Recommended Practices for Evaluation of Well Perforators

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Users of this publication should become completely familiar with its scope and content. This publication is intended to supplement rather than replace individual engineering judgment.

OFFICIAL PUBLICATION

REG. U.S. PATENT OFFICE

RECOMMENDED PRACTICES FOR EVALUATION OF WELL PERFORATORS

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RECOMMENDED PRACTICES FOR EVALUATION OF WELL PERFORATORS

FOREWORD

a. These recommended practices have been prepared by the API Subcommittee on Perforating. This work is under administration of the Executive Committee on Drilling and Production Practices.

b. The tests and test apparatus recommended herein have been developed to establish standard procedures and conditions for evaluating well perforator systems under the stated laboratory conditions. The results of these tests should not be construed as representing perforator system performance under downhole conditions.

c. The recommendations presented in this publication are not intended to inhibit the development of new technology, materials improvements, or improved operational procedures. Qualified engineering analysis and sound judgment will be required for their application to fit a specific situation.

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SECTION G
GENERAL

G.1 Overall. This publication describes standard procedures for evaluating the performance of perforating equipment so that representations of this performance may be made to the industry through the offices of the American Petroleum Institute (API). This process involves certification of representative test data to API by the certifying company. Tests upon which such certification is based may be accomplished by the certifying company itself (self certification) or by an unrelated company (third party certification). The source of the test data shall be clearly indicated on the Data Sheets (Forms 43F, 43G, and 43H). This document supersedes all previously issued editions of API RP 43. Any reference to API RP 43, in the sections which follow, unless otherwise specified, refers to the current document, which may be described more accurately as *RP 43: Recommended Practices for Evaluating Well Perforators*, Fifth Edition, January 1991.*

G.2 Scope. Sections 1-4 of this publication provide means for evaluating perforating systems (multiple shot) under ambient temperature and atmospheric pressure test conditions, perforator performance in stressed Berea sandstone targets (simulated wellbore pressure test conditions), how perforator performance may be changed after exposure to elevated temperature conditions, and flow performance of a perforation under specific stressed test conditions.

G.3 Objective. The purpose of these recommended practices is to specify the materials and methods used to evaluate objectively the performance of perforating systems or perforators.

G.4 Certification. The certification process for Sections 1 and 2 involves four steps: (1) testing the perforating system according to the recommended practices described herein, (2) recording test results on the appropriate API Data Sheet (API Form 43F), (3) attesting the verity of test results by a responsible officer of the certifying company, and (4) filing the Data Sheet(s) (API Form 43F) with API. The appropriate Data Sheet when completed, certified by signature of an officer of the company, and filed with the API Production Department, 2535 One Main Place, Dallas, Texas 75202-3904, shall constitute certification to API. Receipt of each Data Sheet shall be acknowledged by API prior to filing or circulating it to the industry. Such Data Sheets shall be on file for all perforating systems on which a company attests compliance with RP 43. API specifically forbids any representation that a perforating system has been certified to API unless it has been tested in compliance with the relevant sections of API RP 43 and certified as outlined herein.

*Available from American Petroleum Institute, Publications and Distribution Section, 1220 L St., N.W., Washington, D.C. 20005.

G.5 Verification. Section 3 describes tests for use in evaluating perforating systems at elevated temperature conditions. Section 4 describes tests for use in measuring flow performance of a perforation under specific stressed conditions stated therein. These tests are optional and are not required for the certification process (refer to Par. G.4). Verification of these tests involves three steps: (1) testing the perforating system according to procedures in Section 3 or Section 4, (2) recording test results on the appropriate Data Sheet (API Forms 43G and 43H), and (3) verification by a responsible party of the submitting company that tests were made in accordance with RP 43. Section 3 and Section 4 tests are considered special tests and the test results are not filed with API. Users should request these data from the company offering the perforating systems in commercial applications.

G.6 Mandatory Retest. Any change in the design, materials, or method of manufacture of a perforating system, subsequent to its certification, that may adversely affect its performance shall require retesting and certification before the system can be represented as tested according to API RP 43.

G.7 Annual Recertification. Certification of a perforating system to API is purely voluntary. Each company wishing to maintain perforating system certifications on file with API shall submit by January 31 of each year recertified test data for each of the companies' perforating systems within the API certification file. New test data for perforating system certification shall be submitted according to the provisions of Par. G.4.

G.8 Availability of Certification Data Sheets. Each certifying company is responsible for keeping data current as presented on API Certification Data Sheet (API Form 43F), and on file with API for each of its perforating systems in commercial service for which certification to API is claimed. Copies of such data shall be available to the industry so long as the perforating system remains certified to API and is available in commercial service. The API acts purely as a clearing house for the exchange of certification information between the suppliers of perforating services and the users of such services. API, in furnishing certification data to the industry, neither affirms compliance with the recommended test procedures nor the correctness of the reported data; both are the sole responsibility of the certifying company.

G.9 Maintenance of Current File. On February 15 of each year, the API Production Department shall destroy all Certification Data Sheets (API Form 43F) from the previous year.

G.10 Reports and Advertisements. Reports, articles, papers, periodicals, advertisements, or similar publications which refer to results from tests conducted according to API RP 43, must be worded in a fashion to denote that the American Petroleum Institute neither endorses the result cited nor recommends or disapproves the use of the perforating system described. Use of data obtained under API RP 43 tests in reports, articles, papers, periodicals, advertisements, or other published material shall include, as a minimum, data to describe accurately average casing or tubing hole diameter, average target penetration, the casing or tubing outside diameter, casing or tubing weight and grade, positioning of the gun perforating system, concrete compressive strength, and/or porosity of the Berea sandstone (if applicable).

G.11 Compliance Requirements. Compliance with the testing procedures in this publication relevant to the system being tested or those related to the purpose of the test, is required for the test to serve in the API certification process. Mandatory compliance with Section G is required in all cases of certification under API RP 43 regardless of the relevant section or sections used in certification. Any variance from the practices recommended in API RP 43 or the mandatory reporting procedures required in those practices voids the test for certification purposes. If upon review an irregularity or an incomplete form is found, the API shall notify the officer of the submitting company and request corrective action.

G.12 Implementation. These procedures become effective as of the date of publication. All perforator systems tested subsequent to the date of issue shall comply with the procedures contained herein. No perforator system certified under *API RP 43: Recommended Practice for The Evaluation of Well Perforators*, Fourth Edition, August 1985, may be recertified in compliance therewith after July 1, 1992.

SECTION 1
EVALUATION OF PERFORATING SYSTEMS UNDER SURFACE CONDITIONS, CONCRETE TARGETS

1.1 Introduction. The purpose of this section is to describe recommended practices for evaluating perforating systems using concrete targets under multiple shot, ambient temperature, and atmospheric pressure test conditions.

1.2 Test Target. The tests shall be conducted in a concrete target contained within a steel form as illustrated in Figure 1.1.

1.2.1 Target Specifications. Concrete for the target and test briquets shall be mixed using a cement-sand slurry consisting of the following:

1 part or 94 lb (1 sack) of API Class A cement, 2 parts or 188 lb of washed and graded dry sand, and 0.50 part or 47.0 lb (5.6 gallons) of potable water.

The sand shall meet *ASTM Designation C 33-67: Standard Specifications for Concrete Aggregates** (check latest edition) sieve analysis as shown in Table 1.1.

TABLE 1.1
SAND SIEVE ANALYSIS SPECIFICATIONS

Sieve		Percent (%)
Mesh, USA Sieves	Opening, mm	Passing
3/8 in.	9.51	100
No. 4	4.76	95—100
No. 8	2.38	80—100
No. 16	1.19	50—85
No. 30	.589	25—60
No. 50	.297	10—30
No. 100	.149	2—10

1.2.2 Target Configuration. The shape of the outer target form shall be circular and the size determined by the shot pattern and anticipated penetrating capability of the perforating system to be tested. Positioning of the tubing or casing within the target shall be determined by the gun phasing used in the test. For zero-phased perforators, the casing or tubing shall be set in the target form such that a minimum of three inches of the specified concrete composition surrounds the tubing or casing in all directions.

1.2.3 Target Curing Conditions. The target shall be allowed to cure at a temperature within the concrete greater than 32 F (0 C) for a minimum of twenty-eight (28) days. The top surface of the concrete target shall be covered continuously during the entire curing period with a minimum of three inches of potable water. All strength test specimens shall be kept immersed in water at the same temperature as the concrete test target until they are used.

1.2.4 Target Strength Requirements. Prior to or within 24 hours of conducting a test, the concrete briquet shall be tested and must have an average compressive strength of not less than 5,000 psi. The test briquet for compressive strength shall be a 2-inch cube. The compressive strength of the concrete briquet shall be determined in accordance with *API Spec 10: Specification for Materials and Testing of Well Cements** and recorded on API Form 43F.

1.2.5 Casing or Tubing to be Used in Target. Casing or tubing sizes, weights, and grades to be used in the target are shown in Table 1.2.

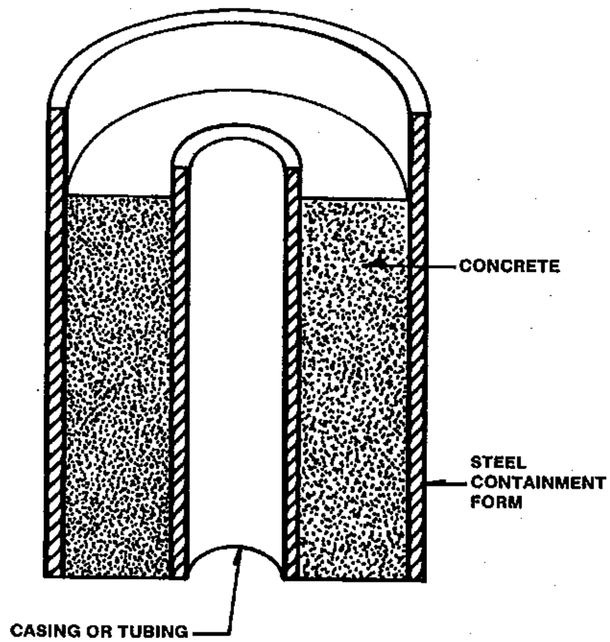


FIGURE 1.1
EXAMPLE CONCRETE TARGET

*Available from American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

*Available from American Petroleum Institute, Publications and Distribution Section, 1220 L St., N.W., Washington, D.C. 20005.

TABLE 1.2
CASING AND TUBING FOR USE IN TEST TARGET

Pipe Size, OD in.	Pipe Nominal Weight, lb/ft	Casing or Tubing, API Grade
2⅜	4.6	L-80
2⅞	6.4	L-80
3½	9.2	L-80
4½	11.6	L-80
5	15.0	L-80
5½	17.0	L-80
7	32.0	L-80
7⅝	33.7	L-80
8⅝	40.0	L-80
9⅝	47.0	L-80
10¾	51.0	L-80
11¾	54.0	L-80
13⅜	61.0	L-80

1.3 Perforating System Selection. The perforating system to be tested shall consist of standard field equipment, including gun body fully loaded with maximum shot density, and with phasing, charges, explosive accessories, and other component parts representative of standard field equipment. Selection of the charges must conform to Par. 1.4.

