Recommended Practice for Presenting Performance Data on Cementing and Hydraulic Fracturing Equipment

API RECOMMENDED PRACTICE 41
SECOND EDITION, FEBRUARY 1, 1995

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

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Exploration and Production Department

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FOREWORD

These recommended practices were prepared by the API Subcommittee on Performance Data for Cementing and Hydraulic Fracturing Equipment. This standard is under the administration of the American Petroleum Institute Exploration & Production Department's Executive Committee on Drilling and Production Practices.

Recommendations presented herein are based on extensive and wide ranging industry experience. This publication does not purport to present all of the practices that can be employed to develop and present performance data on cementing and fracturing pumping equipment. Users of this publication are reminded that constantly developing technology and specialized or limited operations do not permit complete coverage of all operations and/or alternatives. Recommendations presented herein are not intended to inhibit developing technology and equipment improvements or improved operations procedures. These recommended practices are not intended to obviate the need for qualified engineering and operations analyses and sound judgements as to when and where these recommended practices should be utilized.

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Recommended Practices for Presenting Performance Data on Cementing and Hydraulic Fracturing Equipment

0 Introduction

For purposes of this standard, pump refers to high pressure pumps normally used in fracturing, cementing, or other types of oilfield service pumping operations. Curves describing the hydraulic-horsepower output of the pumping unit represent pressure and flow rates that all components (engine, drive train, pumps, cooling system, etc.) should normally be capable of delivering continuously for a period of four (4) hours under typical ambient conditions.

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1 Scope

This standard provides a standard procedure for measuring, reporting, and certifying the hydraulic-horsepower rating of pumping units used in hydraulic fracturing and cementing services operations. The standard also establishes a recommended format for reporting the performance of such pumping units.

This standard is applicable to any type of high pressure pumping unit, regardless of components such as prime movers, transmissions, and pumps.

2 References

The following standard contains provisions which, through reference in this text, constitute provisions of this standard. All standards are subject to revision, and users are encouraged to investigate the possibility of applying the most recent edition of the standard listed below.

ANSI[1]

ANSI-ASME Std 40.1	*Gauges—Pressure Indicating Dial Type—Elastic Element*

3 Preparation of Prime Mover

[1]American National Standards Institute, 1430 Broadway, New York, NY 10018.

3.1 PRIME MOVER CONFIGURATION

3.1.1 All accessories normally used on an operational unit prime mover shall be attached and in use at normal field operational setting during the test.

3.1.2 The prime mover shall, in every respect, be a field standard prime mover adjusted to field operation specifications.

4 Preparation of the Drive Train

4.1 DRIVE TRAIN CONFIGURATION

4.1.1 The drive train shall, in every respect, be a field standard system.

4.1.2 The drive train shall be adjusted and serviced to field operation specifications.

5 Preparation of the Pump

5.1 PUMP

The pump shall be the same type of pump normally used on the unit being tested.

5.2 POWER END

5.2.1 The power end of the pump shall consist of standard parts in field use and shall be adjusted in the same manner as in established operating procedures.

5.2.2 The power end of the pump shall be lubricated with the material and in the manner specified in the using company's operating and maintenance instructions.

5.3 FLUID END

5.3.1 The fluid end shall contain standard field parts in the valves, plungers, packing, and suction and discharge manifolding.

5.3.2 All adjustments shall be made according to established field usage.

6 Preparation and Operation of Pump Suction Pressurizer System

6.1 PRESSURIZED SUCTION SYSTEM

6.1.1 If used, the pressurizing pump shall be operated in such a manner as to duplicate field conditions.

6.1.2 The suction pressure of the pump shall be the same as in normal field usage, and the test curve shall indicate "Pressurized Suction."

7 Preparation and Operation of Measuring Equipment

7.1 MEASURING EQUIPMENT SPECIFICATIONS —RECOMMENDED METHOD

7.1.1 Test Stand

The measuring equipment stipulated in Pars. 7.1.2 through 7.5.6 shall be constructed and maintained to provide consistent performance data. Two procedures are provided for determining pump performance. The recommended method utilizes a flow meter for flow rate measurement and electronic data recording. An alternate method is included that uses conventional gauges and a batch-volume method to determine flow rate.

