Recommended Practices for Evaluation of Well Perforators

API RECOMMENDED PRACTICE 19B
FIRST EDITION, NOVEMBER 2000

American
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Upstream Segment

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Recommended Practices for Evaluation of Well Perforators

0 Scope

0.1 GENERAL

This Recommended Practice describes standard procedures for evaluating the performance of perforating equipment so that representations of this performance may be made to the industry under a standard practice. This document supersedes all previously issued editions of API RP 43.

Sections 1–4 of this publication provide means for evaluating perforating systems (multiple shot) in 4 ways:

1. Performance under ambient temperature and atmospheric pressure test conditions.
2. Performance in stressed Berea sandstone targets (simulated wellbore pressure test conditions).
3. How performance may be changed after exposure to elevated temperature conditions.
4. Flow performance of a perforation under specific stressed test conditions.

The purpose of this Recommended Practice is to specify the materials and methods used to evaluate objectively the performance of perforating systems or perforators.

0.2 IMPLEMENTATION

These procedures become effective as of the date of publication.

0.3 API REGISTERED PERFORATOR SYSTEMS

Information on API Registration of perforator systems can be found in Appendix D.

0.4 REPORTS AND ADVERTISEMENTS

Reports, articles, papers, periodicals, advertisements, or similar publications which refer to results from tests conducted according to API RP 19B must not be worded in a fashion to denote that the American Petroleum Institute either endorses the result cited or recommends or disapproves the use of the perforating system described.

Use of data obtained under API RP 19B tests in reports, articles, papers, periodicals, advertisements, or other published material shall include, as a minimum, all test configuration data not specified by API RP 19B or left to the verifying company's choosing by API RP 19B and the average measured results of the test.

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.

1.2.1 Target Preparation

Concrete for the target and test briquettes shall be mixed using a cement-sand-slurry consisting of the following:

a. 1 part or 94 lb ±1% of API Class A cement

b. 2 parts or 188 lb ±1% of dry sand (The sand shall meet API RP 56, 2nd Edition requirements for 16–30 frac sand. The sand shall be stored in a dry location prior to use.)

c. 0.52 part or 49 lb ±1% of potable water

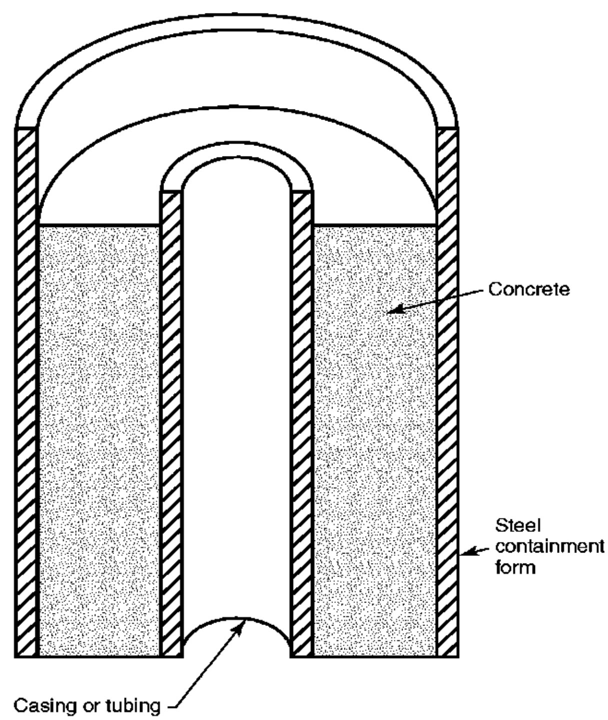


Figure 1—Example Concrete Target

1.2.2 Required Documentation

Each distinct quantity of concrete (truckload or similar) used in the preparation of a target must include a written report from the concrete supplier listing the actual amounts of cement, sand, and water used. Quantities shall be reported in the units utilized during the measuring process, with no conversions or adjustments.

The testing company shall maintain supporting documentation that the sand complies with API RP56 for 16–30 frac sand. At a minimum, this shall consist of sieve analysis data for all loads of frac sand received by the concrete supplier.

1.2.3 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.

1.2.4 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.

1.2.5 Target Compressive Strength Evaluation

Target compressive strength shall be evaluated using 2-in. cubes (briquettes) made from the same concrete as the target, prepared and tested as prescribed in Sections 1.2.1 through 1.2.5. Prior to or within 24 hours after conducting a test, the briquettes shall be tested and must have an average compressive strength of not less than 5,000 psi.

1.2.5.1 Compressive Strength Evaluation Apparatus

The molds shall not have more than three cube compartments. The parts of the molds when assembled shall be positively held together. The molds shall be made of hard metal, not attacked by the cement mortar, with a Rockwell hardness number not less than 55 HRB. The sides of the mold shall be sufficiently rigid to prevent spreading or warping. The interior faces of the molds shall be plane surfaces and shall conform to the tolerances in Table 1. A base plate having a minimum thickness of 1/4 in. shall be used.

Table 1—Permissible Variations of Specimen Molds

Parameter	New	In Use
Planeness of side	<0.001 in.	<0.002 in.
Distance between opposite sides	2 in., ±0.005 in.	2 in., ±0.005 in.
Height of each compartment	2 in., +0.01 to –0.005 in.	2 in., +0.01 to –0.015 in.
Angle between adjacent faces[1]	90, ±0.5°	90, ±0.5°

[1]Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

The testing machine shall conform to the requirements in ASTM C 109. The molds shall be checked for tolerances and the testing machine shall be calibrated within ±1% of the load range to be measured at least once every two years.

1.2.5.2 Preparation of Molds

Apply a thin coating of release agent (WD-40® or similar aerosol lubricant for example) to the interior faces of the mold and contact surface of the base plate. Wipe the mold faces and base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating. Seal the surfaces where the halves of the mold join by applying a coating of light grease. The amount should be sufficient to extrude slightly when the two halves are tightened together. Remove any excess grease with a cloth. After placing the mold on its base plate (and attaching with clamps if applicable), apply grease to the exterior contact line of the mold and base plate to achieve a water tight seal.