1.4 Charge Selection and Aging. The required number of charges shall be samples taken uniformly from a minimum production run of 1000 RDX or PETN charges (a production run of only 300 charges is required for high temperature explosives) and packaged in the manufacturing/service company's standard shipping containers. These charges shall be stored for a minimum of four weeks prior to testing to allow some aging to occur. Charges shall be selected from one or more unopened containers.

1.5 Multi-directional Firing Perforator Systems. For multi-directional firing perforator systems, a sufficient length of continuously loaded active gun shall be tested to provide a minimum of twelve (12) shots or one foot of continuously loaded gun, whichever provides more shots. The perforating device shall be eccentered in the casing.

1.6 Uni-directional Perforator Systems. Uni-directional perforator systems, without positioning devices, shall be tested in two positions. In one position, all shots shall be fired at maximum clearance. In the other position, all shots shall be fired at minimum clearance. A minimum of eight (8) shots shall be fired from each position. Perforator systems with positioning devices shall be fired in the position assumed in a well. A minimum of twelve (12) shots shall be fired.

1.7 Test Fluid. Water shall be used as the test fluid in testing all perforating systems.

1.8 Test Results Validity. No test shall be considered valid if the average depth of penetration of the concrete target is within three inches of the terminal boundary of the target. Any individual shot that penetrates the terminal boundary of the concrete target shall be noted in the reported data, but shall not be counted in averaging the penetration data from the test.

1.9 Data Collection. The following measurements shall be made for each perforating system evaluated: total penetration depth, casing or tubing hole diameter, burr height. All perforator individual or averaged penetration depths shall be reported to the nearest 0.1 inch.

1.9.1 Total Depth. The total depth shall be reported as the distance from the original inside wall of the casing or tubing to the end of the perforation tunnel. The end of the perforation tunnel shall be established as that point where concrete material strength damage ends as qualitatively indicated by manual scraping/probing of the exposed material surface.

1.9.2 Casing or Tubing Hole Diameter. The casing or tubing hole diameter shall be measured along the short and long elliptical axes and reported along with the average of the two measurements. Such measurements shall be made from outside the casing or tubing (prior to cutting) with a caliper, whose arms readily pass through the perforation. The short axis shall be the smallest through-hole diameter measured. Casing or tubing hole diameter shall be reported to the nearest 0.01 inch.

1.9.3 Burr Height. The maximum protrusion from the inside casing or tubing wall next to the perforation shall be measured and reported as the burr height. If debris from the perforator is lodged in the perforation hole in the casing or tubing and cannot be removed with finger pressure, the total height of such obstruction shall be recorded as burr height and explained in the remarks section of API Form 43F, "Certification Data Sheet."* Burr height shall be reported to the nearest 0.01 inch.

1.10 Data Recording and Reporting. Data shall be reported on all shots fired or attempted. Data shall be reported in the same order that it was shot ballistically with #1 being the first charge shot. All data shall be reported on API Form 43F, "Certification Data Sheet".* When more than twenty (20) shots are fired, use the back of the data sheet to report all shots. Additional data analysis or information is optional and may also be included on the back of the data sheet.

*Permission is granted to reproduce or reprint API Form 43F, "Certification Data Sheet, Perforating System Evaluation, RP43, Sections 1 and 2," as shown herein (refer to page 9).

API FORM 43F

CERTIFICATION DATA SHEET
PERFORATING SYSTEM EVALUATION, RP 43, SECTIONS 1 AND 2

Service Company ______________________
Gun OD & Trade Name ______________________
Charge Name ______________________
Manufacturer Charge Part No. __________ Date of Manufacture __________
Gun Type ______________________
Phasing Tested ______ degrees, Firing Order ______ Top down, ______ Bottom up
Debris Description ______________________

Explosive Weight ______ gm, ______ powder, Case Material ______
Max. Temp, F ______ 1 hr ______ 3 hr ______ 24 hr ______ 100 hr ______ ______ hr
Maximum Pressure Rating ______ psi, Carrier Material ______
Shot Density Tested ______ shots/ft
Recommended Minimum ID for Running ______ in.
Available Firing Mode ______ Selective, ______ Simultaneous
Debris Weight ______ gm/charge, Debris ______ in.³/charge

Remarks ______________________

SECTION 1 — CONCRETE TARGET

Casing Data ______ OD, Weight ______ lb/ft. ______ API Grade, Date of Concrete Test ______
Target Data ______ OD, Briquet Compressive Strength ______ psi, Age of Target ______ days

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	
Clearance, in.											
Casing Hole Diameter, Short Axis, in.											
Casing Hole Diameter, Long Axis, in.											
Average Casing Hole Diameter, in.											
Total Depth, in.											
Burr Height, in.											
Shot No.	**No. 11**	**No. 12**	**No. 13**	**No. 14**	**No. 15**	**No. 16**	**No. 17**	**No. 18**	**No. 19**	**No. 20**	**Average**
Clearance, in.											
Casing Hole Diameter, Short Axis, in.											
Casing Hole Diameter, Long Axis, in.											
Average Casing Hole Diameter, in.											
Total Depth, in.											
Burr Height, in.											

Remarks ______________________

SECTION 2 — BEREA SANDSTONE CORE TARGET

Berea Bulk Porosity, __________ %

Date of Berea Test __________ %

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	Average
Faceplate Hole Diameter, Short Axis, in.							
Faceplate Hole Diameter, Long Axis, in.							
Average Faceplate Hole Diameter, in.							
Total Depth, in.							

CERTIFICATION

Type of Certification: ☐ Self ☐ Third Party

I certify that these tests were made according to the procedures as outlined in API RP 43: Recommended Practices for Evaluation of Well Perforators, Fifth Edition, January 1991. All of the equipment used in these tests, such as the guns, jet charges, detonator cord, etc., was standard equipment with our company for use in the gun being tested, and was not changed in any manner for the test. Furthermore, the equipment was chosen at random from stock and therefore will be substantially the same as the equipment which would be furnished to perforate a well for any operator.

______ CERTIFIED BY
______ RECERTIFIED

______________ (Company Officer) ______ (Title) ______ (Date) ______________ (Company) ______________ (Address)

SECTION 2
EVALUATION OF PERFORATORS UNDER STRESS CONDITIONS, BEREA TARGETS

2.1 Introduction. The purpose of Section 2 is to provide a standard test for measuring perforator performance in stressed Berea sandstone with wellbore pressure applied. Charges marketed as gravel pack or big hole charges are specifically excluded, as are charges containing over 600 grains of explosives.

2.2 Berea Sandstone Target. Tests will be conducted using Berea sandstone targets mounted as shown in Figure 2.1. Berea sandstone target material shall have a bulk porosity of not less than 19 percent nor more than 21 percent.

2.3 Preparation of Berea Sandstone for the Target. The Berea sandstone shall be prepared as follows:

2.3.1 Size. For charges 15 grams or less, a 4-inch (± 3%) diameter core will be cut from a large block of Berea sandstone. For charges exceeding 15 grams, a 7-inch (± 3%) diameter core will be cut from a large block of Berea sandstone. Depending on the expected perforation depth, the total length of the core shall approximate 12, 15, 18, 21, 24, or 27 inches, measured to within ± 0.25 inch. The test will be considered valid if at least 3 inches of unpenetrated core remains.

2.3.2 Cutting. The core may be lathe turned or cut with a core barrel.

2.3.3 Drying. The cut and sized core shall be dried at least 24 hours, or to constant weight in a ventilated oven maintained at 200 F, but not above 210 F.

2.3.4 Evacuation. The core shall be evacuated in an airtight chamber provided with a suitably sized evacuation port and pump. There shall also be provided a means of admitting the saturating liquid slowly to the bottom of the chamber in order that the core can be covered with the liquid from the bottom to its top while under vacuum. The core shall be evacuated to a pressure of 1 mm of mercury or less for a minimum of 6 hours before admitting the saturating fluid. The saturating fluid shall not be admitted at a rate faster than the capillary rise of the fluid in the core.

2.3.5 Saturation. The saturating liquid shall be 3% (by weight) sodium chloride brine (specific gravity to be measured at ambient temperature to the nearest thousandth) prepared from sodium chloride and distilled or deionized water. The 3% brine solution shall be evacuated under medium to low vacuum (50 mm Hg pressure) for 30 minutes before use in order to remove dissolved gases, but not enough to increase the salt concentration appreciably. After the core is flooded in the evacuation chamber, vacuum (50 mm Hg pressure or lower) is to be maintained for 2 hours, after which the pressure is to be slowly increased to atmospheric pressure. The restored-state core should be kept stored under the 3% brine until porosity determinations are made. Kerosine may be substituted for the 3% sodium chloride brine.

2.3.6 Porosity Determination. After saturation, the core shall be wiped lightly to remove free brine from the surface and weighed immediately. The porosity shall be calculated by the following formula:

$$\Phi = (V_p/V_b)(100) \qquad (2\text{-}1)$$

The pore volume, V_p, shall be calculated by dividing the difference in weight in the saturated and dry states by the density of the 3% brine. The bulk volume, V_b, shall be calculated from physical measurements of each individual core. The weight shall be determined at room temperature on scales with a precision of 1 gram for loads of 1,000 grams or more.

2.3.7 Core Storage. Cores shall be stored in the 3% brine during the interval between obtaining the core characteristics and shooting operations.

2.4 Test Apparatus.

2.4.1 Rubber Sleeve. For charges 15 grams or less, the sleeve shall have an internal diameter of 4 inches and a wall thickness of 0.25 inch. For charges larger than 15 grams, the sleeve shall have an internal diameter of 7 inches and a wall thickness of 0.25 inch.