7.1.2 Volume Measuring System—Recommended Method

The fluid to be pumped will be water. This method utilizes a flow meter to provide flow-rate recording (cumulative volume features optional). The flow meter should be located in the suction line between the pressurizer and the pump suction. The flow meter should be installed in accordance with recommendations of the flow meter manufacturer.

7.1.3 Discharge Pressure Measuring System—Recommended Method

The discharge pressure measuring device shall be of the recording type and should record over the range of the test run. The pressure measurement is to be taken at a point not to exceed 1 meter (3 ft) from the pump outlet. The pressure recording device installation should permit adjustable dampening so the maximum total fluctuation shall be no greater than 10 percent of the peak indicated pressure. The pressure reading shall be taken as the average of the indicated pressures.

7.1.4 Suction Pressure Measuring System—Recommended Method

The suction pressure measurement device is to be located at a point no more than 1.5 meters (5 ft) from the pump suction. Pressures are to be recorded whether positive or negative.

7.1.5 Fluid Temperature Measuring System—Recommended Method

The temperature of the fluid shall be controlled so that it does not exceed 57°C (135°F). Measurement of temperature is to be taken in the suction between the fluid supply tank and the pump.

7.1.6 Diesel Engine Inlet Air Temperature Measurement System—Recommended Method

Diesel engine inlet air temperature is to be measured at the engine air cleaner inlet. The temperature measuring device should be located so as not to be affected by the operation of the pumping equipment. Only dry-bulb temperatures are to be taken.

7.1.7 Barometric Pressure Measuring System—Recommended Method

A means for reading barometric pressure shall be provided at the test site.

7.2 ACCURACY—RECOMMENDED METHOD

The test stand instrumentation shall meet the following standards of accuracy.

7.2.1 Volume—Recommended Method

The flow meter or combination of flow meters shall be such that their use will be restricted to the manufacturer's rated utility range, wherein the overall accuracy of any reading shall be within 1 percent of the volume read.

7.2.2 Discharge Pressure—Recommended Method

The pressure indicating device must be accurate within the limits specified and calibrated against a dead-weight tester traceable to a recognized standard. Each pressure indicating device shall be tested over its entire scale with readings taken both up and down. The error in pressure indication shall not exceed 1% of the maximum scale graduation. [Refer to *ANSI-ASME Std 40.1: Gauges—Pressure Indicating Dial Type—Elastic Element* for accuracy requirements, Accuracy Grade 1A Gauges.]

7.2.3 Suction Pressure or Vacuum—Recommended Method

The suction pressure measuring device shall be tested over its entire scale with readings taken both up and down. The error in pressure indication shall not exceed 1% of the maximum scale graduation. [Refer to *ANSI-ASME Std 40.1: Gauges—Pressure Indicating Dial Type—Elastic Element* for accuracy requirements, Accuracy Grade 1A Gauges.]

7.2.4 Temperature Measuring Device—Recommended Method

All temperature measuring devices used shall be accurate within 1.1°C (2°F).

7.2.5 Barometric Pressure—Recommended Method

Any good-quality barometer may be used. The barometer must be suitable for reading to .25 mm (0.01 in.) of mercury.

The barometer must indicate the absolute atmospheric pressure for the elevation of the test stand. In other words, the barometer must not be adjusted for altitude to give a reading corrected to sea level.

7.2.6 Calibration—Recommended Method

Any instrumentation will be recalibrated at any time a discrepancy is suspected. The discharge pressure indicating device is to be checked with a dead-weight tester according to the pumping equipment manufacturer's normal instrumentation calibration schedule or to the pressure indicating device manufacturer's recommended service and calibration schedule. If it is found to vary from the prescribed accuracy, it will be corrected and tests using that device will be repeated. Other pressure indicating devices, temperature indicating devices, flow meters, and barometer, should be checked at least every 6 months.

7.3 PERFORMANCE TEST DATA—RECOMMENDED METHOD

7.3.1 Data to be Recorded

The following data, as a minimum, must be observed and recorded at the time the unit is tested:

a. Pump discharge pressure.
b. Rate of volume pumped.
c. Engine air inlet temperature.
d. Pump suction pressure.
e. Barometric pressure.
f. Gear selection tested.

(It is recommended that, in addition, pump input revolutions per minute be recorded as a check of data.)

