (20700 kPa). The vessel shall have sufficient heating capacity to raise the temperature uniformly from 80 F (27 °C) to 340 F (174 °C) in 75 min.
- e. **Cooling Bath:** The cooling bath shall be such that the specimen to be cooled from the curing temperature can be completely submerged in water maintained at 80 ± 5 F (27 ± 3 °C).
- f. **Temperature Indicators:****
 - (1) Thermometer, range 0 to 220 F (-18 to 104 °C), with minimum scale divisions not exceeding 2 F (1 °C) shall be used in non pressure-type vessels.
 - (2) Pyrometer, range 0 to 400 F (-18 to 204 °C), with minimum scale divisions not exceeding 5 F (3 °C) calibrated to accuracy of plus or minus one percent, shall be used in pressure type vessels.
- g. **Puddling Rod:** A glass or noncorroding metal puddling rod shall be approximately 8 in. (203 mm) long by $\frac{1}{4}$ in. (6 mm) in diameter.
- h. **Grease:** Any grease which possesses the following properties when subjected to test temperatures and pressures specified in Table 7.1 or D.1 may be used to seal specimen molds. The grease shall have (1) a consistency to permit ease of application, (2) good adhesive properties to prevent leakage, and (3) water resistance. The grease shall be noncorrosive in the temperature range of 80 to 400 F (27 to 204 °C).

Procedure***

7.2 Preparation of Molds. The molds used for compressive strength test specimens shall be prepared as follows:

The interior faces of the molds and the contact surfaces of the plates shall be thinly covered with grease. The contact surfaces of the halves of each mold shall also be coated with grease to make the joint water tight when assembled. Excess grease shall be removed from the interior faces of the assembled molds, giving particular attention to the corners. The molds shall be placed on a thinly greased plate. It is necessary that grease be applied to the exterior contact line of the mold and the base plate.

7.3 Preparation and Placement of Slurry.

- a. **Slurry.** The cement slurry shall be prepared in accordance with Sect. 5.
- b. **Placing Slurry in Molds.** The slurry shall be placed in the prepared molds in a layer equal to one-half of the mold depth and puddled 25 times per specimen with a puddling rod. The slurry

*For the convenience of those making the tensile strength test, molds and testing machine should conform to requirements in ASTM C 190: *Tensile Strength of Hydraulic Cement Mortars*. Tensile strength equipment is not mandatory.

**See Appendix O for Calibration Procedures for Thermocouples and Temperature Indicators.

***See Appendix K for arctic cementing testing procedures.

shall be placed in all the specimen compartments before commencing the puddling operation. After puddling the layer, the remaining slurry shall be stirred by hand using a puddling rod or spatula to eliminate segregation, the molds filled to overflowing, and puddled as for the first layer. After puddling, the excess slurry shall be struck off even with the top of the mold, using a straight-edge. Specimens in molds which show evidence of leaking shall be discarded. A greased cover plate shall be placed on top of the mold. For one test determination, not less than three specimens shall be employed.

7.4 Curing Periods. The curing period is the elapsed time from subjecting the specimen to temperature in the curing vessel to testing the specimen for strength.

- a. For specimens cured at atmospheric pressure, the curing period starts when specimens are initially placed in the curing bath, immediately after slurry has been placed in the molds. The curing period ends when specimens are tested for strength.
- b. For specimens cured at pressures above atmospheric, the curing period starts with the initial application of pressure and temperature, to be applied immediately after specimens are sealed in the curing vessel. The curing period ends when specimens are tested for strength.
- c. The specified curing periods for test specimens are 8 and 24 hr.

Curing Temperatures and Pressures

7.5 Curing Below 180 F (82 °C). For curing at atmospheric pressure and temperatures of 180 F (82 °C) or less, one or more of the following temperatures are recommended: 80, 100, 120, 140, 160, 180 F (27, 38, 49, 60, 71, 82 °C). For curing at pressures above atmospheric and temperatures of 170 F (77 °C) or less Schedule 4S is specified (see Table 7.1).

7.6 Curing Above 180 F (82 °C). For curing at temperatures above 180 F (82 °C), one or more of the following schedules (see Table 7.1) are specified: 6S, 8S, 9S, 10S.

7.7 Curing at Atmospheric Pressure. For curing at atmospheric pressure, the test specimens, immediately after being placed in molds and covered, shall be immersed in a water bath maintained at the curing temperature.

- a. Where specimens are to be tested at ages of less than 24 hr, they shall be removed from the curing bath approximately 45 min before the age at which they are to be tested, immediately removed from their molds, and placed in a water bath maintained at 80 ± 5 F (27 ± 3 °C) for approximately 35 min.

- b. Where specimens are to be tested at ages of 24 hr or more, they shall be removed from the curing bath 20 to 23 hr after the cement slurry is initially mixed, immediately removed from their molds, and returned to the curing bath. They shall remain in the curing bath until approximately 45 min prior to the age at which they are to be tested, at which time they shall be transferred to a water bath and maintained at 80 ± 5 F (27 ± 3 °C) for approximately 35 min.

7.8 Curing at Pressures Above Atmospheric. For curing pressures greater than atmospheric, the test specimens, immediately after molding and covering, shall be immersed in water at 80 ± 5 F (27 ± 3 °C) in the pressure vessel. Heat and pressure shall be applied in accordance with the appropriate schedule as recommended in Par. 7.5 and 7.6 herein and in Table 7.2. The maximum scheduled temperature and pressure shall be maintained as shown in footnotes 1 and 2 of Table 7.1 until 1 hr and 45 min prior to the age at which the specimens are to be tested, at which time heating shall be discontinued. During the next 60 min, the temperature shall be decreased to 200 F (93 °C) or less without release of the pressure other than that caused by thermal contraction. At 45 min prior to the age at which specimens are to be tested, the pressure then remaining shall be released gradually (to avoid damaging specimens) and the specimens then removed from molds, transferred to a water bath, and maintained at 80 F (27 °C) for approximately 35 min.