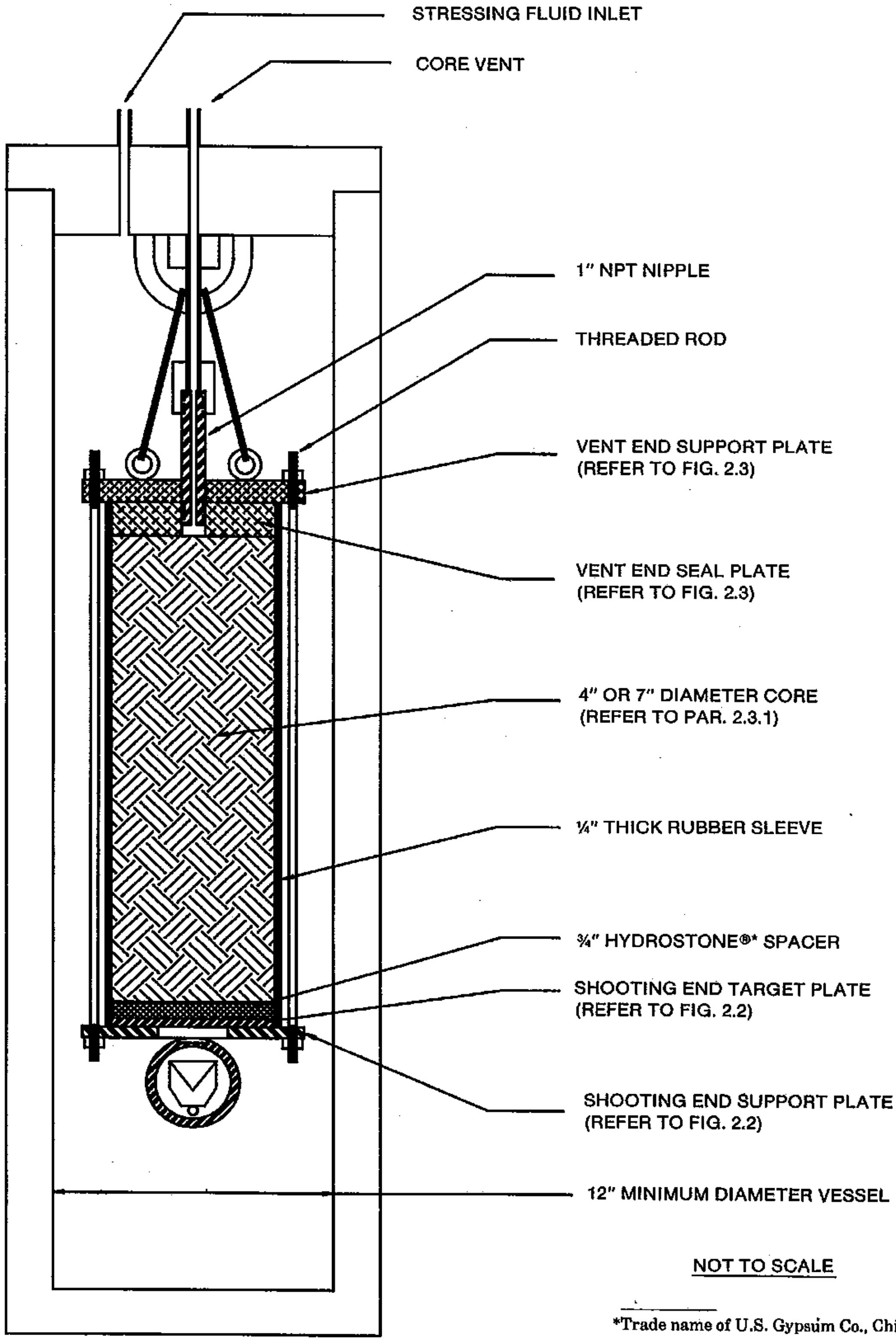
2.4.2 Target End Fixtures. The shooting end fixture shall contain a mild steel faceplate 0.38 inch thick cut from *ASTM A-36* grade steel and a 0.75 inch thick Hydrostone®* spacer. The 0.75 inch Hydrostone spacer may be poured in place or prepared separately at the discretion of the tester. Hydrostone must be used in accordance with the manufacturer's instructions. Refer to Fig. 2.2 for details of the shooting end fixture and Fig. 2.3 for details of the vent end fixture.

2.4.3 Vent Tube. The vent tube shall be a nominal 1-inch outside diameter NPT steel tube with a minimum inside diameter of 0.25 inch.

2.4.4 Pressure Vessel. The minimum inside diameter of the pressure vessel shall be 12 inches. Suitable pressure sensing and remote recording equipment shall be used to obtain a permanent record of the pressure profile for the complete test. All equipment must be calibrated against a suitable reference standard at intervals not exceeding six months.

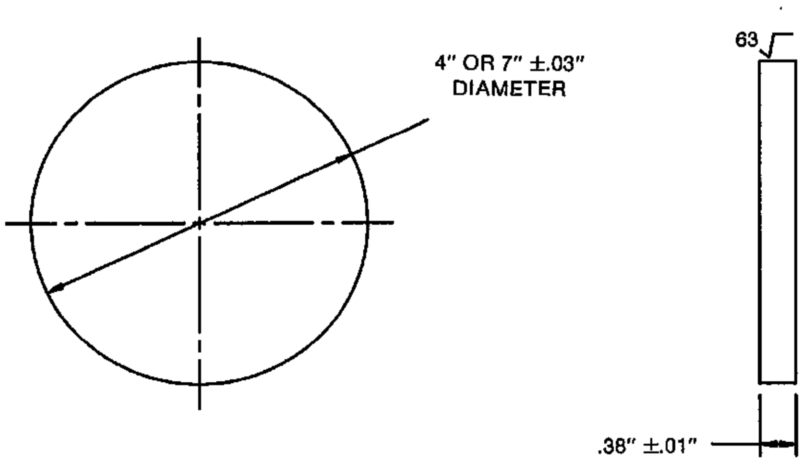
2.4.5 Mounting of Core Target. The gun shall be sufficiently secured to the core target to assure correct clearance and alignment. If bolts are used to

*Trade name of U.S. Gypsum Co., Chicago, IL.

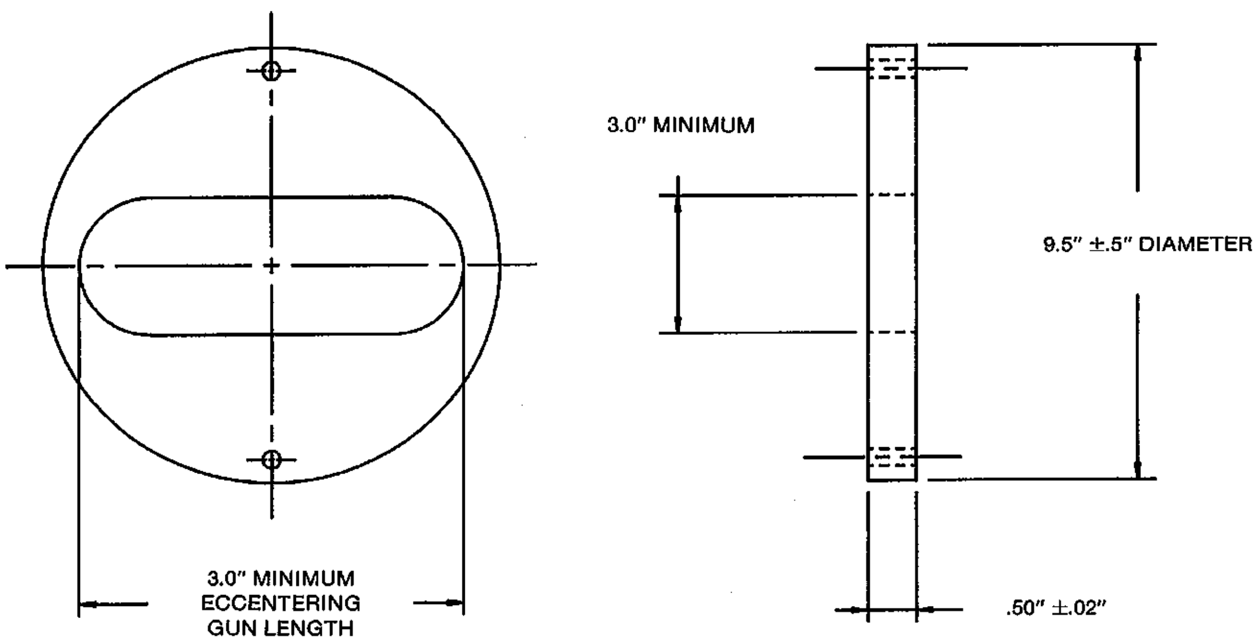


*Trade name of U.S. Gypsum Co., Chicago, IL.

FIGURE 2.1
RP 43, SECTION 2 TARGET CONFIGURATION



TARGET PLATE
MATERIAL: MILD STEEL ASTM-36



NOT TO SCALE

SUPPORT PLATE

FIGURE 2.2
SHOOTING END FIXTURE

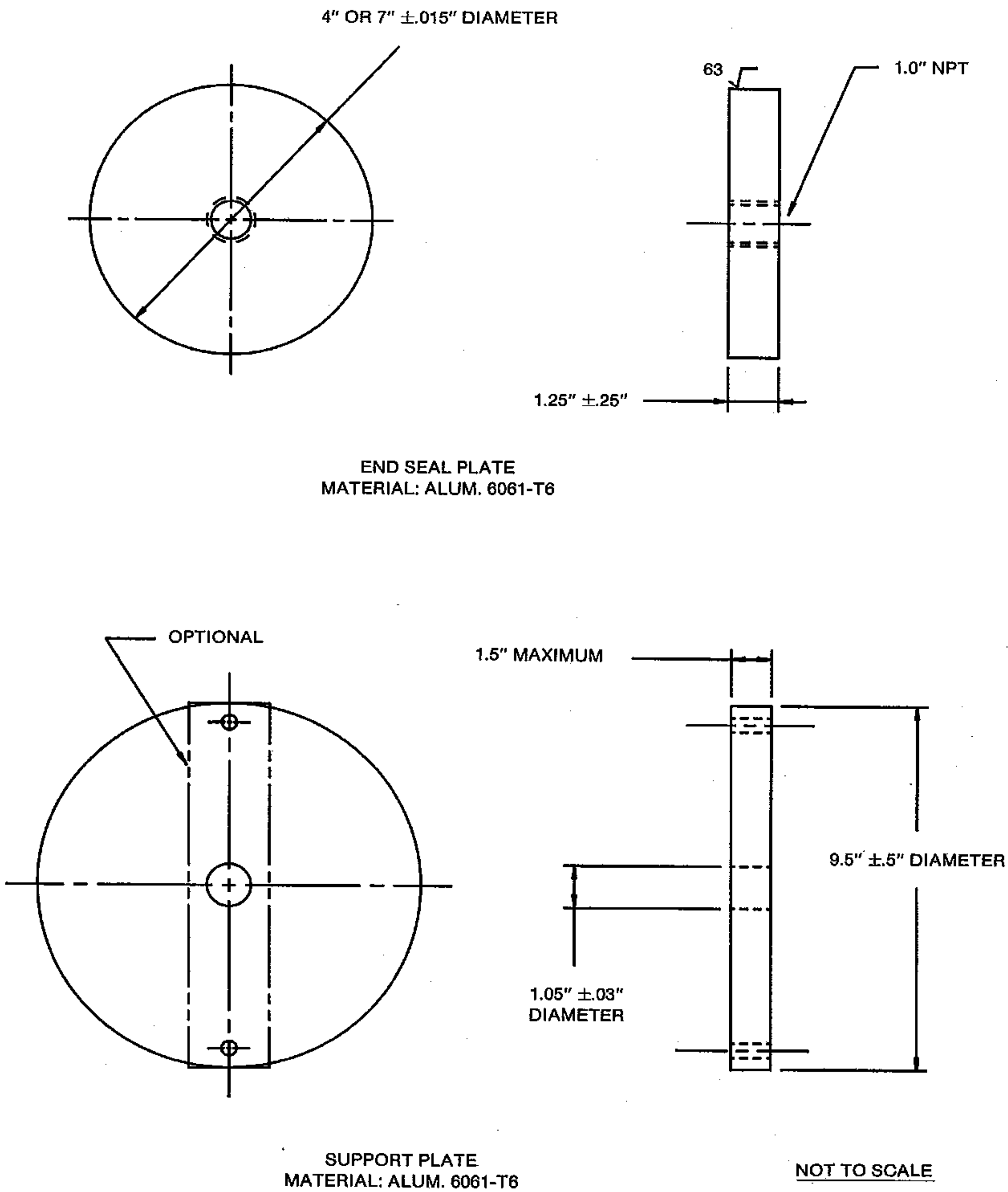


FIGURE 2.3
VENT END AND SEAL FIXTURE

hold the shooting end fixture and vent tube end fixture to the core, the end fixture must be free to travel in the direction of the core so as to transmit the stress uniformly. The entire target shall be centralized (± 1.0 in.) in the shooting vessel (refer to Figure 2).