7.4 MEASURING EQUIPMENT SPECIFICATIONS —ALTERNATE METHOD

7.4.1 Volume Measuring System—Alternate Method

The fluid to be pumped will be water. The tank, preferably cylindrical, is to be sufficiently rigid to resist dimensional change when full of fluid. The height shall not be less than the diameter of a cylindrical tank or the width or length of a rectangular tank. The fluid flow may be either from the tank or to the tank. If from the tank, the system will be termed "inlet flow system". If to the tank, the system will be termed "discharge flow system". Also, systems in which the time required to pump a given volume is measured shall be termed a "time required to pump a fixed volume" method. Systems in which the volume is measured on a fixed timing interval shall be termed a "volume measured in a fixed time" method. Inlet flow systems may be either "time required to pump a fixed volume" or "volume measured in a fixed time" method. Discharge flow systems may be only the "volume measured in a fixed time" method. If a swinging-type switching manifold is used with a discharge flow system, a knife-edge diverter plate should be utilized at the point on the tank where the manifold switches fluid into or out of the tank.

7.4.2 Discharge Pressure Measuring System—Alternate Method

The pressure indicating device shall be of the recording type and should record over the range of the test run. The pressure measurement is to be taken at a point not to exceed 1 meter (3 ft) from the pump outlet. The pressure indicating device installation should permit adjustable dampening so the maximum total fluctuation shall be no greater than 10 percent of the peak indicated pressure. The pressure reading shall be taken as the average of the maximum and minimum indicated pressures.

7.4.3 Suction Pressure Measuring System—Alternate Method

The suction pressure measurement is to be taken at a point no more than 1.5 meters (5 ft) from the pump suction. Both positive and negative pressures are to be taken.

7.4.4 Fluid Temperature Measuring System—Alternate Method

The temperature of the fluid shall be controlled so that it does not exceed 57°C (135°F). Measurement of temperature is to be taken in the suction between the fluid supply tank and the pump.

7.4.5 Engine Inlet Air Temperature Measurement System—Alternate Method

The engine inlet air temperature shall be measured at the engine air cleaner inlet. The thermometer shall be located so as not to be affected by the operation of the pumping equipment. Only dry-bulb temperatures are to be taken.

7.4.6 Barometric Pressure Measuring System—Alternate Method

A means for reading barometric pressure shall be provided at the test site.

7.5 ACCURACY—ALTERNATE METHOD

The test stand instrumentation shall meet the following standards of accuracy.

7.5.1 Volume—Alternate Method

After construction of the tank, a gauge should be made and calibrated for that specific tank. This gauge is to be accurate within 1 percent of the minimum volume pumped per test point.

7.5.2 Discharge Pressure—Alternate Method

The pressure indicating device must be accurate within the limits specified when calibrated against a dead-weight tester traceable to a recognized standard. Each pressure indicating device shall be tested over its entire scale. The error in pressure indication shall not exceed 1% of the maximum scale graduation. [Refer to *ANSI-ASME Std 40.1: Gauges—Pressure Indicating Dial Type—Elastic Element* for accuracy requirements, Accuracy Grade 1A Gauges.]

The discharge pressure to be measured shall determine the proper pressure indicating device to be used, as given in Table 1. Persons performing the test should select the test gauge so that the pump pressure does not exceed the maximum graduation of the pressure gauge.

Table 1—Selection of Pressure Indicating Device

Discharge Pressure Range		Maximum Pressure To Which The Scale Is Graduated	
MPa	psi	MPa	psi
0-15	0-2,000	15	2,000
15-35	1,500-5,000	35	5,000
30-70	4,000-10,000	70	10,000
55-100	8,000-15,000	100	15,000
80-140	12,000-20,000	140	20,000

7.5.3 Pressure Indicating Device Chart

Design of the pressure indicating device chart shall be such that:

a. The pressure graduation shall not exceed the increments shown in Table 2.
b. The minimum distance between pressure increment lines shall be 1mm (0.04 in.).

Table 2—Pressure Indicating Device Chart

Maximum Pressure To Which The Scale Is Graduated		Maximum Increment	
MPa	psi	MPa	psi
15	2,000	.25	50
35	5,000	.50	100
70	10,000	1.00	200
100	15,000	2.00	300
140	20,000	3.00	400

7.5.4 Suction Pressure or Vacuum—Alternate Method

The suction pressure measuring device shall be tested over its entire scale with readings taken both up and down. The error in pressure indication shall not exceed 1% of the maximum scale graduation. [Refer to *ANSI-ASME Std 40.1: Gauges—Pressure Indicating Dial Type—Elastic Element* for accuracy requirements, Accuracy Grade 1A Gauges.]

