ASME PTC 25-2023
(Revision of ASME PTC 25-2018)

Pressure Relief Devices

Performance Test Codes

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Two Park Avenue • New York, NY • 10016 USA

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NOTICE

All ASME Performance Test Codes (PTCs) shall adhere to the requirements of ASME PTC 1, General Instructions. It is expected that the Code user is fully cognizant of the requirements of ASME PTC 1 and has read them before applying ASME PTCs.

ASME PTCs provide unbiased test methods for both the equipment supplier and the users of the equipment or systems. The Codes are developed by balanced committees representing all concerned interests and specify procedures, instrumentation, equipment-operating requirements, calculation methods, and uncertainty analysis. Parties to the test can reference an ASME PTC confident that it represents the highest level of accuracy consistent with the best engineering knowledge and standard practice available, taking into account test costs and the value of information obtained from testing. Precision and reliability of test results shall also underlie all considerations in the development of an ASME PTC, consistent with economic considerations as judged appropriate by each technical committee under the jurisdiction of the ASME Board on Standardization and Testing.

When tests are run in accordance with a Code, the test results, without adjustment for uncertainty, yield the best available indication of the actual performance of the tested equipment. Parties to the test shall ensure that the test is objective and transparent. All parties to the test shall be aware of the goals of the test, technical limitations, challenges, and compromises that shall be considered when designing, executing, and reporting a test under the ASME PTC guidelines.

ASME PTCs do not specify means to compare test results to contractual guarantees. Therefore, the parties to a commercial test should agree before starting the test, and preferably before signing the contract, on the method to be used for comparing the test results to the contractual guarantees. It is beyond the scope of any ASME PTC to determine or interpret how such comparisons shall be made.

FOREWORD

In December 1948, the ASME Boiler and Pressure Vessel Committee recommended to the ASME Performance (then Power) Test Codes Committee that a code be prepared on the testing of safety and relief valves. This request resulted in the publication of the original test code for safety and relief valves (PTC 25-1958) and was applicable only to tests with atmospheric discharge. In June 1964, the ASME Performance (then Power) Test Code Committee authorized PTC Committee Number 25 on Safety and Relief Valves to prepare a single test code (PTC 25.2-1966) to cover testing of valves discharging to atmosphere, superimposed, or built-up back pressure. In March 1971, the ASME Performance Test Codes Committee authorized PTC Committee Number 25 on Safety and Relief Valves to prepare a general revision to the test code, the result of which was PTC 25.3-1976, approved as an American National Standard on August 19, 1976.

In 1978, the ASME Board on Performance Test Codes once again authorized the PTC Committee Number 25 to prepare a general revision of the test code. The revision, PTC 25.3-1988, approved by the ASME Board on Performance Test Codes on March 14, 1988, differed from its predecessors primarily by the omission of the section concerning theoretical relieving capacity and coefficient of discharge.

In 1991, the ASME Board on Performance Test Codes revised the name of PTC Committee Number 25 to "Pressure Relief Devices" and authorized the committee to prepare a revised test code of the same name with a scope that was extended to include a broader range of closing and non-reclosing pressure relief devices and to broaden the discussion of in-service and bench testing. The revised Code, ASME PTC 25-2001, was approved and adopted by the American National Standards Institute (ANSI) as meeting the criteria as an American National Standard on May 25, 2001.

The next edition, ASME PTC 25-2008, divided the Code into its current three-Part structure, as follows:

(a) Part I, "General," includes Sections 1 and 2.

(b) Part II, "Flow Capacity Testing," includes the preceding Sections 1 and 2, along with Sections 3 through 6 and appendices.

(c) Part III, "In-Service and Bench Testing," includes the preceding Sections 1 and 2, along with Sections 7 through 10 and appendices.

ASME PTC 25-2008 was approved by ANSI on September 16, 2008.

ASME PTC 25-2014 was approved by ANSI on May 5, 2014.

ASME PTC 25-2018 was approved by ANSI on October 24, 2018.

This Code is available for public review on a continuing basis. Public review provides an opportunity for additional input from industry, academia, regulatory agencies, and the public-at-large.

ASME PTC 25-2023 was approved by ANSI on October 16, 2023.

ASME PTC COMMITTEE
Performance Test Codes

(The following is the roster of the committee at the time of approval of this Code.)

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General. ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Code should be sent to the staff secretary noted on the committee's web page, accessible at https://go.asme.org/PTCcommittee.

Revisions and Errata. The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata on the committee web page. Errata become effective on the date posted. Users can register on the committee web page to receive e-mail notifications of posted errata.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit the use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code and the paragraph, figure, or table number

(4) the editions of the Code to which the proposed case applies

(d) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Approved cases are posted on the committee web page.

Interpretations. Upon request, the committee will issue an interpretation of any requirement of this Code. An interpretation can be issued only in response to a request submitted through the online Interpretation Submittal Form at https://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic e-mail confirming receipt.

ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers can track the status of their requests at https://go.asme.org/Interpretations.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Interpretations are published in the ASME Interpretations Database at https://go.asme.org/Interpretations as they are issued.

Committee Meetings. The PTC Standards Committee regularly holds meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the committee. Information on future committee meetings can be found on the committee web page at https://go.asme.org/PTCcommittee.

INTRODUCTION

This Code provides standards for conducting and reporting tests on reclosing and non-reclosing pressure relief devices normally used to terminate an abnormal internal or external rise in pressure above a predetermined design value in boilers, pressure vessels, and related piping equipment. This Code covers the methods and procedures to determine relieving capacity and additional operating characteristics that may be required for certification or other purposes by other codes. This is accomplished by dividing the Code into three parts: Part I, "General"; Part II, "Flow Capacity Testing"; and Part III, "In-Service and Bench Testing."

This Code does not necessarily cover the methods and procedures to satisfy operating and other conditions as may be required by other codes. Establishment of pressure relief device ratings and rules of safe construction do not fall within the province of this Code.

PART I
GENERAL

Section 1
Object and Scope

1-1 OBJECT

The object of the test is to determine the performance of pressure relief devices. These tests determine one or more of the following:

(a) dimensional, operational, and mechanical characteristics

(b) relieving pressure

(c) relieving flow capacity at test pressure

(d) individual flow resistance

Procedures for conducting the tests, calculating the results, and making corrections are defined.

1-2 SCOPE

(a) This Code provides instructions in Part II for flow capacity testing and in Part III for in-service and bench testing. Testing of reclosing and non-reclosing pressure relief devices is conducted under various inlet and outlet conditions using steam, gases, and liquids for which valid physical properties are known.

(b) The validity of tests shall be determined in accordance to the requirements of subsection 1-3.

1-3 MEASUREMENT UNCERTAINTY

In order to qualify as a valid code test, the total uncertainties of the test, as calculated by the procedures of ASME PTC 19.1, must be equal to or less than the values of maximum acceptable uncertainty. The maximum acceptable uncertainty of the final flow measurement shall not exceed ±2.0% of the measured value. For results other than flow measurements, the maximum acceptable uncertainty shall not exceed ±0.5% of the measured value as determined in accordance with Part II or ±1.0% of the measured value as determined in accordance with Part III.

1-4 GENERAL

(a) It is assumed that the testing facility has adequate capacity and sufficient pressure to conduct the tests. However, the users of this Code are cautioned that the capacity and pressure limitations of the testing facility may restrict the determination of satisfactory operating conditions and other operational features of the pressure relief device.

(b) In addition, field installation and/or abnormal operating conditions may adversely affect the function of the pressure relief device. It is not the intent of this Code to attempt to assess the suitability or reliability of the pressure relief device under such conditions. It should also be noted that if the temperature of the medium used to test the pressure relief device differs substantially from the temperature to which the pressure relief device is subjected while in service, the functional characteristics will be different from the test pressures, i.e., opening, closing, blowdown, and bursting pressure. In this case, it is necessary to develop appropriate corrections for the pressure relief device under test to account for these differences, which is outside the scope of this Code.

(c) This Code provides recommended test procedures and instrumentation for testing devices. Other test procedures or instrumentation may be used provided they can be demonstrated as having accuracy and reliability at least equal to the requirements of this Code. If another procedure or instrumentation will be used, it is subject to written agreement by the parties to the test prior to the test.

(d) The test results shall be reported as measured and calculated. Only tests that comply fully with the mandatory requirements of this Code may be designated as tests conducted in accordance with ASME PTC 25. References to other codes, unless otherwise indicated, refer to ASME Performance Test Codes. Should any specific direction in this Code, or any particular measurement, differ from those given in other ASME Performance Test Codes for similar measurements, the instructions of this Code shall prevail.

(e) The requirements of ASME PTC 1 shall be met.

(f) In some cases, the testing of pressure relief devices may involve the use of high-pressure and high-temperature fluid. Hazards to personnel will exist unless adequate precautionary measures are taken. Special consideration

should be given to adequate design and overpressure protection to the piping system and components, safe discharge from the pressure relief devices undergoing testing, and the high noise level usually associated with the discharge of pressure relief devices. The users of this Code should consult the authority having jurisdiction over these safety matters to ensure the testing facility meets the mandatory requirements.

Section 2
Definitions and Description of Terms

2-1 PURPOSE

The purpose of this Section is to define pressure relief devices and their functional and operational characteristics and standardize the terminology covering such devices, their characteristics, and testing methods. It also includes a description of terms and symbols used in this Code. These definitions and terms shall take precedence should there be any discrepancy with the referenced material.

2-2 GENERAL

auxiliary lift-assist device: a testing device that is attached to the spindle of a pressure relief valve that may be operated manually, semiautomatically, or automatically and requires measurements of the applied lifting force and system pressure.

The auxiliary lift-assist device, in conjuction with the system pressure, provides a supplemental force (load) to overcome the spring force on the valve disk.

bench testing: testing of a pressure relief device on a test stand using an external pressure source with or without an auxiliary lift device to determine some or all of its operating characteristics.

field testing: testing of a pressure relief device installed on a system to determine some or all of its operating characteristics. It may be either of the following methods:

(a) *in-place testing:* testing of a pressure relief device installed on but not protecting a system, using an external pressure source, with or without an auxiliary lift device to determine some or all of its operating characteristics.

(b) *in-service testing:* testing of a pressure relief device installed on and protecting a system, using system pressure or an external pressure source, with or without an auxiliary lift device to determine some or all of its operating characteristics.

flow capacity testing: testing of a pressure relief device to determine its operating characteristics, including measured relieving capacity.

pressure relief device: a device designed to prevent pressure or vacuum from exceeding a predetermined value in a pressure vessel by the transfer of fluid during emergency or abnormal conditions.

2-3 TYPES OF DEVICES

2-3.1 Reclosing Pressure-Relieving Devices

pressure relief valve (PRV): a pressure relief device designed to actuate on inlet static pressure and reclose after normal conditions have been restored. It may be one of the following types and have one or more of the following design features:

(a) *low-lift PRV:* a pressure relief valve in which the actual discharge area is the curtain area.

(b) *full-lift PRV:* a pressure relief valve in which the actual discharge area is the bore area.

(c) *restricted-lift PRV:* a full-lift pressure relief valve whose lift is restricted such that the capacity is reduced proportionally to the ratio of restricted lift to full lift.

(d) *reduced-bore PRV:* a pressure relief valve in which the flow path area below the seat is less than the flow area at the inlet to the valve.

(e) *full-bore PRV:* a pressure relief valve in which the bore area is equal to the flow area at the inlet to the valve, and there are no protrusions in the bore.

(f) *direct spring-loaded PRV:* a pressure relief valve in which the disk is held closed by a spring.

(g) *pilot-operated PRV:* a pressure relief valve in which the disk is held closed by system pressure, and the holding pressure is controlled by a pilot valve actuated by system pressure.

(h) *conventional direct spring-loaded PRV:* a direct spring-loaded pressure relief valve whose operational characteristics are directly affected by changes in the back pressure.

(i) *balanced direct spring-loaded PRV:* a direct spring-loaded pressure relief valve that incorporates means of minimizing the effect of back pressure on the operational characteristics (opening pressure, closing pressure, and relieving capacity).

(j) *internal spring PRV:* a direct spring-loaded pressure relief valve whose spring and all or part of the operating mechanism is exposed to the system pressure when the valve is in the closed position.

(k) *temperature and pressure relief valve:* a pressure relief valve that may be actuated by pressure at the valve inlet or by temperature at the valve inlet.

(l) *power-actuated PRV:* a pressure relief valve actuated by an externally powered control device.

(m) vacuum PRV: a pressure relief valve designed to admit fluid to prevent excessive internal vacuum.

relief valve: a pressure relief valve characterized by gradual opening that is generally proportional to the increase in pressure. It is normally used for incompressible fluids.

safety relief valve: a pressure relief valve characterized by rapid opening or by gradual opening that is generally proportional to the increase in pressure. It can be used for compressible or incompressible fluids.

safety valve: a pressure relief valve characterized by rapid opening and normally used to relieve compressible fluids.

2-3.2 Non-reclosing Pressure Relief Device

design features: non-reclosing pressure relief devices may include one or more of the following design features:

(a) low-lift device: a device in which the actual discharge area is dependent on the lift of the disk.

(b) full-lift device: a device in which the actual discharge area is independent of the lift of the disk.

(c) reduced-bore device: a device in which the flow path area below the seat is less than the flow path area of the inlet to the device.

(d) full-bore device: a device in which the flow path area below the seat is equal to the flow path area of the inlet to the device.

design types:

(a) rupture disk device: a device containing a disk that ruptures when the static differential pressure between the upstream and downstream side of the disk reaches a predetermined value. A rupture disk device includes a rupture disk and may include a rupture disk holder.

(b) pin device: a device actuated by static differential pressure or static inlet pressure and designed to function by the activation of a load-bearing section of a pin that supports a pressure-containing member. A pin is the load-bearing element of a pin device. A pin device housing is the structure that encloses the pressure-containing members. Examples of these devices include the following:

(1) breaking pin device: a device designed to function by the breakage of a load-carrying section of a pin that supports a pressure-containing member.

(2) buckling pin device: a device designed to function by the buckling of an axially loaded compressive pin that supports a pressure-containing member.

(3) shear pin device: a device designed to function by the shearing of a load-carrying member that supports a pressure-containing member.

(c) fusible plug device: a device designed to function by the yielding or melting of a plug, at a predetermined temperature, that supports a pressure-containing member or contains pressure by itself.

(d) frangible disk device: see *rupture disk device*.

(e) bursting disk device: see *rupture disk device*.

(f) direct spring-loaded device: a device actuated by static differential pressure or static inlet pressure in which the disk is held closed by a spring. Upon actuation, the disk is held open by a latching mechanism.

(g) pilot-operated device: a device in which the disk is held closed by system pressure and the holding pressure is controlled by a pilot actuated by system pressure. The pilot may consist of one of the devices listed in this Section.

non-reclosing pressure relief device: a pressure relief device designed to actuate and remain open after operation. A manual resetting means may be provided.

2-4 PARTS OF PRESSURE RELIEF DEVICES

adjusting ring: a ring assembled to the nozzle or guide of a direct spring valve used to control the opening characteristics and/or the reseat pressure.

adjustment screw: a screw used to adjust the set pressure or the reseat pressure of a reclosing pressure relief device.

backflow preventer: a part or feature of a pilot-operated pressure relief valve used to prevent the valve from opening and flowing backwards when the pressure at the valve outlet is greater than the pressure at the valve inlet.

bellows: a flexible, pressure-containing component of a balance direct spring valve used to prevent changes in set pressure when the valve is subjected to a superimposed back pressure or to prevent corrosion between the disk holder and guide.

blowdown ring: see *adjusting ring*.

body: a pressure-retaining or pressure-containing member of a pressure relief device that supports the parts of the valve assembly and has provision(s) for connecting to the primary and/or secondary pressure source(s).

bonnet: a component of a direct spring valve or of a pilot in a pilot-operated valve that supports the spring. It may or may not be pressure containing.

breaking pin: the load-carrying element of a breaking pin non-reclosing pressure relief device.

breaking pin housing: a pressure-retaining component that supports the breaking pin in a non-reclosing pressure relief device.

buckling pin: the load-carrying element of a buckling device.

cap: a component used to restrict access and/or protect the adjustment screw in a reclosing pressure relief device. It may or may not be a pressure-containing part.

diaphragm: a flexible metallic, plastic, or elastomer pressure-containing member of a reclosing pressure relief device used to sense pressure or provide opening or closing force.

disk: a movable component of a pressure relief device that contains the primary pressure when it rests against the nozzle.

disk holder: a movable component in a pressure relief device that contains the disk.

dome: the volume on the side of the unbalanced moving member opposite the nozzle in the main relieving valve of a pilot-operated pressure relief device.

field test: a device for in-service or bench testing of a pilot-operated pressure relief device to measure the set pressure.

gag: a device used on reclosing pressure relief devices to prevent the device from opening.

guide: a component in a direct spring or pilot-operated pressure relief device used to control the lateral movement of the disk or disk holder.

huddling chamber: the annular pressure chamber between the nozzle exit and the disk or disk holder that produces the lifting force to obtain a pop action.

knife blade: a component with multiple blades used with reverse-acting rupture disks to cut the disk when it reverses.

lift lever: a device to apply an external force to the stem of a pressure relief valve to manually operate the valve at some pressure below the set pressure.

main relieving valve: that part of a pilot-operated pressure relief device through which the rated flow occurs during relief.

nozzle: a primary pressure-containing component in a pressure relief valve that forms a part or all of the inlet flow passage.

pilot: the pressure- or vacuum-sensing component of a pilot-operated pressure relief valve that controls the opening and closing of the main relieving valve.

piston: the moving element in the main relieving valve of a pilot-operated, piston-type pressure relief valve that contains the seat that forms the primary pressure containment zone when in contact with the nozzle.

pressure-containing member: a component that is exposed to and contains pressure.

pressure-retaining member: a component that holds pressure-containing members together but is not exposed to the pressure.

rupture disk: the pressure-containing element in a rupture disk device that is designed to burst at its rated pressure at a specified temperature.

rupture disk holder: the structure that clamps a rupture disk in position.

seat: the pressure-sealing surfaces of the fixed and moving pressure-containing components.

shear pin: the load-carrying element of a shear pin device.

shell: an assembly of pressure-containing members that isolate primary or secondary pressure from atmosphere. Examples of these members include, but are not limited to

(a) for a direct spring-loaded pressure relief valve using a pressurized bonnet, the body, nozzle, bonnet, and cap

(b) for a direct spring-loaded pressure relief valve using a yoke or open bonnet, the nozzle and disk

(c) for a pilot-operated pressure relief valve, the body and cap of the main valve and the body of the pilot

spindle: a part whose axial orientation is parallel to the travel of the disk. It may be used in one or more of the following functions:

(a) assist in alignment

(b) guide disk travel

(c) transfer of internal or external forces to the seats

spring: the element in a pressure relief valve that provides the force to keep the disk on the nozzle.

spring button: see *spring step.*

spring step: a load-transferring component in a pressure relief valve that supports the spring.

spring washer: see *spring step.*

stem: see *spindle.*

vacuum support: a component of a rupture disk to prevent flexing due to upstream vacuum or downstream back pressure.

yoke: a pressure-retaining component in a pressure relief device that supports the spring in a pressure relief valve or pin in a non-reclosing device but does not enclose either from the surrounding ambient environment.

2-5 DIMENSIONAL CHARACTERISTICS — PRESSURE RELIEF VALVES

actual discharge area: the measured minimum net area that determines the flow through a valve.

bore area: the minimum cross-sectional flow area of a nozzle (see Figure 2-5-1).

bore diameter: the minimum diameter of a nozzle.

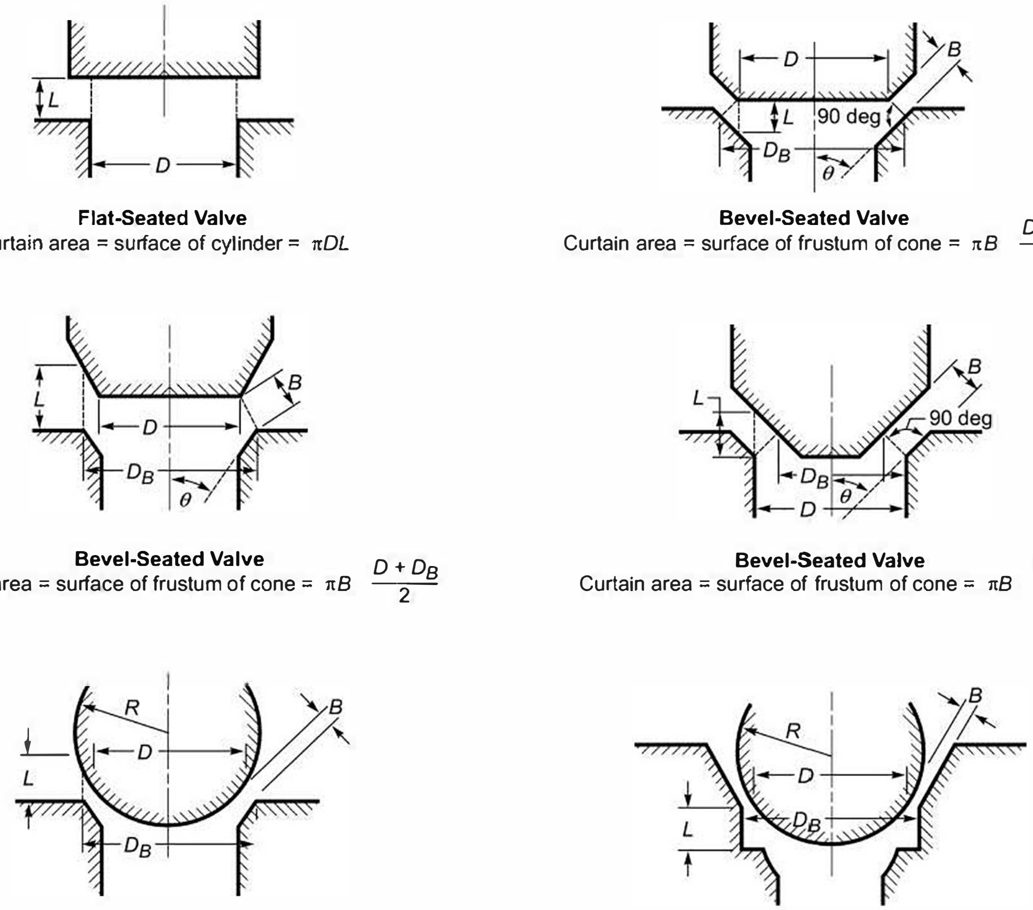
curtain area: the area of the cylindrical or conical discharge opening between the seating surfaces created by the lift of the disk above the seat (see Figure 2-5-1).

developed lift: the actual travel of the disk from closed position to the position reached when the valve is at flow-rating pressure.

discharge area: see *actual discharge area.*

effective discharge area: a nominal or computed area of flow through a pressure relief valve, differing from the actual discharge area, for use in recognized flow formulas to determine the capacity of a pressure relief valve.

Figure 2-5-1
Typical Curtain Areas of Pressure Relief Valves



Flat-Seated Valve
Curtain area = surface of cylinder = πDL

Bevel-Seated Valve
Curtain area = surface of frustum of cone = $\pi B \dfrac{D + D_B}{2}$

Bevel-Seated Valve
Curtain area = surface of frustum of cone = $\pi B \dfrac{D + D_B}{2}$

Bevel-Seated Valve
Curtain area = surface of frustum of cone = $\pi B \dfrac{D + D_B}{2}$

Radial-Seated Valve
Curtain area = surface of frustum of cone = $\pi B \dfrac{D + D_B}{2}$

Radial-Seated Valve
Curtain area = surface of frustum of cone = $\pi B \dfrac{D + D_B}{2}$

Legend:

B = slant height of frustum of cone
D = seat diameter
= smallest diameter at which seat touches disk
D_B = other diameter of frustum of cone
L = lift
R = radius
θ = seat angle
= angle of seating surface with axis of valve

GENERAL NOTE: Curtain area is the discharge area unless the disk attains sufficient lift for the valve bore to become the controlling area. See subsection 2-5, *actual discharge area, bore area,* and *curtain area*.

effective seat area: a computed area for use in calculating the set pressure of a given pressure relief valve when tested using an auxiliary lift-assist device.

flow path: the three-dimensional and geometric characteristics of a device that affects the measured relieving capacity. It is defined from the cross section of the inlet to the cross section of the outlet, including all streamlines in the flow.

inlet size: the nominal pipe size of the inlet of a pressure relief valve, unless otherwise designated.

lift: the actual travel of the disk away from closed position when a valve is relieving.

nozzle area, nozzle throat area: see *bore area*.

nozzle diameter: see *bore diameter*.

orifice area: see *effective discharge area*.

outlet size: the nominal pipe size of the outlet of a pressure relief valve, unless otherwise designated.

rated lift: the design lift at which a valve attains its rated relieving capacity.

seat angle: the angle between the axis of a valve and the seating surface. A flat-seated valve has a seat angle of 90 deg.

seat area: the area determined by the seat diameter.

seat diameter: the smallest diameter of contact between the fixed and moving portions of the pressure-containing elements of a valve.

seat flow area: see *curtain area*.

throat area: see *bore area*.

throat diameter: see *bore diameter*.

2-6 DIMENSIONAL CHARACTERISTICS — NON-RECLOSING PRESSURE RELIEF DEVICES

flow path: the three-dimensional and geometric characteristics of a device that affects the measured relieving capacity. It is defined from the cross section of the inlet to the cross section of the outlet, including all streamlines in the flow.

inlet area: the cross-sectional flow area at the inlet opening of a pressure relief device.

inlet size: the nominal pipe size of the inlet of a pressure relief device, unless otherwise designated.

net flow area: the area that determines the flow after a non-reclosing pressure relief device has operated. The (minimum) net flow area of a rupture disk is the calculated net area after a complete burst of the disk, with appropriate allowance for any structural members that may reduce the net flow area through the rupture disk device.

outlet size: the nominal pipe size of the outlet passage from a pressure relief device, unless otherwise designated.

2-7 OPERATIONAL CHARACTERISTICS OF PRESSURE RELIEF DEVICES

40-cc pressure: the value of increasing inlet static pressure of a pressure relief valve at which the discharge is measured at 40 cm^3/min.

back pressure: the static pressure existing at the outlet of a pressure relief device due to pressure in the discharge system.

blowdown: the difference between actual popping pressure of a pressure relief valve and actual reseating pressure expressed as a percentage of set pressure or in pressure units.

blowdown pressure: the value of decreasing inlet static pressure at which no further discharge is detected at the outlet of a pressure relief valve after the valve has been subjected to a pressure equal to or above the popping pressure.

breaking pressure: the value of inlet static pressure at which a breaking pin or shear pin device functions.

bubble pressure: the value of increasing inlet static pressure of a pressure relief valve at which the onset of a continuous stream of bubbles occurs.

buckling pressure: the value of inlet static pressure at which a buckling pin device functions.

built-up back pressure: pressure existing at the outlet of a pressure relief device caused by the flow through that particular device into a discharge system.

burst pressure: the value of inlet static pressure at which a rupture disk device functions.

chatter: abnormal rapid reciprocating motion of the movable parts of a pressure relief valve in which the disk contacts the seat.

closing pressure: the value of decreasing inlet static pressure at which the valve disk reestablishes contact with the seat or at which lift becomes zero.

coefficient of discharge: the ratio of the measured relieving capacity to the theoretical relieving capacity.

cold differential test pressure: the inlet static pressure at which a pressure relief valve is adjusted to open on the test stand. This test pressure includes corrections for service conditions of superimposed back pressure and/or temperature.

constant back pressure: a superimposed back pressure that is constant with time.

cracking pressure: see opening pressure.

dynamic blowdown: the difference between the set pressure and closing pressure of a pressure relief valve when it is overpressured to the flow-rating pressure.

first steady stream: the value of increasing static inlet pressure of a pressure relief valve at which liquid discharge flow is continuous and separates from the valve outlet flange or pipe nipple at approximately a 90-deg angle to the outlet centerline.

flow capacity: see *measured relieving capacity.*

flow-rating pressure: the inlet stagnation pressure at which the relieving capacity of a pressure relief device is measured.

flow resistance: a dimensionless term (such as used in para. 5-5.7) that expresses the number of velocity heads lost due to flow through a rupture disk device (where velocity head is one-half the velocity squared divided by the acceleration of gravity).

flutter: abnormal, rapid reciprocating motion of the movable parts of a pressure relief valve in which the disk does not contact the seat.

initial audible discharge pressure: the value of increasing static inlet pressure of a pressure relief valve at which the discharge becomes continuous by hearing with the naked ear as specified by the Manufacturer.

leak pressure: see *start-to-leak pressure.*

leak test pressure: the specified inlet static pressure at which a quantitative seat leakage test is performed in accordance with a standard procedure.

lot of rupture disks: those disks manufactured of a material at the same time and of the same size, thickness, type, heat, and manufacturing process, including heat treatment.

marked breaking pressure: the value of pressure marked on a breaking pin or a shear pin device or its nameplate.

marked burst pressure: the value of pressure marked on the rupture disk device or its nameplate or on the tag of the rupture disk, indicating the burst pressure at the coincident disk temperature.

marked relieving capacity: see *rated relieving capacity.*

marked set pressure: the value or values of pressure marked on a pressure relief device.

measured relieving capacity: the relieving capacity of a pressure relief device measured at the flow-rating pressure, expressed in gravimetric or volumetric units.

opening pressure: the value of increasing inlet static pressure of a pressure relief valve at which there is a measurable lift or at which the discharge becomes continuous as determined by seeing, feeling, or hearing.

overpressure: a pressure increase over the set pressure of a pressure relief valve, usually expressed as a percentage of set pressure.

popping pressure: the value of increasing inlet static pressure at which the disk moves in the opening direction at a faster rate as compared with corresponding movement at higher or lower pressures.

primary pressure: the pressure at the inlet in a pressure relief device.

rated relieving capacity: that portion of the measured relieving capacity permitted by the applicable code or regulation to be used as a basis for the application of a pressure relief device.

reference conditions: those conditions of a test medium that are specified by either an applicable standard or an agreement between the parties to the test, which may be used for uniform reporting of measured flow test results.

relieving conditions: the inlet pressure and temperature on a pressure relief device during an overpressure condition. The relieving pressure is equal to the valve set pressure or burst (or the rupture disk burst pressure) plus the overpressure. (The temperature of the flowing fluid at relieving conditions may be higher or lower than the operating temperature.)

relieving pressure: set pressure plus overpressure.

resealing pressure: the value of decreasing inlet static pressure at which no further leakage is detected after closing. The method of detection may be a specified water seal on the outlet or other means appropriate for this application.

reseating pressure: see *closing pressure.*

seal-off pressure: see *resealing pressure.*

secondary pressure: the pressure existing in the passage between the actual discharge area and the valve outlet in a safety, safety relief, or relief valve.

set pressure: the value of increasing inlet static pressure at which a pressure relief device displays one of the operational characteristics as defined under opening pressure, popping pressure, start-to-leak pressure, bubble pressure, 40-cc pressure, burst pressure, buckling pressure, or breaking pressure. (The applicable operating characteristic for a specific device design is specified by the device manufacturer.)

simmer: the audible or visible escape of fluid between the seat and disk at an inlet static pressure below the popping pressure and at no measurable capacity. It applies to safety or safety relief valves on compressible-fluid service.

specified burst pressure (of a rupture disk device): the value of increasing inlet static pressure, at a specified temperature, at which a rupture disk is designed to function.

start-to-discharge pressure: see *opening pressure.*

start-to-leak pressure: the value of increasing inlet static pressure at which the first bubble occurs when a pressure relief valve is tested by means of air under a specified water seal on the outlet.

static blowdown: the difference between the set pressure and the closing pressure of a pressure relief valve when it is not overpressured to the flow-rating pressure.

superimposed back pressure: the static pressure existing at the outlet of a pressure relief device at the time the device is required to operate. It is the result of pressure in the discharge system from other sources.

test pressure: see *relieving pressure*.

theoretical relieving capacity: the computed capacity expressed in gravimetric or volumetric units of a theoretically perfect nozzle having a minumum cross-sectional flow area equal to the actual discharge area of a pressure relief valve or net flow area of a non-reclosing pressure relief device.

vapor-tight pressure: see *resealing pressure*.

variable back pressure: a superimposed back pressure that will vary with time.

warn: see *simmer*.

yield (melt) temperature: the temperature at which the fusible material of a fusible plug device becomes sufficiently soft to extrude from its holder and relieve pressure.