7.9 Specimen Testing. Cube specimens shall be tested immediately after removal from the cooling-bath water. The testing procedure shall be in accordance with ASTM C 109-89: *Compressive Strength of Hydraulic Cement Mortars*, Sect. 10.6.2, 10.6.3, 11 and 12, except that:

- a. A hydraulic testing machine shall be used and the rate of loading for normal strength specimens shall be 4000 psi (16000 lbf) (71.7 kN) per minute. For specimens of low strength, 500 psi (3.5 MPa) or less, a 1000 psi (4000 lbf) (17.9 kN) per minute rate shall be used. When the ultimate strength is approached, no readjustment in the machine control shall be made.
- b. In the calculation of compressive strengths, variations from the specified cross-sectional area [4.00 sq. in. (2580 mm²)] shall be disregarded unless deviations of $\frac{1}{16}$ in. (1.6 mm) or more from the specified linear dimension of 2.00 in. (50.8 mm) are reported. The compressive strength of all acceptable test specimens (see ASTM C109, Sect. 10) made from the same sample and tested at the same period shall be averaged and reported to the nearest 10 psi (0.1 MPa).

7.10 Physical requirements for compressive strength are shown in Table 7.2.

TABLE 7.1
SPECIFICATION TEST SCHEDULES FOR CURING COMPRESSIVE STRENGTH SPECIMENS

1	2	3	4	5	6	7	8	9	10	11	12	13
Schedule Number	Depth, ft (m)	Pressure, ¹ psi (kPa)	TEMPERATURE, F (°C)									
			Elapsed Time from First Application of Heat and Pressure, Hours: Minutes									
			0:30	0:45	1:00	1:15	1:30	2:00	2:30	3:00	3:30	4:00 ²
4S	6,000 (1830)	3000 (20700)	116 (47)	120 (49)	124 (51)	128 (53)	131 (55)	139 (59)	147 (64)	155 (68)	162 (72)	170 (77)
(Schedule 4S is specified for Classes D and E Well Cements, Table 2.2)												
6S	10,000 (3050)	3000 (20700)	133 (56)	148 (64)	154 (68)	161 (72)	167 (75)	180 (82)	192 (89)	205 (96)	218 (103)	230 (110)
(Schedule 6S is specified for Classes D and F Well Cements, Table 2.2)												
8S	14,000 (4270)	3000 (20700)	153 (67)	189 (87)	210 (99)	216 (103)	223 (106)	236 (113)	250 (121)	263 (128)	277 (136)	290 (143)
(Schedule 8S is specified for Classes E and J Well Cements, Table 2.2)												
9S	16,000 (4880)	3000 (20700)	164 (73)	206 (97)	248 (120)	254 (123)	260 (127)	272 (133)	284 (140)	296 (147)	308 (153)	320 (160)
(Schedule 9S is specified for Class F Well Cement, Table 2.2)												

¹The test pressure shall be applied as soon as specimens are placed in the pressure vessel and maintained at the given pressure within the following limits for the duration of the curing period:

Schedule 4S through 10S 3000 ±500 psi (20700 ±3400 kPa)

²Final temperature (Col. 13) shall be maintained ± 3 F (± 2 °C) throughout the remainder of the curing period.

NOTE: See Table D.1 for operating test schedules.

TABLE 7.2
MINIMUM COMPRESSIVE STRENGTH REQUIREMENTS

Cement Class	Schedule No.	Curing Temp.		Curing Pressure		Compressive Strength — psi (MPa) at Indicated Curing Time	
		F	(°C)	psi	(kPa)	Eight Hour	Twenty-four Hour
A	—	100	(38)	Atmos.	—	250 (1.7)	1800 (12.4)
B	—	100	(38)	Atmos.	—	200 (1.4)	1500 (10.3)
C	—	100	(38)	Atmos.	—	300 (2.1)	2000 (13.8)
D	4S	170	(77)	3000 (20700)	—	—	1000 (6.9)
	6S	230	(110)	3000 (20700)	500 (3.5)	—	2000 (13.8)
E	4S	170	(77)	3000 (20700)	—	—	1000 (6.9)
	8S	290	(143)	3000 (20700)	500 (3.5)	—	2000 (13.8)
F	6S	230	(110)	3000 (20700)	—	—	1000 (6.9)
	9S	320	(160)	3000 (20700)	500 (3.5)	—	1000 (6.9)
G,H	—	100	(38)	Atmos.	—	300 (2.1)	—
	—	140	(60)	Atmos.	—	1500 (10.3)	—

SECTION 8 THICKENING TIME TESTS

(Specification Test)

NOTE: Thickening time tests are designed to determine the length of time a given cement slurry remains in a fluid state under given laboratory conditions, and thus serve as a method of comparing various well cements. Following is a description of the recommended test methods.

PRESSURIZED CONSISTOMETER

8.1 Apparatus

- a. Pressurized consistometer unit¹ shall be used. This apparatus consists essentially of a rotating cylindrical slurry container equipped with a stationary paddle assembly, all enclosed in a pressure chamber capable of withstanding the pressures and temperatures described herein. The space between the slurry container and the walls of the pressure container should be completely filled with a hydrocarbon oil having a flash point that satisfactorily meets the safety requirements of the organization performing the test. The selected oil should also have the following physical properties:

Viscosity	= 49-350 SSU @ 100F (7-75cSt)
Specific Heat	= 0.5-0.58 Btu/lb-F (0.28 -0.32 Cal/g-C)
Thermal Conductivity	= 0.0685-0.0770 Btu/h-ft-F (0.0196-0.0220 Cal/s-cm-C)
Specific Gravity	= 0.85-0.91

A heating element capable of raising the temperature of this oil bath at the rate of at least 5 F (3 °C) per min is provided. Thermocouples are provided for determining the temperature of the oil bath and also that of the cement slurry.* The slurry container is rotated at a speed of 150 rpm (2.5 r/s) $\pm$ 15 rpm (.25 r/s). The consistency of the cement slurry is indicated by the amount of deformation of a standardized coil spring connecting the stirring paddle and a stationary head. The stirring paddle and all metal parts of the slurry container exposed to the slurry are made of corrosion-resistant alloys.

- b. Interval Counter: A stopwatch is satisfactory.