2.4.6 Perforating Tool. The tool to be tested will be a single-shot section of the gun. This gun section must be a duplicate of the field gun.

2.5 Test Conditions and Procedure.

2.5.1 Chamber Fluid. The chamber fluid shall be water and maintained at ambient temperature throughout the test.

2.5.2 Clearance. With the exception of zero-phased perforators used with eccentering devices, bullet and jet perforators shall be tested at a clearance of 0.5 inch. Zero-phased perforators used with eccentering devices shall be tested at the clearance assumed in a well.

2.5.3 Charge Selection and Aging. The required number of charges shall be samples taken uniformly from a minimum production run of 1000 RDX or PETN charges (a production run of only 300 charges is required for high temperature explosives) and packaged in the manufacturing/service company's standard shipping containers. These charges shall be stored for a minimum of four weeks prior to testing to allow some aging to occur.

2.5.4 Number of Shots. Tests are to consist of a minimum of 3 shots made under stated conditions. Test shot results must be indicative of average performance expected from production charges.

2.5.5 Firing Pressure. The pressure vessel will be pressured to 3,000 psi. The system will be held static for 5 minutes before shooting to check for leaks. If the core is fully saturated there should be a small fluid flow initially from the vent tube, until stress equilization occurs. The perforating gun is fired with a closed system. The pressure gauges and pumps are thus protected from the shock of firing.

2.5.6 Determination of Depth of Penetration. The depth of penetration shall be determined by the maximum depth from the exterior steel face plate to the end of the perforation tunnel, as determined by probing for weakened rock beyond the perforation tip.

2.5.7 Faceplate Hole Diameter. The hole diameter shall be measured along the short and long elliptical axes and reported along with the average of the two measurements. Such measurements shall be made from outside the faceplate with a caliper, whose arms readily pass through the perforation. The short axis shall be the smallest through hole diameter measured. Hole diameter shall be reported to the nearest 0.01 inch.

2.5.8 Control of Perforation End Position in Target. In 4-inch diameter targets, the perforation tip must be within 1.25 inches of the centerline of the core for the test to be considered valid. In 7-inch diameter targets, the perforation tip must be within 2.0 inches of the centerline of the core for the test to be considered valid.

2.5.9 Recording of Data. Data from tests performed under Section 2 of *API RP 43*, Fifth Edition, are to be recorded on API Form 43F, "Certification Data Sheet, Perforating System Evaluation, RP 43, Sections 1 and 2."

SECTION 3
EVALUATION OF PERFORATOR SYSTEMS AT ELEVATED TEMPERATURE CONDITIONS, STEEL TARGETS

3.1 Introduction. The purpose of this test is to evaluate perforating systems at elevated temperature and atmospheric pressure. Systems employing any type explosive may be evaluated by this method. The test is conducted at temperature, with atmospheric pressure external to the gun to evaluate charge reliability, and utilizing steel as the target material.

Separate tests are conducted at temperature, pressure, and time to verify the operational rating of the system. This is intended as a procedure to be followed for a special test and will not be filed with API.

3.2 Reference Data. A reference charge test shall be conducted at atmospheric pressure and ambient temperature employing the steel target and the test described herein.

3.3 Test Target. Tests shall be conducted with a laminated target consisting of mild-steel *(ASTM A-36)* flat plates, 1 inch thick with a faceplate ⅜ inch thick. Cross sectional area of the plates shall be chosen for repeatable data collection. Typical target configuration is shown in Figure 3.1. The target thickness must be at least 0.5 inch greater than the average penetration depth recorded.

3.4 Perforating System Selection. The perforating system to be tested shall consist of the gun, associated hardware, and firing head. Production equipment (or specially modified hardware to the same specification) shall be utilized, including gun body, adapters, transfer subs, and explosive components. The free volume to explosive load ratio must be the same or less than a fully loaded field configuration gun; or previously established in a separate test by firing a minimum of one charge after holding at time and temperature at an equal or lower free volume to explosive load ratio for this explosive. For tubing conveyed systems, at least one transfer must be demonstrated on the same or a separate test utilizing a production transfer sub. At least one charge shall be fired subsequent to the transfer. For wireline conveyed systems, any electrical or mechanical switches shall be included if recommended by the service company for this application, unless previously qualified in a separate test.

3.5 Charge Selection and Aging. The required number of charges shall be samples taken uniformly from a minimum production run of 1000 RDX or PETN charges (a production run of only 300 charges is required for high temperature explosives) and packaged in the manufacturing/service company's standard shipping containers. These charges shall be stored for a minimum of four weeks prior to testing to allow some aging to occur.

3.6 Gun Configuration. Hollow carrier perforating guns must have pressure-tight enclosures on both ends and must be sealed during full duration of the test.

3.7 Clearance. The gun-to-target clearance for all perforating systems shall be zero inches from the outside diameter of the gun body.

3.8 Number of Shots. For statistical purposes a minimum of six shots shall be fired in the heated gun and the reference gun.

3.9 Temperature Environment. Tests shall be conducted at elevated temperature and atmospheric pressure using the following procedures:

a. The shots shall be made at temperature (± 10 F) after the perforating system has been exposed to the rated temperature for the rated time period, which is one hour for wireline application, or a minimum of 100 hours for tubing conveyed application.

b. The perforating system shall be brought to the rated elevated temperature at a maximum rate of 6 degrees per minute.

c. Average temperature of the test assembly shall be controlled to ± 10 F during the exposure period. Fluctuations out of this range are allowable if the time out of the envelope is less than 10 percent of the total exposure time. Actual average temperature shall be reported on the Verification Data Sheet, API Form 43F.

3.10 Test Fluid Environment. The reference test (refer to Par. 3.2) and elevated temperature test shall be similarly conducted in air or an appropriate liquid environment, at the option of the testing company. A continuous fluid media shall be used to transfer heat to the gun.

3.11 Temperature Monitoring. The temperature of the outer surface of the perforating gun adjacent to the top and bottom shot shall be separately monitored by intimate contact throughout the course of the test. The thermocouple shall be accurately shielded to ensure accurate surface gun body temperature. Suitable thermal sensing and remote recording equipment shall be used to obtain a permanent record of the temperature profile for the complete test. All equipment shall be calibrated and certified on a regular basis.

3.12 Test Assembly. The method used to mount the steel targets to the perforating system shall be at the option of the testing company.

3.13 Data Collection and Recording. The following measurements shall be made for each perforating system evaluated: total depth, faceplate hole diameter, and faceplate hole roundness.

3.13.1 Total Depth. The total depth shall be measured as the distance from the inside faceplate of the target to the farthest point penetrated by the shaped charge perforating system. The penetration shall be

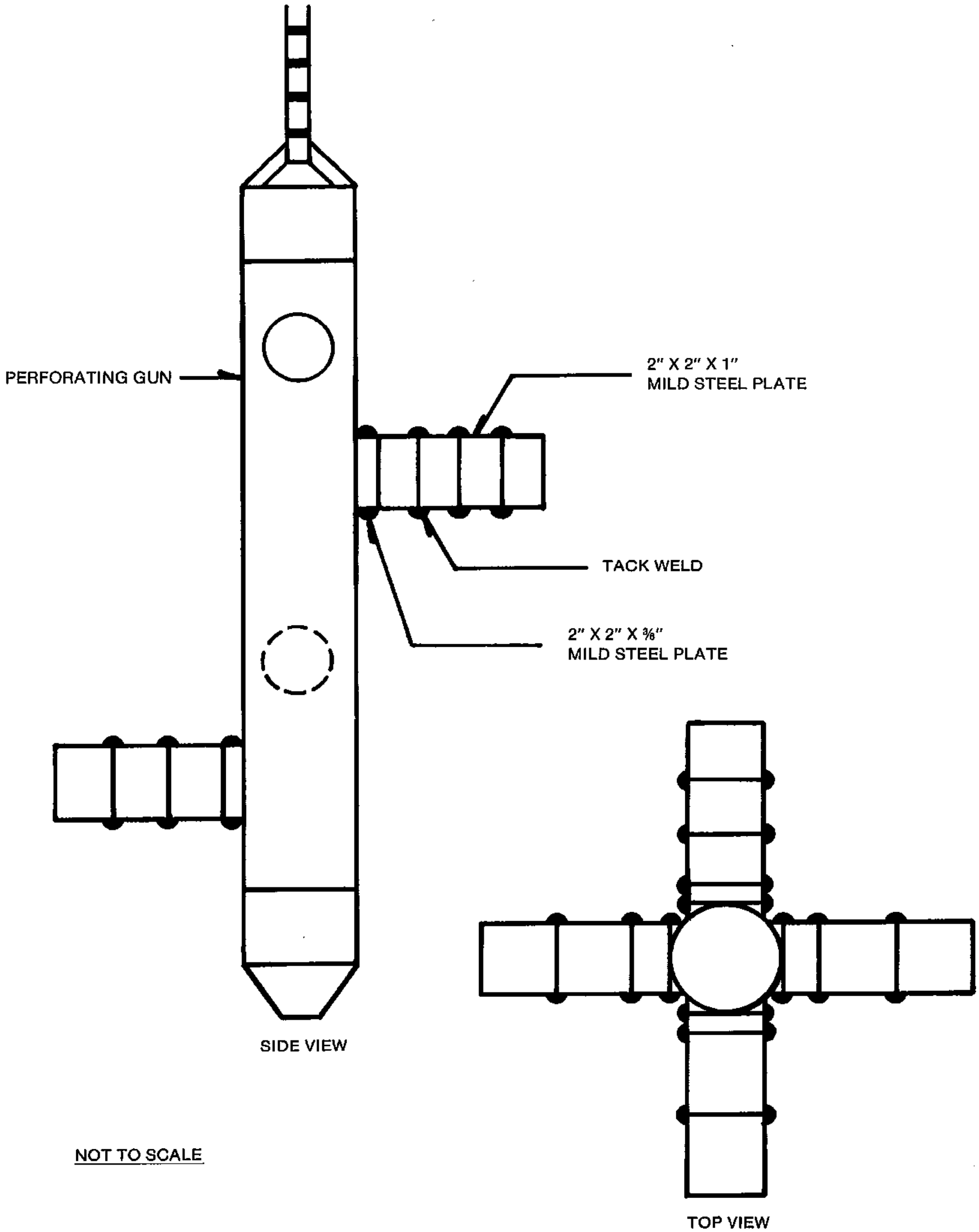


FIGURE 3.1, SCHEMATIC ILLUSTRATION OF STEEL TARGET FOR ELEVATED TEMPERATURE TEST

measured to the nearest 0.01 inch. The data shall be expressed as a ratio of the average hot/cold penetration.