1.2.5.3 Placing Slurry in Molds

The slurry sample shall be procured midway during the target pour. For large targets requiring multiple concrete trucks, the sample shall be taken from the truck filling the middle portion of the target. Preparation of the specimens shall begin within 15 minutes of procuring the sample. Stir the slurry by hand using a non-absorbent spatula or puddling rod to minimize segregation. Place slurry in each specimen compartment in the prepared molds in a layer equal to one-half of the mold depth. The slurry shall be placed in all the specimen compartments before commencing the puddling operation. Puddle each specimen 25 times using a glass or noncorroding metal rod approximately 8 in. long by 1/4 in. in diameter. After puddling the layer, the remaining slurry shall again be stirred. Fill the molds to overflowing and puddle as with the first layer. After puddling, the excess slurry shall be struck even with the top of the mold, using a straightedge. Specimens in molds which show evidence of leaking shall be discarded. For one test determination, not less than six specimens shall be prepared.

1.2.5.4 Curing of Specimens

As soon as possible, but no more than 2 hours after preparation, the molds shall be placed in the water on the top of the Section 1 target. The top of the Section 1 target must have firmed sufficiently to support the molds. The water level in the top of the target must be kept high enough to completely cover each mold. Within 20 to 23 hours after initial placement, remove the molds from the water, remove the specimens from the molds, and place the specimens in a white, plastic container, filled with potable water. Place the container in the water on top of the Section 1 target, where it shall remain for the entire curing period. The container must be at least 6 inches deep, and the specimens shall remain fully submerged in the water until immediately prior to being tested.

1.2.5.5 Specimen Testing

Wipe each specimen to a surface-dry condition and remove any loose material from the faces that will be in contact with the bearing blocks of the testing machine. Check these faces by applying a straightedge. If there is appreciable curvature, grind the face or faces to plane surfaces or discard the specimen.

Apply the load to specimen faces that were in contact with the plane surfaces of the mold. Center the specimen in the testing machine below the upper bearing block. Prior to the testing of each cube, it shall be ascertained that the spherically seated block is free to tilt. The load surfaces shall be clean. Use no cushioning or bedding material. Appropriate safety and handling procedures shall be employed in testing the specimen.

a. The rate of loading shall be 16,000, ±1600 lbf (4000, ±400 psi) per minute. Make no adjustment to the controls of the testing machine while a specimen is yielding before failure.

b. The compressive strength is calculated by dividing the maximum load in lbf by cross-sectional area in square inches. If deviations of $^1/_{16}$ in. or more from the specified linear dimension of 2.00 in. are reported, use the actual area for the calculation of the compressive strength. In determining the compressive strength, do not consider specimens that are manifestly faulty. The maximum permissible range between specimens is 8.7% of the average. If this range is exceeded, discard the result that differs the most, and check the range of the remaining specimens. Repeat until the results comply with the maximum permissible range. A minimum of three specimens is required for a valid test. The compressive strength of all acceptable test specimens shall be averaged and reported to the nearest 10 psi.

1.2.6 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 2.

Table 2—Casing and Tubing for Use in Test Target

Pipe Size, OD in.	Pipe Nominal Weight, lb/ft	Casing or Tubing, API Grade
$2^3/_8$	4.6	L-80
$2^7/_8$	6.4	L-80
$3^1/_2$	9.2	L-80
$4^1/_2$	11.6	L-80
9	15.0	L-80
$5^1/_2$	17.0	L-80
7	32.0	L-80
$7^5/_8$	33.7	L-80
$8^5/_8$	40.0	L-80
$9^5/_8$	47.0	L-80
$10^3/_4$	51.0	L-80
$11^3/_4$	54.0	L-80
$13^3/_8$	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 Section 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. A minimum production run is a continuous run which may span multiple shifts in order to meet the required minimum quantities. 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 shot as it is normally positioned 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 shots that penetrate the terminal boundary of the concrete target or are within the top 12 inches 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:

a. Total penetration depth.
b. Casing or tubing hole diameter.
c. Burr height.

All perforator individual or averaged penetration depths shall be reported to the nearest 0.1 inch.

1.9.1 Total Penetration 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. 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. See Figure 2 for an example data sheet. Any data sheet used must include a similarly positioned watermark indicating that the test is not registered with the API. Comments regarding other gun system configurations should not be included.

2 Evaluation of Perforators Under Stress Conditions, Berea Targets

2.1 INTRODUCTION

This section is intended to provide a test procedure to be followed for measuring perforator performance in stressed Berea sandstone with wellbore pressure applied.

2.2 BEREA SANDSTONE TARGET

Tests will be conducted using Berea sandstone targets mounted as shown in Figure 3. Berea sandstone target material shall have a bulk porosity of not less than 19% nor more than 21%.

2.3 PREPARATION OF BEREA SANDSTONE FOR THE TARGET

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.

Figure 2—Data Sheet—Perforating System Evaluation, API RP 19B Section 1

API Form 19B-Section 1

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 ______ 200 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 ____________________

Casing Data __________ OD, Weight __________ lb/ft, __________ API Grade, Date of Section 1 Test __________

Target Data __________ OD, Amount of Cement __________ lb., Amount of Sand __________ lb., Amount of Water __________ lb.

Date of Compressive Strength Test __________ Briquette 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	No. 11
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. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20	No. 21	No. 22	Average
Clearance, in.												xxxxxxxxx
Casing Hole Diameter, Short Axis, in.												
Casing Hole Diameter, Long Axis, in.												
Average Casing Hole Diameter, in.												
Total Depth, in.												
Burr Height, in.												