Suction Pressure Gauge: 75 MPa (100 psia)

Suction Vacuum Gauge: Maximum scale graduation, 760 mm (30 in.) of mercury.

7.5.5 Thermometer—Alternate Method

All thermometers used shall be accurate within 1.1° C (2° F).

7.5.6 Barometric Pressure—Alternate Method

Any good quality barometer may be used. Either type must be suitable for reading to .25 mm (0.01 in.) of mercury. The barometer must indicate the absolute atmospheric pressure for the elevation of the test stand. In other words, the barometer must not be adjusted for altitude to give a reading corrected to sea level.

7.5.7 Calibration—Alternate Method

Any instrumentation shall be recalibrated at any time a discrepancy is suspected. The discharge pressure indicating device is to be checked with a dead-weight tester according to the pumping equipment manufacturer's normal instrumentation calibration schedule. If it is found to vary from the prescribed accuracy, it will be corrected and tests using that device will be repeated. Other pressure indicating devices, temperature indicating devices, flow meters, and barometer should be checked at least every 6 months.

7.6 PERFORMANCE TEST DATA

7.6.1 Data to be Recorded—Alternate Method

The following data, as a minimum, must be observed and recorded at the time the unit is tested:

a. Pump discharge pressure
b. Volume of fluid pumped
c. Length of run
d. Engine air inlet temperature
e. Pump suction pressure
f. Barometric pressure
g. Gear selection tested

(It is recommended that, in addition, engine revolutions per minute be recorded as a check of data.)

7.7 CALCULATION OF HYDRAULIC HORSEPOWER

7.7.1 Correction Factor for Diesel Engines

Corrections shall be made to the observed pressure readings for observed temperature and barometric pressure. Conditions of 610 meters (2,000 ft.) altitude and 32.2° C (90° F) are considered standard operating conditions. Equation (1) or (2) should be used for applying correction factors.

For SI units:

$$P_c = P_o \times \frac{709.2}{B_o} \times \sqrt{\frac{T_o}{305}} \qquad (1)$$

Where:

P_c = corrected pump discharge pressure, MPa.
P_o = observed pump discharge pressure, MPa.
B_o = observed barometric pressure, mm Hg (barometer not adjusted for altitude).
T_o = observed temperature, degrees C, absolute.

For English units:

$$P_c = P_o \times \frac{27.92}{B_o} \times \sqrt{\frac{T_o}{550}} \quad (2)$$

Where:

P_c = corrected pump discharge pressure, psig.
P_o = observed pump discharge pressure, psig.
B_o = observed barometric pressure, in. Hg (barometer not adjusted for altitude).
T_o = observed temperature, degrees F, absolute.

The altitude portion of the correction formula may be omitted when certified proof can be obtained from the engine manufacturer that engine performance on the test will not be affected in excess of 1 percent as a result of deviation in altitude from standard to test-site conditions. The observed pump discharge pressure will then be corrected for the variation in ambient temperature from standard (32.2°C) by using Equations (3) or (4):

For SI units:

$$P_c = P_o \times \sqrt{\frac{T_o}{305}} \quad (3)$$

Where:

P_c = corrected pump discharge pressure, MPa.
P_o = observed pump discharge pressure, MPa.
T_o = observed temperature, degrees C, absolute.

For English units:

$$P_c = P_o \times \sqrt{\frac{T_o}{550}} \quad (4)$$

Where:

P_c = corrected pump discharge pressure, psig.
P_o = observed pump discharge pressure, psig.
T_o = observed temperature, degrees F, absolute.

7.7.2 Hydraulic Horsepower

Hydraulic horsepower is calculated using Equations (5) or (6):

For SI units:

$$HHP = 16.68 \times P_c \times \text{Volume} \quad (5)$$

Where:

P_c = corrected pump discharge pressure, MPa.
Volume = pumping rate, cubic meters per minute (m^3/min).

For English units:

$$HHP = 0.0245 \times P_c \times \text{Volume} \quad (6)$$

Where:

P_c = corrected pump discharge pressure, psig.
Volume = pumping rate, barrels per minute (bpm).