3.13.2 Faceplate Hole Diameter. The faceplate hole diameter shall be measured on the inside ⅜ inch faceplate of the target along the short and long elliptical axes of the hole. Both the minimum and maximum shall be expressed as a ratio of the average hot/cold faceplate diameter hole. Such measurements shall be made with a caliper, the arms of which will readily pass through the perforation. Faceplate hole diameter shall be measured to the nearest 0.01 inch.

3.13.3 Faceplate Hole Roundness. The faceplate hole diameter roundness shall be reported as the average maximum faceplate hole diameter divided by the average minimum faceplate hole diameter. This ratio shall be calculated for both hot and cold shots.

3.13.4 Extra Shots. The testing company may test more than the minimum number of charges to obtain a more accurate statistical distribution of test results, but data from *all* charges tested in any test conducted under API RP 43 shall be included on Verification Data Sheet, API Form 43G.*

3.14 Pressure Testing of the Gun System. A separate test shall be made to verify the pressure/temperature/time rating of the gun system. No explosives are required to be in the gun system at this time.

3.14.1 Test Requirements. The test must be made in a suitable pressure vessel with provisions for pressure, temperature, and time chart recorders. Gauges should be calibrated and certified on a regular basis. Materials for the gun system are to satisfy engineering design and quality control specifications as to metallurgy, chemical composition, physical properties, and dimensional properties. Gun body length shall have a minimum unsupported section of 8 diameters of nominal outside diameter. If filler bars are used, they must have a maximum outside diameter at least 0.25 inch smaller than the inside diameter of the gun. Seal dimensions are to be adjusted to maximum extrusion gap for the test unless all seal configurations represented in the system have been separately and identically qualified.

3.14.2 Minimum Test Conditions.

Pressure: At the adjusted pressure test value (± 500 psi) (refer to Par. 3.14.3) with a minimum test pressure of 1.05 times the operational pressure rating.

Temperature: At the operational temperature rating (± 10 F).

Duration: One hour at the adjusted pressure test value and operational temperature rating for gun bodies; maximum time rating at adjusted pressure test value and operational temperature for seals.

3.14.3 Determination of Adjusted Pressure Test Value. Compute the collapse of the gun body to be actually tested utilizing those parameters required by recognized engineering practice. Compute the collapse of the gun body at "minimum material conditions" (MMC) utilizing specified physical and dimensional properties. Compute the adjusted test pressure as follows:

$$P_{ATV} = \frac{C_A \times P_r}{C_{MMC}} \qquad (3\text{-}1)$$

where:

P_{ATV} = Calculated adjusted pressure test value to which a specific gun sample is subjected that is equivalent to worst case conditions (minimum material conditions of physical properties, dimensions, and seals), taking into consideration the applicable manufacturing or service company's safety factor, psi.

C_A = Calculated collapse value (or failure) of an actual gun specimen to be evaluated based on its measured (actual) physical properties, dimensions, and seals, psi. (For example, the calculated collapse value for a specific gun specimen may be 24,500 psi, however, this value could drop as low as 21,000 psi under minimum material conditions on other production runs.)

P_r = Operational pressure rating, the maximum to which the gun should be subjected in field service, psi. (This value is related to C_{MMC} by the manufacturing or service company's assigned safety factor. For example, for a gun rated at 20,000 psi, the C_{MMC} is 21,000 psi, providing the safety factor is 1.05.)

C_{MMC} = Calculated collapse value (or failure) of a hypothetical gun sample under worst case conditions or "minimum material conditions" (MMC) of physical properties, dimensions, and seals, as permitted by design specifications and engineering drawings, psi. (If C_{MMC} for a gun sample with lowest permissible tensile strength, minimum permissible wall thickness, and maximum permissible seal gap is calculated to be 21,000 psi, it has an assigned operational pressure rating (P_r) of 20,000 psi providing the safety factor is 1.05.)

*Permission is granted to reproduce or reprint API Form 43G, "Verification Data Sheet, Elevated Temperature Perforator System Evaluation," as shown herein.

NOTE: Using the information in the foregoing examples the adjusted pressure test value, P_{ATV}, would be calculated as follows:

$$P_{ATV} = \frac{C_A \times P_r}{C_{MMC}}$$

$$P_{ATV} = \frac{24{,}500 \times 20{,}000}{21{,}000} = 23{,}333 \text{ psi.}$$

3.14.4 Alternate Procedure for Verification of Adjusted Pressure Test Value. Where the computed collapse valve is deemed not reliable, a gun body or minimum of six expendable charge cases shall be prepared and tested with materials taken uniformly from production run mill stock and verified or prepared to meet minimum physical and dimensional properties. The gun body or expendable charge cases should be verified or prepared to meet minimum material conditions on all dimensions by careful machining with reference to the applicable engineering specifications. Tolerances for minimum material conditions shall be ± 0.001 in. The gun body or expendable charges shall then be tested at a minimum test pressure of 1.05 times the operational pressure rating.

3.14.5 Disposition of Test Data. Details of test data and corresponding specifications and quality control documentation should be retained by the manufacturer as long as the subject equipment is in field service.

VERIFICATION DATA SHEET

API FORM 43G **RP 43, SECTION 3, ELEVATED TEMPERATURE PERFORATING SYSTEM EVALUATION**

Service Company ______________________
Gun OD & Trade Name ______________________
Gun Type ______________________
Shot Density Tested ______________________
Phasing Tested ______________________ degrees
Firing Order __________ Top down, __________ Bottom up
Firing Mode __________ Select, __________ Simultaneous
Remarks ______________________

Charge Name ______________________
Explosive Weight __________ gm; Explosive Type ______________________
Temperature/Time Rating __________ 1 hr __________ 100 hrs __________
Pressure Rating __________ psi @ __________ F
Charge Case Material ______________________
Debris Weight ______________________
Debris Description ______________________

SYSTEM CONFIGURATION

Charge Name ______________________
Charge Part Number ______________________
Detonator Name ______________________
Detonator Part Number ______________________
Detonating Cord Name ______________________
Detonating Cord Part Number ______________________
Booster Name ______________________
Booster Part Number ______________________
Other Explosive Parts ______________________

Gun Name __________ Gun P/N __________
Test Gun P/N __________
Volumetric Ratio (V_r Test Gun/V_r Gun) __________
Firing Head Name __________ Firing Head P/N __________
Seal System Name __________ Seal System Spec. P/N __________
Lubricant Name __________ Lubricant Spec. P/N __________
Other Elastomerics or Volatile Materials (Name and P/N's) __________

Remarks ______________________

TEST RESULTS

EXPLOSIVE DEGRADATION TEST

Test Date __________

	Penetration (P)	Hole Size (H)
Ratio — $\overline{X}$ Hot/$\overline{X}$ Cold	__________	__________
Variance — Hot	__________ %	__________ %
Variance — Cold	__________ %	__________ %

Hole Roundness (H $\overline{max}$/H $\overline{min}$)

Roundness — Hot __________
Roundness — Cold __________
High Order Detonation Transfer Demonstrated __________
Remarks __________

PRESSURE RATING TEST

Test Date __________
Pressure __________ psi
Temperature __________ F
Time __________ hrs
Carrier Length __________ ft
Pressure Rating __________ psi

SEAL SYSTEM TEST

Test Date __________
Test Conditions __________ psi @ __________ F __________ hrs
Remarks __________

VERIFICATION

Type of Verification: ☐ Self ☐ Third Party

I verify that these tests were made according to the procedures as outlined in API RP 43, Recommended Practices for Evaluation of Well Perforators, Fifth Edition, January 1991. This test was conducted at the request of __________. All equipment used in these tests, with the exception of the test gun, was standard equipment with our company and was not changed in any manner for the test. All explosive components were chosen at random from stock and therefore will be substantially the same as the equipment which would be furnished to perforate a well for any operator.

VERIFIED BY __________ __________ __________ __________ __________
(Name) (Title) (Date) (Company) (Address)

SECTION 4
EVALUATION OF PERFORATION FLOW PERFORMANCE UNDER SIMULATED DOWNHOLE CONDITIONS

4.1 Introduction. The purpose of these test procedures is to provide a measure of flow performance of a perforation. The general procedure may be used on quarry rock or well core under conditions chosen to simulate site-specific downhole conditions. A set of standard test conditions is also provided. This is intended as a procedure to be followed for a special test and will not be filed with API.

4.2 Test Target. Tests will be performed in cylindrical cores provided with a faceplate simulating well casing, a flexible jacket to transmit simulated overburden stress to the sample, and provision for applying pore fluid pressure to the boundaries of the sample. Pore fluid pressure may be applied to the cylindrical sides of the sample (radial flow), to the unperforated end of the sample (axial-flow), or both, in a manner simulating in situ pore pressure fields. Typical arrangements are shown in Appendix 4A, Figures 4.1 and 4.2. The specific target geometry will be at the option of the testing company except that:

4.2.1 Target diameter shall not be less than 4 inches.

4.2.2 The entrance hole shall be positioned in the center of the faceplate and, after shooting, the tip of the perforation shall not be further than one-fourth of the target diameter from the axis of the target.

4.2.3 After shooting, there shall be a minimum distance equal to one target diameter between the farthest end of the perforation and the rear of the target.

4.2.4 Only samples oriented with axes parallel to bedding planes should be used in axial-flow geometry.

4.2.5 Simulated overburden stresses shall be applied uniformly to all portions of the sample, although axial and radial stress may be different, if desired.