2-8 DESCRIPTION OF TERMS

a = minimum net flow area, in.^{2} (mm^2)
a_d = actual discharge area, in.^{2} (mm^2)
a_m = meter-bore area, in.^{2} (m^2)
C = valve-inlet temperature correction
= discharge coefficient, dimensionless
C_{tap} = sonic velocity at pressure tap, ft/sec (m/s)
C^* = critical flow function
D = test rig inside diameter, ft (m)
= internal diameter of meter run pipe, in. (m)
d = meter-bore diameter, in. (m)
d_b = minimum holder bore diameter, in. (mm)
= bore diameter, in. (mm)
d_o = diameter of orifice plate, in. (mm)
d_s = seat diameter, in. (mm)
E = pipe roughness, in. (mm)
f = fanning friction factor, dimensionless
F_a = area factor for thermal expansion, dimensionless
G = mass velocity, lbm/ft^2-sec (kg/m^2-s)
= specific gravity with respect to dry air, M/M_a
h_w = differential pressure at the meter, in. water (mm water)
K = flow coefficient
= $\dfrac{c}{\sqrt{1-\beta^4}}$
k = ratio of specific heats
$K_{A\text{-}B}$ = resistance factor between pressure taps A and B
$K_{B\text{-}C}$ = resistance factor between pressure taps B and C
$K_{B\text{-}D}$ = resistance factor between pressure taps B and D
$K_{C\text{-}D}$ = resistance factor between pressure taps C and D
K_o = trial flow coefficient
$K_{pipe\ B\text{-}C}$ = pipe resistance factor between pressure taps B and C without the rupture disk device
$K_{pipe\ B\text{-}D}$ = pipe resistance factor between pressure taps B and D without the rupture disk device
K_{Ri} = individual flow resistance
K_{tap} = total resistance factor to pressure tap
L = ratio of location of pressure taps to D
l = valve-disk lift, in. (mm)
$L_{A\text{-}B}$ = length between taps A and B, ft (m)
$L_{B\text{-}C}$ = length between taps B and C, ft (m)
$L_{B\text{-}D}$ = length between taps B and D, ft (m)
$L_{C\text{-}D}$ = length between taps C and D, ft (m)
M = molecular weight of gas
m = mass flow rate, lbm/hr (kg/h)
M_a = molecular weight of air
M_{tap} = Mach number at pressure tap
M_w = molecular weight
M_1 = Mach number at pipe entrance
N_{Re} = Reynolds number
P = static pressure, psia (kPa)
P_B = base pressure, psia (kPa)
P_b = barometric pressure, psia (kPa)
P_f = flow-rating pressure, psia (kPa)
P_m = static pressure at the meter calorimeter, psia (kPa)
P_o = back pressure, psig (kPag)
P_s = meter inlet stagnation pressure, psia (kPa)
P_{set} = set pressure, psig (kPag)
P_{tapA} = pressure at tap A, psia (kPa)
P_{tapB} = pressure at tap B, psia (kPa)
P_{tapC} = pressure at tap C, psia (kPa)
P_{tapD} = pressure at tap D, psia (kPa)
P_1 = pressure at pipe entrance, psia (kPa)
Q = relieving capacity in gpm (L/m) of water at reference condition, U.S. gallons (gpm) or liters (L/m)
q_b = volumetric rate at base condition at the meter, cfm (m^3/min)
q_r = valve capacity at reference inlet temperature, cfm (m^3/min)
R = gas constant, ft-lbf/lbm-°R (kPa/kgK)
= 1,545.4/M (8.3143/M)
R_D = Reynolds number referred to internal diameter of meter run pipe, D
R_d = throat Reynolds number
S_g = specific gravity (ideal)
T = temperature, °R (K)
= fluid temperature, °F (°C)

t = length of test, min
T_B = base temperature, °F (°C)
T_b = base temperature, absolute, °R (K)
T_{cal} = fluid temperature at the calorimeter, °F (°C)
$T_{cal,\ drum}$ = fluid temperature at the test drum calorimeter, °F (°C)
$T_{cal,\ meter}$ = fluid temperature at the meter calorimeter, °F (°C)
T_m = fluid temperature at the meter, °F (°C)
= temperature upstream of the meter, °F (°C)
T_o = base temperature, °R (K)
T_r = reference temperature at the valve inlet, absolute, °R (K)
T_s = meter inlet stagnation temperature, absolute, °R (K)
T_{tap} = temperature at pressure tap, °R (K)
T_v = fluid temperature, °F (°C)
= temperature at the valve inlet, absolute, °R (K)
T_1 = temperature at pipe entrance, °R (K)
v = specific volume, ft^3/lbm (m^3/kg)
V_{act} = specific volume at inlet conditions, ft^3/lbm (m^3/kg)
$V_{act,\ drum}$ = specific volume at inlet conditions, ft^3/lbm (m^3/kg)
$V_{act,\ meter}$ = specific volume at flowing conditions at the meter, ft^3/lbm (m^3/kg)
V_{ref} = specific volume at reference condition, ft^3/lbm (m^3/kg)
$V_{ref,\ drum}$ = specific volume at reference condition, ft^3/lbm (m^3/kg)
$V_{ref,\ meter}$ = specific volume at reference conditions at the meter, ft^3/lbm (m^3/kg)
V_{tap} = specific volume at pressure tap, ft^3/lbm (m^3/kg)
W = measured relieving capacity, lbm/sec (kg/s)
w = mass of water or condensate, lbm (kg)
W_c = measured relieving capacity adjusted to the reference condition, lbm/hr (kg/h)
$W_{cal,\ drum}$ = test-drum calorimeter flow adjusted to the reference condition, lbm/hr (kg/h)
$W_{cal,\ meter}$ = meter calorimeter flow adjusted to the reference condition, lbm/hr (kg/h)
w_{cl} = condenser leakage, lbm/hr (kg/h)
W_{dc} = test-drum calorimeter flow, lbm/hr (kg/h)
W_{dr} = test-drum drainage, lbm/hr (kg/h)
W_h = flow rate, lbm/hr (kg/h)
= measured relieving capacity adjusted to the reference condition, lbm/hr (kg/h)
W_{mc} = meter calorimeter flow, lbm/hr (kg/h)
W_r = relieving capacity adjusted to water at reference condition, lbm/hr (kg/h)
W_t = trial flow rate, lbm/hr (kg/h)
w_{vl} = valve-steam leakage, lbm/hr (kg/h)
Y = expansion factor
Y_{tap} = expansion factor at pressure tap
Z = compressibility factor as defined in the equation of state, $Pv = ZRT$
Z_b = base compressibility factor
β = beta ratio
= d/D
ρ = fluid density, lbm/ft^3 (kg/m^3)
ρ_{act} = density of water at inlet conditions, lbm/ft^3 (kg/m^3)
ρ_B = density at base temperature and pressure, lbm/ft^3 (kg/m^3)
ρ_m = fluid density at meter inlet, lbm/ft^3 (kg/m^3)
ρ_{ref} = density of water at reference condition, lbm/ft^3 (kg/m^3)
ρ_s = density of dry air at 14.696 psia (101.33 kPa) and at the base temperature, lbm/ft^3 (kg/m^3)
ρ_{std} = density of dry air at 14.696 psia (101.33 kPa) and reference temperature, lbm/ft^3 (kg/m^3)
μ = viscosity, lbm/ft-sec (kg/m-s)
= viscosity of air at T_B and P_B, centipoise
ΔP = differential pressure head across meter, in. water (mm water)
$\Delta P_{A\text{-}B}$ = differential pressure between taps A and B, psia (kPa)
$\Delta P_{B\text{-}C}$ = differential pressure between taps B and C, psia (kPa)
$\Delta P_{C\text{-}D}$ = differential pressure between taps C and D, psia (kPa)

PART II
FLOW CAPACITY TESTING

Section 3
Guiding Principles

3-1 ITEMS ON WHICH AGREEMENT SHALL BE REACHED

The parties to the test shall reach agreement on the following items prior to conducting the test:

(a) object of the test
(b) parties to the test
(c) test site
(d) testing fluid reference condition at flow-rating pressure
(e) methods of measurement, instrumentation, and equipment to be used (calibration of instruments shall be in accordance with subsection 3-7)
(f) number, size, type, condition, source, set pressure, and expected relieving capacity of the device(s) to be tested
(g) person who shall supervise the test
(h) the written test procedure, which shall include the observations and readings to be taken and recorded to comply with the object or objectives of the test

3-2 QUALIFICATION OF PERSON SUPERVISING THE TEST

The person who supervises the test shall have a formal education in thermodynamics and fluid mechanics. In addition, the person shall have practical experience in fluid flow measurement and have had experience in test supervision.

3-3 RESPONSIBILITY OF PERSON SUPERVISING THE TEST

The person supervising the test shall be present at all times during the test and shall be solely responsible for ensuring that all persons who are involved in taking readings, making pressure and temperature adjustments, or any other function that will affect the test results are fully informed as to the correct method of performing such functions. The person supervising the test shall also be responsible for ensuring that the written test procedures are followed. The person supervising the test shall sign and date the test report, thereby verifying to the best of the person's knowledge that the report is correct and that the test was conducted in accordance with the written test procedures.

The person supervising the test shall be responsible for the calibration of instruments as required by subsection 3-7.

3-4 TEST APPARATUS

Procedures and arrangement of the test apparatus shall be in accordance with Section 4.

3-5 PRELIMINARY TESTS

Sufficient preliminary tests shall be conducted to ensure that test conditions can be attained and that operating personnel are completely familiar with the test equipment and their respective assignments. Preliminary tests shall include the recording of all data necessary to the completeness of an actual test.

3-6 SPARE INSTRUMENTS

If intended for use as replacements during the test, spare instruments shall be calibrated in accordance with subsection 3-7.

3-7 CALIBRATION OF INSTRUMENTS

Each instrument used during the test shall be serialized or otherwise positively identified. Each instrument, depending on the type, shall be calibrated in accordance with the following schedule outlined in this subsection. Records of pertinent instrument calibrations shall be available for review by the interested parties.

3-7.1 Pressure

Pressure-measuring instruments shall be calibrated in accordance with ASME PTC 19.2, before and after any test or series of tests, but in no case shall a period of greater than 10 days elapse between pretest calibration and post-test calibration check. Calibration of other means of indicating or recording pressure shall be agreed upon by the interested parties.

3-7.2 Temperature

Temperature-measuring instruments shall be calibrated in accordance with ASME PTC 19.3. Instruments of the types listed in para. 4-2.2(a), except bimetallic thermometers, shall be calibrated against at least two temperatures within a 90-day period preceding the test or series of tests. Bimetallic thermometers shall be calibrated before and after each test or series of tests. Calibration of other means of indicating or recording temperature shall be agreed upon by the interested parties.

3-7.3 Lift Indicators and Recorders

Since these instruments are usually subjected to some shock in the course of tests under this Code, their accuracy shall be checked before and after each test or series of tests.

3-7.4 Weighing Scales

Scales used in test procedures for weighted condensate or gravimetric methods shall have a minimum value of the indicating element equal to or less than 0.25% of the expected load. Weighing scales used in tests conducted under this Code shall be calibrated at sufficient points to ensure their accuracy within their range of intended usage at least once within a 90-day period preceding a test or series of tests.

3-7.5 Steam Calorimeters

Methods of calibrating steam calorimeters are given in ASME PTC 19.11. The calorimeters shall be calibrated separately with steam at the time of their installation and at regular intervals not exceeding 1 yr. Further calibrations shall be carried out if results indicate an obvious error in their readings or if their installation is altered.

3-8 METERING SECTIONS

The calibration of any type of flow meter (see para. 4-2.2) shall include the actual piping and all fittings both upstream and downstream of the meter (see ASME PTC 19.5), including control valves, test vessels, and vessel-to-test device adapters. Such calibration shall be by means of measuring the flow rate through a test device with a known coefficient of discharge upon completion of the initial installation or construction and prior to the performance of any formal test. Agreement with the coefficient of the test object shall be within ±2%.

The initial calibration shall include runs at the smallest, intermediate, and highest flow rates compatible with the comparison installation. Adapter fittings for test devices having different types of inlet connections shall be calibrated by laboratory personnel at the time of their manufacture or purchase. In addition, the meter installation shall undergo a calibration check as described above at least once within each 1-yr period. These calibration checks shall include runs with at least two sizes of adapters. Records of calibrations shall be maintained and available for review by the interested parties. Modifications to the equipment shall be evaluated for the effect they may have on the system calibration, and new calibrations shall be performed if deemed necessary.

3-9 FLOW RESISTANCE TEST RIGS

The calibration of any type of test rig (see para. 4-9.1) shall include the actual piping and all fittings downstream of the test vessel (see Figure 3-9-1). Calibration shall be conducted upon completion of the initial installation or construction and prior to the performance of any formal test and repeated at least once every 5 yr. Records of calibration shall be maintained and available for review by the interested parties. Modifications to the equipment shall be evaluated for the effect they have on the test rig, and new calibrations shall be performed if deemed necessary. The calibration shall be conducted per paras. 3-9.1 and 3-9.2.

3-9.1 Measured Flow Resistance

With no test device installed, conduct three flow resistance tests at the smallest, intermediate, and highest test pressures compatible with the test rig. The measured flow resistance, K_{Ri}, for each test shall be 0 ± 0.075.

3-9.2 Pressure Tap Profile Comparison

With no test device installed, conduct a flow test at an intermediate test pressure; see the following steps:

Step 1. With the data from the flow test, calculate the average friction factor for the length of pipe between taps A-B and C-D.

Step 2. Using the Lapple (1943) and Levenspiel (1977) model of the adiabatic ideal-gas integration of the mechanical energy (or momentum) balance for adiabatic flow from an ideal nozzle on a large reservoir, through an equivalent length of pipe, to a second large reservoir (or to the atmosphere), calculate the equivalent pipe length to tap A using the measured flow rate, the average friction factor from Step 1, and the measured pressure at tap A.

Step 3. Subtract the actual pipe length from the test rig entrance to tap A from the equivalent pipe length from Step 2 to determine a nozzle equivalent length.

Step 4. Repeat Steps 2 and 3 for taps B through D.

Step 5. Calculate the average nozzle equivalent length using the values determined in Steps 1 through 4. This average nozzle equivalent length is used to compensate for the actual pressure loss up to the test rig entrance.

Step 6. Using again the adiabatic ideal-gas integration model of Step 2, calculate the pressure at tap A using the measured flow rate, average friction factor, and average nozzle equivalent length from Step 5 and actual pipe length for tap A.

Step 7. Repeat Step 6 for taps B through D.

Step 8. Calculate the difference between the measured pressure and the calculated pressure from Step 7 at each of the four pressure taps. The difference at each tap shall be within ±6.0% of the calculated pressure.

3-10 ADJUSTMENTS DURING TESTS

No adjustment to the pressure relief device shall be made while readings are being taken. Following any change or deviation of the test conditions, a sufficient period of time shall be allowed to permit the rate of flow, temperature, and pressure to reach stable conditions before readings are taken.

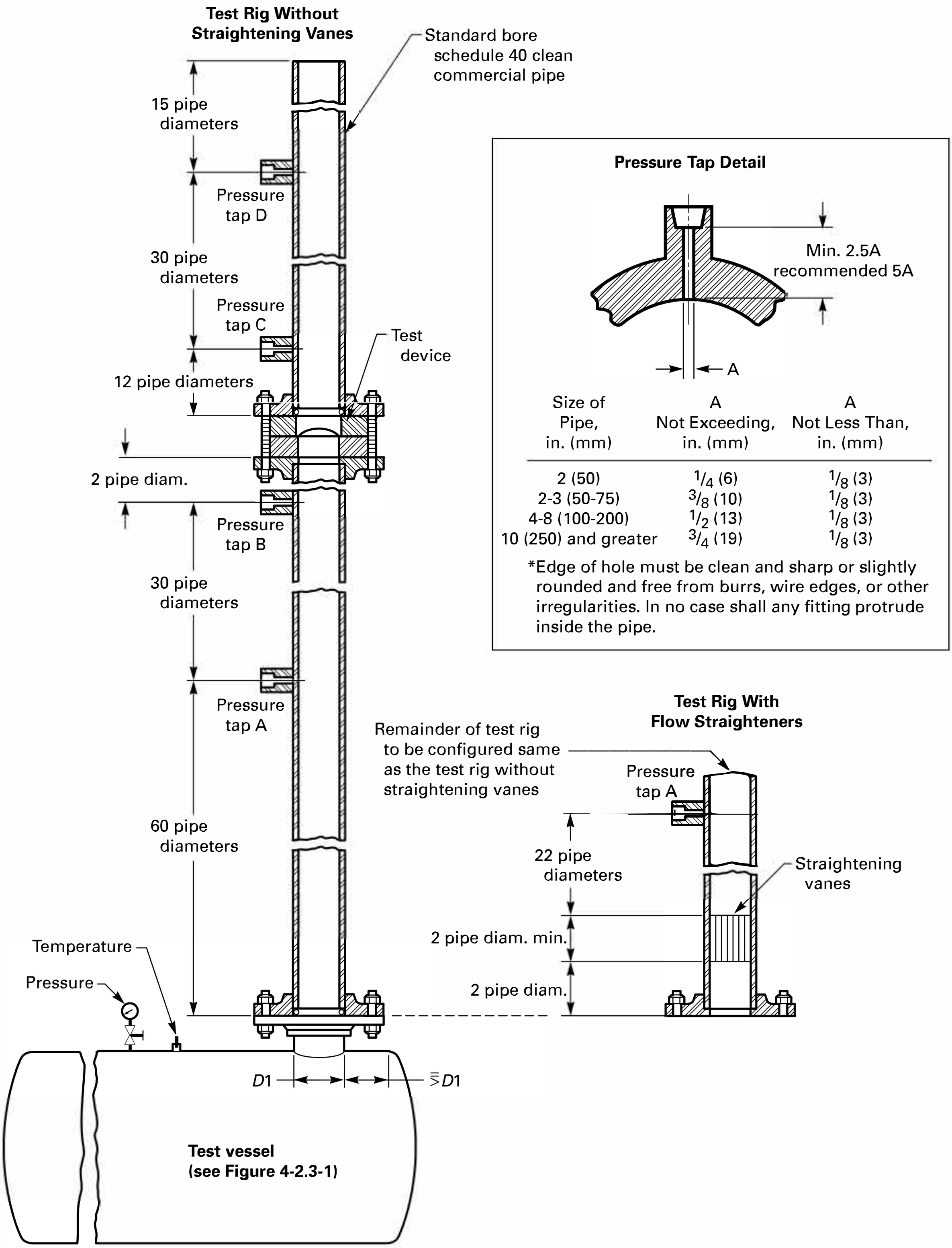
3-11 RECORDS AND TEST RESULTS

The test records shall include all observations, measurements, instrument readings, and instrument calibration records (if required) used in the test. Original test records shall remain in the custody of the facility that conducted the test for a period not fewer than 5 yr. Copies of all test records shall be furnished to each of the parties to the test. Corrections and corrected values shall be entered separately in the test record. The test shall be reported in accordance with Section 6 of this Code.

3-12 MEASUREMENT UNCERTAINTY

A post-test uncertainty analysis shall be performed to determine that the limits of uncertainty of the final flow measurement specified in Section 1 were met. A pretest determination may be performed to determine that the limits of uncertainty of the final flow measurement specified in Section 1 can be met by the specified instrument and procedures. A guide for such determination is given in ASME PTC 19.1. These determinations shall be documented by the laboratory and available for review.

Figure 3-9-1
Recommended Arrangements for Testing Non-reclosing Pressure Relief Device Flow Resistance



Size of Pipe, in. (mm)	A Not Exceeding, in. (mm)	A Not Less Than, in. (mm)
2 (50)	1/4 (6)	1/8 (3)
2-3 (50-75)	3/8 (10)	1/8 (3)
4-8 (100-200)	1/2 (13)	1/8 (3)
10 (250) and greater	3/4 (19)	1/8 (3)

*Edge of hole must be clean and sharp or slightly rounded and free from burrs, wire edges, or other irregularities. In no case shall any fitting protrude inside the pipe.

Section 4
Instruments and Methods of Measurements

4-1 GENERAL

This Section describes the instruments, methods, procedures, and precautions that shall be used in testing pressure relief devices under this Code. The Performance Test Code Supplements on Instruments and Apparatus provide authoritative general information concerning instruments and their use and may be consulted for such information.

4-2 FLUID CONDITIONS, TEST CONDITIONS, AND INSTRUMENTATION

4-2.1 Atmospheric Pressure

Barometric pressure shall be measured with a barometer (see ASME PTC 19.2). In calculations involving the capacity of pressure relief devices having a flow-rating pressure of 20 psig (150 kPa) or higher, the use of the mean barometric pressure at the test site satisfies the accuracy requirements of this Code. In such cases, the recorded pressure may be the mean barometric pressure.

4-2.2 Temperature

Instructions on thermometers or thermocouples and associated instruments are given in ASME PTC 19.3, except that commercial, metal-encased thermometers shall not be used in tests conducted under this Code. Other means of temperature measurement and indication may be used, provided they are of the same or greater degree of accuracy as those described therein.

(a) Depending on operating conditions, or convenience, the temperature may be measured with certified or calibrated liquid-in-glass thermometers, bimetallic thermometers, resistance-type thermometers, or thermocouples. All of the above may be inserted directly into the pipe or wells except for liquid-in-glass thermometers, which must be inserted into wells. The installation of the temperature-measuring device directly into the pipe, without the addition of a well, is desirable for temperatures below 300°F (150°C).

(b) The following precautions shall be taken when making any temperature measurements:

(1) No significant quantity of heat shall be transferred by radiation or conduction to or from the temperature-measuring device other than by the temperature of the medium being observed (see ASME PTC 19.3).

(2) The immediate vicinity of the point of insertion and the external projecting parts shall be insulated.

(3) The temperature-measuring device shall extend across the centerline in pipes of small diameter or shall be inserted at least 6 in. (150 mm) into the fluid stream in pipes over 12 in. (300 mm) in diameter.

(4) Temperature-measuring devices installed in pipes carrying compressible fluids shall, wherever possible, be installed at locations where the maximum fluid velocity during any flow measurement does not exceed 100 ft/sec (30 m/s). Where such an installation is not possible, it may be necessary to correct the temperature readings to the appropriate static or total temperature (see ASME PTC 19.5).

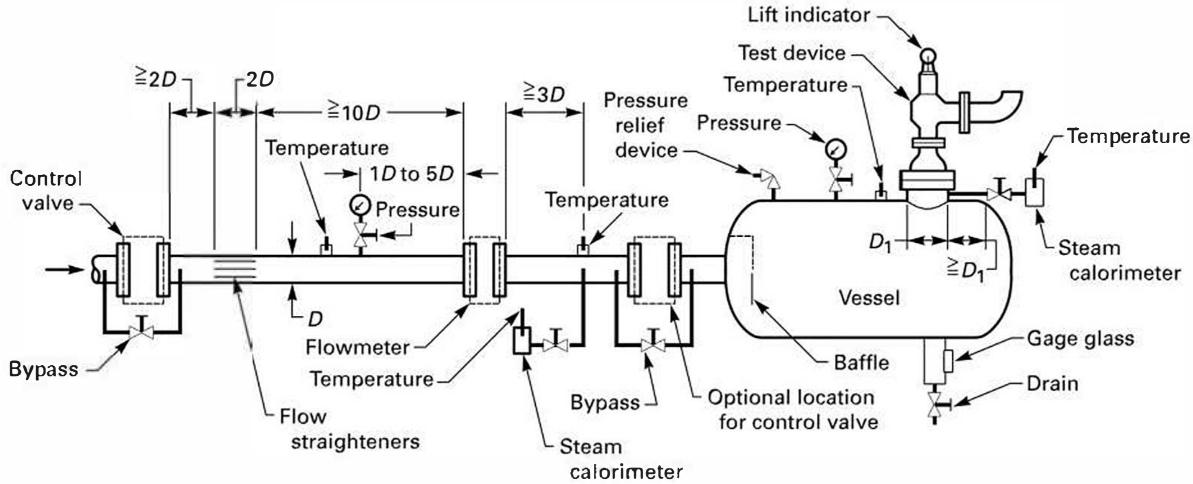
(5) The temperature-measuring devices shall be inserted in locations so as to measure temperatures that are representative of the flowing medium as described under test arrangements.

(c) When measuring temperatures with a mercury-in-glass thermometer, the instrument shall have an etched stem. When the measured temperature differs from the ambient by more than 10°F (5°C), and the mercury is exposed, an emergent stem correction shall be made (see ASME PTC 19.3) or an appropriate emergent-stem thermometer used.

(d) Thermometer wells, when used, shall be of the type shown in ASME PTC 19.3. They shall be as thin-walled and of as small a diameter as practicable; their outer surfaces shall be substantially free from corrosion or foreign matter. The well shall be filled with a suitable fluid. Mercury should not be used for this fluid since its very low vapor pressure presents a serious health hazard to personnel. However, if mercury is used for this purpose, suitable precautions must be taken.

(e) Thermocouples, if used, shall have a welded hot junction and must be calibrated together with their extension wires over the anticipated operating range. They shall be constructed of materials suitable for the temperature and fluid being measured. The electromotive force of a thermocouple shall be measured by a potentiometer instrument or millivoltmeter of such precision that the accuracy of the overall system is within the limit specified in subsection 1-3. The cold junction shall be established by an ice bath, reference standard, or by a compensating circuit built into the potentiometer.

Figure 4-2.3-1
Recommended Arrangements for Testing Devices With Atmospheric Back Pressure — Flowmeter Test Arrangement



4-2.3 Pressure Measurements

Instructions on pressure gages, differential gages, and manometers are given in ASME PTC 19.2. Other means of pressure measurements and indication may be used provided they are of the same or lesser degree of uncertainty as those described therein.

(a) Pressure-measuring stations shall be located in the region where the flow is essentially parallel to the pipe or vessel wall. For the measurement of static gage-pressure differentials below 15 psi (100 kPa), liquid manometers may be used.

(b) The test vessel pressure shall be the static pressure as measured with a pressure tap positioned, as shown in Figure 4-2.3-1.

(c) Back pressure shall be the static pressure measured with a pressure tap positioned, five pipe diameters from the valve outlet.

(d) Proper corrections to the pressure readings shall be made if there is a height of water or other liquid between the point at which the pressure is to be measured and the pressure instrument.

4-2.4 Flow Measurement

(a) This paragraph provides for the measurement of pressure relief device capacity by use of the following methods:

(1) subsonic-inferential meters, including orifice plate, flow nozzle, and venturi

(2) sonic-inferential meters, including choked nozzles

(3) direct volumetric or gravimetric measurement of collected condensate or discharge

(b) To measure pressure relief device capacity, the following methods shall be used:

(1) steam flow, with atmospheric back pressure method (a)(1) or (3) herein

(2) steam flow, with back pressure above atmospheric method (a)(1) herein

(3) gas or air flow, with atmospheric back pressure method (a)(1) or (2) herein

(4) gas or air flow, with back pressure above atmospheric method (a)(1) herein

(5) liquid flow, with atmospheric back pressure method (a)(1) or (3) herein

(6) liquid flow, with back pressure above atmospheric method (a)(1) herein

NOTE: It is not the intent of this Section to exclude pressure-relief-device testing at back pressures above atmospheric wherein capacity is measured by means of a sonic-inferential meter. However, due to the high degree of pressure drop through this type of meter, such testing would probably be impractical.