8.2 Calibration. The potentiometer mechanism and the voltage measuring circuit which indicates consistency shall be calibrated by using a weight-loaded type potentiometer calibrating device¹. This device is used to apply torque to the potentiometer spring, using the radius of the potentiometer frame (normally 52 mm) as a lever arm. The potentiometer shall be calibrated outside the pressure cylinder, but with electrical connections extending from the calibrator to the three potentiometer contact pins located on the outside of the

cylinder. The potentiometer mechanism shall be calibrated at frequent intervals, and shall be calibrated if the spring, contact arm, or resistor is adjusted or replaced. The consistometer apparatus shall be recalibrated a minimum of once each year. The thermocouples and the indicating pyrometer shall be calibrated by a standard reference thermometer or other suitable means at frequent intervals to ensure the accuracy of the temperature measurement. If the temperature indicated by the pyrometer deviates from the true temperature, adjustments in either the instrument or the temperatures imposed during thickening time tests shall be made to compensate for the error.

- a. The weight-loaded type calibration device has produced a set of torque equivalent values for various levels of consistency which can be defined by the following equation:

$$T = 78.2 + 20.02 Bc$$

where:

T = Torque, g-cm

Bc = Bearden units of slurry consistency²

Table 8.1 shows torque equivalent and weight values of various slurry consistency levels. Slurry consistency shall be expressed in Bearden units of consistency, Bc, where 100 Bearden units of consistency is equivalent to the spring deflection observed with 2080 g-cm of torque when using the weight-loaded type calibrating device.

- b. An alternate method for calibrating the potentiometer mechanism is with the use of Paratone calibration oil¹, the viscosity-temperature relationship of which is known over a range of 5 to 100 Bearden units of consistency. (Paratone oil shall be discarded after use, because of possible contamination during the calibration test.)

Procedure

8.3 Operating Instructions. Detailed operating instructions, as furnished by the manufacturer, are applicable under this method and shall be followed.

²Bearden units of consistency (Bc) are dimensionless units.

Bc — Bearden units of consistency obtained on a pressurized consistometer as defined in Section 8 of API Spec 10 and calibrated as per the same section.

ABc — Bearden units of consistency obtained on an atmospheric pressure consistometer as defined in Section 9 of API Spec 10 and calibrated as per the same section.

The relationship between Bc and ABc is approximately $Bc \times 0.69 = ABc$. This relationship is valid only for units of consistency less than 30 Bc.

¹Information on testing devices in common use is available from American Petroleum Institute, 2535 One Main Place, Dallas TX 75202-3904.

*See Appendix O for Calibration Procedures for Thermocouples and Temperature Indicators.

TABLE 8.1
TORQUE EQUIVALENT VS
SLURRY CONSISTENCY

1	2	3
Torque Equivalent, g-cm	Weight, ³ grams	Slurry Consistency in Bearden units of Consistency, ² Bc
260	50	9
520	100	22
780	150	35
1040	200	48
1300	250	61
1560	300	74
1820	350	87
2080	400	100

²Bearden units of consistency (Bc) are dimensionless units.

Bc — Bearden units of consistency obtained on a pressurized consistometer as defined in Section 8 of API Spec 10 and calibrated as per the same section.

ABc — Bearden units of consistency obtained on an atmospheric pressure consistometer as defined in Section 9 of API Spec 10 and calibrated as per the same section.

The relationship between Bc and ABc is approximately $Bc \times 0.69 = ABc$. This relationship is valid only for units of consistency less than 30 Bc.

³For potentiometer mechanism with a radius of 52 mm.

8.4 Filling of Apparatus. The slurry (prepared according to Sect. 5) shall be quickly poured into the inverted slurry container. During this filling operation, the slurry shall be lightly stirred to prevent segregation. When the slurry container is completely filled, the bottom shall be screwed in, care being taken to ensure that all air is excluded. The center plug shall then be screwed in tightly, the container placed in the pressure chamber, and the chamber filled with the bath oil. Next, the head assembly of the pressure chamber shall be screwed in place, the slurry container set to rotating, and the oil-pressure pump started. With the pump in

operation, any air in the top of the chamber shall be vented through the top vent. The operation of filling and sealing the slurry container, placing the container in the pressure chamber, sealing and venting the pressure chamber, and placing the apparatus in operation shall be completed within 5 min after completion of the mixing period.

8.5 Procedure for Filling Slurry Cup From Top. A flat rubber diaphragm is an acceptable alternative for the diaphragm with hub assembly shown in Fig. 8.3 and 8.4. With the paddle assembly removed, place the slurry container in an upright position. The slurry (prepared according to Section 5) shall be poured into the slurry container to $\frac{1}{8}$ in. (1.6 mm) below the shoulder which is located below the threads. The paddle assembly consisting of paddle, diaphragm support ring, rubber diaphragm and top diaphragm collar shall then be installed. The slurry should extrude slightly around edges of the rubber diaphragm. The top ring is then screwed in place. The container is placed in the pressure chamber. Continue the same procedure from this point as described in Par. 8.4.

8.6 Temperature* and Pressure Control. During the test period, the temperature of the cement slurry, determined with thermocouple in position in the center of the slurry container, and the pressure in the slurry container shall be increased in accordance with the specification schedules given herein.

8.7 Casing-Cementing Schedules. Well cement specification test schedules for casing cementing are given in Table 8.3 (Schedules 1, 4, 5, 6, 8 and 9). Cement specification test schedules (Table 8.3) are based on mud densities shown in Table 8.2.

8.8 Temperature and Pressure Ranges. The thickening time for different classes of well cement shall be determined in the following cement specification tests:

- Classes A, B, and C. Casing well cement specification Schedules 1 and 4.

TABLE 8.2
BASIS FOR CASING CEMENT SPECIFICATION TEST SCHEDULES

1	2	3	4	5	6	7	8	9				
Schedule No.	Depth		Mud Density ¹			Surface Pressure ²		Bottom- Hole Circulating Temperature, ³		Bottom- Hole Pressure, ⁴		Time to Reach Bottom ⁵ min
			lb/gal (kg/L)	lb/cu ft	psi per 1,000 ft of depth			(kPa/m)	F (°C)	psi (kPa)		
	ft	(m)					psi	(kPa)				
1	1,000	(305)	10 (1.2)	74.8	519	(0.120)	500 (3400)	80 (27)	1,020 (7000)		7	
4	6,000	(1830)	10 (1.2)	74.8	519	(0.120)	750 (5200)	113 (45)	3,870 (26700)		20	
5	8,000	(2440)	10 (1.2)	74.8	519	(0.120)	1,000 (6900)	125 (52)	5,160 (35600)		28	
6	10,000	(3050)	12 (1.4)	89.8	623	(0.144)	1,250 (8600)	144 (62)	7,480 (51600)		36	
8	14,000	(4270)	16 (1.9)	119.7	831	(0.192)	1,750 (12100)	206 (97)	13,390 (92300)		52	
9	16,000	(4880)	17 (2.0)	127.2	883	(0.204)	2,000 (13800)	248 (120)	16,140 (111300)		60	

¹Mud densities obtained from a review of field data.