Remarks ____________________

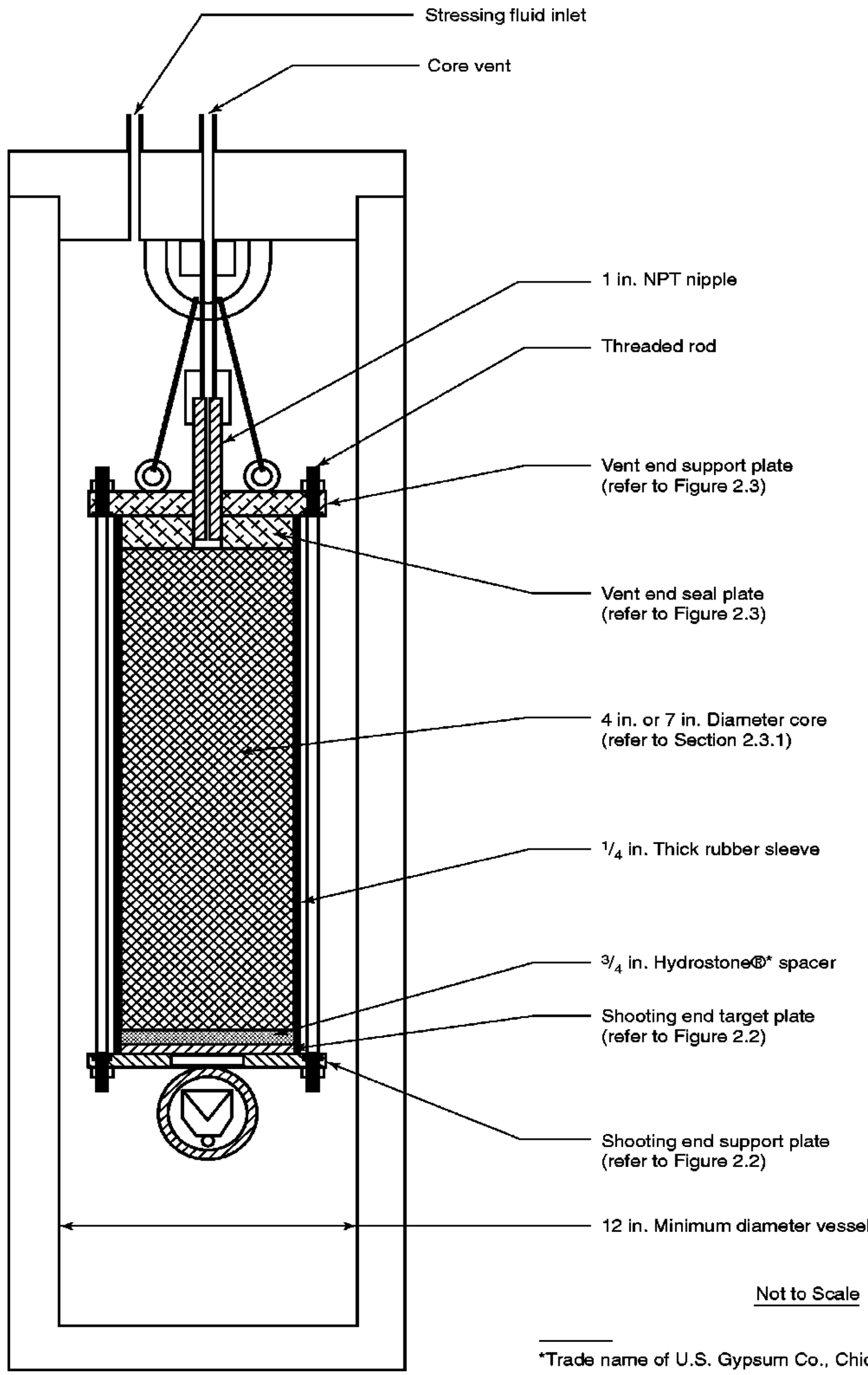
MANUFACTURER'S CERTIFICATION

Type of Certification: ______ Self ______ Third Party

I certify that these tests were made according to the procedures as outlined in API RP 19B: Recommended Practices for Evaluation of Well Perforators, First Edition, November, 2000. All of the equipment used in these tests, such as the guns, jet charges detonator cord, etc., was standard equipment with our company for the 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 that would be furnished to perforate a well for any operator. The American Petroleum Institute neither endorses these test results nor recommends the use of the perforator system described.

______ CERTIFIED BY ______________________________

______ RECERTIFIED (Company Official) (Title) (Date) (Company) (Address)



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

Figure 3—Section 2 Target Configuration

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 (60 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. Kerosene 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:

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

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 Figure 4 for details of the shooting end fixture and Figure 5 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 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).

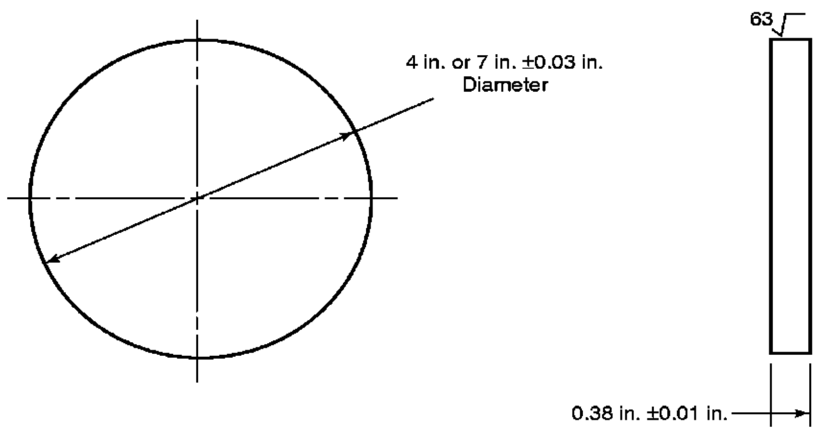
2.4.6 Perforating Tool

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.