4.2.6 The target geometry used shall be tested to assure that no flow bypasses the perforation.

4.3 Testing Equipment. Equipment shall consist of a pressure vessel (the confining pressure vessel) for applying confining pressure to the sample, a second pressure vessel (the simulated wellbore) to contain and apply wellbore pressure to the perforating gun, and a flow system for applying pore pressure to the sample. A schematic drawing is shown in Appendix 4A, Figure 4.3. The specific arrangements are at the discretion of the testing company except that:

4.3.1 The inner diameter of the confining pressure vessel shall be at least 12 inches, or it shall be demonstrated that penetration and flow are the same as would be the case in such a vessel.

4.3.2 The simulated wellbore vessel shall be equipped with an accumulator or other pressure ballast of at least one gallon capacity precharged to one-half the intended wellbore pressure, and connected to the wellbore through tubing with at least ¼ inch inside diameter.

4.3.3 The pore pressure system shall be capable of providing the pressure needed for both initial pressurization and post-shot flow, shall be free of pressure pulsations at the sample, and shall be equipped with a filter on the sample inlet which will eliminate all particles of 3-micron diameter or larger.

4.3.4 Transducers, gauges, or other means of suitable accuracy shall be provided to measure confining pressure, wellbore pressure, pore pressure, fluid inlet temperature, and flow rate through the sample.

4.3.5 The temperature of the fluid used should be measured as it enters the sample.

4.4 Charge Selection and Aging. Where possible, the charges shall be samples taken uniformly from a minimum production run of 1,000 for RDX or PETN charges, or of 300 charges for charges using high temperature explosives, and packaged in the manufacturing/service company's standard shipping containers. These charges shall be stored for a minimum of four weeks prior to testing to allow some aging to occur.

4.5 Gun Configuration. Single shot charge carriers, if needed, shall be fabricated such that internal standoff and gun wall (or port plug) thickness and material are the same as in production run gun stock.

4.6 Systems Calibration.

4.6.1 All transducers and gauges will be calibrated against a suitable reference standard at intervals not exceeding six months. Most recent calibration data shall be kept on file.

4.6.2 Pressure drop due to system impedance and turbulence will be measured as a function of flow rate using a high permeability dummy sample such as 20/40 resin-bonded sand. This test shall be performed at least once per year for both perforation and permeability test fixtures. Most recent data shall be kept on file.

4.7 Permeability Measurement. Suitable measurements of permeability shall be made on each test sample prior to perforating. Permeability shall be measured on the whole sample both parallel ($K_{//}$) and perpendicular ($K_{\perp}$) to bedding planes using methods described in Appendix 4B. The values of $K_{\perp}$ and $K_{//}$ will be used to calculate expected flow into the perforation in Appendix 4C.

For samples with axes perpendicular to bedding, axial flow (Appendix 4B, Par. 4B.1) is used to measure permeability perpendicular to bedding, and flow across the diameter (Appendix 4B, Par. 4B.2) is used for parallel permeability. For samples oriented parallel to bedding, the reverse of the above techniques are used. In the latter case, the flowing segments of the cross-diameter method (Appendix 4B, Par. 4B.2) are oriented to obtain flow perpendicular to bedding. The detailed techniques used are at the discretion of the testing company except that:

4.7.1 The measurement should be performed under the same effective stress as that used during the perforation test.

4.7.2 The core should be at the same fluid saturation condition as that used during the perforation test, and the same fluid and range of flow rates should be used in both tests during the flow measurements.

4.7.3 The same flow system constraints apply as described in Par. 4.6.2.

4.8 Testing Procedure. The prepared sample shall be assembled with faceplate, flexible jacket, and flow distributor and mounted in the pressure vessel. The armed gun to be tested shall be connected to shooting leads and placed in the wellbore vessel following standard safety procedures. Confining, pore, and wellbore pressures shall be brought simultaneously to the desired levels and the shot fired. If desired, the equalized wellbore/pore pressures may be slowly reduced to ambient while simultaneously lowering confining pressure to keep the effective pressure (i.e., confining pressure minus pore pressure) constant.

Flow shall be initiated through the sample by applying pore pressure to the sample to simulate the desired drawdown. (*Note:* This value will depend on the flow geometry chosen and effective permeability of the perforated sample.) Flow at least 10 liters at this pressure or until no further change in flow rate occurs, whichever is longer. Additional flow testing, or further testing at other pressures, is at the discretion of the testing company.

4.9 Data Recording. For each sample tested, the following data shall be recorded:

4.9.1 **Testing Geometry.** A line drawing of the specific test geometry and flow boundary conditions used shall be attached.

4.9.2 Sample source, diameter, length, orientation, and fluid saturation condition.

4.9.3 Sample permeabilities and method of measurement. (Refer to Appendix 4B.)

4.9.4 Test conditions during both shooting and flowing.

4.9.5 **Perforation Geometry.**

a. **Debris-free Depth.** Measured distance from rock face to first debris in the hole, as measured with a blunt probe.

b. **Total Core Penetration.** Distance from rock face to deepest effect of penetration. Determine by probing for weakened rock beyond the perforation tip.

c. **Perforation Diameter Profile.** The diameter of the perforation shall be provided at 1-inch intervals along the length of the perforation. This may be done by recording the diameter in tabular form, by sketching the perforation on an appropriate grid, or by attaching a photograph of the perforation, again with an appropriate scale grid. The average perforation diameter will be recorded to the nearest 0.1 inch.

4.9.6 Differential pressure (corrected for flow system impedance as in Par. 4.6.2) and flow rate at one-liter intervals; differential pressure and flow rate used in calculations; maximum flow rate, differential pressure, and cumulative flow prior to taking data used in calculations.

4.9.7 Inlet temperature of fluid used and corresponding viscosity.

4.9.8 Flow that may enter the debris-free portion of the perforation through the debris should be eliminated or subtracted from the total flow by making and recording a supplementary measurement.

4.10 Data Reduction. Flow rate data will be presented by comparing the maximum observed flow rate to that expected from pre-shot permeability measurement. Core Flow Efficiency (CFE) shall be defined as the ratio, observed flow/calculated flow, normalized to a target with a radius of 3.5 inches. Suitable means will be used to calculate expected flow based on measured debris free perforation depth, average perforation diameter, initial permeability, and applied pressure boundary conditions.

Equations are supplied in Appendix 4C to assist in this calculation for radial flow boundary conditions. In this case, CFE is defined as:

$$CFE = \frac{1.25-\ln(r)}{1.25-\ln(r)+\ln(R/r)\left[\frac{Q_c}{Q_m}-1\right]} \qquad (4\text{-}1)$$

where:

r = average perforation radius, in.

R = sample radius, in.

Q_c = calculated flow from Appendix 4C.2, cm^3/sec.

Q_m = measured flow rate, cm^3/sec.

For use in well productivity models, the permeability of a hypothetical, reduced-permeability zone surrounding the perforation can be estimated by multiplying the matrix permeability used in the model by the Permeability Reduction Factor (PRF):

$$PRF = \frac{CFE \bullet \ln(r_c/r)}{1.25 \bullet (1\text{-}CFE) - \ln(r) + (CFE) \bullet \ln(r_c)} \quad \ldots (4\text{-}2)$$

The value of the damaged zone radius, r_c, must be chosen, for example, by selecting the thickness of the zone.

4.11 Standard Test Conditions. The following additional specifications are provided so that data can be collected and compared under common conditions. All specifications above apply. Data collected under these conditions may not represent and may not be translatable to downhole conditions. Permeability damage caused by the perforator may be different in actual reservoir rock and under actual downhole pressures. Post-shot clean up may differ from standard test results depending on actual reservoir rock properties, the underbalance used, dynamic wellbore storage effects, production drawdown, fluid composition and viscosity, perforating phasing and shot density, and other factors. For best site-specific results, the general test specifications above allow simulation of each of these factors.

4.11.1 Rock Samples. Test samples shall be of Berea sandstone, meeting specifications of Section 2 and having absolute permeability to brine (parallel to bedding) between 100 and 400 md. Sample diameter shall be 4 inches (± .25 inch) for charges ≤ 15g explosive weight and 7 inches (± .25 inch) for larger charges. Tests may be done using samples cut either parallel or perpendicular to bedding planes.

4.11.2 Pore Pressure Boundaries. Pore pressure shall be applied to the cylindrical sides of the sample only, as shown in Appendix 4A, Par. 4A.3.

4.11.3 Pore Fluid. Sodium chloride brine solution (3% by weight).

4.11.4 Pressure Conditions. Applied pressures when the gun is fired shall be as follows:

Confining Pressure	4,500 psi
Pore Pressure	1,500 psi
Wellbore Pressure	1,000 psi

This provides an effective rock stress of 3,000 psi and 500 psi underbalance. Flow testing may be done with wellbore and pore pressure ambient, but effective stress shall be kept at 3,000 psi by simultaneously lowering confining pressure (refer to Par. 4.8).

4.11.5 Differential Pressure. This pressure during flow shall be 50 psi.

4.11.6 The faceplate shall be designed so that the perforator must penetrate ⅜-inch of *ASTM A-36* steel or equivalent and ¾-inch of Hydrostone or equivalent before entering the target.

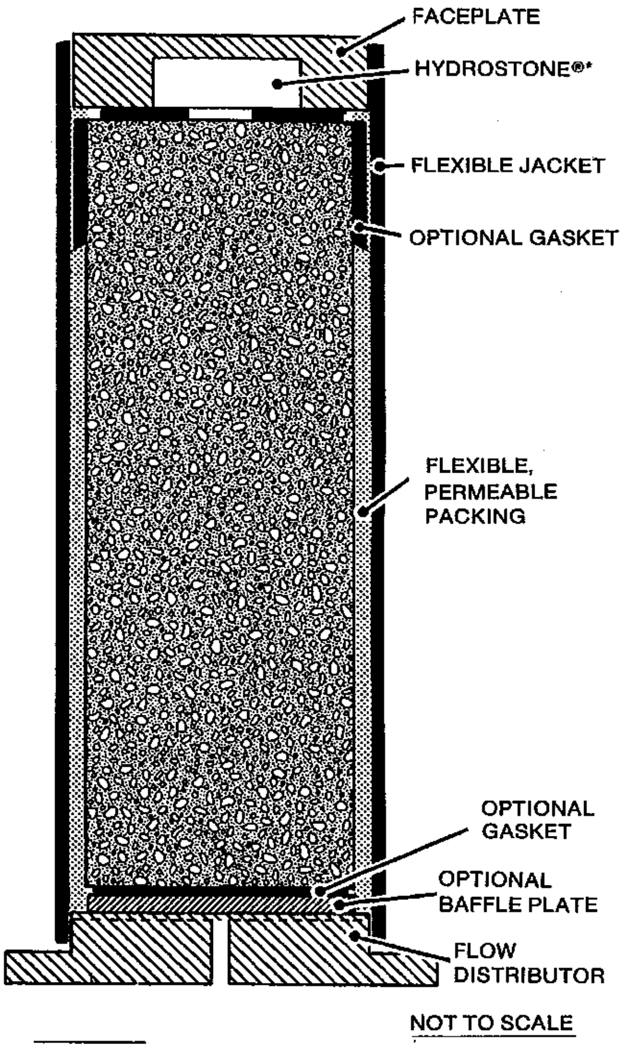
4.11.7 Clearance. With the exception of zero-phased perforators used with eccentering devices, bullet and jet perforators shall be tested at a clearance of ½ inch. Zero-phased perforators used with eccentering devices shall be fired at the clearance assumed in a well.