(c) Instruction on Primary Elements. Instructions on primary elements are given in ASME PTC 19.5. Other means of capacity determinations may be used [see para. 4-3.1(c)], provided they are of the same or greater degree of accuracy as those outlined therein.

(1) The primary element shall be located upstream of the test pressure relief device inlet. A recommended installation arrangement is shown in Figure 4-2.3-1. The ratio of orifice plates to internal pipe diameter shall be between 0.2 and 0.7. The primary element shall be inspected and known to be clean and free of damage prior to the test period.

(2) The differential pressure across the primary element and temperature of the fluid shall be measured. The precautions of para. 4-2.2 shall apply to the measurement of temperature and those of para. 4-2.3 to the measurement of pressure.

(3) There shall be sufficient length of straight pipe ahead of the primary element to secure a fairly uniform velocity profile in the approaching stream (see ASME PTC 19.5). To ensure reliable pressure measurement, there shall also be a sufficient length of straight pipe of the same nominal size as the inlet on the outlet side of the primary element.

(4) The flow during capacity measurements shall be steady state, and differential pressure devices shall not show total pulsations (double amplitude) greater than 2% of the differential pressure being measured. Any greater pulsation in the flow shall be corrected at its source; attempts to reduce pulsations at the instrument are not permissible.

(5) Precautions shall be taken to avoid the use of excessively wet steam, which usually results in unstable conditions. When testing with steam, throttling calorimeters shall be used (see para. 4-2.6).

(6) ASME PTC 19.5 provides detailed information relative to most of the flow techniques and flow elements recommended for this Code. The equations for the calculation of discharge coefficients for orifices, flow nozzles, and venturi meters contained in that document shall be used.

These equations are valid for uncalibrated nozzles constructed in strict accordance with ASME PTC 19.5. Calibrated nozzles may be used to give additional accuracy.

4-2.5 Valve-Lift Measurements

(a) The lift of the valve disk, under flowing conditions, shall be determined by suitable means to whatever degree of accuracy is imposed by the procedure under which the valve is being tested.

(b) In open- or vented-bonnet designs, when the top of the spindle may be exposed during the tests, a dial indicator of appropriate range may be attached to the top of the valve to indicate the movement of the spindle. In closed-bonnet valves where the top of the spindle cannot be exposed, arrangements shall be made to permit indicating, reading, or recording spindle movement outside the valve bonnet or cap. In either case, care must be exercised that the arrangement does not impose an additional load on the valve spindle or interfere with the operation of the valve.

Possible misreading of lift indicators may occur under conditions of testing valves with steam with superimposed back pressure (see subsection 4-6). When introducing steam into the back-pressure portion of the valve, the temperature of the steam may cause thermal expansion of the valve parts, producing an erroneous initial reading on the lift indicator. When extreme accuracy in results is desired, measures shall be taken to distinguish between this thermal expansion and actual valve lift.

4-2.6 Steam Quality

Quality of steam flowing shall be measured by means of throttling calorimeters, installed in the test vessel nozzle, with the tube extending to the test device centerline. Alternatively, the steam-sampling tube may be installed directly on the vessel, provided that the tube extends into the flow path directly below the centerline of the device inlet nozzle and not lower than the horizontal centerline of the test vessel. Instructions for their use are given in ASME PTC 19.11.

4-2.7 Reference Conditions for Which Corrections May Be Applied

(a) Steam. The reference condition shall be dry saturated steam, and the condition of the steam during test at the device inlet shall be within limits of 98% minimum quality and 20°F (10°C) maximum superheat.

(b) Water. The reference condition of water shall be between 65°F (20°C) and 75°F (25°C), and the temperature limit of water during test at the device inlet shall be between 40°F (5°C) and 125°F (50°C).

(c) Air and Other Gases. The reference condition of air or other gases shall be between 55°F (10°C) and 75°F (25°C), and the temperature limit of air or other gases during test at the device inlet shall be between 0 °F (-20°C) and 200°F (90°C).

(d) If reference conditions are not within the above stated limits, then no corrections from actual test conditions may be applied. Furthermore, no corrections shall be made from actual test pressure.

4-2.8 Specific Gravity

The specific gravity of the fluid, other than air or water, used for the test shall be determined in accordance with ASTM D1070 or ASTM D1298.

NOTE: In some special cases, it may be a requirement that tests be conducted on liquids outside the range of these specifications. In these cases, agreement shall be reached on the method of specific gravity (density–specific volume) determination.

4-2.9 Chemical Composition

If the physical properties of the fluid are in doubt [see para. 1-2(a)], they shall be determined by physical tests or from chemical analysis.

4-2.10 General Features of Tests

The proper number and size of pressure relief devices to be tested shall be provided at the test site. There shall be assurance that the pressure relief devices are properly assembled with components that meet the design specification requirements. The pressure relief device shall be clean and ready for test.

The pressure relief device to be tested shall be installed with adapter fittings (flanged, screwed, welded, etc.) directly on a test vessel (see Figure 4-2.10-1 for acceptable contours). Other adapter fittings may be used provided the accuracy of the test is not affected. The diameter and volume of the test vessel should be large enough to obtain an accurate static pressure measurement and an accurate determination of the operational characteristics of the pressure relief device to be tested. Operating conditions shall be maintained in accordance with the requirements of the procedure used (see subsections 4-3 through 4-9). The duration of the test shall be that required to obtain the necessary performance and capacity data under stable conditions.

(a) For testing with atmospheric back pressure before discharging, the test arrangement shall provide discharge from the pressure relief device directly to the atmosphere or condenser (see Figures 4-2.3-1, 4-2.10-2, and 4-2.10-3). If discharge piping is used, it shall be at least the same size as the pressure relief device outlet. This pipe shall be supported independently of the pressure relief device and in such a way as to not affect the operation of the pressure relief device. Precautions must be taken to ensure that the pressure relief device and discharge piping are adequately secured to resist the resultant forces generated by the discharge.

(b) For testing with superimposed back pressure before discharging, the test arrangement shall provide a means for introducing and maintaining back pressure on the test pressure relief device outlet (see Figure 4-2.10-4). The discharge pipe shall have at least the same nominal size as the pressure relief device outlet and shall discharge into a system of sufficient size to allow satisfactory back-pressure control. A control pressure relief device shall be provided to regulate the building up and maintaining of any desired back pressure while the pressure relief device is discharging.

The remainder of this Section is divided into seven parts according to the back pressure, fluid used, and type of device tested. The first three parts for tests with atmospheric back pressure before discharging are: steam (see subsection 4-3); gases, including air (see subsection 4-4); and liquids (see subsection 4-5). The second three parts for test with superimposed back pressure before discharging are: steam (see subsection 4-6); gases, including air (see subsection 4-7); and liquids (see subsection 4-8). The last part (see subsection 4-9) concerns testing rupture disks to determine resistance factors.

(c) Tests of non-reclosing pressure relief devices in combination with pressure relief valves shall be conducted in accordance with subsections 4-3 through 4-8 (see Figure 4-2.10-5).

4-2.11 Establishing Set Pressure and Blowdown

(a) Increase the pressure at the device inlet. During the pressure interval starting at 90% of the expected set pressure, the rate of pressure increase shall not exceed 2.0 psi/sec (15 kPa/s) or whatever lesser rate of increase is necessary for the accurate reading of the pressure. Observe and record the set pressure of the device and any other desired or pertinent characteristics.

(b) For reclosing pressure relief devices, continue increasing the pressure at the device inlet until the device remains open. Observe the action of the device. Gradually decrease the inlet pressure until the device closes. Record the reseating pressure of the device. Observe the action of the device.

(c) For reclosing pressure relief devices, repeat (a) and (b) herein until the set pressure is established and stabilized.

(d) Set pressure is established by computing the average of at least the last three measured values. Set pressure is considered stable when the measured values show no significant upward or downward trend whereby all are within ±1% or ±0.5 psi (4 kPa), whichever is greater, of the average value. If the parties to the test agree, an alternative criteria of stability may be used.

(e) Blowdown is established by computing the average of the individual blowdowns of those tests used to determine set pressure in (d) herein.

4-3 TESTING WITH STEAM, PRESSURE RELIEF DEVICE DISCHARGING TO ATMOSPHERIC PRESSURE

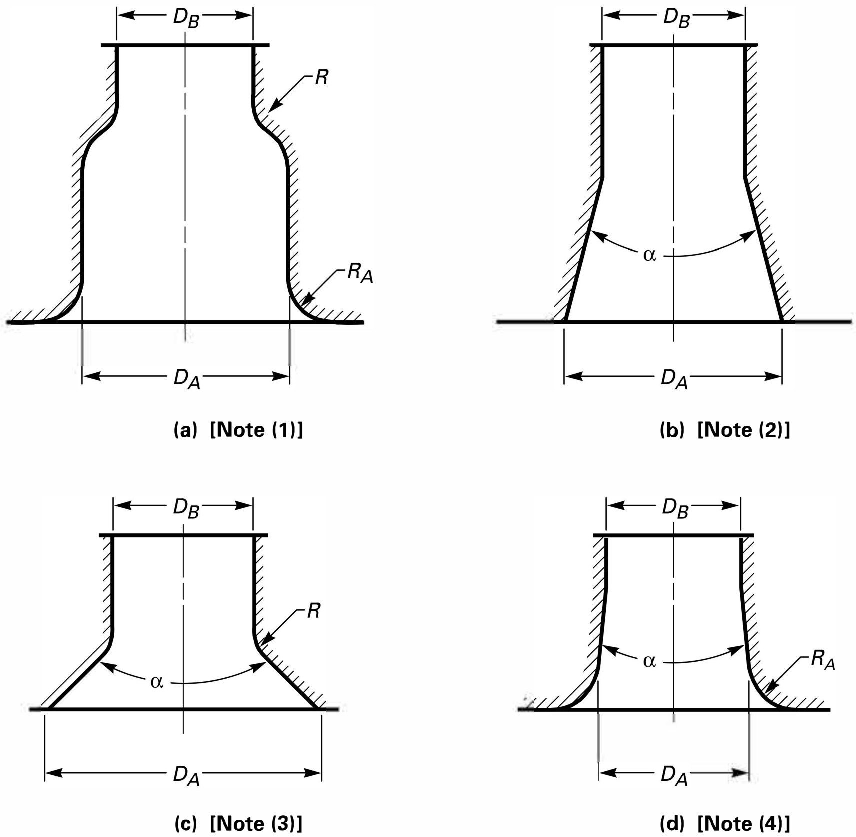
4-3.1 Test Arrangements

(a) Flowmeter Method. Figure 4-2.3-1 illustrates the use of a flowmeter together with its associated instrumentation. The use of calorimeters at the pressure relief devices inlet and primary element is mandatory; however, the thermometers at the primary element and test vessel may be omitted. Provisions shall be made for collecting and measuring the condensate accumulating in the test vessel during a test run.

(b) Weighed Condensate. Figure 4-2.10-2 illustrates the weighed-condensate method of test, including the condenser and associated instrumentation. The use of a calorimeter at the device inlet is mandatory.

NOTE: If the test pressure relief device is of the open- or vented-bonnet design, this test arrangement will not measure all the steam passing through the pressure relief device. A loss may occur due to steam leakage around the spindle and through drains. Therefore, the capacity results obtained by test will be less than the actual device capacity. When considered necessary by the interested parties, agreement shall be reached as to the method used for determining the rate of this steam leakage.

Figure 4-2.10-1
Recommended Internal Contours of Nozzles, Fittings, Adapters, and Reducers Between Test Vessel and Test Device



GENERAL NOTE: In no case shall the size of the fitting exceed the size of the connection on the test vessel.

NOTES:
(1) If $D_B \geq 0.75\ D_A$, then $R_A \geq 0.25\ D_A$.
If $D_B < 0.75\ D_A$, then $R \geq 0.25\ D_B$.
(2) If $\alpha \leq 30$ deg and $D_B < 0.75\ D_A$, break all edges.
(3) If $\alpha > 30$ deg and $D_B < 0.75\ D_A$, then $R \geq 0.25\ D_B$.
(4) If $\alpha \leq 30$ deg and $D_B \geq 0.75\ D_A$, then $R_A \geq 0.25\ D_A$.

Figure 4-2.10-2
Recommended Arrangements for Testing Devices With Atmospheric Back Pressure — Weighed-Condensate Test Arrangement

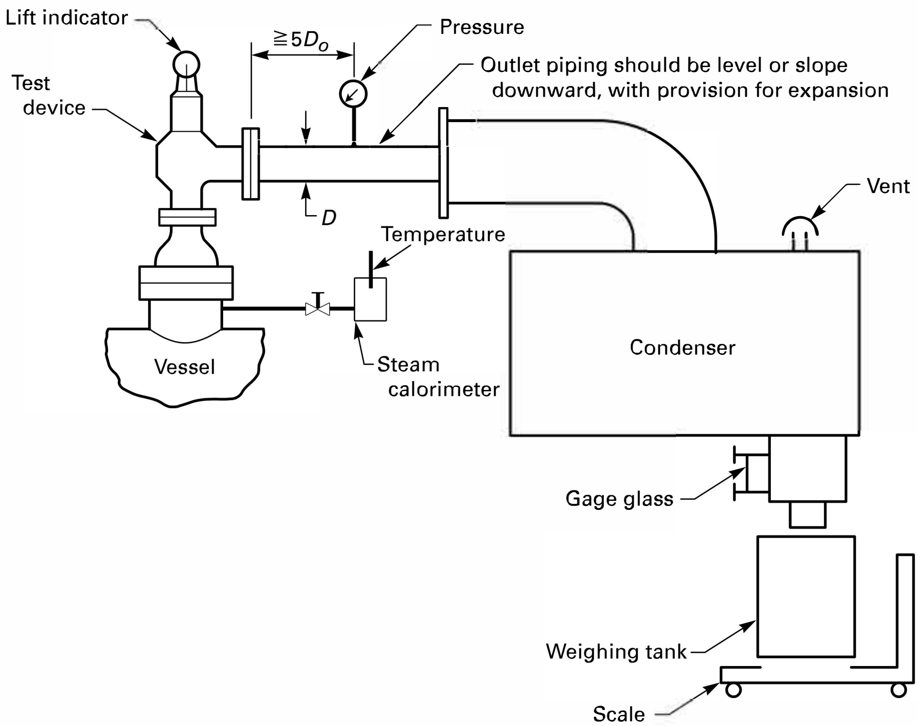


Figure 4-2.10-3
Recommended Arrangements for Testing Devices With Atmospheric Back Pressure — Weighed-Water Test Arrangement

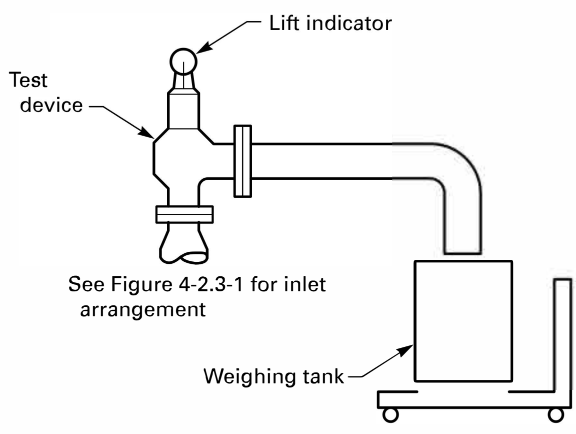


Figure 4-2.10-4
Recommended Discharge Arrangement for Testing Devices With Superimposed Back Pressure

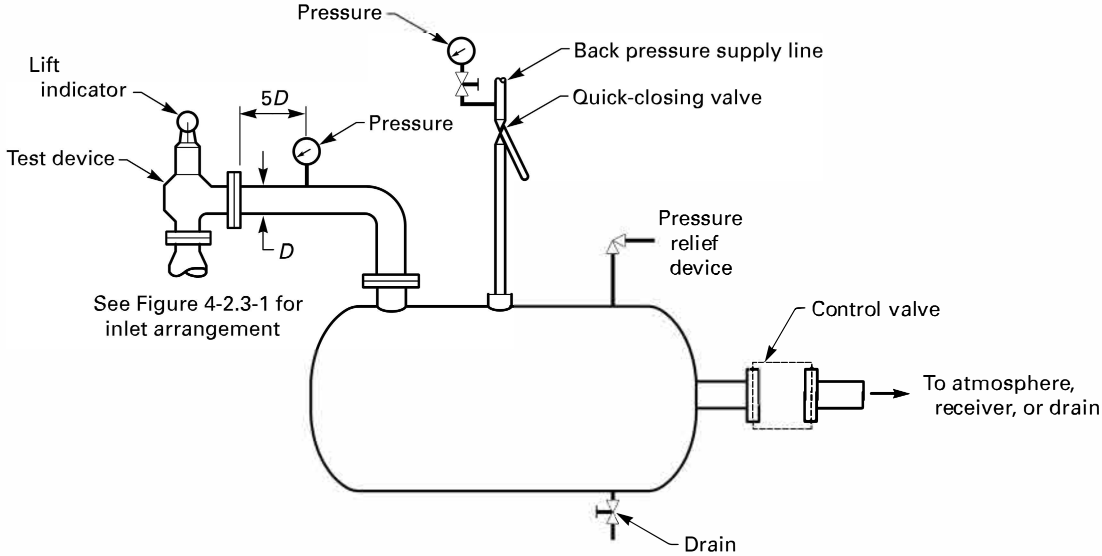
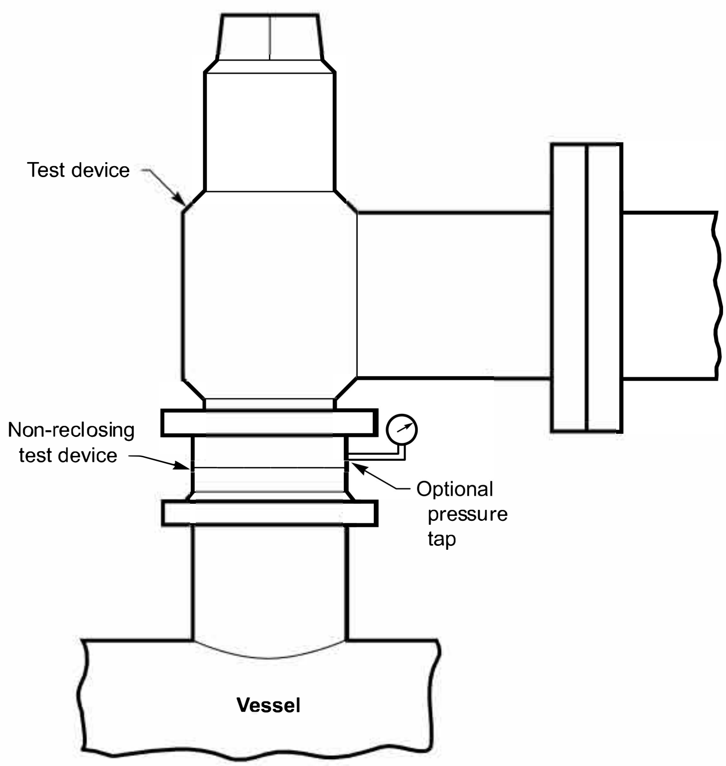


Figure 4-2.10-5
Recommended Arrangement for Testing Non-reclosing Pressure Relief Devices in Combination With Pressure Relief Valves



(c) Other test arrangements may be used if agreed to by all interested parties, provided the uncertainty of the final results is within ±2.0% (see subsection 1-1).

4-3.2 Preliminary Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or device being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus and that primary element reservoirs are filled, properly cooled, and initially vented.

4-3.3 Barometric Pressure

Record the barometric pressure (see para. 4-2.1).

4-3.4 Details of Procedure for Flow Measurement of Devices Using the Flowmeter Method

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.
(b) Establish and maintain the flow-rating pressure until flow instruments indicate stable condition.
(c) Close test-drum drain, and establish and record or mark starting condensate level in gage glass.
(d) Record the following:
(1) device-inlet pressure
(2) device-inlet calorimeter discharge temperature
(3) device-disk lift, as applicable
(4) flowmeter static pressure
(5) flowmeter differential pressure
(6) flowmeter calorimeter discharge temperature
(e) Maintain stable conditions, and read and record data in same sequence for period of run as agreed upon.
(f) Record length of run and times of recording data as measured by stopwatch, electric synchronous clock with second hand, or other appropriate means.
(g) Determine test vessel condensate by weight or volume measure, and record.
(h) Decrease inlet pressure slowly, and again record reseating pressure of a reclosing pressure relief device.

4-3.5 Details of Procedure for Flow Measurement of Devices Using the Weighed-Condensate Method

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.
(b) Establish and maintain flow-rating pressure until flow instruments indicate stable condition.
(c) Establish condenser hot-well level.
(d) Record the following:
(1) device-inlet pressure
(2) device-inlet calorimeter discharge temperature
(3) device-disk lift, as applicable
(e) Maintain stable conditions, and read and record data in same sequence for period of run as agreed upon.
(f) Record length of run and times of recording data as measured by stopwatch, electric synchronous clock with second hand, or other appropriate means.
(g) Reestablish condenser hot-well level, and accurately determine and record amount (volume or weight) of condensate formed in condensers during run.
(h) Decrease inlet pressure slowly, and again record reseating pressure of a reclosing pressure relief device.

4-3.6 Observation of the Device Mechanical Characteristics

During the flowmeter and weighed-condensate methods of test, the mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat (as designed) satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the device may be readjusted or repaired and retested.

4-3.7 Recording Additional Data

During the flowmeter or weighed-condensate methods of test, it may be desirable or a requirement to record pressure other than, or in addition to, those listed in para. 4-3.4 or para. 4-3.5. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I. With closed discharge systems, such as para. 4-3.1(b), it is not possible to observe or record some characteristic pressures.

4-4 TESTING WITH GAS OR AIR, PRESSURE RELIEF DEVICE DISCHARGING TO ATMOSPHERIC PRESSURE

4-4.1 Test Arrangement

A recommended test arrangement is shown in the flowmeter test arrangement, Figure 4-2.3-1. The primary element shall be either a subsonic-inferential meter [see para. 4-2.4(a)(1)] or a sonic-inferential meter [see para. 4-2.4(a)(2)].

Instrumentation for each type of meter is listed in the following subparagraphs. The test pressure relief device discharge may be provided as shown in Figure 4-2.3-1. See para. 4-2.10(a) for long discharge connections.

(a) Subsonic-Inferential Meters. Measurements associated with subsonic-inferential meters are
(1) inlet static pressure
(2) inlet temperature
(3) differential pressure

(b) Sonic-Inferential Meters. Measurements associated with sonic-inferential meters are
(1) inlet total (stagnation) pressure
(2) inlet total (stagnation) temperature

4-4.2 Preliminary Device Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or device being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus.

4-4.3 Barometric Pressure

Record the barometric pressure (see para. 4-2.1).

4-4.4 Details of Procedure for Flow Measurement of Devices Using Subsonic-Inferential-Meter Method

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.

(b) Establish and maintain flow-rating pressure until flow instruments indicate a steady-state condition.

(c) Record the following:

(1) device-inlet pressure

(2) device-inlet temperature

(3) device-disk lift, as applicable

(4) flowmeter-inlet static pressure

(5) flowmeter-inlet temperature

(6) flowmeter differential pressure

(d) Decrease inlet pressure slowly, and again record reseating pressure of the device.

4-4.5 Details of Procedure for Flow Measurement of Devices Using Sonic-Inferential-Meter Method

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.

(b) Establish and maintain flow-rating pressure until flow instruments indicate a steady-state condition.

(c) Record the following:

(1) device-inlet pressure

(2) device-inlet temperature

(3) device-disk lift, as applicable

(4) flowmeter-inlet total pressure

(5) flowmeter-inlet total temperature

(d) Decrease inlet pressure slowly, and again record reseating pressure of a reclosing pressure relief device.

4-4.6 Observation of the Mechanical Characteristics

During the subsonic- or sonic-inferential-meter method of test, the mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the valve may be readjusted or repaired and retested. Excessive and continual chatter could cause mechanical failure of the valve and thereby create a hazard to personnel in the test area.

4-4.7 Recording Additional Data

During the subsonic- or sonic-inferential-meter method of test, it may be desirable or a requirement to record pressures other than or in addition to those listed in para. 4-4.4 or para. 4-4.5. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I.

4-5 TESTING WITH LIQUIDS, PRESSURE RELIEF DEVICE DISCHARGING TO ATMOSPHERIC PRESSURE

4-5.1 Test Arrangements

The pressure source may be a pump or an accumulator of liquid in combination with high-pressure compressed gas. Measures shall be taken to ensure that pressure pulsations in the system are reduced to a minimum. The flowmeter test arrangement shown in Figure 4-2.3-1 illustrates a recommended arrangement up to and including the test pressure relief device. Figure 4-2.10-3 illustrates a recommended discharge arrangement.

(a) If a flowmeter [see para. 4-2.4(a)(1)] is used, the associated measurements shall include, as a minimum, flowmeter differential pressure, device-inlet pressure, and liquid temperature. In this case, the use of a means of determining the volume or weight of the discharge is not a requirement.

NOTE: When conducting flowmeter tests involving a pressure relief device having high inlet pressure and low flow rates, it may be desirable to install the flowmeter downstream of the pressure relief device. Such installations are acceptable provided the installation has been calibrated in accordance with subsection 3-8.

(b) If a flowmeter is not used, volumetric or gravimetric determination of the pressure relief device discharge over a period of time shall be made. Readings of the device-inlet pressure and liquid temperature shall be made and recorded. Means shall be provided for directing the discharge into and diverting it from the tank used for measuring purposes.

4-5.2 Preliminary Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or device being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus and ensure that all gas or air has been vented from the component parts of the system, except those referred to in para. 4-5.1.

4-5.3 Details of Procedure for Flow Measurement of Devices Using the Flowmeter Method

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.

(b) Establish and maintain flow-rating pressure until instruments indicate a steady-state condition.

(c) Record the following:

(1) device-inlet pressure

(2) device-disk lift, as applicable

(3) liquid temperature

(4) flowmeter differential pressure

(d) Decrease inlet pressure slowly, and again record reseating pressure of a reclosing pressure relief device.

4-5.4 Details of Procedure for Flow Measurement of Devices Using the Volumetric or Gravimetric Method

NOTE: The period of the test is determined by the measured time the discharge of the device is directed into the tank used for measuring purposes. Care shall be taken that the pressure at the device inlet remains stable during this period.

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11.

(b) Establish and maintain flow-rating pressure until instruments indicate a steady-state condition.

(c) Record the following:

(1) device-inlet pressure

(2) device-disk lift, as applicable

(3) liquid temperature

(d) Direct valve discharge into measuring tank.

(e) Repeat (c) herein at specified intervals.

(f) Divert device discharge from measuring tank.

(g) Record length of runs and times of recording data as measured by stopwatch, electric synchronous clock with second hand, or other appropriate means.

(h) Decrease inlet pressure slowly, and again record reseating pressure of a reclosing pressure relief device.

4-5.5 Observation of Mechanical Characteristics

During the flowmeter or volumetric method of test, the mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the valve may be readjusted or repaired and retested.

4-5.6 Recording Additional Data

During the flowmeter or volumetric method test, it may be desirable or a requirement to record pressures other than or in addition to those listed in paras. 4-5.3 and 4-5.4. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I. With closed discharge systems, it is not possible to observe or record some characteristic pressures.

4-6 TESTING WITH STEAM, WITH BACK PRESSURE ABOVE ATMOSPHERIC

4-6.1 Test Arrangements

Recommended test arrangements are illustrated in Figures 4-2.3-1, 4-2.10-4, and 4-6.1-1. Capacity determination shall be made by means of a flowmeter [see para. 4-2.4(a)(1)] installed at the upstream side of the valve. Figure 4-2.3-1 shows a recommended test arrangement, up to and including the test valve. Figures 4-2.10-4 and 4-6.1-1 show discharge arrangements.

(a) Figure 4-2.10-4 illustrates a recommended test arrangement for testing with superimposed back pressure. Means are provided for applying back pressure to the valve prior to the valve reaching its set pressure [see para. 4-5.5(b)]. A control valve shall be provided for controlling the back pressure prior to, during, and after the opening of the test valve. The piping shall be so arranged that condensate will not collect in the piping and a drain shall be provided on the back pressure vessel.

(b) Figure 4-6.1-1 illustrates a recommended test arrangement for testing with built-up back pressure. Required equipment includes a means of controlling the degree of back pressure built up on the test valve after opening and for measuring the static pressure in the test-valve discharge.

4-6.2 Preliminary Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or valve being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus and that flowmeter reservoirs (meterpots) are filled, properly cooled, and initially vented.

4-6.3 Barometric Pressure

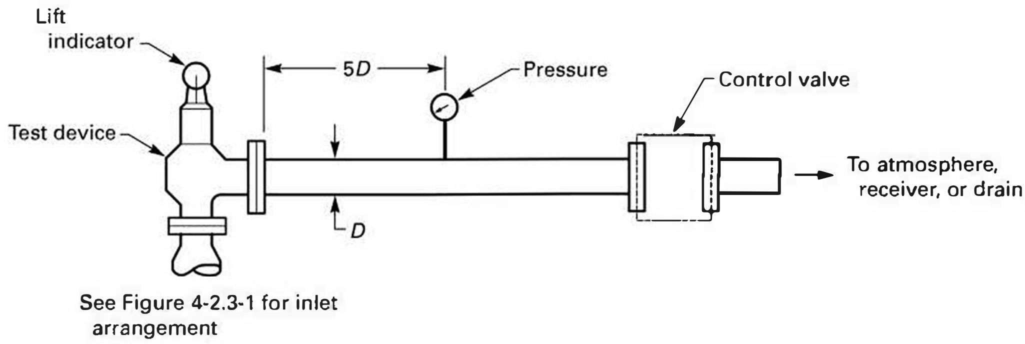
Record the barometric pressure (see para. 4-2.1).