²Surface pressure obtained from a review of field data.

³Bottom-hole circulating temperatures averaged from actual field tests run at various depths.

⁴Bottom-hole pressure calculated from surface pressure, mud density and depth as shown in the table.

⁵Time to reach bottom is based on a survey of field operations and reflects conditions as severe as 75 percent of the jobs surveyed.

*See Appendix O for Calibration Procedures for Thermocouples and Temperature Indicators.

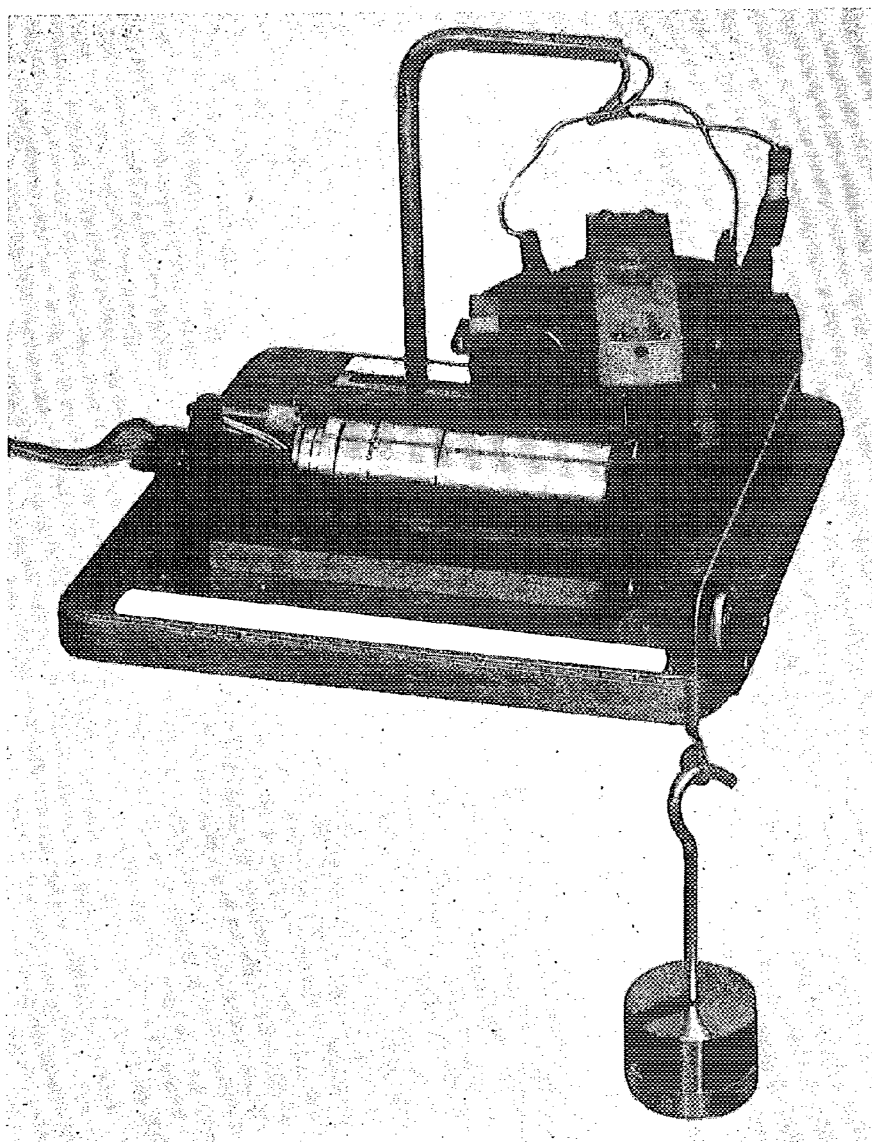
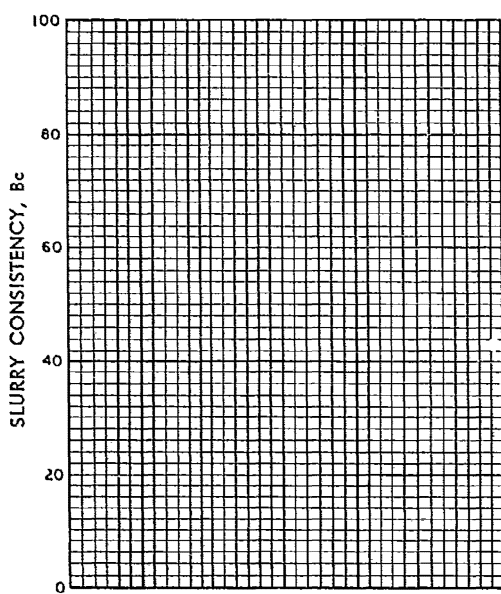


FIG. 8.1
POTENTIOMETER CALIBRATING DEVICE
PRESSURIZED CONSISTOMETER

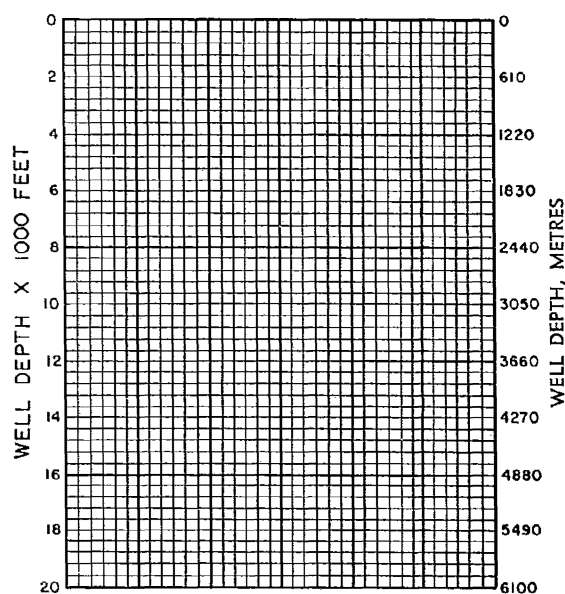
API CEMENT EVALUATION TESTS PRESSURIZED CONSISTOMETER

Brand _____ Source _____
 Class _____ Mixing Water, _____
 per cent _____ Slurry Density, _____
 lb/gal (kg/L) _____
 Thickening Time Conditions _____ F(°C) _____
 lb/cu ft (kg/L) _____
 Reached in _____ minutes _____
 psi per M ft (kPa/m) _____
 Tested by _____ Date Tested _____

THICKENING TIME DATA



SUMMARY OF THICKENING TIME DATA



TIME IN HOURS

TIME IN HOURS

Bath Temp, F (°C), or Test Schedule	Compressive Strength, psi (MPa)						
	Time cured under water, hr						
	8	12 *	18 *	24	36 *	48 *	72 *

Remarks: _____

*Operating compressive strength test.