7.8 TEST PROCEDURE

7.8.1 Test Conditions

During the entire test no adjustments shall be made on the equipment tested, except as required for actual changes of throttle, gear setting, suction pressure, and discharge pressure regulating device to obtain the desired pressure and volume conditions. Before beginning any run, the equipment will be brought to a normal condition of stabilized operation pertaining to engine and lubricant temperature.

7.8.2 Actual Test Run—Recommended Method

Step 1—Select the gear range.

Step 2—Set throttle at the maximum power position.

Step 3—Adjust the discharge pressure regulating device to obtain desired test condition as specified in Par. 7.8.6.1 or 7.8.6.2.

Step 4—After operating conditions have stabilized, record: 1) discharge pressure; 2) flow rate; 3) engine inlet air temperature; 4) suction pressure or vacuum; 5) barometric pressure; and 6) gear range tested.

7.8.3 Actual Test Run—Alternate Method

Step 1—Select the gear range.

Step 2—Set throttle at the maximum power position.

Step 3—Adjust the discharge pressure regulating device to obtain desired discharge pressure as specified in Par. 7.8.6.1 or 7.8.6.2.

Step 4—After operating conditions have stabilized, start the test run. When using the "time required to pump a fixed volume" method, start the timing interval as level passes the calibrated position. When using the "volume measured in a fixed time" method, divert the fluid flow into or from the measuring tank.

Step 5—Record: 1) discharge pressure; 2) engine inlet air temperature; 3) suction pressure or vacuum; 4) gear range tested; and 5) barometric pressure.

Step 6—At the end of the test run using the "time required to pump a fixed volume" method, stop the timing interval as the level passes the calibrated position. When using the "volume measured in a fixed time" method, divert the fluid flow into or from the measuring tank.

Step 7—Record: 1) total volume of fluid pumped; 2) length of run.

7.8.4 Length of Run Per Point—Alternate Method

The minimum test time per test point shall be 1 minute. The volume pumped per test point shall be not less than .5 m^3 (3 bbl) nor less than the tank volume equivalent to 115 mm (4.5 in.) of fluid level change.

7.8.5 Runs to be Made

Pumping units shall be tested over their recommended operating range and will have a curve sheet prepared directly from the test on each pump. This procedure applies to both torque converter and straight transmission drive arrangements. Torque converters equipped with lockup clutches will be run in modes to reflect normal field operating conditions. All gear ranges shall be run that are available under and up to the maximum recommended operating pressure of the pump in each gear and within the pump's speed limitations.

7.8.6 Test Points

7.8.6.1 Straight Transmission and Torque Converter Lockup Drives

The number of test points per gear range will be no less than 5. The required 5 test points will be taken at or near:

a. The maximum volume to be published on the curve sheet for the gear range.
b. The minimum volume to be published on the curve sheet for the gear range.
c. The maximum power output.
d. A point halfway between items a and c.
e. A point halfway between items b and c.

7.8.6.2 Torque Converter Drives

The number of test points per gear range will be no less than 5. The required 5 test points will be taken at or near:

a. The lowest speed ratio of the torque converter where continuous operation of the torque converter can be maintained.
b. The highest speed ratio of the torque converter where continuous operation of the torque converter can be maintained.
c. The maximum power output point.
d. A point halfway between items a and c.
e. A point halfway between items b and c.

7.8.6.3 Additional Test Points

Additional test points, as required to accurately describe the shape and characteristics of the curve, should be taken at the discretion of the person in charge of the test.

8 Preparation of Performance Curves

8.1 CURVE FORM

The actual test data shall be plotted on graphs as described in Pars. 8.1.1 through 8.1.3, and a representative sample is shown in Figs. 1 and 2.

8.1.1 Coordinates

The coordinates will be log-log.

8.1.2 Scale

8.1.2.1 The abscissa will be volume and will be labeled "Flow Rate—cubic meters per minute" (m^3/min) for curves in SI units or "Flow Rate—barrels per minute" (bpm) for curves in English units. The range will be selected to cover the normal pump operating range.

8.1.2.2 The ordinate will be pressure and will be labeled "Pressure—MPa" for curves in SI units or "Pressure—psi" for curves in English units. The range will be selected to cover the normal pump operating range.