4-6.4 Details of Procedure for Flow Measurement

(a) Atmospheric Back-Pressure Test. Tests may be conducted to determine the performance of the valve when discharging at atmospheric back pressure. The valve shall be equipped with an atmospheric discharge, as shown in Figure 4-2.3-1. Test procedure shall be in accordance with paras. 4-3.4(a) through 4-3.4(h), performing such portions of the procedure and recording such data as has been agreed upon.

NOTE: The objectives of this portion of the test may be only to determine and record the set pressure and closing pressure of the valve, and the lift of the valve at the flow-rating pressure,

Figure 4-6.1-1
Recommended Discharge Arrangement for Testing Devices With Built-Up Back Pressure



when the valve is discharging to atmosphere. In this case, the portions of paras. 4-3.4(a) through 4-3.4(h) relating to capacity determination may be eliminated.

(b) Back-Pressure Test. Following the atmospheric back-pressure test, if performed, install the discharge arrangement required by Figure 4-2.10-4 or Figure 4-6.1-1 depending on the type of back pressure desired.

4-6.5 Testing With Superimposed Back Pressure [See Para. 4-6.1(a)]

(a) Adjust the back pressure on the valve and the discharge piping to the required value.

(b) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. The back pressure shall be maintained as uniformly as possible and recorded during the tests in paras. 4-2.11(a) and 4-2.11(b).

(c) Establish and maintain flow-rating pressure until flow instruments and back pressure gage indicate a steady-state condition.

(d) Close test-drum drain, and establish and record or mark starting condensate level in a gage glass.

(e) Record the following:

(1) valve-inlet pressure
(2) valve-inlet calorimeter discharge temperature
(3) valve-disk lift
(4) flowmeter static pressure
(5) flowmeter differential pressure
(6) flowmeter calorimeter discharge temperature
(7) back pressure

(f) Reestablish original gage-glass level or new level at end of run, determine condensate by weight or volume measurement, and record.

(g) Decrease inlet pressure slowly, and again record reseating pressure of valve and back pressure.

(h) In most instances, it is desirable or a requirement that the valve be tested over a given range of back pressure. In such cases, it is convenient if the value of back pressure chosen in (a) herein be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (c) through (g) herein at each incremental value.

4-6.6 Testing With Built-Up Back Pressure [See Para. 4-6.1(b)]

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. During the para. 4-2.11(b) test, back pressure shall be adjusted to the desired value and recorded. Prior to repeating tests in paras. 4-2.11(a) and 4-2.11(b) as applicable in para. 4-2.11(c), remove any flow restriction in the discharge test arrangement imposed during the previous test, as failure to do so may prevent the valve from achieving the same lift as the initial test.

(b) Establish and maintain flow-rating pressure until flow instruments and back pressure gage indicate a steady-state condition.

(c) Close test-drum drain, and establish and record or mark starting condensate level in a gage glass.

(d) Record the following:

(1) valve-inlet pressure
(2) valve-inlet calorimeter discharge temperature
(3) valve-disk lift
(4) flowmeter static pressure
(5) flowmeter differential pressure
(6) flowmeter calorimeter discharge temperature
(7) back pressure

(e) Reestablish original gage-glass level or new level at end of run, determine condensate by weight or volume measurement, and record.

(f) Decrease inlet pressure slowly, and again record reseating pressure of valve and back pressure.

(g) In most instances, it is desirable or a requirement that the valve be tested over a given range of back pressure. In such cases, it is convenient if the value of back pressure chosen in (a) herein be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (a) through (f) herein at each incremental value.

4-6.7 Observation of Mechanical Characteristics

During the tests with superimposed or built-up back pressure, mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the valve may be readjusted or repaired and retested. When testing valves against back pressure, any range in which the valve does not reach rated lift at the flow-rating pressure shall be recorded.

4-6.8 Recording Additional Data

During tests with superimposed or built-up back pressure, it may be desirable or a requirement to record pressures other than or in addition to those listed in para. 4-6.5 or para. 4-6.6. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I. With closed discharge systems, such as described in para. 4-6.1(a), it is not possible to observe or record some characteristic pressures.

4-7 TESTING WITH GAS OR AIR, WITH BACK PRESSURE ABOVE ATMOSPHERIC

4-7.1 Test Arrangements

Recommended test arrangements are illustrated in Figures 4-2.3-1, 4-2.10-4, and 4-6.1-1. Capacity determination shall be made by means of a flowmeter [see para. 4-2.4(a)(1)] installed at the upstream side of the valve. Figure 4-2.3-1 shows a recommended test arrangement, up to and including the test valve. Figures 4-2.10-4 and 4-6.1-1 show discharge arrangements.

(a) Figure 4-2.10-4 illustrates a recommended test arrangement for testing with superimposed back pressure to the valve prior to the valve reaching its set pressure [see para. 4-2.5(b)]. A control valve shall be provided for controlling the back pressure prior to, during, and after the opening of the test valve. The piping shall be so arranged that condensate will not collect in the piping and a drain shall be provided on the back-pressure vessel.

(b) Figure 4-6.1-1 illustrates a recommended test arrangement for testing with built-up back pressure. Required equipment includes a means of controlling the degree of back pressure built up on the test valve after opening and for measuring the static pressure in the test-valve discharge.

4-7.2 Preliminary Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or valve being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus.

4-7.3 Barometric Pressure

Record the barometric pressure (see para. 4-2.1).

4-7.4 Details of Procedure for Flow Measurement

(a) Atmospheric Back-Pressure Test. Tests may be conducted to determine the performance of the valve when discharging at atmospheric back pressure. The valve shall be equipped with an atmospheric discharge, as shown in Figure 4-2.3-1. Test procedure shall be in accordance with paras. 4-4.4(a) through 4-4.4(d), performing such portions of the procedure and recording such data as has been agreed upon.

NOTE: The objectives of this portion of the test may be only to determine and record the set pressure and closing pressure of the valve, and the lift of the valve at the flow-rating pressure, when the valve is discharging to atmosphere. In this case, the portions of paras. 4-4.4(a) through 4-4.4(d) relating to capacity determination may be eliminated.

(b) Back-Pressure Test. Following the atmospheric back-pressure test, if performed, install the discharge arrangement required by Figure 4-2.10-4 or Figure 4-6.1-1, depending on the type of back pressure desired.

4-7.5 Testing With Superimposed Back Pressure [See Para. 4-7.1(a)]

(a) Adjust the back pressure on the valve and the discharge piping to the required value.

(b) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. The back pressure shall be maintained as uniformly as possible and recorded during the tests in paras. 4-2.11(a) and 4-2.11(b).

(c) Establish and maintain flow-rating pressure until flow instruments and back pressure gage indicate a steady-state condition.

(d) Record the following:

(1) valve-inlet pressure
(2) valve-inlet temperature
(3) valve-disk lift
(4) flowmeter-inlet static pressure
(5) flowmeter-inlet temperature
(6) flowmeter differential pressure
(7) back pressure

(e) Decrease inlet pressure slowly, and again record reseating pressure of valve and back pressure.

(f) In most instances, it is desirable or a requirement that the valve be tested over a given range of back pressure. In such cases, it is convenient if the value of back pressure chosen in (a) be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (b) through (e) herein at each incremental value.

4-7.6 Testing With Built-Up Back Pressure [See Para. 4-7.1(b)]

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. During the para. 4-2.11(b) test, back pressure shall be adjusted to the desired value and recorded. Prior to repeating tests in paras. 4-2.11(a) and 4-2.11(b) as applicable in para. 4-2.11(c), remove any flow restriction in the discharge test arrangement imposed during the previous test, as failure to do so may prevent the valve from achieving the same lift as the initial test.

(b) Establish and maintain flow-rating pressure and back pressure until flow instruments and back pressure gage indicate a steady-state condition.

(c) Record the following:

(1) valve-inlet pressure

(2) valve-inlet temperature

(3) valve-disk lift

(4) flowmeter-inlet static pressure

(5) flowmeter-inlet temperature

(6) flowmeter differential pressure

(7) back pressure

(d) Decrease inlet pressure slowly, and again record reseating pressure and back pressure.

(e) In most instances, it is desirable or a requirement that the valve be tested over a given range or back pressure. In such cases, it is convenient if the value of back pressure chosen in para. 4-7.5(a) be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (a) through (d) herein at each incremental value.

4-7.7 Observation of Mechanical Characteristics

During the tests with superimposed or built-up back pressure, mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the valve may be readjusted or repaired and retested. When testing valves against back pressure, any range in which the valve does not reach rated lift at the flow-rating pressure shall be recorded.

4-7.8 Recording Additional Data

It may be desirable or a requirement to record pressures other than or in addition to those listed in para. 4-3.4. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I. With closed discharge systems, it is not possible to observe or record some characteristic pressures.

4-8 TESTING WITH LIQUIDS, WITH BACK PRESSURE ABOVE ATMOSPHERIC

4-8.1 Test Arrangements

Pressure sources can be a pump or an accumulator of liquid, in combination with high-pressure compressed gas. Precautions shall be taken to ensure that pressure pulsations are reduced to a minimum. Figure 4-2.3-1 shows a recommended test arrangement, up to and including the test valve. Figures 4-2.10-4 and 4-6.1-1 show discharge arrangements for testing with superimposed and built-up back pressure, respectively. A flowmeter [see para. 4-2.4(b)(1)] shall be used in either case. Instrumentation shall be suitably installed to indicate or record the following:

(a) liquid temperature

(b) flowmeter differential pressure

(c) valve-inlet pressure

(d) back pressure

4-8.2 Preliminary Tests

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or valve being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus and that all gas or air has been vented from the component parts of the system.

4-8.3 Details of Procedure for Flow Measurement

(a) Atmospheric Back-Pressure Test. Tests may be conducted to determine the performance of the valve when discharging at atmospheric back pressure. The valve shall be equipped with an atmospheric discharge, as shown in Figure 4-2.3-1. Test procedure shall be in accordance with paras. 4-5.3(a) through 4-5.3(d) performing such portions of the procedure and recording such data as has been agreed upon.

NOTE: The objectives of this portion of the test may be only to determine and record the set pressure and closing pressure of the valve, and the lift of the valve at the flow-rating pressure, when the valve is discharging to atmosphere. In this case, the portions of paras. 4-5.3(a) through 4-5.3(d) relating to capacity determination may be eliminated.

(b) Back-Pressure Test. Following the atmospheric back-pressure test, if performed, install the discharge arrangement required by Figure 4-2.10-4 or Figure 4-6.1-1, depending on the type of back pressure desired.

4-8.4 Testing With Superimposed Back Pressure (See Figure 4-2.10-4)

(a) Adjust the back pressure on the valve and discharge piping to the required value.

(b) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. The back pressure shall be maintained as uniformly as possible and recorded during the tests in paras. 4-2.11(a) and 4-2.11(b).

(c) Establish and maintain flow-rating pressure until flow instruments and back pressure gage indicate a steady-state condition.

(d) Record the following:

(1) valve-inlet pressure
(2) valve-disk lift
(3) liquid-inlet temperature
(4) flowmeter differential pressure
(5) back pressure

(e) Decrease inlet pressure slowly, and again record reseating pressure of valve and back pressure.

(f) In most instances, it is desirable or a requirement that the valve be tested over a given range of back pressure. In such cases, it is convenient if the value of back pressure chosen in (a) be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (b) through (e) herein at each incremental value.

4-8.5 Testing With Built-Up Back Pressure (See Figure 4-6.1-1)

(a) Establish the set pressure, and blowdown if applicable, in accordance with para. 4-2.11. During the para. 4-2.11(b) test, back pressure shall be adjusted to the desired value and recorded. Prior to repeating tests in paras. 4-2.11(a) and 4-2.11(b) as applicable in para. 4-2.11(c), remove any flow restriction in the discharge test arrangement imposed during the previous test, as failure to do so may prevent the valve from achieving the same lift as the initial test.

(b) Establish and maintain flow-rating pressure and back pressure until flow instruments and back-pressure gage indicate a steady-state condition.

(c) Record the following:

(1) valve-inlet pressure
(2) valve-disk lift
(3) liquid-inlet temperature
(4) flowmeter differential pressure
(5) back pressure

(d) Decrease inlet pressure slowly, and again record reseating pressure of valve and back pressure.

(e) In most instances, it is desirable or a requirement that the valve be tested over a given range of back pressure. In such cases, it is convenient if the value of back pressure chosen in para. 4.8.4(a) be either the lowest or highest of this range. Back pressure may then be increased or decreased in increments, repeating (a) through (d) herein at each incremental value.

4-8.6 Tests With Built-Up Back Pressure With Measuring Tank

The use of volumetric or gravimetric determination of valve discharge when testing with built-up back pressure is permissible. In such cases, the interested parties shall agree on a test procedure prior to conducting the tests.

4-8.7 Observation of Mechanical Characteristics

During the tests with superimposed or built-up back pressure, mechanical characteristics shall be observed by hearing, feeling, or seeing and recorded during the flow test. If the valve chatters, flutters, or does not reseat satisfactorily, such action shall be recorded. Upon agreement of all interested parties, the valve may be readjusted, repaired, and retested. When testing valves against back pressure, any range in which the valve does not reach rated lift at the flow-rating pressure shall be recorded.

4-8.8 Recording Additional Data

During the tests with superimposed or built-up back pressure, it may be desirable or a requirement to record pressures other than or in addition to those listed in para. 4-8.4 or para. 4-8.5. Where possible, such recorded pressure shall be identified in accordance with Mandatory Appendix I. With closed discharge systems, it is not possible to observe or record some characteristic pressures.

4-9 TESTING WITH GAS OR AIR, NON-RECLOSING PRESSURE RELIEF DEVICE FLOW RESISTANCE METHOD

4-9.1 Test Arrangement

A recommended flow resistance test rig arrangement is shown in Figure 3-9-1, which represents the test vessel and test device of Figure 4-2.3-1. The device shall have the same nominal pipe size dimension as the test rig. Differential pressure measurement instruments or transducers shall be used between pressure taps A-B, B-C, and C-D. The primary element shall be either a subsonic-inferential meter or a sonic-inferential meter as shown in Figure 4-2.3-1 and described in para. 4-2.4(a).

Instrumentation for each type of meter is listed in the following:

(a) Subsonic-Inferential Meters. Measurements associated with subsonic-inferential meters are

(1) inlet static pressure
(2) inlet temperature
(3) differential pressure

(b) Sonic-Inferential Meters. Measurements associated with sonic-inferential meters are

(1) inlet total (stagnation) pressure
(2) inlet total (stagnation) temperature

4-9.2 Preliminary Tests

Preliminary tests may be permitted for testing the test apparatus. Such tests may be necessary to ensure the absence of leaks in the test apparatus and that all differential pressure measurement devices are functioning properly and within their pressure measurement range.

4-9.3 Barometric Pressure

Record the barometric pressure (see para. 4-2.1).

4-9.4 Details of Procedure for Flow Resistance Measurement Using Subsonic-Inferential-Meter Method

(a) Install the device into the flow resistance test rig.

(b) Increase the pressure at pressure tap B. During the interval starting at 90% of the expected set pressure, the rate of pressure increase shall not exceed 2.0 psi/sec (15 kPa/s) or whatever lesser rate of increase is necessary for the accurate reading of the pressure. Observe and record the set pressure of the device and any other desired or pertinent characteristics.

(c) Establish and maintain flow-rating pressure until flow instruments indicate a steady-state condition.

(d) Simultaneously record the following measurements (it is preferable to use a data acquisition system for these measurements):

(1) test rig inlet pressure
(2) test rig inlet temperature
(3) flowmeter-inlet static pressure
(4) flowmeter-inlet total temperature
(5) flowmeter differential pressure
(6) tap B pressure
(7) differential pressure tap A-B
(8) differential pressure tap B-C
(9) differential pressure tap C-D

4-9.5 Details of Procedure for Flow Resistance Measurement Using Sonic-Inferential-Meter Method

(a) Install the device into the flow resistance test rig.

(b) Increase the pressure at pressure tap B. During the interval starting at 90% of the expected set pressure, the rate of pressure increase shall not exceed 2.0 psi/sec (15kPa/s) or whatever lesser rate of increase is necessary for the accurate reading of the pressure. Observe and record the set pressure of the device and any other desired or pertinent characteristics.

(c) Establish and maintain flow-rating pressure until flow instruments indicate a steady-state condition.

(d) Simultaneously record the following measurements (it is preferable to use a data acquisition system for these measurements):

(1) test rig inlet pressure
(2) test rig inlet temperature
(3) flowmeter-inlet total pressure
(4) flowmeter-inlet total temperature
(5) tap B pressure
(6) differential pressure tap A-B
(7) differential pressure tap B-C
(8) differential pressure tap C-D

4-9.6 Recording Additional Data

During the subsonic- or sonic-inferential-meter method of test, it may be desirable or a requirement to record pressures other than or in addition to those listed in para. 4-9.4 or para. 4-9.5. Where possible, such recorded pressures shall be identified in accordance with Mandatory Appendix I.

4-9.7 Resistance Testing on Non-reclosing Pressure Relief Devices With Connections Not Compatible With Figure 3-9-1

The use of an adapter for devices with inlet/outlet connections that are not compatible with the test rigs of Figure 3-9-1 is allowed provided the devices are the same nominal size as the test rigs and the adapter's resistance to flow, if the adapter constitutes part of a flow path, is properly accounted for as follows:

(a) Install the adapter into the test rig of Figure 3-9-1, and conduct three baseline flow tests to determine the average flow resistance of the adapter.

(b) Proceed with determining the flow resistance of the combined assembly, the test device, and adapter, per para. 4-9.4 or para. 4-9.5.

(c) Calculate the test device individual flow resistance, K_{Ri}, by subtracting the average flow resistance of the adapter. The use of, and specification of, the adapter shall be included in the test report.

4-10 TESTING NON-RECLOSING PRESSURE RELIEF DEVICES TO DETERMINE A SET PRESSURE FOR INCOMPRESSIBLE FLUIDS

4-10.1 Test Arrangement

A recommended test arrangement for conducting set pressure tests on incompressible fluids is shown in Figure 4-10.1-1. The test arrangement shall have the same or larger nominal pipe size dimensions as the device. Unless no portion of the device extends into the outlet connection arrangement, the outlet connection shall match the internal bore of the flow resistance test arrangement of subsection 4-9. The test medium shall be water or other suitable incompressible fluid. The test shall be conducted in such a way as to prevent compressed gas from passing through the device at any time. After set pressure tests have been conducted, the device shall be removed from this test arrangement and installed within the resistance factor test arrangement shown in

Figure 3-9-1. The device flow resistance factor shall be tested per subsection 4-9 using gas or air as the fluid.

4-10.2 Preliminary Test

Preliminary tests may be permitted for testing and adjusting operation of the test apparatus and/or device being tested (see subsection 3-5). Such tests may be necessary to ensure the absence of leaks in the test apparatus.

4-10.3 Details of Procedure for Determining a Nonreclosing Pressure Relief Device Flow Resistance Factor Applicable for Incompressible Fluids

(a) Install the device between the flanges of the test apparatus.

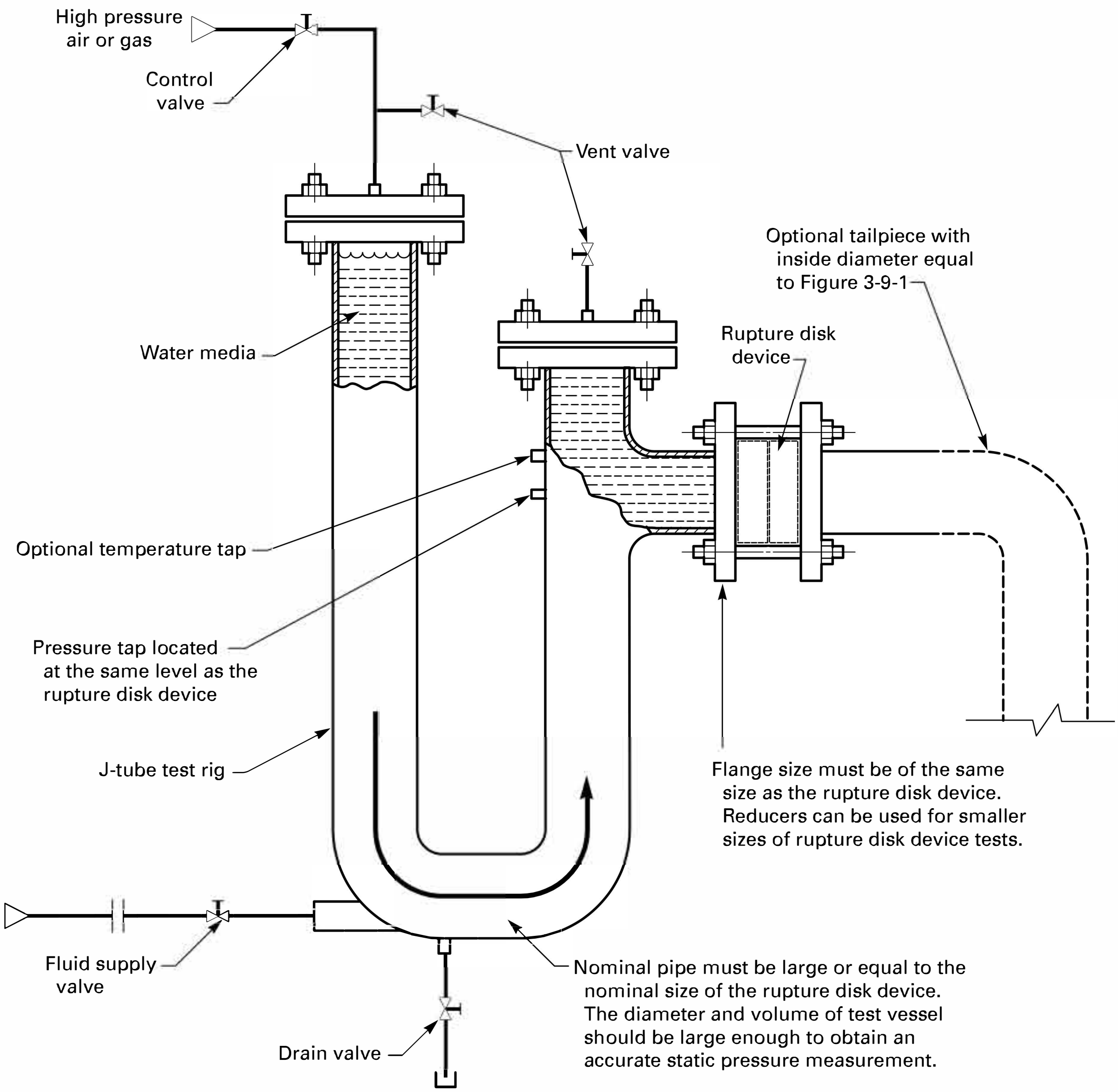
(b) Position valves to fill the test apparatus with liquid, and vent any trapped gas immediately upstream to the device.

(c) Reposition valves to pressurize the system. Increase the pressure at the pressure tap. During the interval starting at 90% of the expected set pressure, the rate of pressure increase shall not exceed 2.0 psi/sec (15kPa/s) or whatever lesser rate of increase is necessary for the accurate reading of the pressure. Observe and record the set pressure of the device and any other desired or pertinent characteristics.

(d) Remove the device from the test apparatus. Care shall be taken not to disturb the opening pattern of the device.

(e) Complete the device flow resistance testing per para. 4-9.4 using gas or air as the test medium.

Figure 4-10.1-1
Recommended Arrangement for Conducting Opening Test on Non-reclosing Pressure Relief Devices With Incompressible Fluids



Section 5
Computation of Results

5-1 CORRECTION OF MEASURED VARIABLES

The values of measured variables shall be corrected in accordance with instrument calibrations. No other corrections to the data are permitted.

5-2 REVIEW OF INSTRUMENT READINGS

Before calculations are undertaken, the instrument readings, as recorded in the log, shall be reviewed for inconsistency and large fluctuation in accordance with ASME PTC 19.1.

5-3 USE OF EQUATION SYMBOLS

The symbols used in this Code are ones that are already in common use in the particular fields of engineering involved. In a few cases, the same letter has different meanings in different parts of the Code according to its application. In order to avoid confusion, each equation has been provided with its own list of definitions of symbols. Users are cautioned not to assume that a symbol has the same meaning in another equation.

5-4 DENSITY

Computation of density shall be made from measured values of pressure, temperature, and specific gravity.

(a) For steam and other condensible fluids, the density ρ shall be taken as $1/v$ where v, the specific volume, in ft^3/lbm (m^3/kg), is obtained from the latest edition of ASME Steam Tables for steam or other established tables for other fluids at the measured pressure and temperature.

(b) The following relations shall be used for computing the density of gases where the physical properties are accurately known:

(1) For any dry gas

(U.S. Customary Units)

$$\rho = \frac{144P}{ZRT}$$

(SI Units)

$$\rho = \frac{P}{ZRT}$$

(2) For dry air, ρ reduces to

(U.S. Customary Units)

$$\rho = \frac{2.699P}{ZT}$$

(SI Units)

$$\rho = \frac{3.488P}{ZT}$$

(3) For air and other gases

(U.S. Customary Units)

$$\rho = \frac{2.699GP}{ZT}$$

(SI Units)

$$\rho = \frac{3.488GP}{ZT}$$

where

G = specific gravity with respect to dry air
= M/M_a
M = molecular weight of gas
M_a = molecular weight of air
P = static pressure, psia (kPa)
R = gas constant, ft-lbf/lbm-°R (kPa/kgK)
= $1{,}545.4/M(8.3143/M)$
T = temperature, °R (K)
Z = compressibility factor as defined in the equation of state, $Pv = ZRT$. If more details are desired, see ASME PTC 19.5.

5-5 CAPACITY CALCULATIONS

The following is presented to assist in the use of the calculation sheets and aid in carrying out the several methods of computing capacity. Flow equations, correction factors, and procedures for calculations are in accordance with ASME PTC 19.5.

5-5.1 Volumetric or Weighed-Water Method

This technique requires the collection of the discharge from the valve under test either as a mass or a volume over a known period of time. Care must be taken to ensure that the valve-inlet conditions are maintained throughout the test and that neither extraneous water is measured nor any valve discharge is lost.

Form 5-5.1-1 (Form 5-5.1-1M) should be used for recording the data and computing the results. The first eight items on this form are primarily for identification purposes. Items 9 through 12 record the amount of water collected over the given time interval. Item 11 is any leakage after the valve throat that might be at the valve stem, drain hole in the valve, or in the discharge piping. The manner in which this leakage is to be evaluated shall be agreed upon by the parties to the test, and the amount shall be added to the total accumulated (see Item 20, Item 27, or both). Item 12 is to account for any leakage of the condenser circulating water into the condensate. This is determined by a condenser leakage test, and the amount is to be subtracted from the total accumulated (see Item 20).

Items 13 through 20 record more data and show the calculation of the steam flow through the valve per hour, corrected to dry and saturated conditions at the valve inlet. In the equation for Item 20, the weight of water accumulated is divided by the time interval and multiplied by 60 to obtain the accumulated flow rate in pounds-mass (kilograms) per hour. This is multiplied by the ratio of the square root of the specific volume of the flowing steam at the valve inlet to the specific volume of dry and saturated steam at the inlet pressure. To this quantity is added the valve-stem leakage. The condenser leakage is subtracted for the test using water.

Items 21 through 25 record additional data. Item 27 determines the measured relieving capacity for a water test with no correction being made for either specific volume or condenser leakage (it being assumed that a condenser was required). Item 28 provides a capacity correction to whatever reference condition has been specified for the test. Item 29 changes the unit to gallons (liters) per minute at the reference condition.

5-5.2 Steam — Flowmeter Method

This technique meters the steam flow upstream of the valve under test. Care must be taken that all the metered steam passes through the valve or is accounted for in the calculations. In addition to leakage, metered steam that does not reach the valve can occur by condensation of the steam in connecting piping and particularly in the test vessel.

The flow equations, correction factors, and procedures for calculations incorporated in Form 5-5.2-1 (Form 5-5.2-1M) are in accordance with ASME PTC 19.5.

Form 5-5.2-1 (Form 5-5.2-1M) should be used for recording the data and computing the results. The first eight items on this form are primarily for identification purposes. Form 5-5.2-1 (Form 5-5.2-1M) proceeds through the trial flow calculation in order to evaluate the proper factors and goes on to Item 28, which provides the flow rate of steam at the reference condition in pounds-mass (kilograms) per hour.

Items 29 through 38 transfer and adjust the meter flow to the flow through the valve. Item 35 and its use in calculating the valve-relieving capacity assumes the meter calorimeter's sampling tube is downstream of the meter. If this is not the case, the subtraction should not be made, since the correction shown is to account for metered steam not reaching the valve. All values used are corrected to the reference condition.

5-5.3 Liquids — Flowmeter Method

This technique meters the liquid flow upstream of the valve under test. Care must be taken that all the metered liquid passes through the valve or is accounted for in the calculations.

The flow equations, correction factors, and procedures for calculations incorporated in Form 5-5.3-1 (Form 5-5.3-1M) are in accordance with ASME PTC 19.5.

Form 5-5.3-1 (Form 5-5.3-1M) should be used for recording data and computing the results. The first eight items on this form are primarily for identification purposes. The form proceeds through the trial flow calculation in order to evaluate the proper factors and goes on to Item 26, the measured relieving capacity through the meter at the meter conditions.

Items 27 through 33 provide the data and equation to calculate the relieving capacity at a reference condition if it is specified by the test. The evaluation assumes no change in fluid temperature between the meter and valve inlet.

5-5.4 Air or Gas — Flowmeter Method

This technique meters the gas flow upstream of the valve under test. Care must be taken that all the metered gas passes through the valve or is accounted for in the calculations.