FIG. 8.2

FORM FOR REPORTING COMPRESSIVE STRENGTH TESTS AND RESULTS OBTAINED FROM
THICKENING TIME TESTS ON THE PRESSURIZED CONSISTOMETER

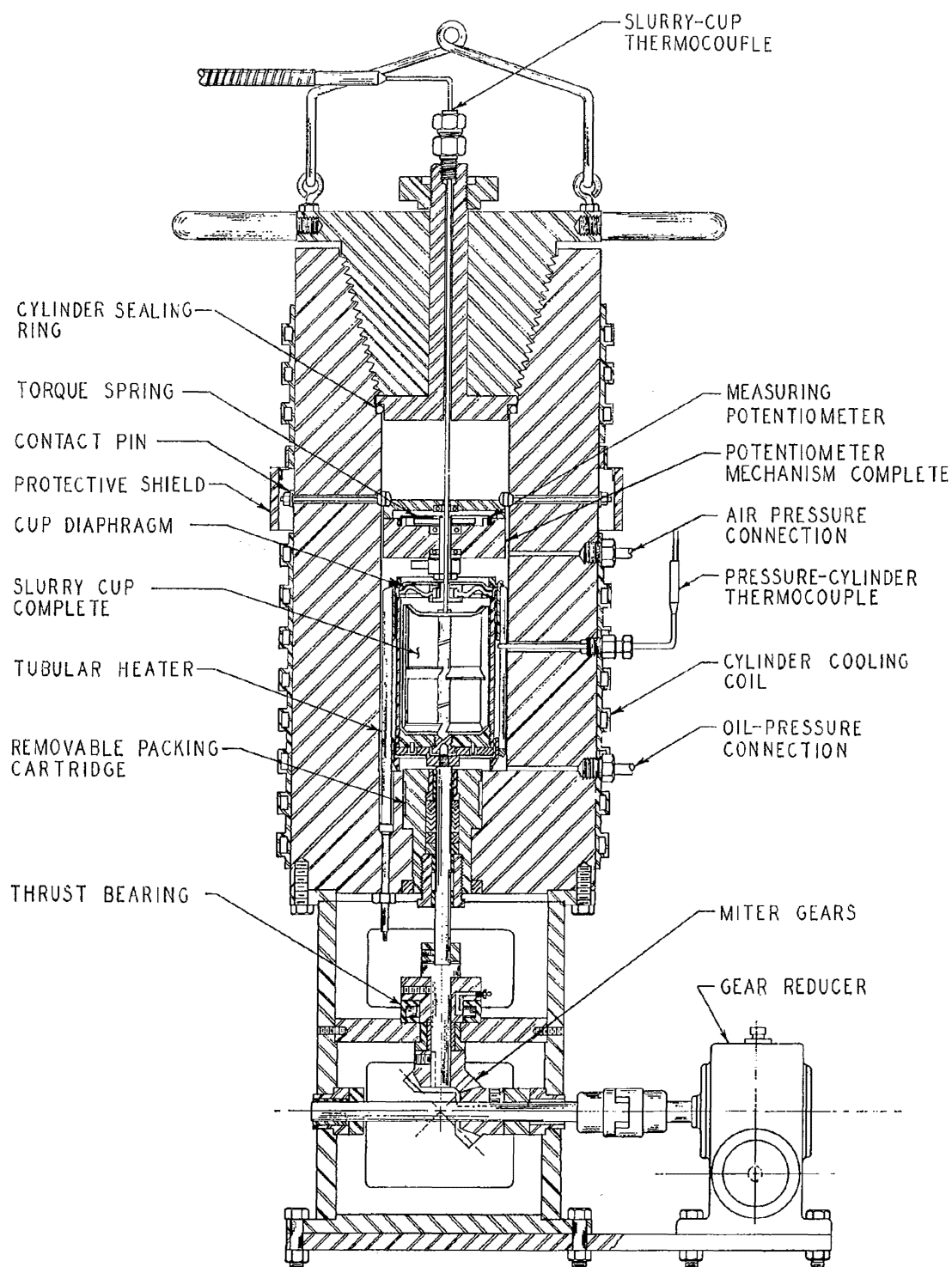
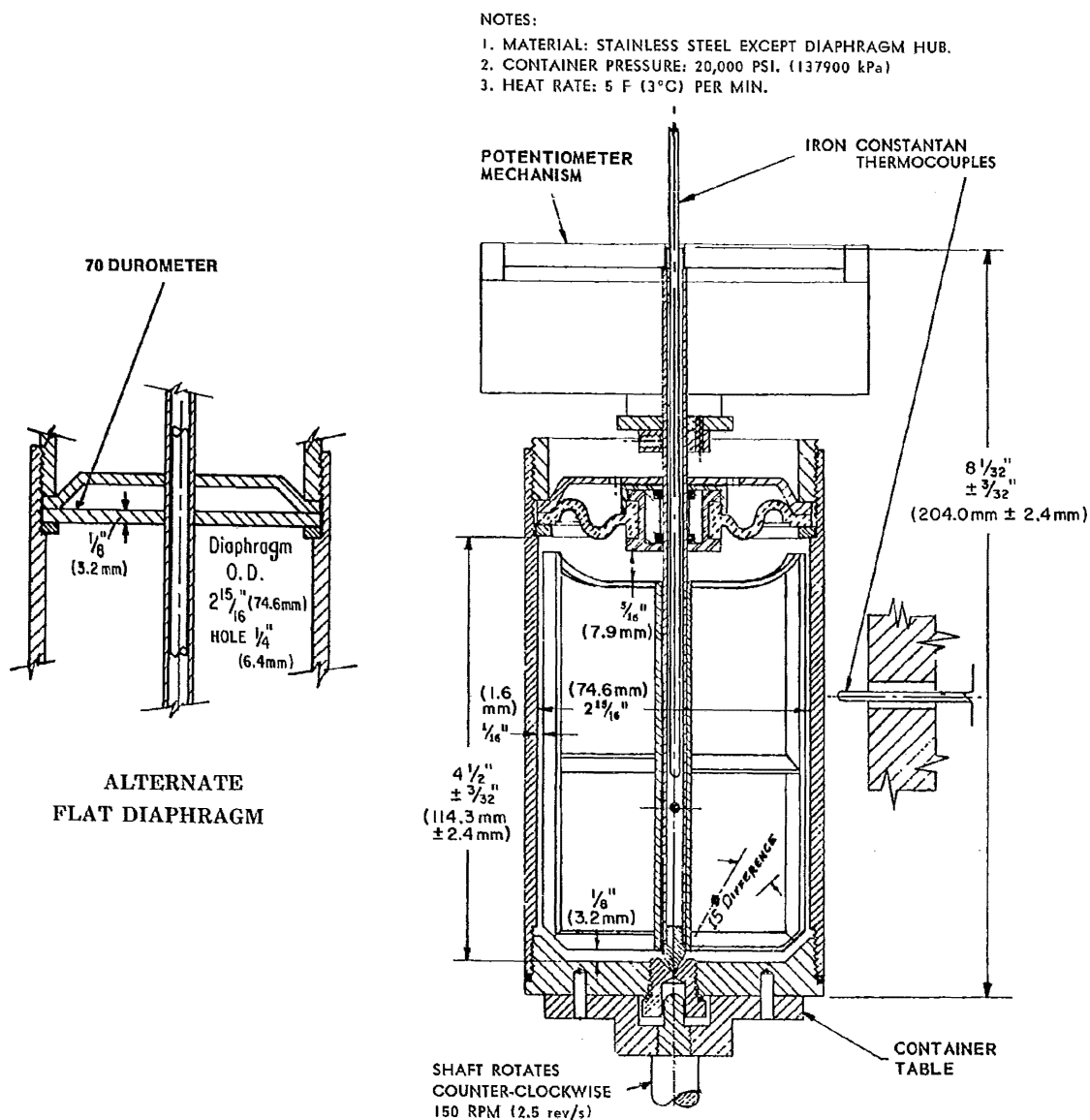
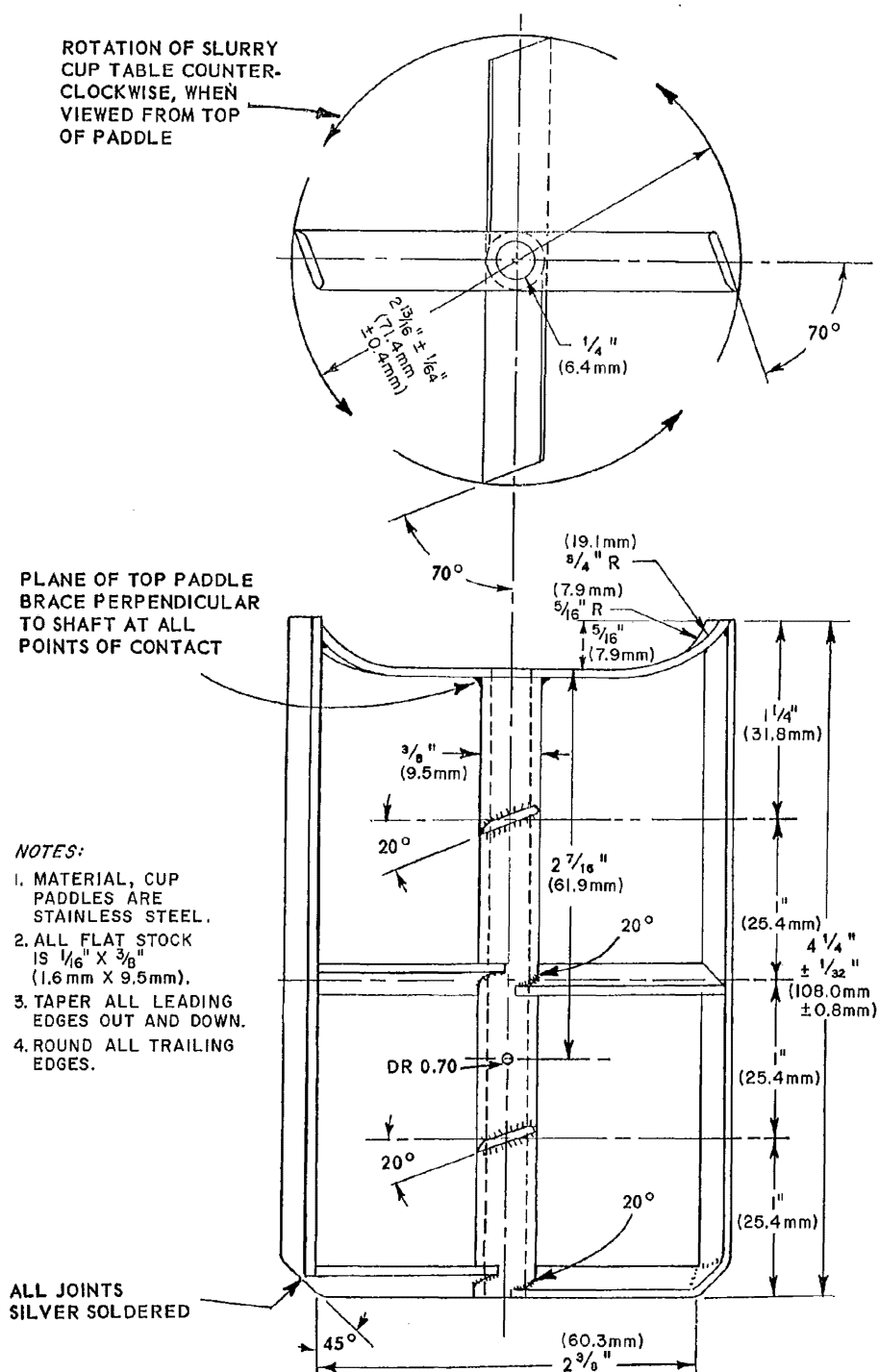


FIG. 8.3
ASSEMBLY
TYPICAL PRESSURIZED CONSISTOMETER





- b. Class D. Casing well cement specification Schedules 4 and 6.
- c. Class E. Casing well cement specification Schedules 6 and 8.
- d. Class F. Casing well cement specification Schedules 6 and 9.
- e. Classes G and H. Casing well cement specification Schedule 5.