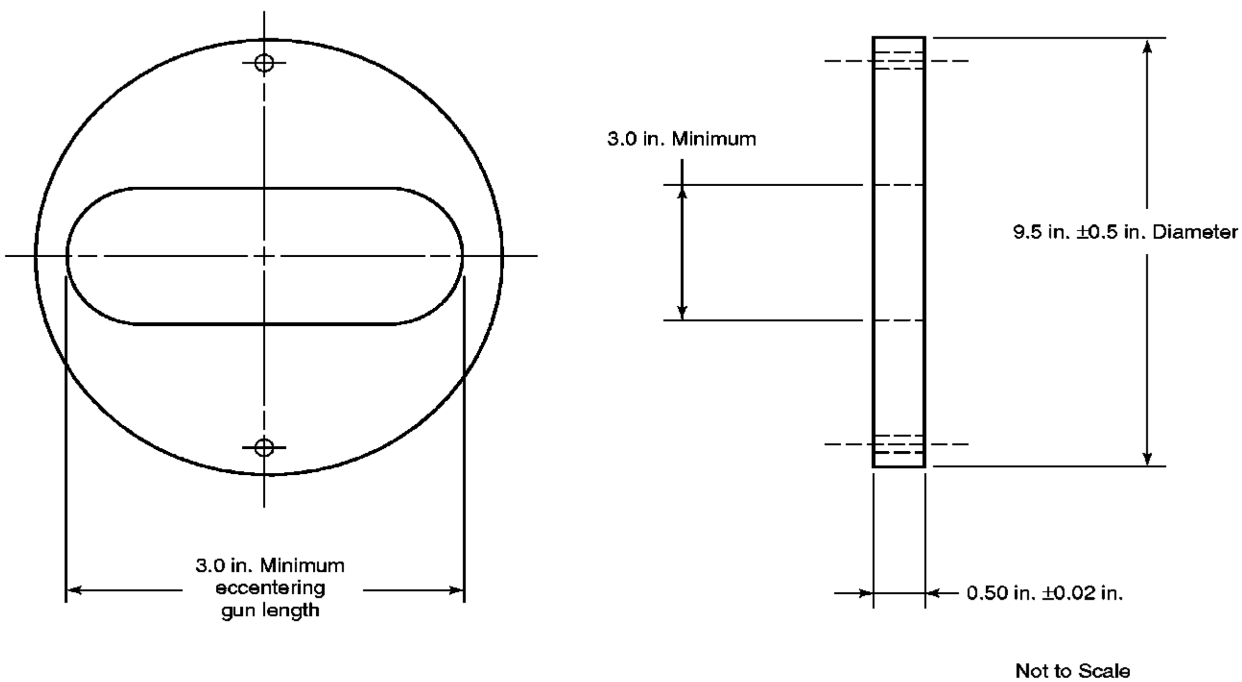
2.5 TEST CONDITIONS AND PROCEDURE

2.5.1 Chamber Fluid

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

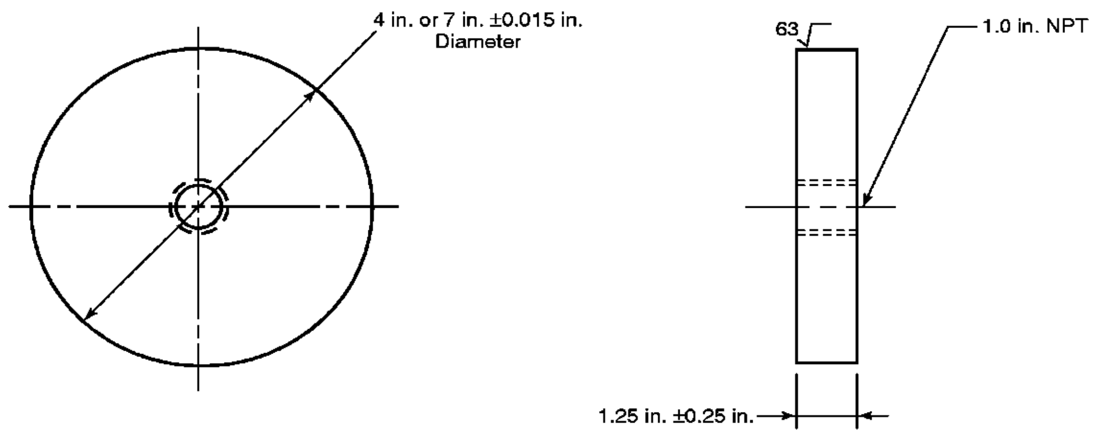


Target Plate
Material: Mild Steel ASTM-36

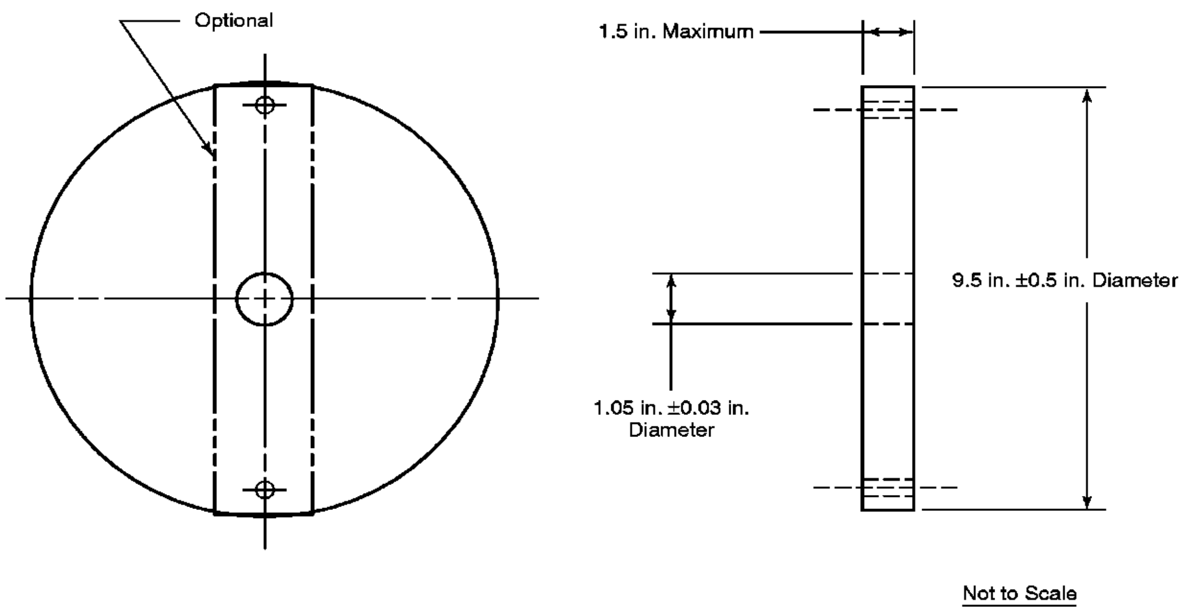


Support Plate

Figure 4—Shooting End Fixture



End Seal Plate
Material: Alum. 6061.T6



Support Plate
Material: Alum. 6061.T6

Figure 5—Vent End and Seal Fixture

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 equalization 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 19B, shall be reported. See Figure 6 for an example data sheet. Any data sheet used must include a similarly positioned watermark indicating that the test is not registered with the API. Comments regarding other gun system configurations should not be included.