The flow equations, correction factors, and procedures for calculations incorporated in Form 5-5.4-1 (Form 5-5.4-1M) are in accordance with ASME PTC 19.5.

Form 5-5.4-1 (Form 5-5.4-1M) should be used for recording the data and computing the results. The first 12 items on this form are primarily for identification purposes. Form 5-5.4-1 (Form 5-5.4-1M) proceeds through the trial flow calculation to be able to evaluate the proper factors for refinement, through the measured capacity in pounds-mass (kilograms) per hour (Item 25), and on to the flow rate through the meter in cubic feet (meters) per minute at some prespecified base condition.

Items 35 through 40 then provide for the calculation of the flow through the valve in cubic feet (meters) per minute at a reference inlet condition.

5-5.5 Air or Gas — Sonic-Flow Method

This technique meters the gas flow upstream of the valve under test. Care must be taken that all the metered gas passes through the valve or is accounted for in the calculations.

The flow equations, flow functions, correction factors, and procedures for calculation incorporated in Form 5-5.5-1 (Form 5-5.5-1M) are in accordance with ASME PTC 19.5.

The use of Form 5-5.5-1 (Form 5-5.5-1M) is recommended for either air or gas, and with the addition of basic data and valve identification, the form follows the procedure of ASME PTC 19.5.

This calculation follows through to evaluate the flow through the meter (Item 23) in pounds-mass (kilograms) per hour.

Items 24 through 30 are then used to determine the flow through the valve in cubic feet (meters) per minute at a reference condition.

5-5.6 Fuel-Gas Flow — Flowmeter Method

This technique meters the gas flow upstream of the valve under test. Care must be taken that all of the metered gas passes through the valve or is accounted for in the calculations.

The flow equations, correction factors, and procedures for calculation incorporated in Form 5-5.6-1 (Form 5-5.6-1M) are in accordance with ASME PTC 19.5.

Form 5-5.6-1 (Form 5-5.6-1M) should be used for recording the data and computing the results. The first 12 items on this form are primarily for identification purposes.

Form 5-5.6-1 (Form 5-5.6-1M) proceeds through the trial flow calculation to be able to evaluate the proper factors for refinement, through the measured capacity in cubic feet (meters) per hour at some prespecified base condition converted from the required pounds-mass (kilograms) per hour (Item 32).

Items 35 through 40 provide for the calculation of the flow through the valve in cubic feet (meters) per minute at a reference inlet condition.

5-5.7 Air or Gas — Non-reclosing Pressure Relief Device Flow Resistance Method

This technique measures the resistance due to the presence of a non-reclosing pressure relief device in a piping system. It is used in conjunction with either the flowmeter or sonic-flow methods described in para. 5-5.4 or para. 5-5.5, respectively.

Form 5-5.7-1 (Form 5-5.7-1M) should be used for recording the data and computing the results. The first 17 items on this form are for identification purposes and listing of the measured variables. Item 6 is obtained from either Form 5-5.4-1 (Form 5-5.4-1M) or Form 5-5.5-1 (Form 5-5.5-1M). Care must be taken that all of the metered gas passes through the test arrangement (see Figure 4-6.1-1) or is accounted for in the calculations.

The remaining items on Form 5-5.7-1 (Form 5-5.7-1M) are used to determine the resistance factor between each of the established pressure taps. An individual flow resistance associated with the non-reclosing pressure relief device is then calculated from these results.

Two test checks must be done to verify the test results.

(a) First, verify that the value $K_{C\text{-}D}$ is within 3% of the value $K_{A\text{-}B}$. If not, verify that the test arrangement is properly set up. Next, run a calibration test with no non-reclosing pressure relief device installed to verify that the value $K_{C\text{-}D}$ is within 3% of the value $K_{A\text{-}B}$. If so, calculate the resistance factor $K_{B\text{-}D} = K_D - K_B$ and the pipe length $L_{B\text{-}D} = L_D - L_B$. Complete the non-reclosing pressure relief device individual flow resistance calculation, replacing $K_{B\text{-}C}$, $K_{pipe\ B\text{-}C}$, and $L_{B\text{-}C}$ with $K_{B\text{-}D}$, $K_{pipe\ B\text{-}D}$, and $L_{B\text{-}D}$, respectively, in Items 34 and 35. This is done since the air turbulence caused by the non-reclosing pressure relief device is affecting the true pressure reading of tap C.

(b) Second, verify that the calculated pipe roughness from Item 33 is within the range 0.0018 in. to 0.00006 in. (0.0460 mm to 0.00150 mm). This is the range for schedule 40 clean commercial pipe.

TEST REPORT FORM 5-5.1-1
PRESSURE RELIEF DEVICE TESTED WITH STEAM AND WATER — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Weighed-Water Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve

(4) Bore diameter, in. (d_b)
(5) Seat diameter, in. (d_s)
(6) Seat angle, deg
(7) Valve-disk lift, in. (l)
(8) Actual discharge area, in.^{2} (a_d)

Non-reclosing Devices

(4) Minimum holder-bore diameter, in. (d_b)
(5) Minimum net flow area, in.^{2} (a)

Observed Data

(9) Length of test, min (t)
(10) Mass of water or condensate, lbm (w)
(11) Valve-steam leakage, lbm/hr (w_{vl})
(12) Condenser leakage, lbm/hr (w_{cl})

STEAM
Observed Data and Computed Results at the Device Inlet

(13) Set pressure, psig (P_{set})
(14) Flow-rating pressure, psia (P_f)
(15) Back pressure, psig (P_o)
(16) Fluid temperature at the calorimeter, °F (T_{cal})
(17) Percent quality or deg superheat
(18) Specific volume at reference condition, ft^3/lbm (V_{ref})
(19) Specific volume at inlet conditions, ft^3/lbm (V_{act})
(20) Measured relieving capacity adjusted to the reference condition, lbm/hr

$$W_h = \frac{60 \times w}{t}\sqrt{\frac{V_{act}}{V_{ref}}} + w_{vl} - w_{cl}$$

WATER
Observed Data and Computed Results at the Device Inlet

(21) Set pressure, psig (P_{set})
(22) Flow-rating pressure, psia (P_f)
(23) Back pressure, psig (P_o)
(24) Fluid temperature, °F (T)
(25) Density of water at inlet conditions, lbm/ft^3 (ρ_{act})
(26) Density of water at reference condition, lbm/ft^3(ρ_{ref})
(27) Measured relieving capacity, lbm/hr

$$W_h = \frac{60 \times w}{t} + w_{vl}$$

(28) Relieving capacity adjusted to water at reference condition, lbm/hr

$$W_r = W_h \times \sqrt{\frac{\rho_{ref}}{\rho_{act}}}$$

(29) Relieving capacity in gpm of water at reference condition (U.S. gallons), Q (gpm)

$$Q = 0.1247\,\frac{W_r}{\rho_{ref}}$$

TEST REPORT FORM 5-5.1-1M
PRESSURE RELIEF DEVICE TESTED WITH STEAM AND WATER — SI UNITS
Observed Data and Computed Results — Weighed-Water Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve

(4) Bore diameter, mm (d_b)
(5) Seat diameter, mm (d_s)
(6) Seat angle, deg
(7) Valve-disk lift, mm (l)
(8) Actual discharge area, mm^2 (a_d)

Non-reclosing Devices

(4) Minimum holder-bore diameter, mm (d_b)
(5) Minimum net flow area, mm^2 (a)

Observed Data

(9) Length of test, min (t)
(10) Mass of water or condensate, kg (w)
(11) Valve-steam leakage, kg/h (w_{vl})
(12) Condenser leakage, kg/h (w_{cl})

STEAM
Observed Data and Computed Results at the Device Inlet

(13) Set pressure, kPag (P_{set})
(14) Flow-rating pressure, kPa (P_f)
(15) Back pressure, kPag (P_o)
(16) Fluid temperature at the calorimeter, °C (T_{cal})
(17) Percent quality or deg superheat
(18) Specific volume at reference condition, m^3/kg (V_{ref})
(19) Specific volume at inlet conditions, m^3/kg (V_{act})
(20) Measured relieving capacity adjusted to the reference condition, kg/h

$$W_h = \frac{60 \times w}{t}\sqrt{\frac{V_{act}}{V_{ref}}} + w_{vl} - w_{cl}$$

WATER
Observed Data and Computed Results at the Device Inlet

(21) Set pressure, kPag (P_{set})
(22) Flow-rating pressure, kPa (P_f)
(23) Back pressure, kPag (P_o)
(24) Fluid temperature, °C (T)
(25) Density of water at inlet conditions, kg/m^3 (ρ_{act})
(26) Density of water at reference condition, kg/m^3 (ρ_{ref})
(27) Measured relieving capacity, kg/h

$$W_h = \frac{60 \times w}{t} + w_{vl}$$

(28) Relieving capacity adjusted to water at reference condition, kg/h

$$W_r = W_h \times \sqrt{\frac{\rho_{ref}}{\rho_{act}}}$$

(29) Relieving capacity in L/m of water at reference condition (liters), Q (L/m)

$$Q = 16.67\,\frac{W_r}{\rho_{ref}}$$

TEST REPORT FORM 5-5.2-1
PRESSURE RELIEF DEVICE TESTED WITH STEAM — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve

(4) Bore diameter, in. (d_b)
(5) Seat diameter, in. (d_s)
(6) Seat angle, deg
(7) Valve-disk lift, in. (l)
(8) Actual discharge area, in.^{2} (a_d)

Non-reclosing Devices

(4) Minimum holder-bore diameter, in. (d_b)
(5) Minimum net flow area, in.^{2} (a)

Flowmeter Calculations

(9) Internal diameter of meter run pipe, in. (D)
(10) Meter-bore diameter, in. (d)
(11) Meter-bore diameter squared, in.^{2} (d^2)
(12) Beta ratio ($\beta = d/D$)
(13) Trial flow coefficient (K_o)
(14) Differential pressure at the meter, inches of water (h_w)
(15) Barometric pressure, psia (P_b)
(16) Static pressure at the meter calorimeter, psia (P_m)
(17) Fluid temperature at the meter calorimeter, °F ($T_{\text{cal, meter}}$)
(18) Percent quality or deg superheat
(19) Area factor for thermal expansion (F_a)
(20) Expansion factor (Y)
(21) Specific volume at flowing conditions at the meter, ft^3/lbm ($V_{\text{act, meter}}$)
(22) Specific volume at reference conditions at the meter, ft^3/lbm ($V_{\text{ref, meter}}$)
(23) Trial flow rate, lbm/hr

$$W_t = 358.93 \times d^2 \times K_o \times F_a \times Y \times \sqrt{\frac{h_w}{V_{\text{act, meter}}}}$$

(24) Viscosity, lbm/ft-sec (μ)
(25) Reynolds number

$$R_D = \frac{0.00424 \times W_h}{(D)(\mu)}$$

(26) Orifice plate discharge coefficient (C)

(27) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(28) Flow rate (lbm/hr)

$$W_h = \frac{W_t \times K}{K_o}\sqrt{\frac{V_{\text{act, meter}}}{V_{\text{ref, meter}}}}$$

Observed Data and Computed Results at the Device Inlet

(29) Set pressure, psig (P_{set}) (burst pressure for non-reclosing device)
(30) Flow-rating pressure, psia (P_f)
(31) Fluid temperature at the test drum calorimeter, °F ($T_{\text{cal, drum}}$)
(32) Percent quality or deg superheat

TEST REPORT FORM 5-5.2-1
PRESSURE RELIEF DEVICE TESTED WITH STEAM — U.S. CUSTOMARY UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Observed Data and Computed Results at the Device Inlet (Cont'd)

(33) Specific volume at reference condition, ft^3/lbm ($V_{ref, drum}$)
(34) Specific volume at inlet conditions, ft^3/lbm ($V_{act, drum}$)
(35) Meter calorimeter flow, lbm/hr (W_{mc})
(36) Meter calorimeter flow adjusted to the reference condition, lbm/hr

$$W_{cal, meter} = W_{mc} \sqrt{\frac{V_{act, meter}}{V_{ref, meter}}}$$

(37) Test-drum calorimeter flow, lbm/hr (W_{dc})
(38) Test-drum calorimeter flow adjusted to the reference condition, lbm/hr

$$W_{cal, drum} = W_{dc} \sqrt{\frac{V_{act, drum}}{V_{ref, drum}}}$$

(39) Test-drum drainage, lbm/hr (W_{dr})
(40) Measured relieving capacity adjusted to the reference condition, lbm/hr

$$W_c = W_h \sqrt{\frac{V_{act, drum}}{V_{ref, drum}}} - W_{cal, meter} - W_{cal, drum} - W_{dr}$$

TEST REPORT FORM 5-5.2-1M
PRESSURE RELIEF DEVICE TESTED WITH STEAM — SI UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve	Non-reclosing Devices
(4) Bore diameter, mm (d_b)	(4) Minimum holder-bore diameter, mm (d_b)
(5) Seat diameter, mm (d_s)	(5) Minimum net flow area, mm^2 (a)
(6) Seat angle, deg	
(7) Valve-disk lift, mm (l)	
(8) Actual discharge area, mm^2 (a_d)	

Flowmeter Calculations

(9) Internal diameter of meter run pipe, m (D)
(10) Meter-bore diameter, m (d)
(11) Meter-bore diameter squared, m^2 (d^2)
(12) Beta ratio ($\beta = d/D$)
(13) Trial flow coefficient (K_o)
(14) Differential pressure at the meter, millimeters of water (ΔP)
(15) Barometric pressure, kPa (P_b)
(16) Static pressure at the meter calorimeter, kPa (P_m)
(17) Fluid temperature at the meter calorimeter, °C ($T_{\text{cal, meter}}$)
(18) Percent quality or deg superheat
(19) Area factor for thermal expansion (F_a)
(20) Expansion factor (Y)
(21) Specific volume at flowing conditions at the meter, m^3/kg ($V_{\text{act, meter}}$)
(22) Specific volume at reference conditions at the meter, m^3/kg ($V_{\text{ref, meter}}$)
(23) Trial flow rate, kg/h

$$W_t = 12\,510 \times d^2 \times K_o \times F_a \times Y \times \sqrt{\frac{\Delta P}{V_{\text{act, meter}}}}$$

(24) Viscosity, kg/m-s (μ)
(25) Reynolds number

$$R_D = \frac{0.35368 \times W_h}{(D)(\mu)}$$

(26) Orifice plate discharge coefficient (C)

(27) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(28) Flow rate (kg/h)

$$W_h = \frac{W_t \times K}{K_o}\sqrt{\frac{V_{\text{act, meter}}}{V_{\text{ref, meter}}}}$$

Observed Data and Computed Results at the Device Inlet

(29) Set pressure, kPag (P_{set}) (burst pressure for non-reclosing device)
(30) Flow-rating pressure, kPa (P_f)
(31) Fluid temperature at the test drum calorimeter, °C ($T_{\text{cal, drum}}$)
(32) Percent quality or deg superheat

TEST REPORT FORM 5-5.2-1M
PRESSURE RELIEF DEVICE TESTED WITH STEAM — SI UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Observed Data and Computed Results at the Device Inlet (Cont'd)

(33) Specific volume at reference condition, m^3/kg ($V_{ref,\ drum}$)
(34) Specific volume at inlet conditions, m^3/kg ($V_{act,\ drum}$)
(35) Meter calorimeter flow, kg/h (W_{mc})
(36) Meter calorimeter flow adjusted to the reference condition, kg/h

$$W_{cal,\ meter} = W_{mc}\sqrt{\frac{V_{act,\ meter}}{V_{ref,\ meter}}}$$

(37) Test-drum calorimeter flow, kg/h (W_{dc})
(38) Test-drum calorimeter flow adjusted to the reference condition, kg/h

$$W_{cal,\ drum} = W_{dc}\sqrt{\frac{V_{act,\ drum}}{V_{ref,\ drum}}}$$

(39) Test-drum drainage, kg/h (W_{dr})
(40) Measured relieving capacity adjusted to the reference condition, kg/h

$$W_c = W_h\sqrt{\frac{V_{act,\ drum}}{V_{ref,\ drum}}} - W_{cal,\ meter} - W_{cal,\ drum} - W_{dr}$$

TEST REPORT FORM 5-5.3-1
PRESSURE RELIEF DEVICE TESTED WITH LIQUIDS — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve

(4) Bore diameter, in. (d_b)
(5) Seat diameter, in. (d_s)
(6) Seat angle, deg
(7) Valve-disk lift, in. (l)
(8) Actual discharge area, in.^{2} (a_d)

Non-reclosing Devices

(4) Minimum holder-bore diameter, in. (d_b)
(5) Minimum net flow area, in.^{2} (a)

Flowmeter Calculations

(9) Internal diameter of meter run pipe, in. (D)
(10) Meter-bore diameter, in. (d)
(11) Meter-bore diameter squared, in.^{2} (d^2)
(12) Beta ratio ($\beta = d/D$)
(13) Temperature upstream of the meter, °F (T_m)
(14) Differential pressure at the meter, inches of water (h_w)
(15) Barometric pressure, psia (P_b)
(16) Static pressure at the meter, psia (P_m)
(17) Fluid temperature at the meter, °F (T_m)
(18) Area factor for thermal expansion (F_a)
(19) Trial flow coefficient (K_o)
(20) Fluid density at meter inlet, lbm/ft^3 (ρ_m)
(21) Trial flow rate, lbm/hr (W_t)

$$W_t = 358.93 \times d^2 \times F_a \times K_o \sqrt{h_w \times \rho_m}$$

(22) Viscosity, lbm/ft-sec (μ)
(23) Reynolds number

$$R_D = \frac{0.00424 \times W_h}{(D)(\mu)}$$

(24) Orifice plate discharge coefficient (C)

(25) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(26) Measured relieving capacity, lbm/hr

$$W_h = W_t \times K/K_o$$

Observed Data and Computed Results at the Device Inlet

(27) Set pressure, psig (P_{set}) (burst pressure for non-reclosing device)
(28) Flow-rating pressure, psig (P_f)
(29) Back pressure, psig (P_o)
(30) Fluid temperature, °F (T_v)
(31) Density of liquid at inlet conditions, lbm/ft^3 (ρ_{act})
(32) Density of liquid at reference condition, lbm/ft^3 (ρ_{ref})
(33) Relieving capacity adjusted to liquid at reference condition, lbm/hr

$$W_r = W_h \sqrt{\rho_{ref}/\rho_{act}}$$

TEST REPORT FORM 5-5.3-1M
PRESSURE RELIEF DEVICE TESTED WITH LIQUIDS — SI UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name

Measured Device Dimensions

Valve	Non-reclosing Devices
(4) Bore diameter, mm (d_b)	(4) Minimum holder-bore diameter, mm (d_b)
(5) Seat diameter, mm (d_s)	(5) Minimum net flow area, mm^2 (a)
(6) Seat angle, deg	
(7) Valve-disk lift, mm (l)	
(8) Actual discharge area, mm^2 (a_d)	

Flowmeter Calculations

(9) Internal diameter of meter run pipe, m (D)
(10) Meter-bore diameter, m (d)
(11) Meter-bore diameter squared, m^2 (d^2)
(12) Beta ratio ($\beta = d/D$)
(13) Temperature upstream of the meter, °C (T_m)
(14) Differential pressure at the meter, millimeters of water (ΔP)
(15) Barometric pressure, kPa (P_b)
(16) Static pressure at the meter, kPa (P_m)
(17) Fluid temperature at the meter, °C (T_m)
(18) Area factor for thermal expansion (F_a)
(19) Trial flow coefficient (K_o)
(20) Fluid density at meter inlet, kg/m^3 (ρ_m)
(21) Trial flow rate, kg/h (W_t)

$$W_t = 12\,510 \times d^2 \times F_a \times K_o \sqrt{\Delta P \times \rho_m}$$

(22) Viscosity, kg/m-s (μ)
(23) Reynolds number

$$R_D = \frac{0.35368 \times W_h}{(D)(\mu)}$$

(24) Orifice plate discharge coefficient (C)

(25) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(26) Measured relieving capacity, kg/h

$$W_h = W_t \times K / K_o$$

Observed Data and Computed Results at the Device Inlet

(27) Set pressure, kPag (P_{set}) (burst pressure for non-reclosing device)
(28) Flow-rating pressure, kPag (P_f)
(29) Back pressure, kPag (P_o)
(30) Fluid temperature, °C (T_v)
(31) Density of liquid at inlet conditions, kg/m^3 (ρ_{act})
(32) Density of liquid at reference condition, kg/m^3 (ρ_s)
(33) Relieving capacity adjusted to liquid at reference condition, kg/h

$$W_r = W_h \sqrt{\rho_{ref} / \rho_{act}}$$

TEST REPORT FORM 5-5.4-1
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve	Non-reclosing Devices
(8) Bore diameter, in.	(8) Minimum holder-bore diameter, in. (d_b)
(9) Seat diameter, in.	(9) Minimum net flow area, in.^{2} (a)
(10) Seat angle, deg	
(11) Valve-disk lift, in. (l)	
(12) Actual discharge area, in.^{2} (a_d)	

Flowmeter Calculations

(13) Internal diameter of meter run pipe, in. (D)
(14) Meter-bore diameter, in. (d)
(15) Meter-bore diameter squared, in.^{2} (d^2)
(16) Beta ratio ($\beta = d/D$)
(17) Trial flow coefficient (K_o)
(18) Differential pressure at the meter, inches of water (h_w)
(19) Barometric pressure, psia (P_b)
(20) Static pressure at the meter, psia (P_m)
(21) Fluid temperature at the meter, °F (T_m)
(22) Expansion factor (Y)
(23) Area factor for thermal expansion (F_a)
(24) Fluid density at meter inlet, lbm/ft^3 (ρ_m)
(25) Trial flow rate (W_t), lbm/hr

$$W_t = 358.93 \times d^2 \times K_o \times Y \times F_a \sqrt{h_w \times \rho_m}$$

(26) Viscosity, lbm/ft-sec (μ)
(27) Reynolds number

$$R_D = \frac{0.00424 \times W_t}{(D)(\mu)}$$

(28) Orifice plate discharge coefficient (C)

(29) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(30) Measured relieving capacity, lbm/hr

$$W_h = \frac{(W_t)(k)}{K_o}$$

(31) Base pressure, psia (P_B)
(32) Base temperature, °F (T_B)
(33) Density of dry air at 14.696 psia and at the base temperature, lbm/ft^3 (ρ_s)
(34) Density at base condition, lbm/ft^3

$$\rho_b = S_g \times P_B \rho_s / 14.696$$

TEST REPORT FORM 5-5.4-1
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — U.S. CUSTOMARY UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Observed Data and Computed Results at the Device Inlet

(35) Volumetric rate at base condition at the meter, cfm

$$q_b = \frac{w_t}{60P_B}$$

(36) Set pressure, psig (P_{set}) (burst pressure for non-reclosing device)
(37) Flow-rating pressure, psig (P_f)
(38) Temperature at the valve inlet, absolute °R (T_v)
(39) Reference temperature at the valve inlet, absolute °R (T_r)
(40) Valve-inlet temperature correction

$$C = \sqrt{T_v / T_R}$$

(41) Valve capacity at reference inlet temperature, cfm

$$q_r = q_b \times C$$

TEST REPORT FORM 5-5.4-1M
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — SI UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve

(8) Bore diameter, mm
(9) Seat diameter, mm
(10) Seat angle, deg
(11) Valve-disk lift, mm (l)
(12) Actual discharge area, mm^2 (a_d)

Non-reclosing Devices

(8) Minimum holder-bore diameter, mm (d_b)
(9) Minimum net flow area, mm^2 (a)

Flowmeter Calculations

(13) Internal diameter of meter run pipe, m (D)
(14) Meter-bore diameter, m (d)
(15) Meter-bore diameter squared, m^2 (d^2)
(16) Beta ratio ($\beta = d/D$)
(17) Trial flow coefficient (K_o)
(18) Differential pressure at the meter, millimeters of water (ΔP)
(19) Barometric pressure, kPa (P_b)
(20) Static pressure at the meter, kPa (P_m)
(21) Fluid temperature at the meter, °C (T_m)
(22) Expansion factor (Y)
(23) Area factor for thermal expansion (F_a)
(24) Fluid density at meter inlet, kg/m^3 (ρ_m)
(25) Trial flow rate (W_t), kg/h

$$W_t = 12\,510 \times d^2 \times K_o \times Y \times F_a \sqrt{\Delta P \times \rho_m}$$

(26) Viscosity, kg/m-s (μ)
(27) Reynolds number

$$R_D = \frac{0.35368 \times W_t}{(D)(\mu)}$$

(28) Orifice plate discharge coefficient (C)

(29) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(30) Measured relieving capacity, kg/h

$$W_h = \frac{(W_t)(k)}{K_o}$$

(31) Base pressure, kPa (P_B)
(32) Base temperature, °C (T_B)
(33) Density of dry air at 101.33 kPa and at the base temperature, kg/m^3 (ρ_s)
(34) Density at base condition, kg/m^3

$$\rho_b = S_g \times P_B \rho_s / 101.33$$

TEST REPORT FORM 5-5.4-1M
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — SI UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Observed Data and Computed Results at the Device Inlet

(35) Volumetric rate at base condition at the meter, m^3/min

$$q_b = \frac{w_t}{60P_B}$$

(36) Set pressure, kPag (P_{set}) (burst pressure for non-reclosing device)
(37) Flow-rating pressure, kPag (P_f)
(38) Temperature at the valve inlet, absolute K (T_v)
(39) Reference temperature at the valve inlet, absolute K (T_r)
(40) Valve-inlet temperature correction

$$C = \sqrt{T_v / T_R}$$

(41) Valve capacity at reference inlet temperature, m^3/min

$$q_r = q_b \times C$$

TEST REPORT FORM 5-5.5-1
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Sonic-Flow Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve	Non-reclosing Devices
(8) Bore diameter, in.	(8) Minimum holder-bore diameter, in. (d_b)
(9) Seat diameter, in.	(9) Minimum net flow area, in.^{2} (a)
(10) Seat angle, deg	
(11) Valve-disk lift, in. (l)	
(12) Actual discharge area, in.^{2} (a_d)	

Flowmeter Calculations

(13) Internal diameter of meter run pipe, in. (D)
(14) Meter-bore diameter, in. (d)
(15) Beta ratio ($\beta = d/D$)
(16) Meter discharge coefficient at sonic-flow conditions (C)
(17) Meter-bore area, in.^{2} (a_m)
(18) Critical flow function (C^*)
(19) Barometric pressure, psia (P_b)
(20) Meter inlet stagnation pressure, psia (P_s)
(21) Meter inlet stagnation temperature, absolute °R (T_s)
(22) Measured relieving capacity, lbm/hr

$$W_h = 3{,}600 \times C \times a_m \times C^* \times \frac{P_s}{\sqrt{1{,}545.4 \times T_s}} \times \sqrt{32.2}$$

Observed Data and Computed Results at the Device Inlet

(23) Set pressure, psig (P_{set}) (burst pressure for non-reclosing device)
(24) Flow-rating pressure, psig (P_f)
(25) Temperature at the valve inlet, absolute °R (T_v)
(26) Reference temperature at the valve inlet, absolute °R (T_r)
(27) Density of dry air at 14.696 psia and reference temperature, lbm/ft^3 (ρ_{std})
(28) Density of fluid at reference condition, lbm/ft^3

$$\rho_{ref} = S_g \times P_f \times \frac{\rho_{std}}{14.696}$$

(29) Valve capacity at reference condition, cfm

$$q_r = \frac{W_h}{60 \times \rho_{ref}} \sqrt{T_v / T_r}$$

TEST REPORT FORM 5-5.5-1M
PRESSURE RELIEF DEVICE TESTED WITH AIR OR GAS — SI UNITS
Observed Data and Computed Results — Sonic-Flow Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve	Non-reclosing Devices
(8) Bore diameter, mm	(8) Minimum holder-bore diameter, mm (d_b)
(9) Seat diameter, mm	(9) Minimum net flow area, mm^2 (a)
(10) Seat angle, deg	
(11) Valve-disk lift, mm (l)	
(12) Actual discharge area, mm^2 (a_d)	

Flowmeter Calculations

(13) Internal diameter of meter run pipe, m (D)
(14) Meter-bore diameter, m (d)
(15) Beta ratio ($\beta = d/D$)
(16) Meter discharge coefficient at sonic-flow conditions (C)
(17) Meter-bore area, m^2 (a_m)
(18) Critical flow function (C^*)
(19) Barometric pressure, kPa (P_b)
(20) Meter inlet stagnation pressure, kPa (P_s)
(21) Meter inlet stagnation temperature, absolute K (T_s)
(22) Measured relieving capacity, kg/h

$$W_h = 3\,600 \times C \times a_m \times C^* \times \frac{P_s}{\sqrt{8\,314.3 \times T_s}}$$

Observed Data and Computed Results at the Device Inlet

(23) Set pressure, kPag (P_{set}) (burst pressure for non-reclosing device)
(24) Flow-rating pressure, kPag (P_f)
(25) Temperature at the valve inlet, absolute K (T_v)
(26) Reference temperature at the valve inlet, absolute K (T_r)
(27) Density of dry air at 101.33 kPa and reference temperature, kg/m^3 (ρ_{std})
(28) Density of fluid at reference condition, kg/m^3

$$\rho_{ref} = S_g \times P_f \times \frac{\rho_{std}}{101.33}$$

(29) Valve capacity at reference condition, m^3/min

$$q_r = \frac{W_h}{60 \times \rho_{ref}} \sqrt{T_v / T_r}$$

TEST REPORT FORM 5-5.6-1
PRESSURE RELIEF DEVICE TESTED WITH FUEL GAS — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve	Non-reclosing Devices
(8) Bore diameter, in.	(8) Minimum holder-bore diameter, in. (d_b)
(9) Seat diameter, in.	(9) Minimum net flow area, in.^{2} (a)
(10) Seat angle, deg	
(11) Valve-disk lift, in. (l)	
(12) Actual discharge area, in.^{2} (a_d)	