APPENDIX 4A
TEST TARGET AND EQUIPMENT

4A.1 Introduction. Within the test target specification (refer to Par. 4.2), pressure can be applied to the cylindrical sides of the sample, to its ends, or both, depending on the anticipated pore pressure field in situ. The following illustrates methods for achieving these boundary conditions.

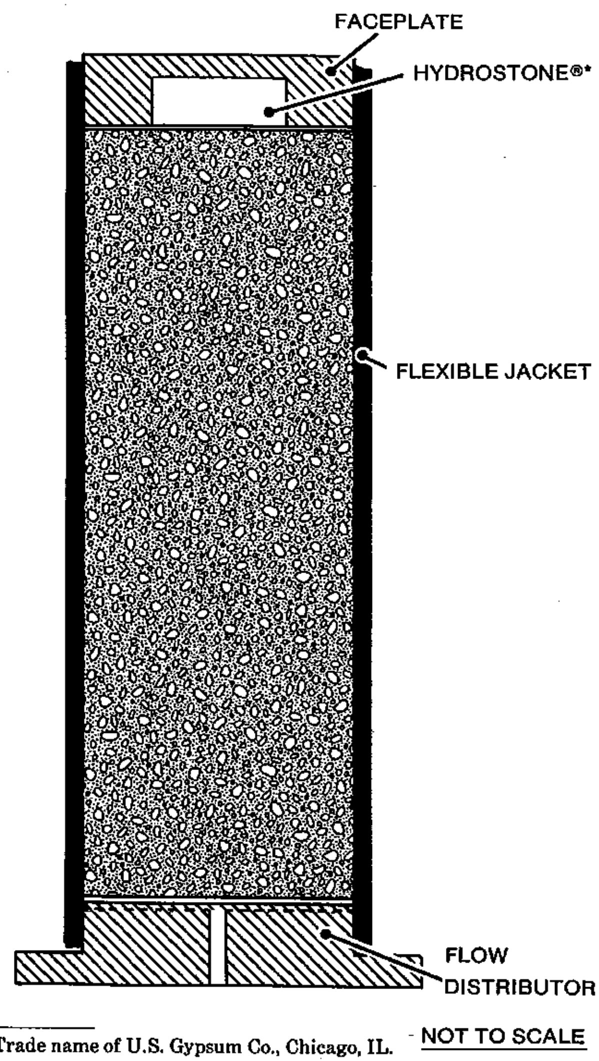
4A.2 Radial Flow. Pore pressure is applied to the cylindrical sides of the target. The gap between jacket and sample (refer to Figure 4.1) is filled with a flexible material with at least 2 darcies permeability. Bauxite proppant (20/40 mesh) or ⅛ inch diameter metal rods have been successfully used. A gasket with central hole between the faceplate and sample prevents bypass of fluid. An optional gasket and baffle plate at the rear of the sample prevents flow into the end of the sample as required in Par. 4.11.2. Flow may also be blocked from a portion of the target nearest the entrance hole to roughly "simulate" drilling damage. The entire assembly is placed in the confining pressure vessel and pressurized.

4A.3 Axial Flow. Pore pressure is applied to the unperforated end of the sample only. The bottom end cap (refer to Figure 4.2) distributes fluid across the end of the sample through a system of grooves and steel screen. The entire assembly is placed in the confining pressure vessel and pressurized.



*Trade name of U.S. Gypsum Co., Chicago, IL.

FIGURE 4.1
TYPICAL RADIAL FLOW GEOMETRY



*Trade name of U.S. Gypsum Co., Chicago, IL.

FIGURE 4.2
TYPICAL AXIAL-FLOW GEOMETRY

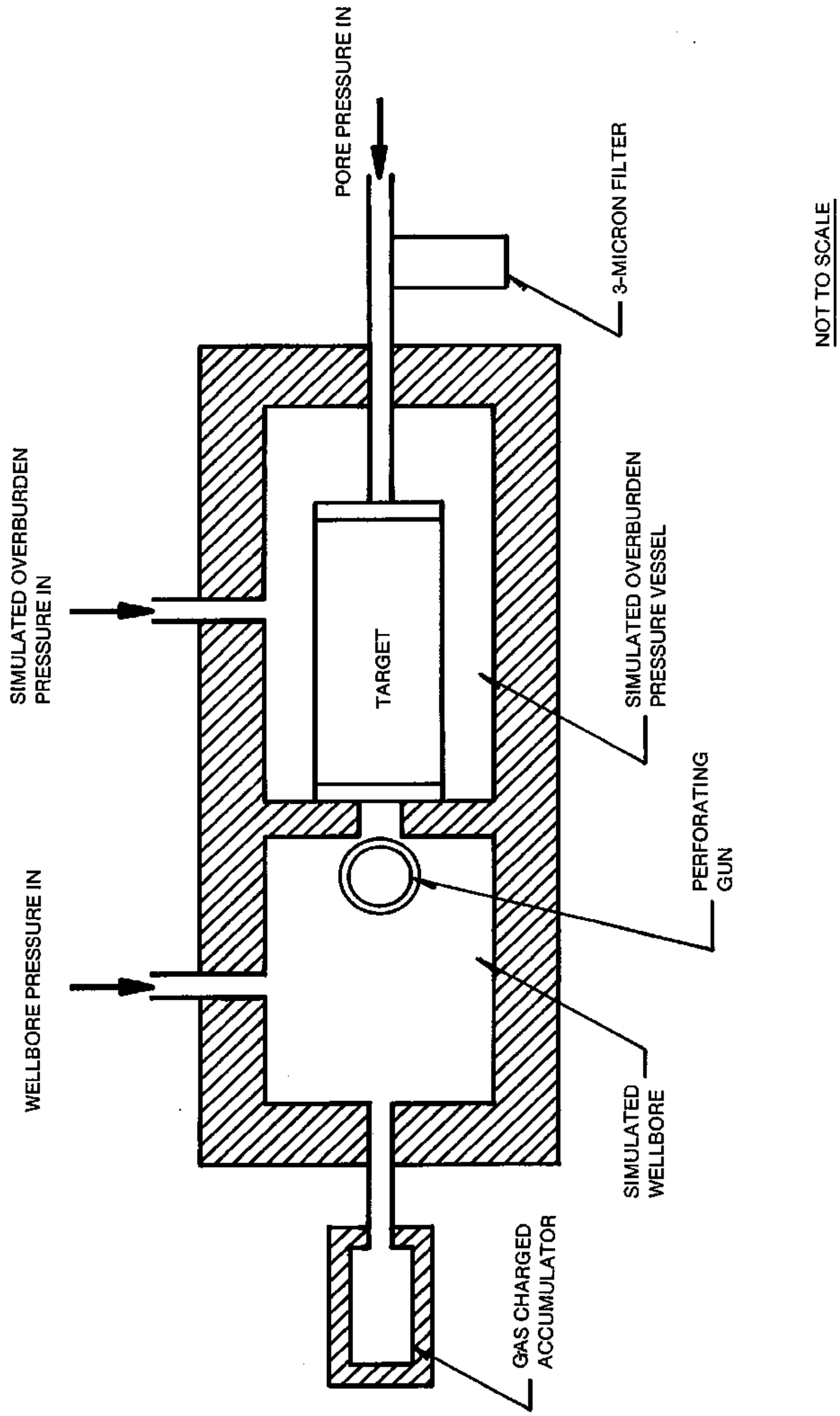


FIGURE 4.3
SCHEMATIC OF TYPICAL TESTING EQUIPMENT

APPENDIX 4B
PERMEABILITY MEASUREMENT

4B.1 Axial Flow. Permeability can be measured using a conventional Hassler permeameter as shown schematically in Fig. 4.4. Flow enters the apparatus through one end cap and is distributed over the end of the core through a system of screens and grooves. Fluid is collected at the opposite end through a similar end cap. The entire apparatus is pressurized to obtain the desired confining pressure on the sample. The data are reduced to permeability using Equation (4-3).

$$K = 1.84\times10^{3} \frac{Q\mu L}{R^{2}\Delta P} \quad \text{.................... (4-3)}$$

where:

K = permeability, md

Q = flow rate, cm^3/sec

μ = viscosity, cp

L = core length, in.

R = core radius, in.

ΔP = differential pressure corrected for the flow system pressure drop, psi.

4B.2 Flow across the core diameter provides a measure of permeability with flow in a direction similar to that in a radial flow target. Fluid is introduced into a 90° segment along one side of the sample, flows across the sample, and exists through a similar segment on the opposite side (refer to Fig. 4.5). The segments may be constructed in a manner similar to that used in Appendix 4A, Par. 4A.2, employing proppant or rods to provide a flexible, permeable zone. The test zone, L′, should cover only the expected depth of the perforation as shown in Fig. 4.5. The entire apparatus is pressurized to obtain the desired confining pressure on the sample.

The flow data are converted to permeability using Equation (4-4):

$$K = 5.79\times10^{3} \frac{Q\mu}{L'\Delta P} \quad \text{.................... (4-4)}$$

where:

K = permeability, md

Q = measured flow rate, cm^3/sec

μ = fluid viscosity, cp

L′ = length along the core of the test zone, in.

ΔP = differential pressure corrected for flow system pressure drop, psi.

4B.3 Variable Permeability. In a core cut with the axis perpendicular to bedding, permeability may vary along the length of the perforation. This may affect distribution of flow into the perforation. In such cases, the variation of permeability along the expected length of the perforation may be measured by sequentially blocking off flow along the core or in a separately drilled ideal perforation. Alternatively, small plugs may be taken laterally along the core.