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 explosive system 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.

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 $^3/_8$ inch thick. Cross sectional area of the plates shall be chosen for repeatable data collection. Typical target configuration is shown in Figure 7. 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

Figure 6—Data Sheet—Perforating System Evaluation, API RP 19B Section 2

API Form 19B-Section 2

Service Company ____________________ Explosive Weight ________ gm, ____________ powder, Case Material ____________

Charge Name ____________________ Max. Temp, °F ______ 1 hr ________ 3 hr ________ 24 hr ________ 100 hr ________ 200 hr

Manufacturer Charge Part No. ____________ Date of Manufacture ____________ Maximum Pressure Rating ________________ psi,

Gun Type ____________________

Available Firing Mode ____________ Selective, ____________ Simultaneous

Remarks ____________________

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.							

MANUFACTURER'S CERTIFICATION

Type of Certification: __________ Self __________ Third Party

I certify that these tests were made according to the procedures as outlined in API RP 19B: Recommended Practices for Evaluation of Well Perforators, First Edition, November, 2000. All of the equipment used in these tests, such as the guns, jet charges detonator cord, etc., was standard equipment with our company for the 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 that would be furnished to perforate a well for any operator. The American Petroleum Institute neither endorses these test results nor recommends the use of the perforator system described.

______ CERTIFIED BY ____________________ __________ ____________________ ____________________

______ RECERTIFIED (Company Official) (Title) (Date) (Company) (Address)

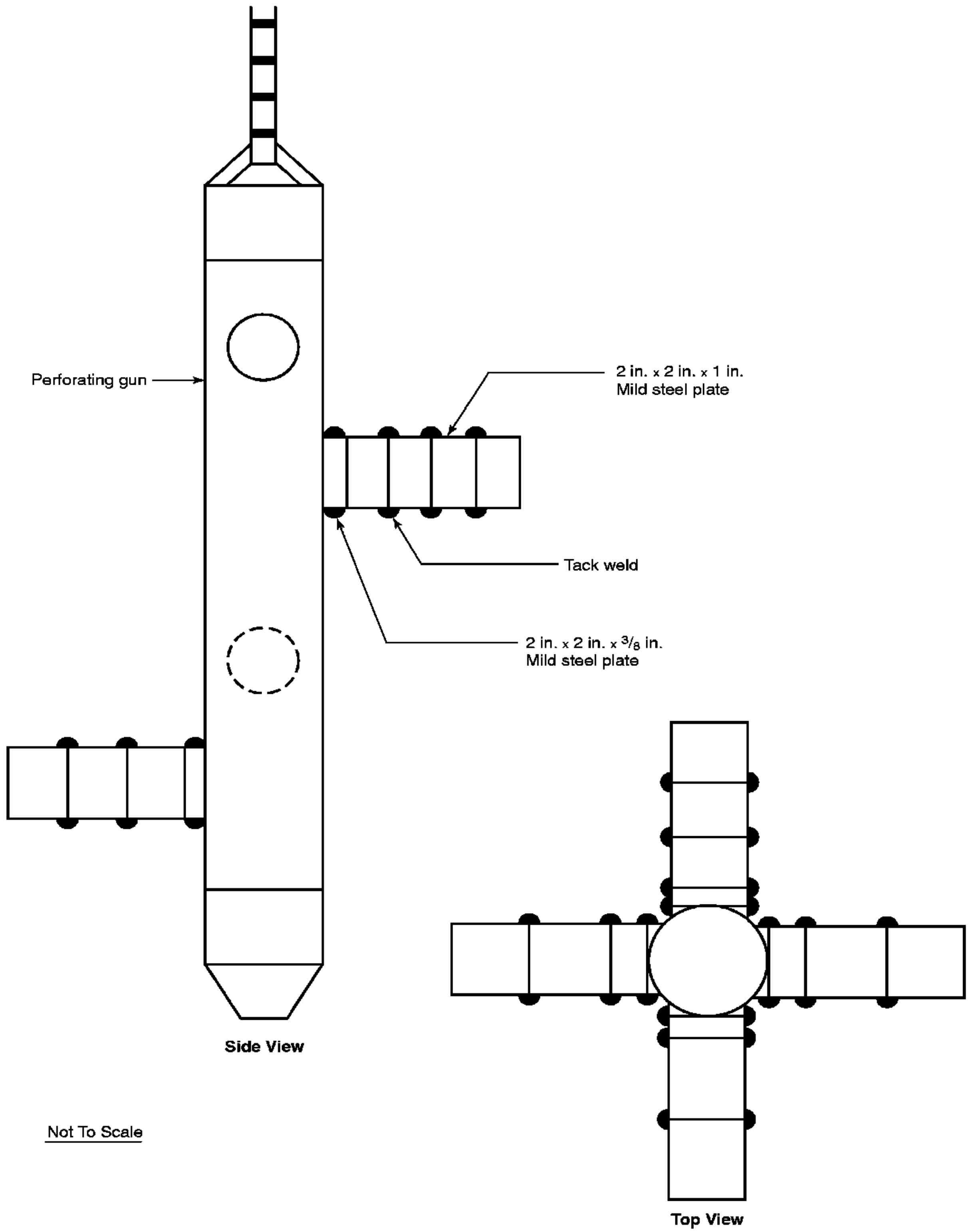


Figure 7—Schematic Illustration of Steel Target for Elevated Temperature Test

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.

3.10 TEST FLUID ENVIRONMENT

The reference test (refer to Section 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:

a. Total depth.
b. Faceplate hole diameter.
c. 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 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 $^3/_8$-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 19B, Section 3, shall be reported.

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

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

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

3.14.2.3 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 CMMC, 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.)

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 value 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.

4 Evaluation of Perforation Flow Performance Under Simulated Downhole Conditions (See Also Appendices A, B, and C).

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 rack 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.

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 A, Figures A.1 and A.2. The specific target geometry will be at the option of the testing company except for the following:

a. Target diameter shall not be less than 4 inches.

b. 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.

c. 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.