Flowmeter Calculations

(13) Internal diameter of meter run pipe, in. (D)
(14) Meter-bore diameter, in. (d)
(15) Meter-bore diameter squared, in.^{2} (d^2)
(16) Beta ratio ($\beta = d/D$)
(17) Trial flow coefficient (K_o)
(18) Differential pressure at the meter, inches of water (h_w)
(19) Barometric pressure, psia (P_b)
(20) Static pressure at the meter, psia (P_m)
(21) Fluid temperature at the meter, absolute °R (T_m)
(22) Expansion factor (Y)
(23) Area factor for thermal expansion, absolute °R (F_a)
(24) Compressibility at meter (Z)
(25) Density, lbm/ft^3

$$\rho_m = \frac{(2.69991)(S_g)(P_m)}{(T_m)(Z)}$$

(26) Trial flow rate, lbm/hr

$$W_t = 358.93 \times d^2 \times K_o \times Y \times F_g \sqrt{h_w \times \rho_m}$$

(27) Viscosity, lbm/ft-sec (μ)
(28) Reynolds number

$$R_D = \frac{0.00424 \times W_t}{(D)(\mu)}$$

(29) Orifice plate discharge coefficient (C)

(30) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(31) Base pressure, psia (P_a)
(32) Base temperature, absolute °R (T_b)
(33) Base compressibility factor (Z_b)

TEST REPORT FORM 5-5.6-1
PRESSURE RELIEF DEVICE TESTED WITH FUEL GAS — U.S. CUSTOMARY UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Flowmeter Calculations (Cont'd)

(34) Density at base temperature and pressure

$$\rho_B = \frac{2.6991 \times S_g \times P_B}{T_b \times Z_b}$$

(35) Relieving capacity at base condition, cfh

$$q_b = \frac{(W_t)(K)}{(K_o)(\rho_B)}$$

Observed Data and Computed Results at the Device Inlet

(36) Set pressure, psig (P_{set}) (burst pressure for non-reclosing device)
(37) Flow-rating pressure, psig (P_f)
(38) Temperature at the valve inlet, absolute °R (T_v)
(39) Reference temperature at the valve inlet, absolute °R (T_r)
(40) Valve-inlet temperature correction

$$C = \sqrt{T_v / T_R}$$

(41) Valve capacity at reference inlet temperature, cfm

$$q_r = \frac{(q_b)(c)}{60}$$

TEST REPORT FORM 5-5.6-1M
PRESSURE RELIEF DEVICE TESTED WITH FUEL GAS — SI UNITS
Observed Data and Computed Results — Flowmeter Method

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Test fluid
(5) Specific gravity (ideal) (S_g)
(6) Ratio of specific heats (k)
(7) Molecular weight (M_w)

Measured Device Dimensions

Valve	Non-reclosing Devices
(8) Bore diameter, mm	(8) Minimum holder-bore diameter, mm (d_b)
(9) Seat diameter, mm	(9) Minimum net flow area, mm^2 (a)
(10) Seat angle, deg	
(11) Valve-disk lift, mm (l)	
(12) Actual discharge area, mm^2 (a_d)	

Flowmeter Calculations

(13) Internal diameter of meter run pipe, m (D)
(14) Meter-bore diameter, m (d)
(15) Meter-bore diameter squared, m^2 (d^2)
(16) Beta ratio ($\beta = d/D$)
(17) Trial flow coefficient (K_o)
(18) Differential pressure at the meter, millimeters of water (ΔP)
(19) Barometric pressure, kPa (P_b)
(20) Static pressure at the meter, kPa (P_m)
(21) Fluid temperature at the meter, absolute K (T_m)
(22) Expansion factor (Y)
(23) Area factor for thermal expansion, absolute K (F_a)
(24) Compressibility at meter (Z)
(25) Density, kg/m^3

$$\rho_m = \frac{(0.003483)(S_g)(P_m)}{(T_m)(Z)}$$

(26) Trial flow rate, kg/h

$$W_t = 12\,510 \times d^2 \times K_o \times Y \times F_g \sqrt{\Delta P \times \rho_m}$$

(27) Viscosity, kg/m-s (μ)
(28) Reynolds number

$$R_D = \frac{0.35368 \times W_t}{(D)(\mu)}$$

(29) Orifice plate discharge coefficient (C)

(30) Flow coefficient

$$K = \frac{C}{\sqrt{1 - \beta^4}}$$

(31) Base pressure, kPa (P_a)
(32) Base temperature, absolute K (T_b)
(33) Base compressibility factor (Z_b)

TEST REPORT FORM 5-5.6-1M
PRESSURE RELIEF DEVICE TESTED WITH FUEL GAS — SI UNITS (CONT'D)
Observed Data and Computed Results — Flowmeter Method

Flowmeter Calculations (Cont'd)

(34) Density at base temperature and pressure

$$\rho_B = \frac{0.003483 \times S_g \times P_B}{T_b \times Z_b}$$

(35) Relieving capacity at base condition, m^3/h

$$q_b = \frac{(W_t)(K)}{(K_o)(\rho_B)}$$

Observed Data and Computed Results at the Device Inlet

(36) Set pressure, kPag (P_{set}) (burst pressure for non-reclosing device)
(37) Flow-rating pressure, kPag (P_f)
(38) Temperature at the valve inlet, absolute K (T_v)
(39) Reference temperature at the valve inlet, absolute K (T_r)
(40) Valve-inlet temperature correction

$$C = \sqrt{T_v / T_R}$$

(41) Valve capacity at reference inlet temperature, m^3/min

$$q_r = \frac{(q_b)(c)}{60}$$

TEST REPORT FORM 5-5.7-1
NON-RECLOSING PRESSURE RELIEF DEVICE TESTED WITH AIR — U.S. CUSTOMARY UNITS
Observed Data and Computed Results — Flow Resistance

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Ratio of specific heats (k)
(5) Molecular weight (M_w)
(6) Measured relieving capacity, lbm/hr (W_h) (from Form 5-5.4-1 or Form 5-5.5-1)
(7) Base pressure, psia (P_B)
(8) Base temperature, absolute °R (T_o)
(9) Test rig inside diameter, ft (D)
(10) Length between taps A and B, ft ($L_{A\text{-}B}$)
(11) Length between taps B and C, ft ($L_{B\text{-}C}$)
(12) Length between taps C and D, ft ($L_{C\text{-}D}$)
(13) Pressure at tap B, psia (P_{tapB})
(14) Differential pressure between taps A and B, psia ($\Delta P_{A\text{-}B}$)
(15) Differential pressure between taps B and C, psia ($\Delta P_{B\text{-}C}$)
(16) Differential pressure between taps C and D, psia ($\Delta P_{C\text{-}D}$)

Flow Resistance Factor Calculation

(17) Mass velocity, lb/ft^2-sec (G)

$$G = W_h/(3{,}600 \times \pi \times D^2/4)$$

(18) Mach number at pipe entrance

$$M_1 = G/144\ P_B \sqrt{\frac{Y_1^{[(k+1)/(k-1)]}}{32.2 \times M_w \times k/(1{,}544 \times T_o)}}$$

Solve by iteration

$$Y_1 = 1 + \frac{(k-1) \times M_1^2}{2}$$

(19) Pressure at pipe entrance

$$P_1 = P_B\left(\frac{2}{2 + (k-1) \times M_1^2}\right)^{\left(\frac{k}{k-1}\right)}$$

(20) Temperature at pipe entrance

$$T_1 = T_o \times (P_1/P_B)^{(k-1)/k}$$

Calculate total resistance factor at each pressure tap A, B, C, and D. Repeat steps (21) through (26) for each tap.

(21) Temperature at pressure tap, absolute °R

$$T_{tap} = T_1\left[\frac{-1 + \sqrt{1 + 2 \times (k-1) \times M_1^2 \times (P_1/P_{tap})^2 \times [1 + (k-1) \times M_1^2/2]}}{(k-1) \times M_1^2 \times (P_1/P_{tap})^2}\right]$$

(22) Sonic velocity at pressure tap, ft/sec

$$C_{tap} = \sqrt{32.2 \times k \times 1{,}544 \times T_{tap}/M_w}$$

(23) Specific volume at pressure tap, ft^3/lbm

$$V_{tap} = (1{,}544 \times T_{tap})/(M_w \times 144 P_{tap})$$

(24) Mach number at pressure tap

$$M_{tap} = G \times V_{tap}/C_{tap}$$

(25) Expansion factor at pressure tap

$$Y_{tap} = 1 + \frac{(k-1) \times (M_{tap})^2}{2}$$

TEST REPORT FORM 5-5.7-1
NON-RECLOSING PRESSURE RELIEF DEVICE TESTED WITH AIR — U.S. CUSTOMARY UNITS (CONT'D)
Observed Data and Computed Results — Flow Resistance

Flow Resistance Factor Calculation (Cont'd)

(26) Total resistance factor to pressure tap

$$K_{tap} = \frac{1/M_1^2 - 1/(M_{tap})^2 - [(k+1)/2] \times \ln[(M_{tap}^2 \times Y_1)/(M_1^2 \times Y_{tap})]}{k}$$

(27) Resistance factor between pressure taps A and B

$$K_{A\text{-}B} = K_B - K_A$$

(28) Resistance factor between pressure taps B and C

$$K_{B\text{-}C} = K_C - K_B$$

(29) Resistance factor between pressure taps C and D

$$K_{C\text{-}D} = K_D - K_C$$

(30) Friction factor

$$f = K_{A\text{-}B} \times D/(4 \times L_{A\text{-}B})$$

(31) Obtain the viscosity of air at T_B and P_B, μ (centipoise)
(32) Reynolds number

$$N_{Re} = D \times G/(\mu/1{,}488)$$

(33) Pipe roughness, in.

$$E = 44.4 \times D \times [10^{[-1/(4 \times \sqrt{f})]} - 1.256/(N_{Re} \times \sqrt{f})]$$

(34) Pipe resistance factor between pressure taps B and C

$$K_{pipe\ B\text{-}C} = \frac{4fL_{B\text{-}C}}{D}$$

(35) Test object individual flow resistance

$$K_{Ri} = K_{B\text{-}C} - K_{pipe\ B\text{-}C}$$

GENERAL NOTE: Equations for calculations are in accordance with Lapple (1943), Levenspiel (1977), Perry and Green (1984), and Colebrook equation.

Colebrook. "Perry's Chemical Engineers' Handbook," 6th ed. McGraw-Hill 1984.
Lapple, C. E. (1943). "Isothermal and Adiabatic Flow of Compressible Fluids." Transactions of the American Institute of Chemical Engineers, 39, 385–432.
Levenspiel, O. (1977, May). "The Discharge of Gases From a Reservoir Through a Pipe." AIChE Journal, 23(3), 402–403.
Perry, R. H., and Green, D. W. (Eds.) (1984). Perry's Chemical Engineers' Handbook (6th ed.). McGraw-Hill.

TEST REPORT FORM 5-5.7-1M
NON-RECLOSING PRESSURE RELIEF DEVICE TESTED WITH AIR — SI UNITS
Observed Data and Computed Results — Flow Resistance

(1) Test number
(2) Test date
(3) Manufacturer's name
(4) Ratio of specific heats (k)
(5) Molecular weight (M_w)
(6) Measured relieving capacity, kg/h (W_h) (from Form 5-5.4-1M or Form 5-5.5-1M)
(7) Base pressure, kPa (P_B)
(8) Base temperature, absolute K (T_o)
(9) Test rig inside diameter, m (D)
(10) Length between taps A and B, m ($L_{A\text{-}B}$)
(11) Length between taps B and C, m ($L_{B\text{-}C}$)
(12) Length between taps C and D, m ($L_{C\text{-}D}$)
(13) Pressure at tap B, kPa (P_{tapB})
(14) Differential pressure between taps A and B, kPa ($\Delta P_{A\text{-}B}$)
(15) Differential pressure between taps B and C, kPa ($\Delta P_{B\text{-}C}$)
(16) Differential pressure between taps C and D, kPa ($\Delta P_{C\text{-}D}$)

Flow Resistance Factor Calculation

(17) Mass velocity, kg/m^2-s (G)

$$G = W_h/(3\,600 \times \pi \times D^2/4)$$

(18) Mach number at pipe entrance

$$M_1 = G/1\,000 \times P_B \sqrt{\frac{Y_1^{[(k+1)/(k-1)]}}{M_w \times k/(8\,314.3 \times T_o)}}$$

Solve by iteration

$$Y_1 = 1 + \frac{(k-1) \times M_1^2}{2}$$

(19) Pressure at pipe entrance

$$P_1 = P_B\left(\frac{2}{2 + (k-1) \times M_1^2}\right)^{\left(\frac{k}{k-1}\right)}$$

(20) Temperature at pipe entrance

$$T_1 = T_o \times (P_1/P_B)^{(k-1)/k}$$

Calculate total resistance factor at each pressure tap A, B, C, and D. Repeat steps (21) through (26) for each tap.

(21) Temperature at pressure tap, absolute K

$$T_{tap} = T_1\left[\frac{-1 + \sqrt{1 + 2 \times (k-1) \times M_1^2 \times (P_1/P_{tap})^2 \times [1 + (k-1) \times M_1^2/2]}}{(k-1) \times M_1^2 \times (P_1/P_{tap})^2}\right]$$

(22) Sonic velocity at pressure tap, m/s

$$C_{tap} = \sqrt{k \times 8\,314.3 \times T_{tap}/M_w}$$

(23) Specific volume at pressure tap, m^3/kg

$$V_{tap} = (8.3143 \times T_{tap})/(M_w \times P_{tap})$$

(24) Mach number at pressure tap

$$M_{tap} = G \times V_{tap}/C_{tap}$$

(25) Expansion factor at pressure tap

$$Y_{tap} = 1 + \frac{(k-1) \times (M_{tap})^2}{2}$$

TEST REPORT FORM 5-5.7-1M
NON-RECLOSING PRESSURE RELIEF DEVICE TESTED WITH AIR — SI UNITS (CONT'D)
Observed Data and Computed Results — Flow Resistance

Flow Resistance Factor Calculation (Cont'd)

(26) Total resistance factor to pressure tap

$$K_{tap} = \frac{1/M_1^2 - 1/(M_{tap})^2 - [(k+1)/2] \times \ln [(M_{tap}^2 \times Y_1)/(M_1^2 \times Y_{tap})]}{k}$$

(27) Resistance factor between pressure taps A and B

$$K_{A\text{-}B} = K_B - K_A$$

(28) Resistance factor between pressure taps B and C

$$K_{B\text{-}C} = K_C - K_B$$

(29) Resistance factor between pressure taps C and D

$$K_{C\text{-}D} = K_D - K_C$$

(30) Friction factor

$$f = K_{A\text{-}B} \times D/(4 \times L_{A\text{-}B})$$

(31) Obtain the viscosity of air at T_B and P_B, μ (centipoise)
(32) Reynolds number

$$N_{Re} = D \times G/(\mu/1\,000)$$

(33) Pipe roughness, mm

$$E = 3\,700 \times D \times [10^{[-1/(4 \times \sqrt{f})]} - 1.256/(N_{Re} \times \sqrt{f})]$$

(34) Pipe resistance factor between pressure taps B and C

$$K_{pipe\ B\text{-}C} = \frac{4fL_{B\text{-}C}}{D}$$

(35) Test object individual flow resistance

$$K_{Ri} = K_{B\text{-}C} - K_{pipe\ B\text{-}C}$$

GENERAL NOTE: Equations for calculations are in accordance with Lapple (1943), Levenspiel (1977), Perry and Green (1984), and Colebrook equation.

Colebrook. "Perry's Chemical Engineers' Handbook," 6th ed. McGraw-Hill 1984.
Lapple, C. E. (1943). "Isothermal and Adiabatic Flow of Compressible Fluids." Transactions of the American Institute of Chemical Engineers, 39, 385–432.
Levenspiel, O. (1977, May). "The Discharge of Gases From a Reservoir Through a Pipe." AIChE Journal, 23(3), 402–403.
Perry, R. H., and Green, D. W. (Eds.) (1984). Perry's Chemical Engineers' Handbook (6th ed.). McGraw-Hill.

Section 6
Test Summary Report Form

6-1 GENERAL INSTRUCTIONS

(a) The Report of Test shall be prepared for the purpose of formally recording observed data and computed results. It shall contain sufficient supporting information to prove that all objectives of any tests conducted in accordance with this Code have been attained.

(b) The procedures described in Section 5 are recommended for use in computing the test results.

(c) The Report of Test shall include Parts I to IV as listed in (1) through (4) herein. It may also be appropriate to include any of the remaining sections, depending on the circumstances or by agreement of multiple parties of the test.

(1) Part I: General Information
(2) Part II: Summary of Results
(3) Part III: Description of Device Under Test
(4) Part IV: Observed Data and Computed Results
(5) Part V: Test Conditions and Corrections Agreements
(6) Part VI: Test Methods and Procedures
(7) Part VII: Supporting Data
(8) Part VIII: Graphical Presentation of Back-Pressure Test Results

Subsections 6-2 through 6-9 give a discussion of each Part of the Test Report.

6-2 PART I: GENERAL INFORMATION

This Part shall include the following items:
(a) date of test
(b) location of test facilities
(c) device manufacturer's name
(d) manufacturer's serial number and complete identification of device
(e) inlet and outlet connections (stating size, pressure ratings, and type, such as screwed, flanged, etc.)
(f) test conducted by
(g) representatives of interested parties
(h) object of test
(i) fluid through device (wherever applicable, give name, molecular weight, specific gravity, and ratio of specific heats)

6-3 PART II: SUMMARY OF RESULTS

This Part shall include those quantities and characteristics that describe the performance of the device at test conditions. The Test Summary Report Form for the particular test shall list the quantities, characteristics, and units of measurement required for the report.

6-4 PART III: DESCRIPTION OF DEVICE UNDER TEST

This Part may include assembly drawings, manufacturing drawings, and measured dimensions. Manufacturing drawings for these parts may be submitted with the assembly drawing. The dimensions of these parts shall include the following, if applicable:
(a) bore diameter, in. (mm)
(b) seat diameter, in. (mm)
(c) seat angle, deg
(d) inlet opening diameter, in. (mm)
(e) ratio of throat diameter to the diameter of the inlet opening
(f) actual discharge area, in.^{2} (mm^2)

Forms 6-5-1 through 6-5-4 shall be used to record this information for steam; liquids and water; or air, gas, or fuel gas.

6-5 PART IV: OBSERVED DATA AND COMPUTED RESULTS

This Part shall include a record of data and calculations required for the results of the tests. Computed results shall include final flow measurement uncertainty. The data shall be corrected for instrument calibrations and conditions prevailing for each test run.

The calculations for measured relieving capacity may be made in accordance with the procedures in Section 5 and reported in the recommended Report of Test using Forms 6-5-1 through 6-5-4 as applicable. These forms follow this Section. Calculation forms are provided in Section 5 for the following listed fluids:
(a) steam
(b) air or gas
(c) fuel gas
(d) liquids
(e) water

6-6 PART V: TEST CONDITIONS AND CORRECTIONS AGREEMENTS

Operating conditions, such as the following, that have been agreed upon prior to the test shall be reported for each test:

(a) device-maximum-inlet pressure
(b) device-inlet temperature
(c) setting of device
(d) back pressure (built-up and/or superimposed)

6-7 PART VI: TEST METHODS AND PROCEDURES

This Part shall include a detailed description of the instruments and apparatus used to measure the various quantities and procedures for observing the mechanical characteristics of the device under test.

6-8 PART VII: SUPPORTING DATA

This Part shall include pertinent material supplementing data presented elsewhere in the test report, whereby an independent verification of the report results can be made. This material may include, but not necessarily be limited to, the following:

(a) instrument calibration records
(b) detailed log sheets
(c) sample calculations

6-9 PART VIII: GRAPHICAL PRESENTATION OF BACK-PRESSURE TEST RESULTS

Where a series of tests have been made with several back pressures for a given opening pressure, the test results can be presented by plotting curves, such as the following:

(a) *Abscissa:* back pressures in percent of the opening pressure at atmospheric back pressure

Ordinate: percent variation of opening pressures from the opening pressure at atmospheric back pressure

(b) *Abscissa:* back pressures in percent of the relieving pressure at atmospheric back pressure

Ordinate: relieving capacities in percent of relieving capacity at atmospheric back pressure

(c) *Abscissa:* back pressures in percent of the opening pressure at atmospheric back pressure

Ordinate: percent variation of closing pressures from the closing pressure at atmospheric back pressure

TEST SUMMARY REPORT FORM 6-5-1
Pressure and Relief Valve Performance Test Report
STEAM

General Information

(1) Test number
(2) Test date
(3) Location
(4) Manufacturer's name and address
(5a) Valve type or model number
(5b) Valve serial or identification number
(5c) Inlet connection (size, pressure rating, and type)
(5d) Outlet connection (size, pressure rating, and type)
(5e) Stamped pressure and tolerance, units
(6) Test objective

Summary of Test Results

(7) Simmer, units (factory setting)
(8) Simmer, units (reset)
(9) Set pressure, units (factory setting)
(10) Set pressure, units (reset)
(11) Reseating pressure, units (factory setting)
(12) Reseating pressure, units (reset)
(13) Blowdown, units (factory setting)
(14) Blowdown, units (reset)
(15) Back pressure, units, superimposed and/or built-up
(16) Flow-rating pressure (valve inlet), units
(17) Valve-disk lift, units
(18) Measured relieving capacity, units
(19) Final flow measurement uncertainty

Measured Valve Dimensions

(20) Bore diameter, units
(21) Seat diameter, units
(22) Seat angle, deg
(23) Valve-inlet-opening diameter, units
(24) Ratio of valve-disk lift to bore diameter
(25) Ratio of bore diameter to the diameter of the valve-inlet opening
(26) Actual discharge area, units
(27) Remarks and conclusions concerning the objective of the test and applicable items, such as chatter, flutter, and vibration.

Test Supervisor (Signed) ____ Date ______________

TEST SUMMARY REPORT FORM 6-5-2
Pressure and Relief Valve Performance Test Report
LIQUIDS AND WATER

General Information

(1) Test number
(2) Test date
(3) Location
(4) Manufacturer's name and address
(5a) Valve type or model number
(5b) Valve serial or identification number
(5c) Inlet connection (size, pressure rating, and type)
(5d) Outlet connection (size, pressure rating, and type)
(5e) Stamped pressure, units
(6) Test objective
(7) Test fluid
(8) Specific gravity (ideal)

Summary of Test Results

(9) Set pressure, units (factory setting)
(10) Set pressure, units (reset)
(11) Reseating pressure, units (factory setting)
(12) Reseating pressure, units (reset)
(13) Back pressure, units, superimposed and/or built-up
(14) Flow-rating pressure (valve inlet), units
(15) Valve-disk lift, units
(16) Measured relieving capacity, units
(17) Final flow measurement uncertainty

Measured Valve Dimensions

(18) Bore diameter, units
(19) Seat diameter, units
(20) Seat angle, deg
(21) Valve-inlet-opening diameter, units
(22) Ratio of valve-disk lift to bore diameter
(23) Ratio of bore diameter to the diameter of the valve-inlet opening
(24) Actual discharge area, units
(25) Remarks and conclusions concerning the objective of the test and applicable items, such as chatter, flutter, and vibration.

Test Supervisor (Signed) ______________________________ Date ______________

TEST SUMMARY REPORT FORM 6-5-3
Pressure and Relief Valve Performance Test Report
AIR, GAS, OR FUEL GAS

General Information

(1) Test number
(2) Test date
(3) Location
(4) Manufacturer's name and address
(5a) Valve type or model number
(5b) Valve serial or identification number
(5c) Inlet connection (size, pressure rating, and type)
(5d) Outlet connection (size, pressure rating, and type)
(5e) Stamped pressure and tolerance, units
(6) Test objective
(7) Test fluid
(8) Specific gravity (ideal)
(9) Ratio of specific heats
(10) Molecular weight

Summary of Test Results

(11) Start-to-discharge, units (factory setting)
(12) Start-to-discharge pressure, units (reset)
(13) Simmer, units (factory setting)
(14) Simmer, units (reset)
(15) Set pressure, units (factory setting)
(16) Set pressure, units (reset)
(17) Reseating pressure, units (factory setting)
(18) Reseating pressure, units (reset)
(19) Resealing pressure, units (factory setting)
(20) Resealing pressure, units (reset)
(21) Blowdown, units (factory setting)
(22) Blowdown, units (reset)
(23) Back pressure, units, superimposed and/or built-up
(24) Flow-rating pressure (valve inlet), units
(25) Valve-disk lift, units
(26) Measured relieving capacity, units
(27) Final flow measurement uncertainty

Measured Valve Dimensions

(28) Bore diameter, units
(29) Seat diameter, units
(30) Valve-inlet-opening diameter, units
(31) Ratio of valve-disk lift to bore diameter
(32) Ratio of bore diameter to the diameter of the valve-inlet opening
(33) Actual discharge area, units
(34) Remarks and conclusions concerning the objective of the test and applicable items, such as chatter, flutter, and vibration.

Test Supervisor (Signed) ______________________________________ Date ______________

TEST SUMMARY REPORT FORM 6-5-4
Non-reclosing Pressure Relief Device Performance Test Report
AIR, GAS, OR FUEL GAS

General Information

(1) Test number
(2) Test date
(3) Location
(4) Manufacturer's name and address
(5a) Device type or model number
(5b) Device lot or identification number
(5c) Connection (size, pressure rating, and type)
(5d) Marked set pressure and tolerance, units
(5e) Minimum net flow area, units (manufacturer specified)
(6) Test objective
(7a) Test fluid for set pressure
(7b) Test fluid for flow test
(8) Specific gravity (ideal)
(9) Ratio of specific heats
(10) Molecular weight

Summary of Test Results

(11) Set pressure, units
(12) Flow-rating pressure at device inlet, units
(13) Resistance factor (K_{Ri})

Measured Device Dimensions

(14) Minimum device bore diameter, units
(15) Remarks and conclusions concerning the objective of the test and applicable items, such as vibrations.

Test Supervisor (Signed) ____ Date ______________

PART III
IN-SERVICE AND BENCH TESTING

Section 7
Guiding Principles

7-1 ITEMS ON WHICH AGREEMENT SHALL BE REACHED

The parties to the test shall reach agreement on the following items prior to conducting the test:

(a) object of the test
(b) parties to the test
(c) test site
(d) testing fluid
(e) methods of measurement, instrumentation, and equipment to be used (calibration of instruments shall be in accordance with subsection 3-7)
(f) number, size, type, condition, source, and set pressure of the device(s) to be tested
(g) method of determining seat tightness
(h) persons who shall conduct the test
(i) the written test procedure that shall include the observation and readings to be taken and recorded to comply with the object or objectives of the test

7-2 QUALIFICATION OF PERSON CONDUCTING THE TEST

A person who conducts the test shall have a working knowledge of pressure relief device operating characteristics. The person shall have practical experience in the safe and accurate operation of the testing equipment.

7-3 RESPONSIBILITY OF PERSON CONDUCTING THE TEST

A person who meets the qualifications of subsection 7-2 shall be present at all times during the test and shall be solely responsible for ensuring that all persons who are involved in taking readings, making pressure and temperature adjustments, or any other function that will affect the test results are fully informed as to the correct method of performing such functions. This person conducting the test shall also be responsible for ensuring that the written test procedures are followed. This person shall sign and date the test report, thereby verifying to the best of the person's knowledge that the report is correct and that the test was conducted in accordance with the written test procedures. This person shall verify that the instruments have been calibrated as required by subsection 7-7.

7-4 TEST APPARATUS

Procedures and arrangement of the test apparatus shall be in accordance with Section 8.

7-5 PRELIMINARY TRAINING

Sufficient training shall be conducted to ensure that operating personnel are completely familiar with the test equipment and their respective assignments.

7-6 SPARE INSTRUMENTS

If intended for use as replacements during the test, spare instruments shall be calibrated in accordance with subsection 7-7.

7-7 CALIBRATION OF INSTRUMENTS

Each instrument used during the test shall be serialized or otherwise positively identified and shall be calibrated against certified equipment having known valid relationships to nationally recognized standards. Each instrument, depending on the type, shall be calibrated in accordance with this Section. Records of instrument calibrations shall be available for review by the interested parties.

7-7.1 Pressure

Pressure-measuring instruments shall be calibrated in accordance with ASME PTC 19.2 within 30 days prior to the tests. Portable pressure-measuring instruments shall be calibrated at a frequency to ensure that measurements are within the uncertainty limits. Calibration of other means of indicating or recording pressure shall be agreed upon by the interested parties.

7-7.2 Temperature

Temperature-measuring instruments shall be calibrated in accordance with ASME PTC 19.3. Instruments of the types listed in para. 4-2.1(a), except bimetallic thermometers, shall be calibrated to at least two temperatures within a 90-day period preceding the test or series of tests. Bimetallic thermometers shall be calibrated before and after each test or series of tests. Calibration of other means of indicating or recording temperature shall be agreed upon by the interested parties.

7-7.3 Force

Force-measuring instruments shall be calibrated at a time interval to ensure the desired accuracy using secondary force-measuring standards. Secondary force-measuring standards, such as higher accuracy force transducers or force proving rings, shall be calibrated at least once per year against a standard that is traceable to a nationally recognized standard.

7-8 ADJUSTMENTS DURING TEST

If adjustments are necessary during in-service or bench testing, a sufficient number of tests shall be performed to determine final operating characteristics.

7-9 RECORDS AND TEST RESULTS

The test records shall include all observations, measurements, instrument readings, and instrument identification (if required) for the objective(s) of the test. The parties of the test shall agree upon the responsibility of record retention and distribution. Corrections to data and corrected values shall be entered separately in the test record. The test shall be reported in accordance with Section 10 of this Code.