8.1.3 Curve Information

The following information is considered the minimum to be included on the curve sheet:

a. Name of manufacturer.
b. Name of unit. The description shall be in such a form as to correlate the curve with other published literature of the company.
c. Prime mover—type, make, and model.
d. Transmission—type, make, and model.
e. Pump—type, make, bore, stroke, and maximum rpm (spm).
f. Date of test.
g. Pressurized or non-pressurized suction, with suction operating pressure.
h. Maximum operating pressure.
i. Maximum flow rate.
j. Serial number of the test unit.
k. Sign off of the person in charge of the test.

8.2 TEST DATA

The data from which the curve is plotted shall be maintained on file by the equipment owner as long as the unit is offered for commercial service.

9 Certification of Performance Curves

Each curve shall be certified by the person in charge of the actual test runs, in the space provided on the curve sheet.

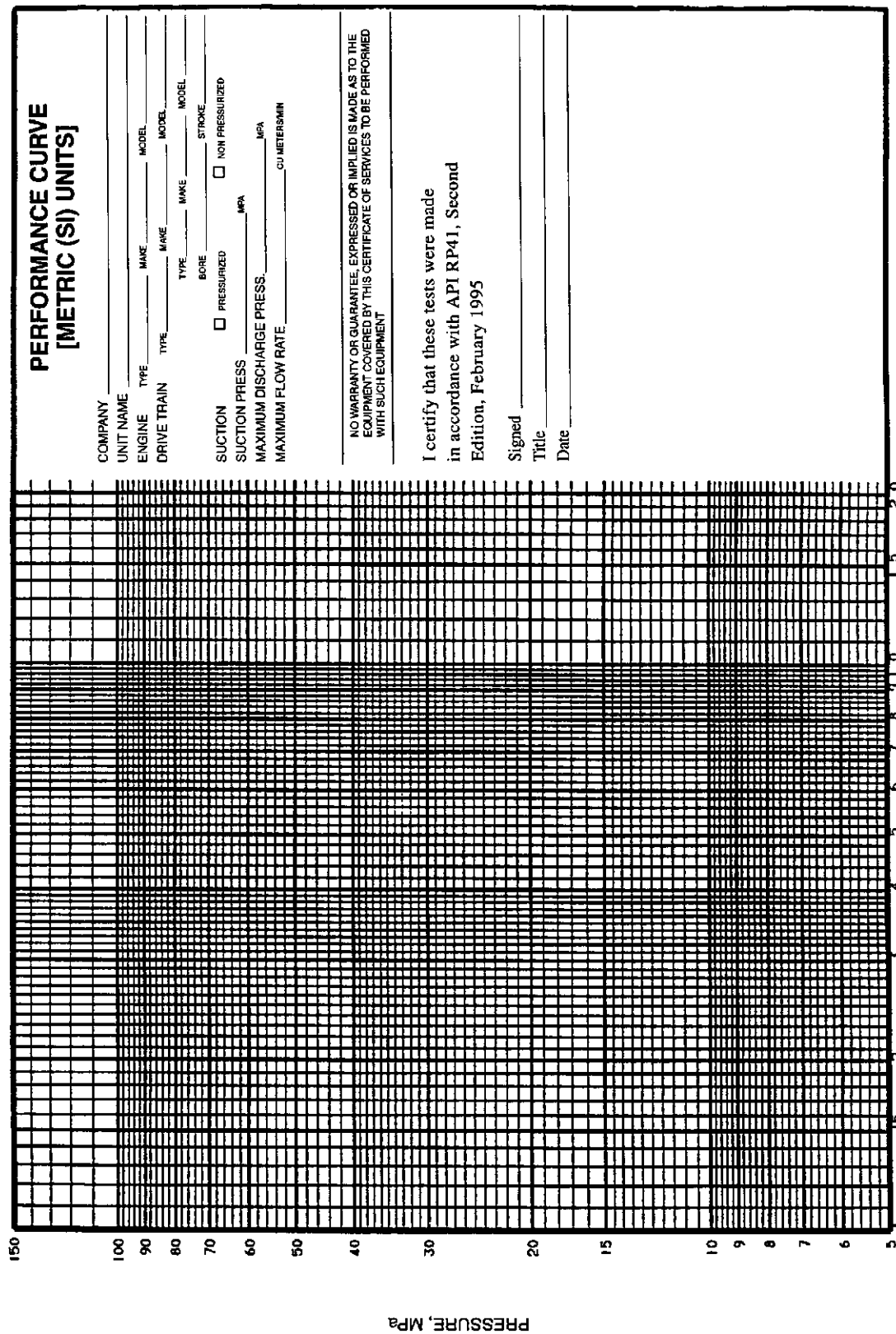

Figure 1—Performance Curve, Metric (SI) Units

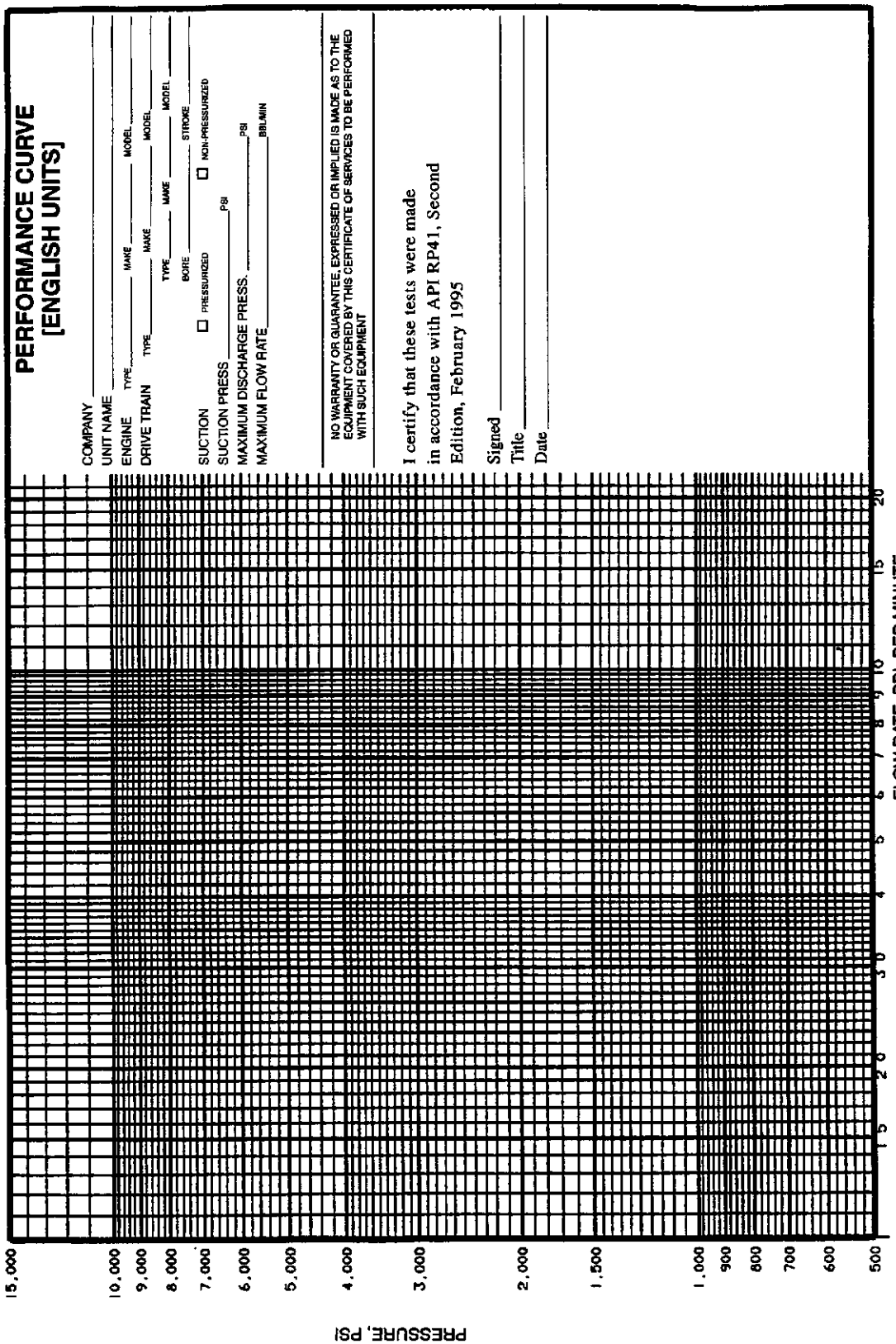

Figure 2—Performance Curve, English Units

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