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

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

f. 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 A, Figure A.3. The specific arrangements are at the discretion of the testing company except for the following:

a. 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.

b. 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 $^{1}/_{4}$-inch inside diameter.

c. 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.

d. 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.

e. 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 B. The values of $K_{\perp}$ and $K_{//}$ will be used to calculate expected flow into the perforation in Appendix C.

For samples with axes perpendicular to bedding, axial flow (Appendix B, Section B.1) is used to measure permeability perpendicular to bedding, and flow across the diameter (Appendix B, Section B.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 B, Section B.2) are oriented to obtain flow perpendicular to bedding. The detailed techniques used are at the discretion of the testing company except for the following:

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

b. 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.

c. The same flow system constraints apply as described in Section 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 draw down. (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 if appropriate:

a. A line drawing of the specific test geometry and flow boundary conditions used shall be attached.

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

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

d. Test conditions during both shooting and flowing.

e. Perforation geometry including the following:

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

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

3. 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.

f. Differential pressure (corrected for flow system impedance as in Section 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.

g. Inlet temperature of fluid used and corresponding viscosity.

Note: 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 pro 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 C to assist in this calculation for radial flow boundary conditions. In this case, *CFE* is defined as:

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

where:

r = average perforation radius, in.,

R = sample radius, in.,

Q_c = calculated flow from Appendix C, Section C.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):

$$PRF = \frac{CFE \times \ln\left(\frac{r_c}{r}\right)}{1.25 \times (1 - CFE) - \ln(r) + (CFE) \times \ln(r_c)} \quad (4\text{-}2)$$

The value of the damaged zone radius, re, 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 5 and having absolute permeability to brine (parallel to bedding) between 100 and 400 md. Sample diameter shall be 4 inches (±0.25 inch) for charges ≤15g explosive weight and 7 inches (±0.25 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 A, Section A.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 Section 4.8).

4.11.5 Differential Pressure

This pressure during flow shall be 50 psi.

4.11.6 Penetration

The faceplate shall be designed so that the perforator must penetrate $^3/_8$-inch of ASTM A-36 steel or equivalent and $^3/_4$-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 $^1/_2$ inch. Zero-phased perforators used with eccentering devices shall be fired at the clearance assumed in a well.

5 REFERENCES

API RP 56 2nd Edition

ASTM C 109

ASTM A-36

APPENDIX A—TEST TARGET AND EQUIPMENT—SECTION 4 TESTING

A.1 Introduction

Within the test target specification (refer to Section 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.

A.2 Radial Flow

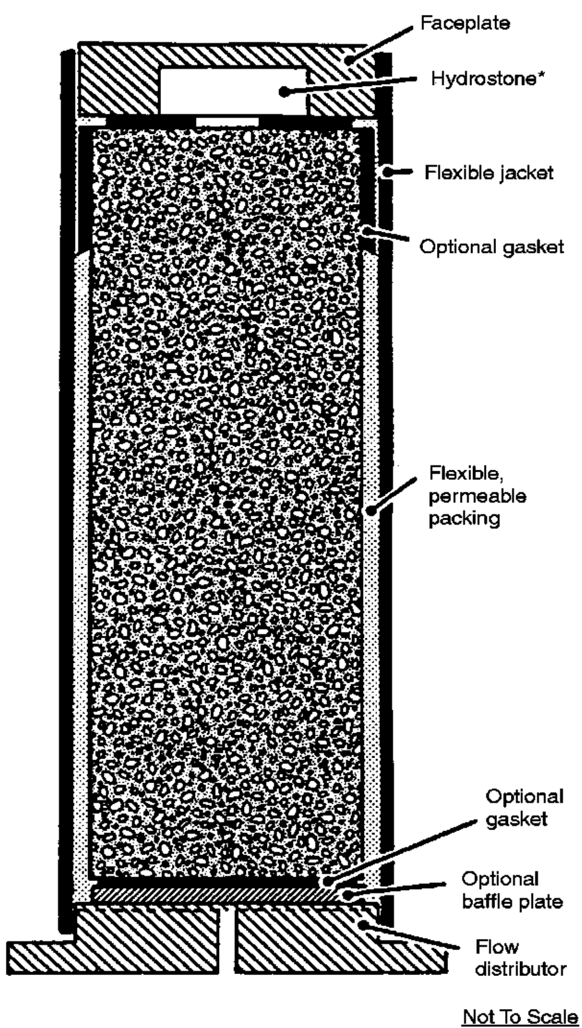
Pore pressure is applied to the cylindrical sides of the target. The gap between jacket and sample (refer to Figure A.1) is filled with a flexible material with at least 2 darcies permeability. Bauxite proppant (20/40 mesh) or $^1/_2$ inch diameter metal rods have been successfully used. A gasket with 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 Section 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.

A.3 Axial Flow

Pore pressure is applied to the unperforated end of the sample only. The bottom end cap (refer to Figure A.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.

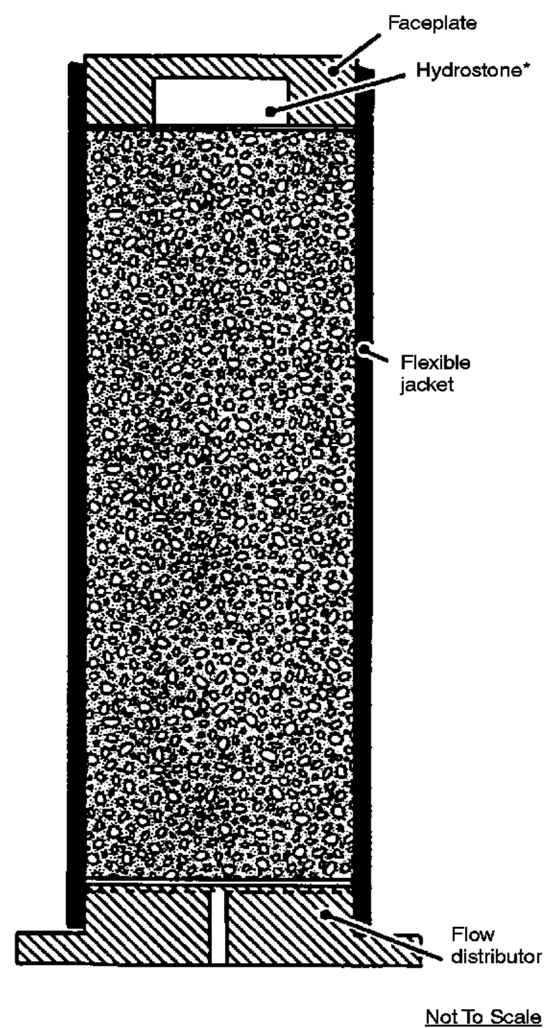
A.4 Test Equipment

Figure A.3 shows a schematic of typical testing equipment.