7-10 MEASUREMENT UNCERTAINTY

A pretest determination shall be performed to determine that the limits of uncertainty of the final measurement specified in Section 1 can be met by the specified instrumentation and procedures. A post-test uncertainty analysis shall also be performed unless the parties to the test agree and verify that the specified instrumentation and procedures, including data scatter, were used and carried out in accordance with the test specification, thereby confirming the post-test validity of the pretest uncertainty determination. A guide for such determination is given in ASME PTC 19.1. These determinations shall be documented by the facility and available for review.

Section 8
Instruments and Methods of Measurements

8-1 GENERAL

This Section describes the instruments, methods, procedures, and precautions that shall be used in testing pressure relief devices under this Code. The Performance Test Code Supplements on Instruments and Apparatus provide authoritative general information concerning instruments and their use and may be consulted for such information.

8-2 INSTRUMENTATION

Where measurements of temperature, pressure, or lift are required in this Section, the instrumentation used shall comply with the following specifications.

8-2.1 Temperature

Instructions on thermometers or thermocouples and associated instruments are given in ASME PTC 19.3, except that commercial, metal-encased thermometers shall not be used in tests conducted under this Code. Other means of temperature measurement and indication may be used, provided they are of the same or greater degree of accuracy as for those described therein.

(a) Depending on operating conditions, or convenience, the temperature may be measured with certified or calibrated liquid-in-glass thermometers, bimetallic thermometers, resistance-type thermometers, or thermocouples. All of the above may be inserted directly into the pipe or wells except for liquid-in-glass thermometers, which must be inserted into wells. The installation of the temperature-measuring device directly into the pipe, without the addition of a well, is desirable for temperatures below 300°F (150°C).

(b) The following precautions shall be taken when making any temperature measurements:

(1) No significant quantity of heat shall be transferred by radiation or conduction to or from the temperature-measuring device other than by the temperature of the medium being observed (see ASME PTC 19.3).

(2) The immediate vicinity of the point of insertion and external projecting parts shall be insulated.

(3) The temperature-measuring device shall extend across the centerline in pipes of small diameter or shall be inserted at least 6 in. (150 mm) into the fluid stream in pipes over 12 in. (300 mm) in diameter.

(4) Temperature-measuring devices installed in pipes carrying compressible fluids shall, wherever possible, be installed at locations where the maximum fluid velocity does not exceed 100 ft/sec (30 m/s). Where such an installation is not possible, it may be necessary to correct the temperature readings to the appropriate static or total temperature (see Bean, 1971, para. I-3-17).

(5) The temperature-measuring devices shall be inserted in locations so as to measure temperatures that are representative of the flowing medium as described under test arrangements.

(c) Thermometer wells, when used, shall be of the type shown in ASME PTC 19.3. They shall be as thin walled and of as small a diameter as practicable; their outer surfaces shall be substantially free from corrosion or foreign matter. The well shall be filled with a suitable fluid. Mercury should not be used for this fluid since its very low-vapor pressure presents a serious health hazard to personnel.

(d) Thermocouples, if used, shall have a welded hot junction and must be calibrated together with their extension wires over the anticipated operating range. They shall be constructed of materials suitable for the temperature and fluid being measured. The electromotive force of a thermocouple shall be measured by a potentiometric instrument or millivoltmeter of such precision that the accuracy of the overall system is within the limit specified in subsection 1-3. The cold junction shall be established by an ice bath, reference standard, or compensating circuit built into the potentiometer.

8-2.2 Pressure Measurements

Instructions on pressure gages, water U-tubes, differential gages, and manometers are given in ASME PTC 19.2. Other means of pressure measurements and indication may be used provided they are of the same or greater degree of accuracy as those described therein.

(a) Pressure-measuring stations shall be located in the region where the flow is essentially parallel to the pipe or vessel wall. For the measurement of static gage-pressure differentials below 15 psi (100 kPa), liquid manometers may be used.

(b) Pressure relief device-inlet pressure shall be the static pressure as measured with a pressure tap positioned as shown in Figures 8-2.2-1 and 8-2.2-2.

Figure 8-2.2-1
Recommended Arrangement for Testing Valves With Compressible Fluids

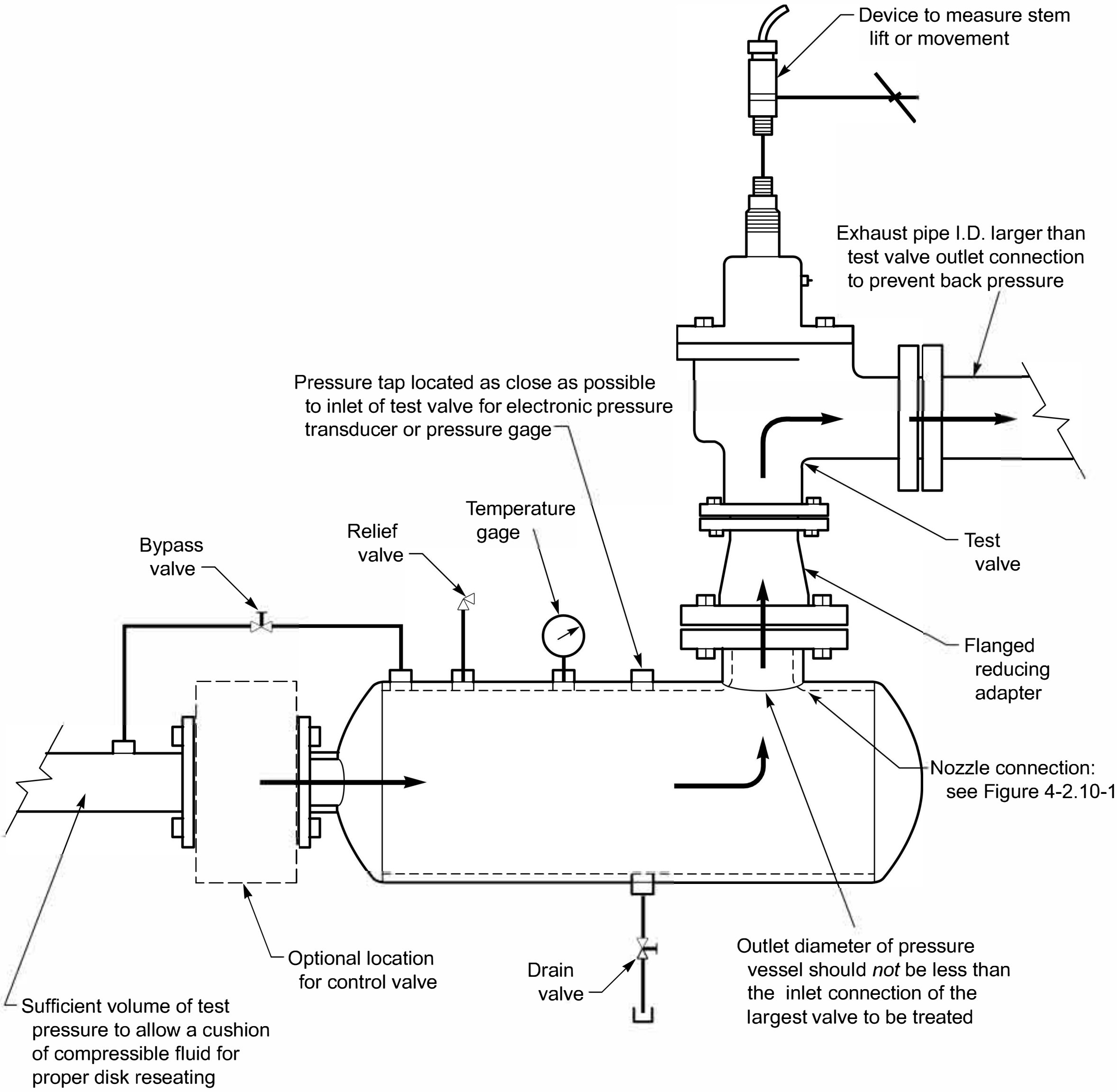
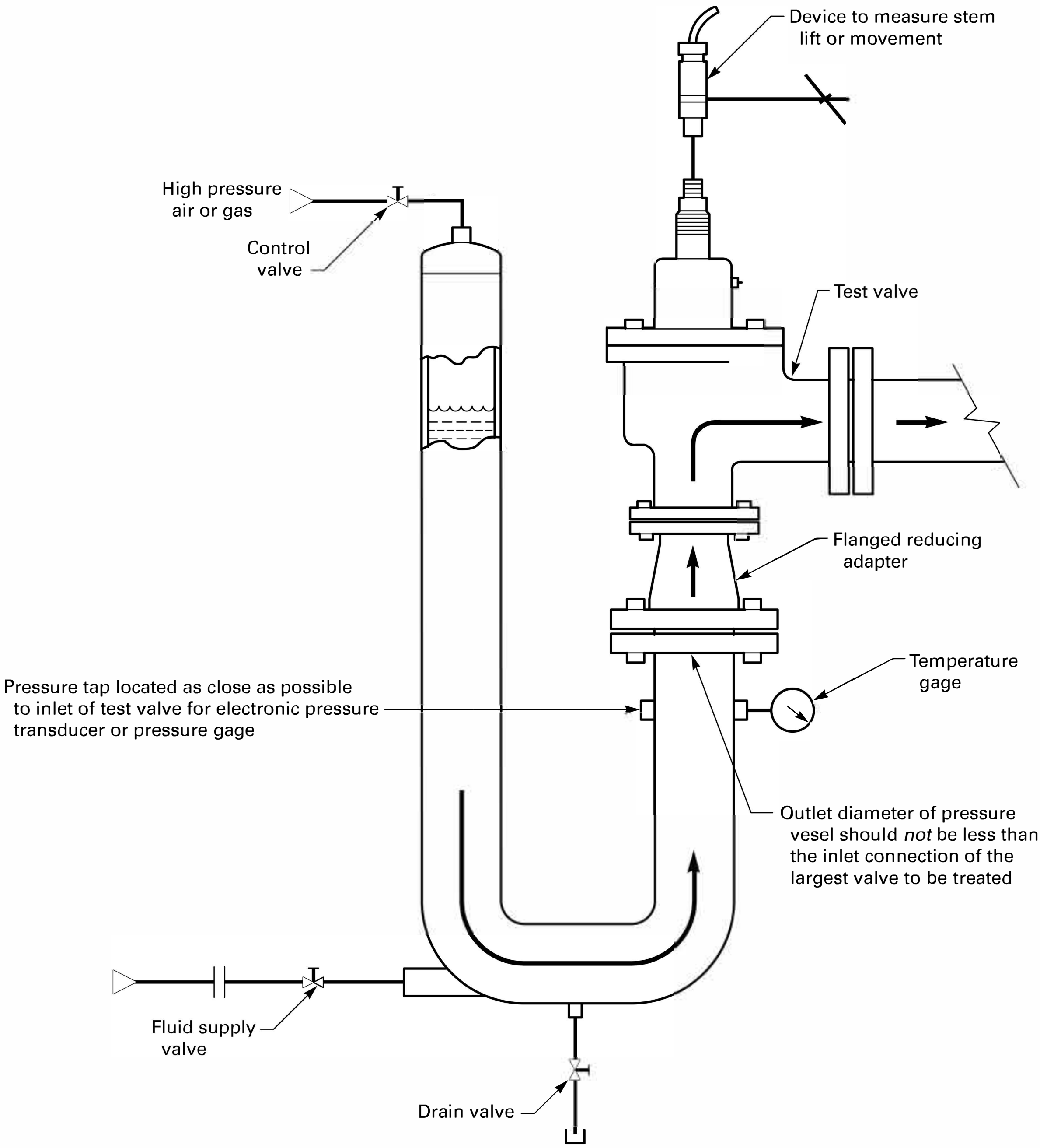


Figure 8-2.2-2
Recommended Arrangement for Testing Valves With Incompressible Fluids



(c) Back pressure shall be the static pressure measured with a pressure tap positioned as shown in Figures 4-2.10-2, 4-2.10-4, and 4-6.1-1.

(d) Proper corrections to the pressure readings shall be made if there is a height of water or other liquid between the point at which the pressure is to be measured and the pressure instrument.

8-2.3 Valve-Lift Measurements

(a) The lift of the valve disk, under testing conditions, shall be determined by suitable means to whatever degree of accuracy is imposed by the procedure under which the valve is being tested.

(b) In open- or vented-bonnet designs, when the top of the spindle may be exposed during the tests, an indicator of appropriate range may be attached to the top of the valve to indicate the movement of the spindle. In closed-bonnet valves where the top of the spindle cannot be exposed, arrangements shall be made to permit indicating, reading, or recording spindle movement outside the valve bonnet or cap. In either case, care must be exercised that the arrangement does not impose an additional load on the valve spindle or interfere with the operation of the valve.

Erroneous lift indications are possible under conditions of testing valves with fluids at elevated temperatures. The temperature of the fluid may cause thermal expansion of the valve parts, producing an erroneous initial reading on the lift indicator. When extreme accuracy in results is desired, measures shall be taken to distinguish between this thermal expansion and actual valve lift.

8-3 IN-SERVICE TESTING PROCEDURES

8-3.1 General Features of Tests

(a) These valve tests are designed to ensure service readiness for valve set pressure and operation, not necessarily to demonstrate total valve conformance to this Code or its specifications. The test methods per para. 8-3.2 or para. 8-3.3 are acceptable to meet this requirement subject to agreement between the interested parties.

(b) As a safety precaution, all operating personnel shall be properly trained in the appropriate test equipment procedures, test preparations, and emergency plans. Care shall be taken to protect personnel from elevated temperature, noise levels, and escaping fluids during testing. Prior to testing, a visual inspection of the valve is recommended. Observations should include the following as a minimum:

(1) gagging of the valve
(2) valve leakage
(3) inspection of discharge piping
(4) corrosion or residue
(5) installation of appropriate cap and lever
(6) seal integrity (to ensure against unauthorized adjustment)
(7) proper valve installation

CAUTION: Valves should be gagged during inspection when personnel are within close proximity to the valve, provided adequate overpressure protection of the system is maintained. The gag should be removed from the valve following inspection and prior to the test. Gagging of valves should be performed in accordance with the instructions outlined by the valve manufacturer.

(c) A suitable pressure measurement instrument meeting the requirements of para. 8-4.2 shall be installed at a location that allows accurate measurement of system pressure at the valve inlet. Other measurement instruments used with various test devices shall be in conformance with the requirements of the device manufacturer.

8-3.2 Test Methods

(a) Testing With System Pressure. The pressure to the valve inlet is increased until the set pressure is reached. Observe and record the set pressure of the pressure relief device and any other desired or pertinent valve characteristics. Gradually decrease the inlet pressure until the valve closes, and, if required, record the reseat pressure. This test shall be repeated such that the operational characteristics can be computed in accordance with the requirements of subsection 9-3.

Test conditions such as ambient temperature, valve temperature, fluid conditions, back pressures, and installation conditions should approximate the normal operating conditions under which the pressure relief valve would be exposed.

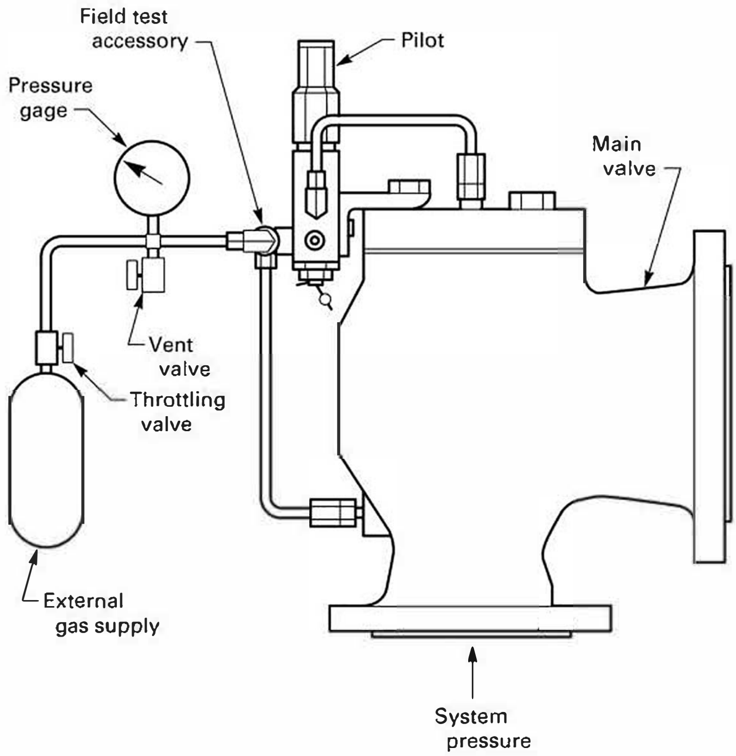
Seat leakage testing should be conducted per the requirements of subsection 8-5.

(b) Testing With Other Pressure Sources. On installations with pilot-operated pressure relief valves where increasing system pressure above normal operating pressure may not be desirable, a field test accessory may be used in accordance with the valve manufacturer's recommendations to determine set pressure. See Figure 8-3.2-1 for a typical arrangement using a field test accessory.

Tests by this method shall be repeated such that the operational characteristics can be computed in accordance with the requirements of subsection 9-3.

(c) Testing With Auxiliary Lift-Assist Devices. On valve installations where increasing system pressure above normal operating pressure may not be desirable, auxiliary lift devices may be used in accordance with the valve lift-assist device manufacturer's procedure and the manufacturer's recommendations. The valve opening is characterized by an audible sound, momentary drop in assist load, and/or system fluid release. At the time of the opening, simultaneous readings of system pressure and applied load are recorded. The load is released from the lift-assist device. Valve set pressure may be presented graphically or be calculated using measured system pressure,

Figure 8-3.2-1
Pilot-Operated Pressure Relief Valve Field Test Accessory



measured lifting force, and the effective area of the valve seat. The effective area of the valve seat can be calculated from characterization tests or tests where the lift-assist test is performed and the results compared with a full pressure test. Before initial use of the lift-assist device, function and valve effective seat area shall be validated by demonstrating that the calculated set pressure determined by the lift-assist test compares with the actual set pressure determined by a full pressure test within an acceptable deviation agreed to by the parties of the test. Validation tests may be required for the specific valve design, size, and fluid conditions of the test. This test shall be repeated such that the operational characteristics can be computed in accordance with the requirements of subsection 9-3. Valve reseat pressure cannot be determined using this test method. Valve control elements shall be set to the valve manufacturer's specification.

CAUTION: Auxiliary lift devices can cause valve damage at inlet pressure too low relative to valve-set pressure. Auxiliary lift devices may not provide reliable results if there is damage to valve internal parts or if the valve has excessive leakage.

8-3.3 In-Service Verification of Pressure-Relieving Capacity

(a) If the parties of the test agree, an approximation of the relief valve flowing capacity can be determined in-service following completion of one of the tests described in para. 8-3.2. In most cases, the purpose of such tests is to verify that the pressure-relieving devices in service are of adequate size to prevent an overpressure condition.

CAUTION: Precautions must be taken during the tests to ensure that the maximum allowable working pressure of the system being protected is not exceeded beyond permissible safe limits. Therefore, the safety procedures noted in para. 8-3.1(b) should be applied during the test.

(b) An accumulation test may be used if a quantitative value of capacity is not desired. Such a test is conducted by shutting off all the outlets from the vessel and maximizing the energy and mass flow input, which will be relieved by the pressure relief device. If the device is properly sized, the pressure in the vessel should not rise above a predetermined acceptable point. This method should not be used on a steam boiler with a superheater or reheater on a high-temperature water boiler.

(c) An estimated quantitative measure of flowing capacity can be determined for pressure relief valves mounted on steam boilers. As in the accumulation test described herein, all steam discharge outlets are shut while firing the boiler at a controlled rate sufficient to keep the valve open at a specified pressure. While maintaining steady steaming conditions over a long period of time, pressure relief valve capacity may be estimated from a measure of the rate of feed water input to the boiler.

(d) Other test arrangements may be used if agreed to by all interested parties. As an example, the arrangements may include the attachment of a vessel to the valve outlet for collection of the discharged fluid and release to atmosphere through a flowmetering device. Precautions should be taken to ensure that the built-up back pressure that may result does not affect the valve operation.

8-4 BENCH TESTING PROCEDURES

8-4.1 General Features of Tests

There shall be assurance that the pressure relief devices are properly assembled with components that meet the design specification requirements. The pressure relief device shall be clean and ready for test.

The pressure relief device to be tested shall be installed on a test vessel with adapter fittings (flanged, screwed, welded, etc.). See Figure 4-2.10-1 for acceptable adapter fitting contours for minimum inlet pressure drop. Other adapter fittings may be used provided the accuracy of the test is not affected. Operating and environmental conditions shall be maintained in accordance with the requirements of the procedure used. The duration of the test shall be that required to obtain the necessary performance data under stable conditions.

8-4.2 Compressible Fluids

(a) Valves marked for steam service shall be tested on steam. Valves marked for air, gas, or vapor service shall be tested with air or gas.

(b) Pressure relief valve-inlet pressure shall be the static pressure as measured with a pressure tap positioned as shown in Figure 8-2.2-1.

NOTE: For steam testing, the quality of the steam may affect the operational characteristics of the valve. The steam quality may be affected by inadequate moisture separation, an underheated test vessel, and/or improper steam trap operation.

(c) Increase the pressure at the valve inlet to 90% of the expected set pressure. Then increase at a rate equal to 2% of set pressure per second or at a rate that permits accurate pressure readings. Observe and record the set pressure and other pertinent valve characteristics. Decrease the inlet pressure until the valve closes.

This test shall be repeated such that operational characteristics can be computed in accordance with subsection 9-3.

(d) To obtain an accurate reseat pressure measurement, an adequate volume of test medium is required at the valve inlet. When determining this volume, consideration must be given to the cycle time and size of the device being tested relative to the rate of supply of the test medium.

8-4.3 Incompressible Fluids

(a) Valves marked for liquid service shall be tested with water or another suitable liquid.

(b) Pressure relief valve-inlet pressure shall be the static pressure as measured with a pressure tap positioned as shown in Figure 8-2.2-2.

(c) Same as para. 8-4.2(c).

8-5 SEAT TIGHTNESS TEST

Seat tightness can be determined, when required, using API Standard 527 or another method agreed to by the parties of the test. These methods may include wet paper towel, soap bubble, cold bar, mirror, or fluid collection tests.

Section 9
Computation of Results

9-1 CORRECTION OF MEASURED VARIABLES

The values of measured variables shall be corrected in accordance with instrument calibrations. No other corrections to the data are permitted.

9-2 REVIEW OF INSTRUMENT READINGS

Before calculations are undertaken, the instrument readings recorded in the log shall be reviewed for inconsistency and large fluctuation in accordance with ASME PTC 19.1.

9-3 COMPUTATION OF OPERATIONAL CHARACTERISTICS

When specified in Section 8 to determine specific operational characteristics, the result will be computed as per paras. 9-3.1 through 9-3.3.

9-3.1 Set Pressure

The computed set pressure will be the average of at least the last three measured set pressures once established and stabilized. A set pressure is considered stable when the measured set pressures show no significant upward or downward trend whereby all are within ±1% or ±0.5 psi (4 kPa), whichever is greater, of the computed set pressure.

9-3.2 Blowdown

The computed blowdown shall be the average of the individual blowdowns of those tests used to determine the computed set pressure in para. 9-3.1.

9-3.3 Lift

The computed lift shall be the average of the individual lift measurements of those tests used to determine the computed set pressure.

Section 10
Test Summary Report Form

10-1 GENERAL INSTRUCTIONS

(a) The Report of Test shall be prepared for the purpose of formally recording observed data and computed results. It shall contain sufficient supporting information to prove that all objectives of any tests conducted in accordance with this Code have been attained.

(b) The procedures described in Section 9 are recommended for use in computing the test results.

(c) The Report of Test shall include Parts I to IV as listed in (1) through (4) herein and may include any of the remaining parts as agreed to by the contracting parties.

(1) Part I: General Information
(2) Part II: Summary of Results
(3) Part III: Description of Valve Under Test
(4) Part IV: Observed Data and Computed Results
(5) Part V: Contract and Agreed Test Conditions Corrections
(6) Part VI: Test Methods and Procedures
(7) Part VII: Supporting Data

Subsections 10-2 through 10-8 give a discussion of each Part of the Test Report.

10-2 PART I: GENERAL INFORMATION

This Part shall include the following items:

(a) date of test
(b) location of test facilities
(c) valve manufacturer's name
(d) valve type or model number
(e) valve identification
(f) marked set pressure
(g) inlet and outlet connection sizes
(h) person conducting test
(i) operational characteristics to be measured
(j) test fluid

10-3 PART II: SUMMARY OF RESULTS

This Part shall include those computed values with units of measurement and characteristics listed in subsection 10-2 that describe the performance of the valve at test conditions.

10-4 PART III: DESCRIPTION OF VALVE UNDER TEST

This Part may include assembly drawings, manufacturing drawings, and measured dimensions. Manufacturing drawings for these parts may be submitted with the assembly drawing. The dimensions of these parts shall include the following, if applicable:

(a) bore diameter, in. (mm)
(b) seat diameter, in. (mm)
(c) seat angle, deg
(d) inlet opening diameter, in. (mm)
(e) ratio of throat diameter to the diameter of the inlet opening
(f) actual discharge area, in.^{2} (mm^2)

10-5 PART IV: OBSERVED DATA AND COMPUTED RESULTS

This Part shall include a record of data and calculations required for the results of the tests. The data shall have been corrected for instrument calibrations and conditions prevailing for each test run.

10-6 PART V: CONTRACT AND AGREED TEST CONDITIONS CORRECTIONS

Operating conditions, such as the following, that have been agreed upon prior to the test shall be reported for each test:

(a) valve-maximum-inlet pressure
(b) valve-inlet temperature
(c) valve temperature profile

10-7 PART VI: TEST METHODS AND PROCEDURES

This Part shall include a description of the instruments and apparatus used to measure the various quantities and procedures for observing the mechanical characteristics of the valve under test.

10-8 PART VII: SUPPORTING DATA

This Part shall include pertinent material supplementing data presented elsewhere in the report, whereby an independent verification of the report results can be made. This material may include, but not necessarily be limited to, the following:

(a) instrument calibration records
(b) detailed log sheets
(c) sample calculations
(d) graphical presentation of data

MANDATORY APPENDIX I
SI (METRIC) UNITS AND CONVERSION FACTORS

See Tables I-1 and I-2.

Table I-1
SI (Metric) Units

Quantity	Unit	Symbol	Other Units or Limitations
Space and Time			
Plane angle	radian	rad	degree (decimalized)
Length	meter	m	...
Area	square meter	m^2	...
Volume	cubic meter	m^3	liter (L) for fluids only (use without prefix)
Time	second	s	minute (min), hour (h), day, week, and year (y)
Periodic and Related Phenomena			
Frequency	hertz	Hz	hertz = cycle per second
Rotational speed	radian per second	rad/s	revolutions per minute (rpm)
Fluence	nvt	...	...
Neutron energy	MeV	E_n	...
Sound (pressure level)	decibel	db	...
Mechanics			
Mass	kilogram	kg	...
Density	...	kg/m^3	...
Moment of inertia	...	$kg{\cdot}m^2$	...
Force	newton	N	...
Moment or force (torque)	newton-meter	N·m	...
Pressure and stress	pascal	Pa	pascal = newton per square meter
Energy, work	joule	J	kilowatt-hour (kW·h)
Power	watt	W	...
Impact strength	joule	J	...
Section modulus	cubic meter	m^3	...
Moment of section (second moment of area)	...	m^4	...
Fracture tougheners	$Pa{\cdot}\sqrt{m}$	K_{1C}	...
Heat			
Temperature (thermodynamic) [Note (1)]	kelvin	K	degree Celsius (°C)
Temperature (other than thermodynamic)	degree Celsius	°C	kelvin (K)
Linear expansion coefficient	...	K^{-1}	$°C^{-1}$
Quantity of heat	joule	J	...
Heat flow rate	watt	W	...
Thermal conductivity	...	W/(m·K)	W/(m·°C)
Thermal diffusivity	...	m^2/s	...
Specific heat capacity	...	J/(kg·K)	J/(kg·°C)
Electricity and Magnetism			
Electric current	ampere	A	...
Electric potential	volt	V	...
Current density	...	A/m^2	...
Electrical energy	watt	W	...
Magnetization current	ampere/meter	A/m	...
Light			
Illumination	lux	lx	...
Wavelength	angstrom	Å	...

NOTE: (1) Preferred use for temperature and temperature interval is degree Celsius (°C), except for thermodynamic and cryogenic work where kelvins may be more suitable. For temperature interval, 1K = 1°C exactly.

Table I-2
Commonly Used Conversion Factors

Quantity	Conversion From	Conversion To	Multiplication Factor [Notes (1)-(3)]
Plane angle	degree	rad	1.745 329 E−02
Length	in.	m	2.54* E−02
	ft	m	3.048* E−01
	yd	m	9.144* E−01
Area	in.^{2}	m^2	6.451 6* E−04
	ft^2	m^2	9.290 34* E−02
	yd^2	m^2	8.361 274 E−01
Volume	in.^{3}	m^3	1.638 706 E−05
	ft^3	m^3	2.831 685 E−02
	U.S. gallon	m^3	3.785 412 E−05
	Imperial gallon	m^3	4.546 090 E−03
	liter	m^3	1.0* E−03
Mass	lb (avoir.)	kg	4.535 924 E−01
	ton (metric)	kg	1.000 00* E+03
	ton (short 2,000 lbm)	kg	9.071 847 E+02
Force	kgf	N	9.806 65* E+00
	lbf	N	4.448 222 E+00
Bending, torque	kgf-m	N·m	9.806 65* E+00
	lbf-in.	N·m	1.129 848 E−01
	lbf-ft	N·m	1.355 818 E+00
Pressure, stress	kgf/m^2	Pa	9.806 65* E+00
	lbf/ft^2	Pa	4.788 026 E−01
	lbf/in.^{2} (psi)	Pa	6.894 757 E+03
	kips/in.^{2}	Pa	6.894 757 E+06
	bar	Pa	1.0* E−05
	in. water (60°F)	Pa	2.488 4 E+02
Energy, work	Btu (IT) [Note (4)]	J	1.055 056 E+03
	ft-lbf	J	1.355 818 E+00
Power	hp (550 ft-lbf/sec)	W	7.456 999 E+02
Temperature	°C	K	$t_K = t_C + 273.15$
	°F	K	$t_K = (t_F + 459.67)/1.8$
	°F	°C	$t_C = (t_F - 32)/1.8$
Temperature interval	°C	K	1.0* E+00
	°F	K or °C	5.555 556 E−01
Viscosity, dynamic	lbf-sec/ft^2	Pa·s	4.788 026 E+01
	lbm/ft-sec	Pa·s	1.488 164 E+00

GENERAL NOTE: A more extensive list of conversion factors between SI (metric) units and U.S. Customary units is given in ASME SI-1 and ASTM E380.