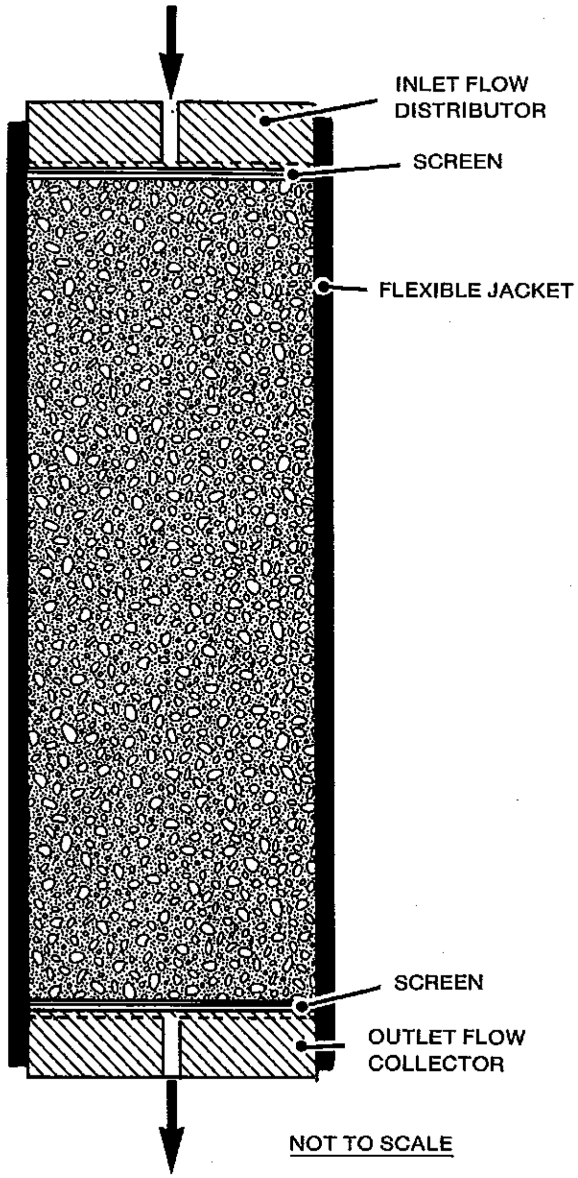


FIGURE 4.4
TYPICAL AXIAL FLOW PERMEABILITY EQUIPMENT

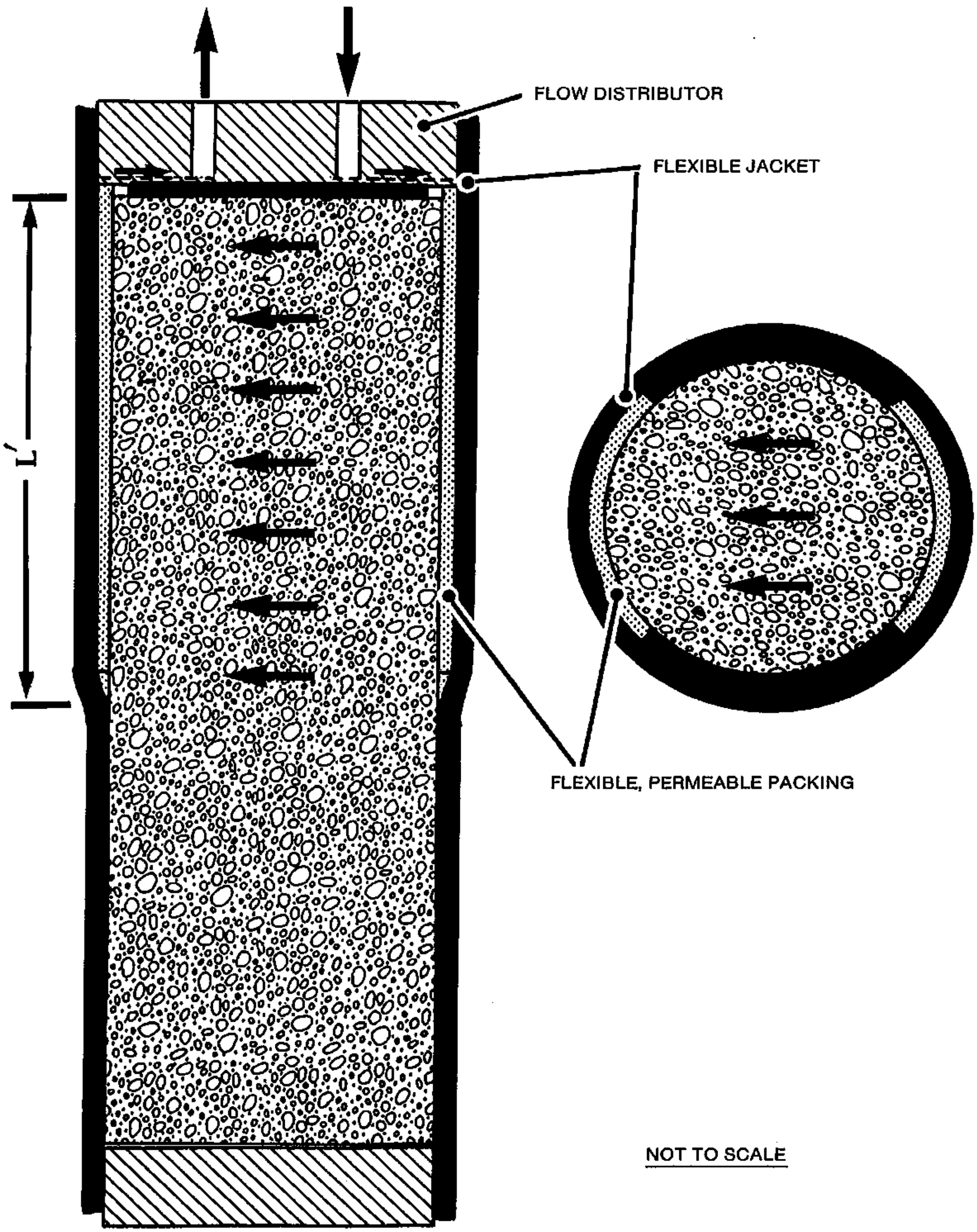


FIGURE 4.5
TYPICAL DIAMETRAL FLOW PERMEAMETER

APPENDIX 4C
DATA REDUCTION; EXPECTED FLOW RATES

4C.1 Introduction. This Appendix contains guidance for calculating expected flow rates in the various flow geometries described in Appendix 4A. More refined calculations using direct finite element modeling of the observed perforation may be substituted, if desired.

4C.2 Radial Flow Target. Refer to Appendix 4A, Par., 4A.2. Equation (4-5) is applicable where permeability is uniform and cylindrically symmetrical. If the target meets the criterion of Par. 4.2.3, the error will be small whether flow is allowed through the rear end of the sample or not. Flow rate may be calculated by:

$$Q_c = 1.08 \times 10^{-3} \frac{\Delta P}{\mu}\left[\frac{K_1 D}{\ln(R/r)} + \frac{K_2 r R}{R-r}\right] \quad \text{.... (4-5)}$$

where:

Q_c = flow rate, cm^3/sec

ΔP = differential pressure, psi

μ = fluid viscosity, cp

D = perforation depth, in.

r = perforation radius, in.

R = sample radius, in.

The permeability values, K_1 and K_2 (in millidarcies), are derived from measured permeabilities parallel and perpendicular to bedding. The exact method used is at the discretion of the testing company and will depend on the target orientation. The following formulae shall be used for tests meeting standard conditions of Par. 4.11, and may be used for other tests at the discretion of the testing company.

4C.2.1 For cores oriented with axes parallel to bedding:

$$K_1 = K_2 = (K_\perp K_{//})^{1/2} \quad \text{........................ (4-6)}$$

4C.2.2 For cores oriented with axes perpendicular to bedding:

$$K_1 = K_{//}$$

$$K_2 = (K_\perp K^2_{//})^{1/3} \quad \text{.............................. (4-7)}$$

The values of K_1 and K_2 used shall be recorded on the data sheet (API Form 43H)* along with the measured values parallel and perpendicular to bedding.

4C.3 Axial Flow. (Appendix 4A, Par. 4A.3). This geometry requires finite element analysis for calculating ideal flow to determine CFE.

*Permission is granted to reproduce or reprint API Form 43H, "Verification Data Sheet, Evaluation of Perforation Flow Performance, Section 4, API RP 43," as shown herein.

Check if test complies with standard conditions in Par. 4… (✓) ☐

API FORM 43H

VERIFICATION DATA SHEET
RP43, SECTION 4, EVALUATION OF PERFORATION FLOW PERFORMANCE

Service Company ____________ Charge Name and Part Number ____________

Gun OD and Trade Name ____________ Explosive Weight ________ g Explosive Type ____________

Gun Type ____________ Date/Shift Code ____________

Test Rock Source ____________ Date of Test ____________

Saturation Fluids ____________

Angle of Core Axis to Bedding ________ degrees Permeability, md:

Fluid Used During Flow Testing ____________ Parallel to Bedding ____________

Target Diameter ________ in. Perpendicular to Bedding ____________

Target Length ________ in. Values Used for CFE Calculation: K_1 ________ K_2 ________

Test Geometry Used: Axial Flow (Appendix 4B, Par. 4B.1 (✓) ____

Radial Flow (Appendix 4B, Par. 4B.2 (✓) ____ Flow Through End? (Yes/No) ____ Length masked to "simulate wellbore damage" ____ in.

Shooting Conditions: Confining Pressure ________ psi Pore Pressure ________ psi Wellbore Pressure ________ psi

Flowing Conditions: Confining Pressure ________ psi Wellbore Pressure ________ psi

DATA USED TO CALCULATE CORE FLOW EFFICIENCY (CFE): (See reverse for raw data.)

Differential Pressure	________	psi
Fluid Temperature	________	C
Fluid Viscosity	________	cp
Debris-Free Penetration	________	in.
Mean Penetration Radius	________	in.
Gross Flow Rate	________	cm³/sec
Correction for Flow Through Debris (if measured)	________	cm³/sec
Net Flow Rate	________	cm³/sec

Additional Data:

Cumulative Flow before CFE Data	________	liters
Maximum Flow Rate before CFE Data	________	cm³/sec
Maximum Differential Pressure Before CFE Data	________	psi
Overall Penetration Depth	________	in.

Perforation Diameter Profile. Provide diameter at one inch intervals, or attach sketch or photograph with appropriate scale.

Additional Comments:

Calculated flow using debris-free depth ________ cm³/sec. (Refer to Appendix 4C.) CFE from Par. 4.10 ________.

VERIFICATION

Type of Verification: Self ________ Third Party ________

I verify that these tests were made according to the procedures as outlined in *API RP 43: Recommended Practices for Evaluation of Well Perforators*, Fifth Edition, January 1991. This test was conducted at the request of ____________. All equipment used in these tests, with the exception of the test gun, was standard equipment with our company and was not changed in any manner for the test. All explosive components were chosen at random from stock and therefore will be substantially the same as the equipment which would be furnished to perforate a well for any operator.

VERIFIED BY: ____

(Name) (Title) (Date) (Company) (Address)

API FORM 43H (Continued)

DATA RECORD SHEET

Cumulative Flow, liters	Measured Flow Rate, cm³/sec	Differential Pressure, psi*	Fluid Temperature, C	Fluid Viscosity, cp

* Corrected for system back pressure.

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