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

Figure A.1—Typical Radial-Flow Geometry



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

Figure A.2—Typical Axial-Flow Geometry

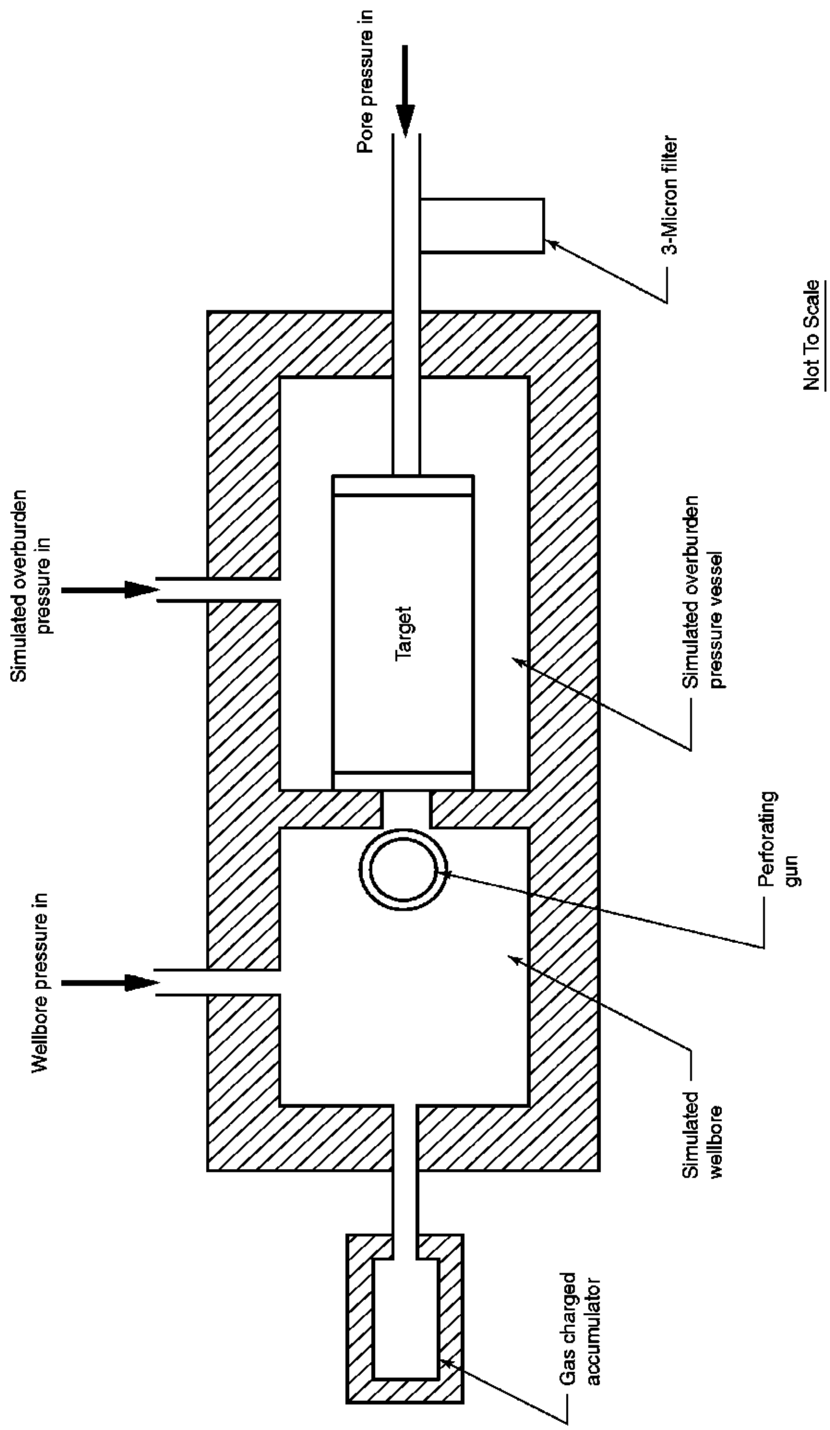


Figure A.3—Schematic of Typical Testing Equipment

APPENDIX B—PERMEABILITY MEASUREMENT—SECTION 4 TESTING

B.1 Axial Flow

Permeability can be measured using a conventional Hassler permeameter as shown schematically in Figure B.1. 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.

$$K = 1.84 \times 10^3 \quad \frac{Q\mu L}{R^2 \Delta P} \qquad (4\text{-}3)$$

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.

B.2 Flow Across the Core Diameter

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 Figure B.2). The segments may be constructed in a manner similar to that used in Appendix A, Section A.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 Figure B.2. 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:

$$K = 5.79 \times 10^3 \quad \frac{Q\mu}{L' \Delta P} \qquad (4\text{-}4)$$

where:

K = permeability, md,

Q = measured flow rate, cm^3/sec,

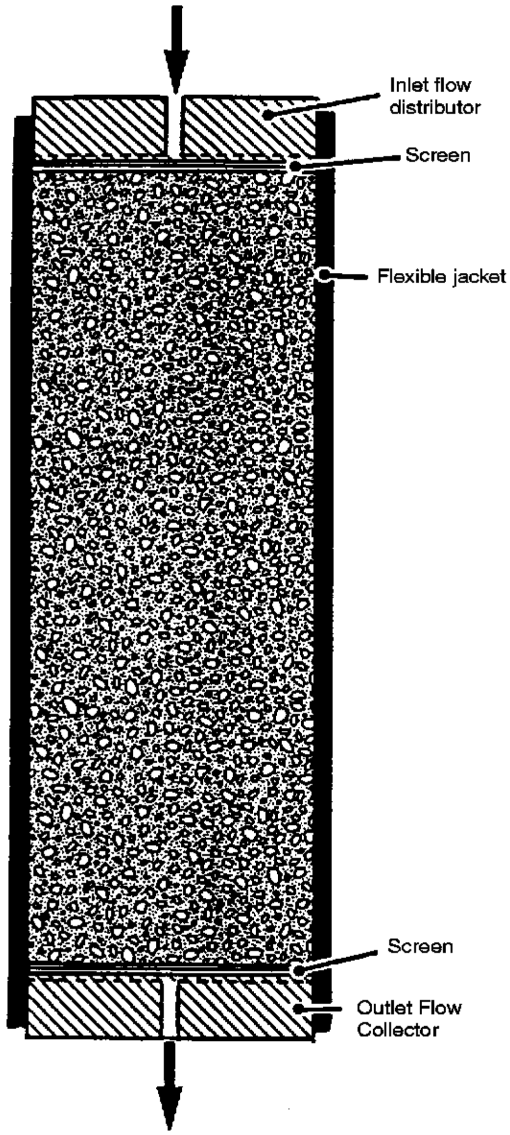
μ = fluid viscosity, cp,

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

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

B.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.



Not To Scale

Figure B.1—Typical Axial-Flow Permeability Equipment

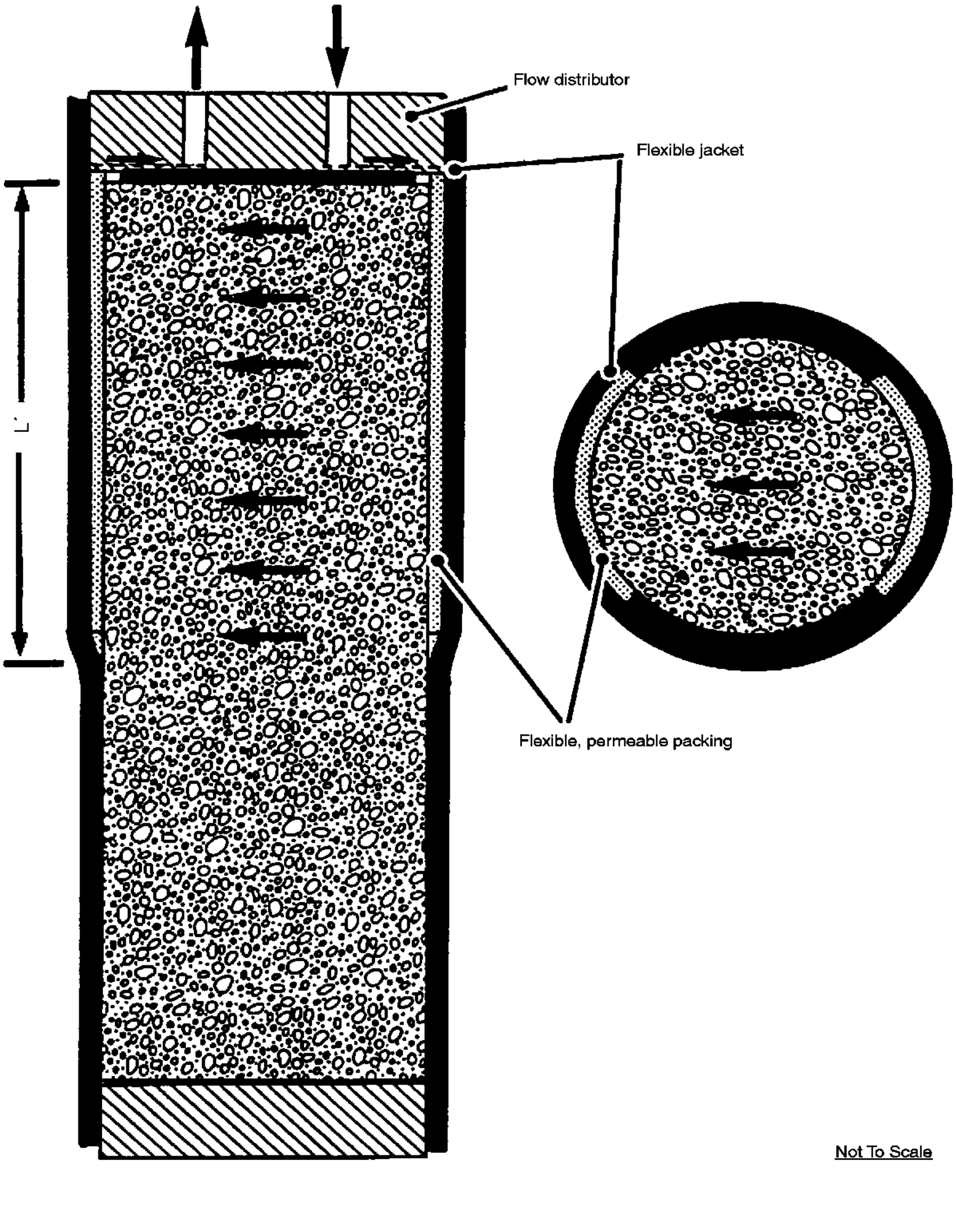


Figure B.2—Typical Diametral Flow Permeameter

APPENDIX C—DATA REDUCTION; EXPECTED FLOW RATES—SECTION 4 TESTING

C.1 Introduction

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

C.2 Radial Flow Target

(Refer to Appendix A, Section A.2) Equation 4-5 is applicable where permeability is uniform and cylindrically symmetrical. If the target meets the criterion of Section 4.2.c, the error will be small whether flow is allowed through the rear end of the sample or not. Flow rate may be calculated by:

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

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 Section 4.11, and may be used for other tests at the discretion of the testing company.

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

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

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

$$K_1 = K_{//}$$

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

The values of K_1 and K_2 used shall be recorded, along with the measured values parallel and perpendicular to bedding.

C.3 Axial Flow

(Refer to Appendix A, Section A.3). This geometry requires finite element analysis for calculating ideal flow to determine CFE.

APPENDIX D—API REGISTERED PERFORATOR SYSTEMS

Applications for Perforator System Registration are available from API. To obtain an application, please the API Quality Program web site http://www.api.org/programs_services/quality/ or call (202) 962-4791 or write to API Quality Programs, 1220 L Street, NW, Washington, DC 20005.

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

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