8.9 Thickening Time. The elapsed time between the initial application of pressure and temperature of the apparatus and the occurrence of a consistency of 100 Bc shall be reported as the thickening time for the cement at the particular specification test schedule. For the schedules involving temperatures 200 F (93 °C) or higher, it is permissible to stop the test at a consistency of approximately 70 Bc and extrapolate to the 100 Bc value by plotting the results.

8.10 Recording of Results. The results of the thickening time tests shall be recorded on forms similar to that shown on Fig. 8.2. The results shall be reported in Bc for each time interval.

8.11 Acceptance requirements shall be as shown in Table 8.3.

TABLE 8.3
SCHEDULE 1
SPECIFICATION TEST FOR
CLASSES A, B and C

1	2		3	
Time, min	Pressure,		Temperature,	
	psi	(kPa)	F	(°C)
0	500	(3400)	80	(27)
2	600	(4100)	80	(27)
4	800	(5500)	80	(27)
6	900	(6200)	80	(27)
7	(BHP)1020	(7000)	(BHT)80	(27)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes
A	30	90
B	30	90
C	30	90

TABLE 8.3 continued
SCHEDULE 4
SPECIFICATION TEST FOR
CLASSES A, B, C and D

1	2		3	
Time, min	Pressure,		Temperature,	
	psi	(kPa)	F	(°C)
0	750	(5200)	80	(27)
2	1100	(7600)	83	(28)
4	1400	(9700)	87	(31)
6	1700	(11700)	90	(32)
8	2000	(13800)	93	(34)
10	2300	(15900)	97	(36)
12	2600	(17900)	100	(38)
14	2900	(20000)	103	(39)
16	3200	(22100)	106	(41)
18	3600	(24800)	110	(43)
20	(BHP)3870	(26700)	(BHT)113	(45)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes
A	30	90
B	30	90
C	30	90
D	30	90

TABLE 8.3 continued
SCHEDULE 5
SPECIFICATION TEST FOR
CLASSES G and H

1 Time, min	2 Pressure,		3 Temperature,	
	psi	(kPa)	F	(°C)
0	1000	(6900)	80	(27)
2	1300	(9000)	83	(28)
4	1600	(11000)	86	(30)
6	1900	(13100)	90	(32)
8	2200	(15200)	93	(34)
10	2500	(17300)	96	(36)
12	2800	(19300)	99	(37)
14	3100	(21400)	102	(39)
16	3400	(23400)	106	(41)
18	3700	(25500)	109	(43)
20	4000	(27600)	112	(44)
22	4300	(29600)	115	(46)
24	4600	(31700)	119	(48)
26	4900	(33800)	122	(50)
28	(BHP) 5160	(35600)	(BHT) 125	(52)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes	Maximum Thickening Time (100 Bc), Minutes
G	30	90	120
H	30	90	120

TABLE 8.3 continued
SCHEDULE 6
SPECIFICATION TEST FOR
CLASSES D, E and F

1 Time, min	2 Pressure,		3 Temperature,	
	psi	(kPa)	F	(°C)
0	1250	(8600)	80	(27)
2	1600	(11000)	84	(29)
4	1900	(13100)	87	(31)
6	2300	(15900)	91	(33)
8	2600	(17900)	94	(34)
10	3000	(20700)	98	(37)
12	3300	(22800)	101	(38)
14	3700	(25500)	105	(41)
16	4000	(27600)	108	(42)
18	4400	(30300)	112	(44)
20	4700	(32400)	116	(47)
22	5100	(35200)	119	(48)
24	5400	(37200)	123	(51)
26	5700	(39300)	126	(52)
28	6100	(42100)	130	(54)
30	6400	(44100)	133	(56)
32	6800	(46900)	137	(58)
34	7100	(49000)	140	(60)
36	(BHP) 7480	(51600)	(BHT) 144	(62)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes
D	30	100
E	30	100
F	30	100

TABLE 8.3 continued
SCHEDULE 8
SPECIFICATION TEST FOR
CLASS E

1 Time, min	2 Pressure,		3 Temperature,	
	psi	(kPa)	F	(°C)
0	1,750	(12100)	80	(27)
2	2,200	(15200)	85	(29)
4	2,600	(18000)	90	(32)
6	3,100	(21400)	95	(35)
8	3,500	(24100)	99	(37)
10	4,000	(27600)	104	(40)
12	4,400	(30300)	109	(43)
14	4,900	(33800)	114	(46)
16	5,300	(36500)	119	(48)
18	5,800	(40000)	124	(51)
20	6,200	(42700)	128	(53)
22	6,700	(46200)	133	(56)
24	7,100	(49000)	138	(59)
26	7,600	(52400)	143	(62)
28	8,000	(55200)	148	(64)
30	8,500	(58600)	153	(67)
32	8,900	(61400)	158	(70)
34	9,400	(64800)	162	(72)
36	9,800	(67600)	167	(75)
38	10,300	(71000)	172	(78)
40	10,700	(73800)	177	(81)
42	11,200	(77200)	182	(83)
44	11,600	(80000)	187	(86)
46	12,000	(82700)	191	(88)
48	12,500	(86200)	196	(91)
50	12,900	(88900)	201	(94)
52	(BHP) 13,390	(92300)	(BHT) 206	(97)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes
E	30	154

TABLE 8.3 continued
SCHEDULE 9
SPECIFICATION TEST FOR
CLASS F

1 Time, min	2 Pressure,		3 Temperature,	
	psi	(kPa)	F	(°C)
0	2,000	(13800)	80	(27)
2	2,500	(17200)	86	(30)
4	2,900	(20000)	91	(33)
6	3,400	(23400)	97	(36)
8	3,900	(26900)	102	(39)
10	4,400	(30300)	108	(42)
12	4,800	(33100)	114	(46)
14	5,300	(36500)	119	(48)
16	5,800	(40000)	125	(52)
18	6,200	(42700)	130	(54)
20	6,700	(46200)	136	(58)
22	7,200	(49600)	142	(61)
24	7,700	(53100)	147	(64)
26	8,100	(55800)	153	(67)
28	8,600	(59300)	158	(70)
30	9,100	(62700)	164	(73)
32	9,500	(65500)	170	(77)
34	10,000	(68900)	175	(79)
36	10,500	(72400)	181	(83)
38	11,000	(75800)	186	(86)
40	11,400	(78600)	192	(89)
42	11,900	(82000)	198	(92)
44	12,400	(85500)	203	(95)
46	12,800	(88300)	209	(98)
48	13,300	(91700)	214	(101)
50	13,800	(95100)	220	(104)
52	14,300	(98600)	226	(108)
54	14,700	(101400)	231	(111)
56	15,200	(104800)	237	(114)
58	15,700	(108200)	242	(117)
60	(BHP) 16,140	(111300)	(BHT) 248	(120)

Final temperature and pressure should be held constant to completion of test, within ± 2 F (± 1 °C) and ± 100 psi (± 700 kPa), respectively.

ACCEPTANCE REQUIREMENTS

Cement Class	Maximum Consistency 15-30 Minute Stirring Period Bc	Minimum Thickening Time (100 Bc), Minutes
F	30	190

SECTION 9

ATMOSPHERIC PRESSURE CONSISTOMETER

(Specification Test)

9.1 Apparatus. The apparatus or the alternate apparatus listed below shall be used for determination of free water content (Section 6). Also, the apparatus described in this section may be used for (1) water content of slurry (Appendix B), (2) fluid loss test (Appendix F), and (3) determination of rheological properties (Appendix H).

- a. **Apparatus.** Atmospheric Pressure Consistometer.¹
- b. **Alternate Apparatus.** Pressurized consistometer, described in Section 8 and illustrated in Fig. 8.3, 8.4 and 8.5 herein.

NOTE: The alternate apparatus may be used provided that it is run at atmospheric pressure.

9.2 Calibration. The apparatus shall be calibrated with Paratone calibration oil¹ or equivalent, the viscosity-temperature relationship of which is known over a range of 5 to 100 Bearden units of consistency (Bc)* or (where instruments are equipped with a calibrating spring — Fig. 9.7) by a tentatively alternate method using a weight-loaded type torque indicator calibrating device.¹ This device is described in Section 8 and illustrated in Fig. 9.1 to show the modification required to calibrate the torque indicator. The apparatus shall be recalibrated at least once each year, also whenever wear of any metallic part in contact with cement slurry becomes noticeable or when such part is replaced. (Paratone shall be discarded after use because of possible contamination during the calibration test.)

Preparation of Apparatus

9.3 Cleaning and Lubricating. Care shall be taken to ensure that all surfaces which come in contact with the cement slurry are clean. After each test, such surfaces (particularly the outside edges of the paddles) shall be cleaned and brushed with a brass cement-mold brush. Surfaces which come in contact with the slurry shall be given a thin coating of waterproof grease or light oil before each test. The ball bearings in the lid and those in the torque indicator shall be kept clean by frequent washings in kerosene and shall be oiled with a light grade of lubricating oil.

¹Information on testing devices in common use is available from the American Petroleum Institute, 211 N. Ervay, Suite 1700, Dallas TX 75201.

*Bc — Bearden units of consistency obtained on a pressurized consistometer as defined in Section 8 of API Spec 10 and calibrated as per the same section.

ABc — Bearden units of consistency obtained on an atmospheric pressure consistometer as defined in Section 9 of API Spec 10 and calibrated as per the same section.

The relationship between Bc and ABc is approximately $Bc \times 0.69 = ABc$. This relationship is valid only for units of consistency less than 30 Bc.

9.4 Water Cabinet. Water shall always be used as the bath liquid. For this reason, all exposed steel parts shall be kept clean and lightly oiled or greased.

The water cabinet shall be filled with water to the middle of the sight glass and both slurry containers in place before turning on the heater.

9.5 Assembly. The slurry container mechanism shall be assembled and the paddle rotated by hand to ensure that none of the parts scrape. The index of the torque indicator shall point to zero when the slurry container is empty and rotating. If it does not, the index shall be adjusted. The slurry container assembly shall rotate at a speed of 150 rpm (2.5 r/s) $\pm$ 15 rpm (.25 r/s).

Procedure

9.6 Filling of apparatus. The slurry shall be quickly poured into the slurry container to the proper fill level, which is indicated by a groove around the inside of the container. The paddle shall then be inserted and the lid placed in position by engaging the pin, located in the torque shaft of the lid, with the slotted paddle shaft. The assembly shall then be placed in the bath so that the driving pins which secure the lid to the slurry container also engage the driving cylinder, and the torque-indicator cord passed around the torque drum and looped over the pin. Care shall be taken to ensure that the cord is properly aligned on the 1¼ in. (44.5 mm) drums of both the torque-indicator ring and the torque drum in order to preserve a constant radius of pull. Instruments equipped with calibration spring and pointer-dial are direct reading and do not require a torque-indicator cord. The motor shall then be started. The interval between the completion of mixing and the starting of the apparatus shall not exceed 1 min.

NOTE: In the operation of the apparatus, a moment is created which pulls the pendulum from the vertical position. This moment is at a maximum when the pendulum is in a horizontal position. The quadrant scale behind the pendulum is graduated in ten equal increments of torque and readings taken on this scale indicate units of consistency.

9.7 Temperature Control.** When testing slurries within the ranges of 80 to 100 F, 80 to 120 F and 80 to 140 F (27 to 38 °C, 27 to 49 °C, and 27 to 60 °C), the rate of temperature increase shall be 1 F (0.5 °C) per min. When testing within the ranges of 80 to 160 F, 80 to 180 F and 80 to 200 F (27 to 71 °C, 27 to 82 °C, and 27 to 93 °C), the rate of increase shall be 2 F (1 °C) per minute. Final temperature should be maintained within ± 2 F (± 1 °C).

**See Appendix O for Calibration Procedures for Thermocouples and Temperature Indicators.