NOTES:
(1) The factors are written as a number greater than 1 and less than 10 with six decimal places. The number is followed by the letter "E" (for exponent), a plus or minus symbol, and two digits that indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example, 3.523907 E−02 is 3.523907 × 10^{-2} or 0.035239 07.
(2) Relationships that are exact in terms of the base units are followed by a single asterisk.
(3) Precaution should be taken when making conversions for metric units that constants are adjusted to their metric values.
(4) International table.

MANDATORY APPENDIX II EXAMPLES OF DETERMINING FLOW RATE UNCERTAINTIES

II-1 PURPOSE

The purpose of this Mandatory Appendix is to present an example of the various methods used to establish meaningful estimates for the limits of uncertainty of the final flow measurement specified in subsection 1-3. The terms and methods described in ASME PTC 19.1-2013 were used in this example to establish the estimate of measurement uncertainty. The techniques and procedures specified in ASME PTC 25 and ASME PTC 19.5 were used in this example for determination of valve flow rates. This Appendix is not intended to be definitive, and the latest editions of ASME PTC 19.1 and ASME PTC 19.5 should be consulted for possible updates to equations and terminology.

II-2 EXAMPLE DETERMINATION

Meter type:	ASME concentric thin-plate square-edged orifice with flange taps
Purpose:	Establish estimate for limits of uncertainty for flow test results
Medium:	Water
Assumption:	The coefficient for the meter has not been calibrated against a standard.

The following is a typical set of test data:

Diameter of meter:	D = 3.117 in. (79.17 mm)
Diameter of orifice plate:	d_o = 0.935 in. (23.75 mm)
Pressure drop across meter:	ΔP = 387.8 in. (9850 mm) water
Temperature:	T = 77°F (26°C)
Beta ratio:	$\beta = d_o/D$ = 0.300

Define the functional relationship

(U.S. Customary Units)

$$m = \frac{358.93\, C\, d_o^2 F_a \sqrt{\rho(\Delta P)}}{\sqrt{1 - \left(\frac{d_o}{D}\right)^4}} \tag{II-2-1}$$

(SI Units)

$$m = \frac{12\,510\, C\, d_o^2 F_a \sqrt{\rho(\Delta P)}}{\sqrt{1 - \left(\frac{d_o}{D}\right)^4}}$$

where

C = discharge coefficient, dimensionless
D = diameter of meter, in. (mm)
d_o = diameter of orifice plate, in. (mm)
F_a = thermal expansion number, dimensionless
m = mass flow rate, lbm/hr (kg/h)
ΔP = differential pressure head across meter, in. water (mm water)
ρ = water density, lbm/ft^3 (kg/m^3)

List elemental error sources, and list estimated systematic and precision errors for each [see Table II-2-1 (Table II-2-1M)].

II-2.1 Parameter *C* — Discharge Coefficient

Per Benedict (1977), the discharge coefficient for orifice plate meters is characterized by a systematic error of ±0.55% for pipes 2 in. (50 mm) and greater with Reynolds numbers exceeding

(a) 5,000 × D, where D is in inches
(b) 200 × D, where D is in millimeters

Also, ASME PTC 19.5 recommends that a 0.5% margin be added to all other identified systematic errors to account for installation variations.

The total relative systematic error for C is determined as follows:

$$B_{C\%} = 0.5\% + 0.55\% = 1.05\%$$

The coefficient of discharge is calculated based on the equations listed in ASME PTC 19.5.

The calculated value for C is 0.599.

The absolute value for the systematic limit is

$$B_C = (0.0105)(0.599) = 0.00627 \approx 0.007$$

The absolute precision error for the coefficient of discharge is zero.

Table II-2-1
Table of Uncertainty Parameters — U.S. Customary Units

Parameter	Absolute Systematic Error, B	Absolute Precision Error, S	Nominal Value (Based on Test Data)	Relative Systematic Error, B_R	Relative Precision Error, S_R	Relative Sensitivity Coefficient, θ^1
C	±0.007	0	0.599	$\frac{0.007}{0.599} = \pm 0.0117$	0	1
d_o	±0.001 in.	0	0.935 in.	$\frac{0.001}{0.935} = \pm 0.00107$	0	$\frac{2}{1-\beta^4} = 2.0163$
D	±0.003 in.	0	3.117 in.	$\frac{0.003}{3.117} = \pm 0.00096$	0	$\frac{2\beta^4}{1-\beta^4} = 0.0163$
F_a	0	0	1.00002	0	0	1
ρ	±0.04 lbm/ft^3	±0.02 lbm/ft^3	62.25 lbm/ft^3	$\frac{0.04}{62.25} = \pm 0.00064$	$\frac{0.02}{62.25} = \pm 0.00032$	0.5
ΔP	11 in. water	5 in. water	387.8 in. water	$\frac{11}{387.8} = \pm 0.02836$	$\frac{5}{387.8} = \pm 0.01290$	0.5

Table II-2-1M
Table of Uncertainty Parameters — SI Units

Parameter	Absolute Systematic Error, B	Absolute Precision Error, S	Nominal Value (Based on Test Data)	Relative Systematic Error, B_R	Relative Precision Error, S_R	Relative Sensitivity Coefficient, θ^1
C	±0.007	0	0.599	$\frac{0.007}{0.599} = \pm 0.0117$	0	1
d_o	±0.025 mm	0	23.75 mm	$\frac{0.025}{23.75} = \pm 0.00105$	0	$\frac{2}{1-\beta^4} = 2.0163$
D	±0.075 mm	0	79.19 mm	$\frac{0.075}{79.19} = \pm 0.00095$	0	$\frac{2\beta^4}{1-\beta^4} = 0.0163$
F_a	0	0	1.0001	0	0	1
ρ	±0.64 kg/m^3	±0.32 kg/m^3	997.1 kg/m^3	$\frac{0.64}{997.1} = \pm 0.00064$	$\frac{0.32}{997.1} = \pm 0.00032$	0.5
ΔP	260 mm water	125 mm water	9 850 mm water	$\frac{260}{9\,850} = \pm 0.0264$	$\frac{125}{9\,850} = \pm 0.01269$	0.5

II-2.2 Parameter d_o — Diameter of Orifice Plate

The estimated systematic error for the orifice plate diameter is ±0.001 in. (±0.025 mm). This absolute systematic error estimate accounts for the inaccuracies in the measurement device and the potential personnel error in reading the measurement device.

The absolute precision error for the orifice plate diameter is zero.

II-2.3 Parameter D — Diameter of Meter

The estimated systematic error for the meter diameter is ±0.003 in. (±0.075 mm). This estimate in absolute systematic error accounts for both measurement device and personnel inaccuracies.

The absolute precision error for the meter diameter is zero.

II-2.4 Parameter F_a — Thermal Expansion Number

$$F_a = \int (T)$$

where

T = water temperature, °F (°C)

Per ASME MFC-3M–1989, Appendix E, F_a is determined from the following equation:

$$F_a = 1 + \frac{2}{1-\beta^4}(\alpha_{PE} - \beta^4 \alpha_p)(T - T_{ref})$$

where

β = 0.300 from above
T_{ref} = 68°F (20°C)
α_P = 6.05×10^{-6} (1.089×10^{-5}) (for carbon steel pipe)
α_{PE} = 9.08×10^{-6} (1.635×10^{-5}) (for 316 orifice plate)

The coefficients of thermal expansion are referenced from ASME PTC 19.5, Tables F-1-1 and F-1-2 and are assumed to be constant for the range in allowable temperature error used for the following derivation:

(U.S. Customary Units)

$$F_a = 1 + \frac{2}{1-(0.300)^4}\left[9.08 \times 10^{-6} - 0.300^4\left(6.05 \times 10^{-6}\right)\right](T-68)$$

$$F_a = 1 + (2.0163)\left(9.031 \times 10^{-6}\right)(T-68)$$

$$F_a = \left(1.8209 \times 10^{-5}\right)(T) + 0.9988$$

$$B_{Fa} = \frac{\partial F_a}{\partial T}(B_T)$$

$$\frac{\partial F_a}{\partial T} = \frac{dF_a}{dT} = 1.8209 \times 10^{-5}$$

where

B_{Fa} = $(1.8209 \times 10^{-5})(5) = \pm 0.00009$

B_T = assumed to be ±5°F

F_a based on a nominal temperature of 77°F is

F_a = $(1.8209 \times 10^{-5})(77) + 0.9988$

= 1.0002 at 77°F

(SI Units)

$$F_a = 1 + \frac{2}{1-(0.300)^4}\left[1.635 \times 10^{-5} - 0.300^4\left(1.089 \times 10^{-5}\right)\right](T-20)$$

$$F_a = 1 + (2.0163)\left(1.6262 \times 10^{-5}\right)(T-20)$$

$$F_a = \left(3.2789 \times 10^{-5}\right)(T) + 0.9993$$

$$B_{Fa} = \frac{\partial F_a}{\partial T}(B_T)$$

$$\frac{\partial F_a}{\partial T} = \frac{dF_a}{dT} = 3.2789 \times 10^{-5}$$

where

B_{Fa} = $(3.2789 \times 10^{-5})(3) = \pm 0.00010$

B_T = assumed to be ±3°C

F_a based on a nominal temperature of 26°C is

F_a = $(3.2789 \times 10^{-5})(26) + 0.9993$

= 1.0001 at 26°C

The relative variation in F_a for a 5°F (3°C) error in water temperature would equate to

(U.S. Customary Units)

$$\text{\% error } F_a = \frac{0.00009}{1.00002} = 0.01\%$$

(SI Units)

$$\text{\% error } F_a = \frac{0.00010}{1.00001} = 0.01\%$$

Therefore, the absolute systematic error is considered zero.

The absolute precision error for the thermal expansion number, F_a, is zero.

II-2.5 Parameter ρ — Density of Water

$$\rho = \int(TP)$$

where

P = pressure, psia (kPa)

T = water temperature, °F (°C)

Water density, ρ, is determined from Table 3 of the ASME Steam Tables (1971).

The variation in ρ due to pressure is negligible and not considered.

The variation in ρ due to a ±5% error in water temperature would equate to

$$B_\rho = \pm\ 0.03875$$

The absolute systematic error for ρ is taken as ±0.04 lb/ft^3 (±0.64 kg/m^3).

The absolute precision error, S_ρ, for water density is estimated from past experience to be ±0.02 lbm/ft^3 (±0.32 kg/m^3).

II-2.6 Parameter ΔP — Differential Pressure Head Across Meter, in. (mm) Water

ΔP is measured on a strip chart recorder that is calibrated using a transfer gage with a range of 0 in. (0 mm) water to 1,000 in. (25 400 mm) water. The transfer gage is in turn calibrated using a deadweight tester.

The systematic error limit for the strip chart recorder is based on one-half the smallest subdivision, which is ±10 in. (±250 mm) water.

The accepted tolerance for the transfer gage is ±0.25% of full scale, which equates to an absolute systematic error of ±2.5 in. (±63.5 mm) water.

The calibrator (deadweight tester) for the transfer gage is two times as accurate as the transfer gage, and the systematic error induced is ±0.3 in. (±7.6 mm) water. See Taylor (1988), pages 54 to 55.

The RSS technique for combining the systematic errors in water yields

(U.S. Customary Units)

$$B_{\Delta P} = \left[(10)^2 + (2.5)^2 + (0.3)^2\right]^{1/2} = 10.3 \approx 11.0$$

(SI Units)

$$B_{\Delta P} = \left[(250)^2 + (63.5)^2 + (7.6)^2\right]^{1/2} = 258 \approx 260$$

The absolute precision error $S_{\Delta P}$ for the meter differential pressure is estimated based on previous experience to be ±5 in. (±125 mm) water.

II-2.7 Uncertainty Calculation

All the absolute and relative systematic and precision errors are tabulated in the following equations. Also tabulated for each parameter are the relative sensitivity coefficients, θ', which were determined in accordance with ASME PTC 19.1-2005.

The individual parameter errors are propagated separately for systematic and precision into the result according to a Taylor (1988) series expansion.

The relative systematic error for the flow rate is

$$\frac{B_m}{m} = \left[\left(1 \times \frac{B_c}{C}\right)^2 + \left(\frac{2}{1-\beta^4} \times \frac{B_{d_o}}{d_o}\right)^2 + \left(\frac{2\beta^4}{1-\beta^4} \times \frac{B_D}{D}\right)^2 + \left(1 \times \frac{B_{F_a}}{F_a}\right)^2 + \left(0.5 \times \frac{B_\rho}{\rho}\right)^2 + \left(0.5 \times \frac{B_{\Delta P}}{\Delta P}\right)^2\right]^{1/2} \tag{II-2-2}$$

The relative precision error for the flow rate is

$$\frac{S_m}{m} = \left[\left(1 \times \frac{S_c}{C}\right)^2 + \left(\frac{2}{1-\beta^4} \times \frac{S_{d_o}}{d_o}\right)^2 + \left(\frac{2\beta^4}{1-\beta^4} \times \frac{S_D}{D}\right)^2 + \left(1 \times \frac{S_{F_a}}{F_a}\right)^2 + \left(0.5 \times \frac{S_\rho}{\rho}\right)^2 + \left(0.5 \times \frac{S_{\Delta P}}{\Delta P}\right)^2\right]^{1/2} \tag{II-2-3}$$

Substituting the appropriate values into eqs. (II-2-2) and (II-2-3)

(U.S. Customary Units)

$$\begin{aligned}\frac{B_m}{m} &= \left[(0.0117)^2 + (2.016 \times 0.00107)^2\right] + (0.0163 \times 0.00096)^2 + (0) + (0.5 \times 0.00064)^2 + (0.5 \times 0.02836)^2\Big]^{1/2} \\ &= \left(0.0001370 + 0.0000046 + 2.45 \times 10^{-10} + 0 + 1.02 \times 10^{-7} + 0.0002011\right)^{1/2} \\ &\pm 0.0185\end{aligned} \tag{II-2-4}$$

(SI Units)

$$\begin{aligned}\frac{B_m}{m} &= \left[(0.0117)^2 + (2.016 \times 0.00105)^2\right] + (0.0163 \times 0.00095)^2 + (0) + (0.5 \times 0.00064)^2 + (0.5 \times 0.0264)^2\Big]^{1/2} \\ &= \left(0.0001370 + 0.0000045 + 2.398 \times 10^{-10} + 0 + 1.02 \times 10^{-7} + 0.0001742\right)^{1/2} \\ &\pm 0.0178\end{aligned}$$

(U.S. Customary Units)

$$\begin{aligned}\frac{S_m}{m} &= \pm[(0) + (0) + (0) + (0) + (0.5 \times 0.00032)^2 + (0.5 \times 0.01290)^2\Big]^{1/2} \\ &= \pm\left(2.5 \times 10^{-8} + 0.0000416\right)^{1/2} \\ &= \pm 0.0065\end{aligned} \tag{II-2-5}$$

(SI Units)

$$\begin{aligned}\frac{S_m}{m} &= \pm[(0) + (0) + (0) + (0) + (0.5 \times 0.00032)^2 + (0.5 \times 0.01289)^2\Big]^{1/2} \\ &= \pm\left(2.5 \times 10^{-8} + 0.0000415\right)^{1/2} \\ &= \pm 0.0065\end{aligned}$$

Examination of the individual factors for each parameter in eqs. (II-2-4) and (II-2-5) clearly indicates which parameters contribute most to the systematic and precision error limits of the result. In this example, the largest contributors to the systematic error limit are the differential pressure, ΔP, and the discharge coefficient, C. The largest contributor to the precision error limit is the differential pressure measurement, ΔP.

Since all the estimates for precision errors of the independent parameters are based on experience, the degrees of freedom can be assumed to be greater than 30, so that the t value can be taken as 2. Therefore, the relative precision error limit is (2)(0.0065) = ±0.013.

The total uncertainty in the flow rate can be obtained by combining the systematic and precision errors as follows:

(U.S. Customary Units)

$$\frac{U_{RSS}}{m} = \left[\left(\frac{B_m}{m}\right)^2 + \left(2 \times \frac{S_m}{m}\right)^2\right]^{1/2} \quad \text{(II-2-6)}$$

$$= \left[(0.0185)^2 + (2 \times 0.0065)^2\right]^{1/2}$$

$$= \pm 2.26\% \text{ at} \sim 95\% \text{ coverage}$$

(SI Units)

$$\frac{U_{RSS}}{m} = \left[\left(\frac{B_m}{m}\right)^2 + \left(2 \times \frac{S_m}{m}\right)^2\right]^{1/2}$$

$$= \left[(0.0178)^2 + (2 \times 0.0065)^2\right]^{1/2}$$

$$= \pm 2.20\% \text{ at} \sim 95\% \text{ coverage}$$

Note that the requirement of ASME PTC 25 for $m \pm 2\%$ has not been achieved.

The largest contributor to uncertainty is the differential pressure, ΔP. The first step is to eliminate the transfer gage for calibration of the strip chart recorder. The strip chart recorder will be calibrated directly using a deadweight tester.

The systematic error limit for the deadweight tester is ±0.1% of full scale. The full scale range for the deadweight tester is 0 in. (0 mm) water to 500 in. (12 700 mm) water. The absolute systematic error limit is 0.001 × 500 = 0.5 in. water (0.001 × 12 700 = 12.7 mm water).

In addition, the calibration range for ΔP is changed to reduce the smallest subdivision on the strip chart recorder from 20 in. (500 mm) water to 10 in. (250 mm) water. The systematic error limit is based on one-half the smallest subdivision, which results in a reduction of the bias error limit from 10 in. (250 mm) water to 5 in. (125 mm) water.

The RSS technique for combining systematic errors is used to recalculate the absolute systematic error for ΔP:

(U.S. Customary Units)

$$B_{\Delta P} = \left[(5)^2 + (0.5)^2\right]^{1/2} = 5.02 \text{ in. water}$$

(SI Units)

$$B_{\Delta P} = \left[(125)^2 + (12.7)^2\right]^{1/2} = \pm 125.6 \text{ mm water}$$

Round up to 6 in. (150 mm) water.

The revised relative systematic error is

(U.S. Customary Units)

$$(B_{\Delta P})_R = \frac{6}{387.8} = 0.01547$$

(SI Units)

$$(B_{\Delta P})_R = \frac{150}{9850} = 0.01523$$

The revised value for $\frac{B_m}{m}$ is

(U.S. Customary Units)

$$\frac{B_m}{m} = 0.0145$$

(SI Units)

$$\frac{B_m}{m} = \pm 0.0136$$

Combining systematic and precision errors yields

(U.S. Customary Units)

$$\frac{U_{RSS}}{m} = 1.959 \text{ at} \sim 95\% \text{ coverage}$$

(SI Units)

$$\frac{U_{RSS}}{m} = \pm 1.881 \text{ at} \sim 95\% \text{ coverage}$$

The mass flow rate, m, based on the nominal values noted herein is 29,300 lbm/hr (13 290 kg/h).

The following test was conducted to verify the estimate for the precision error index.

All instruments were calibrated in accordance with the tolerance limits stated herein.

A steady-state flow test was conducted with the 0.935-in. (23.75-mm) diameter orifice plate. The temperature was a constant 77°F (26°C) for the entire test. During the test, ten separate sets of data were taken to establish the precision error limit of uncertainty. The results of the test are as follows:

Data Set	m
1	29,410 (13 340)
2	29,280 (13 280)
3	29,170 (13 230)
4	29,320 (13 300)
5	29,190 (13 240)
6	29,450 (13 360)
7	29,305 (13 290)
8	29,260 (13 270)
9	29,380 (13 330)
10	29,350 (13 310)

$\bar{x}$, average value m for sample, is

(U.S. Customary Units)

$$\bar{x} = \frac{1}{N}\sum_{k=1}^{N} X_k = \frac{1}{10}(293{,}115) = 29{,}311\ \text{lbm/hr}$$

(SI Units)

$$\bar{x} = \frac{1}{N}\sum_{k=1}^{N} X_k = \frac{1}{10}(132950) = 13295\ \text{kg/h}$$

The sample standard deviation is

(U.S. Customary Units)

$$S = \left[\frac{\sum_{k=1}^{N}(X_k - \bar{x})^2}{N-1}\right]^{1/2} = 90.4\ \text{lbm/hr}$$

(SI Units)

$$S = \left[\frac{\sum_{k=1}^{N}(X_k - \bar{x})^2}{N-1}\right]^{1/2} = \pm 42.0\ \text{kg/h}$$

Degrees of freedom $N - 1 = 10 - 1 = 9$.

The t value for the 95 percentile point for a two-tailed Student's t distribution with 9 degrees of freedom is 2.262.

Relative precision error limit is calculated as follows:

(U.S. Customary Units)

$$\frac{S_m}{m} = \pm\frac{90.4}{29{,}311}(2.262) = \pm 0.0069$$

(SI Units)

$$\frac{S_m}{m} = \pm\frac{42.0}{13295}(2.262) = \pm 0.0071$$

This value is roughly half the original estimated. Combining the new precision error limit obtained by test with the systematic error estimate yields

(U.S. Customary Units)

$$\frac{U_{RSS}}{m} = \pm\left[(0.0145)^2 + (0.0069)^2\right]^{1/2} = \pm 0.016$$
$$= \pm 1.6\%\ \text{at} \sim 95\%\ \text{coverage, precision (process) error}$$

(SI Units)

$$\frac{U_{RSS}}{m} = \pm\left[(0.0136)^2 + (0.0071)^2\right]^{1/2} = \pm 0.015$$
$$= \pm 1.5\%\ \text{at} \sim 95\%\ \text{coverage, precision (process) error}$$

Note that the test objective of ±2% has been achieved; however, the uncertainty error limits can be further reduced by conducting calibration tests to better define the meter coefficient of discharge.

The report summary is as follows:

(U.S. Customary Units)

$$\frac{B_m}{m} = \pm 0.0145,\ \text{systematic error}$$
$$\frac{S_m}{m} = \pm 0.0069,\ \text{uncertainty of mass flow rate}$$
$$\frac{U_{RSS}}{m} = \pm 1.6\%\ \text{at} \sim 95\%\ \text{coverage, precision (process) error}$$

(SI Units)

$$\frac{B_m}{m} = \pm 0.0136,\ \text{systematic error}$$
$$\frac{S_m}{m} = \pm 0.0071,\ \text{uncertainty of mass flow rate}$$
$$\frac{U_{RSS}}{m} = \pm 1.5\%\ \text{at} \sim 95\%\ \text{coverage, precision (process) error}$$

II-3 REFERENCES

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MANDATORY APPENDIX III EXAMPLE OF PRESSURE TAP PROFILE COMPARISON

III-1 PURPOSE

This Appendix presents an example of the calibration procedure described in para. 3-9.2 for flow resistance test rigs.

III-2 EXAMPLE DETERMINATION

III-2.1 Sample Data

Table III-2.1-1 lists sample data from a flow resistance test conducted according to subsection 4-9. Calculated values were determined using Form 5-5.7-1 (Form 5-5.7-1M).

Table III-2.1-1
Sample Test Data

Parameter	Calculated Values
Ratio of specific heats, k	1.405
Test rig inside diameter, D	0.085 ft (0.025908 m)
Actual pipe length to tap A, L_A	5.608 ft (1.709 m)
Actual pipe length to tap B, L_B	8.223 ft (2.506 m)
Actual pipe length to tap C, L_C	9.457 ft (2.882 m)
Actual pipe length to tap D, L_D	12.082 ft (3.683 m)
Actual length between taps A and B, $L_{A\text{-}B}$	2.615 ft (0.79705 m)
Actual length between taps C and D, $L_{C\text{-}D}$	2.625 ft (0.8001 m)
Mach number at pipe entrance, M_1	0.375094230450
Expansion factor at pipe entrance, Y_1	1.02849087555
Pressure at pipe entrance, P_1	52.92760355 psia (364.923 kPa)
Tap A pressure, P_A	43.0240195 psia (296.6402 kPa)
Tap B pressure, P_B	38.561844 psia (265.8746 kPa)
Tap C pressure, P_C	36.0269315 psia (248.3969 kPa)
Tap D pressure, P_D	28.9483255 psia (199.5917 kPa)
Total resistance factor to tap A, K_A	1.3389762771
Total resistance factor to tap B, K_B	1.8082572438
Total resistance factor to tap C, K_C	2.0365010346
Total resistance factor to tap D, K_D	2.5214688060
Resistance between taps A and B, $K_{A\text{-}B}$	0.469280967
Resistance between taps C and D, $K_{C\text{-}D}$	0.484967771

III-2.2 Calculations

Step 1 (From Para. 3-9.2, Step 1)

(a) Calculate the friction factor, f, for the pipe segment from tap A to tap B:

(U.S. Customary Units)

$$f_{\text{A-B}} = \frac{K_{\text{A-B}}D}{4L_{\text{A-B}}} = \frac{0.469280967 \times 0.085}{4 \times 2.615} = 0.003813469$$

(SI Units)

$$f_{\text{A-B}} = \frac{K_{\text{A-B}}D}{4L_{\text{A-B}}} = \frac{0.469280967 \times 0.025908}{4 \times 0.79705} = 0.003813469$$

(b) Repeat (a) for the pipe segment between tap C and tap D:

(U.S. Customary Units)

$$f_{\text{C-D}} = \frac{K_{\text{C-D}}D}{4L_{\text{C-D}}} = \frac{0.484967771 \times 0.085}{4 \times 2.625} = 0.003925930$$

(SI Units)

$$f_{\text{C-D}} = \frac{K_{\text{C-D}}D}{4L_{\text{C-D}}} = \frac{0.484967771 \times 0.025908}{4 \times 0.8001} = 0.003925930$$

(c) Average the values from (a) and (b):

$$f = \frac{f_{\text{A-B}} + f_{\text{C-D}}}{2} = \frac{0.003813469 + 0.003925930}{2} = 0.003869699$$

Step 2 (From Para.3-9.2, Step 2). Paragraph 3-9.2 calls for the use of the Lapple (1943) and Levenspiel (1977) model to calculate equivalent pipe length in this step. The total resistance to tap A based on measured flow rate and tap pressure has already been determined using the formulas in Form 5-5.7-1 (Form 5-5.7-1M), which conform to the Lapple and Levenspiel model. Calculate the equivalent length to tap A, ℓ_A, from the total resistance using the average friction factor from Step 1(c):

(U.S. Customary Units)

$$\begin{aligned} \ell_A &= \frac{K_A D}{4f} \\ &= \frac{1.3389762771 \times 0.085}{4 \times 0.003869699} \\ &= 7.352831578 \text{ ft} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell_A &= \frac{K_A D}{4f} \\ &= \frac{1.3389762771 \times 0.025908}{4 \times 0.003869699} \\ &= 2.2411430 65 \text{ m} \end{aligned}$$

Step 3 (From Para. 3-9.2, Step 3). The equivalent length from Step 2 should exceed the actual pipe length to the tap. The excess resistance can be attributed to energy loss in the nozzle connecting the test rig to the vessel shown in Figure 3-9-1. Estimate the equivalent pipe length of the nozzle, $\ell_{0,A}$, by subtracting the actual length to tap A from the equivalent length:

(U.S. Customary Units)

$$\begin{aligned} \ell_{0,A} &= \ell_A - L_A \\ &= 7.352831578 - 5.608 \\ &= 1.744831578 \text{ ft} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell_{0,A} &= \ell_A - L_A \\ &= 2.241143065 - 1.7093184 \\ &= 0.531824665 \text{ m} \end{aligned}$$

Step 4 (From Para. 3-9.2, Step 4). Repeat Steps 2 and 3 for the remaining taps.

(a) Tap B

(U.S. Customary Units)

$$\begin{aligned} \ell_B &= \frac{K_B D}{4f} \\ &= \frac{1.8082572438 \times 0.085}{4 \times 0.003869699} \\ &= 9.929833414 \text{ ft} \end{aligned}$$

$$\begin{aligned} \ell_{0,B} &= \ell_B - L_B \\ &= 9.92833414 - 8.223 \\ &= 1.706833414 \text{ ft} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell_B &= \frac{K_B D}{4f} \\ &= \frac{1.8082572438 \times 0.025908}{4 \times 0.003869699} \\ &= 3.026613225 \text{ m} \end{aligned}$$

$$\begin{aligned} \ell_{0,B} &= \ell_B - L_B \\ &= 3.020753385 - 2.506 \\ &= 0.520242825 \text{ m} \end{aligned}$$

(b) Tap C

(U.S. Customary Units)

$$\begin{aligned} \ell_C &= \frac{K_C D}{4f} \\ &= \frac{2.0365010346 \times 0.085}{4 \times 0.003869699} \\ &= 11.18320753 \text{ ft} \end{aligned}$$

$$\begin{aligned} \ell_{0,C} &= \ell_C - L_C \\ &= 11.18320753 - 9.457 \\ &= 1.726207527 \text{ ft} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell_C &= \frac{K_C D}{4f} \\ &= \frac{2.0365010346 \times 0.025908}{4 \times 0.003869699} \\ &= 3.408641655 \text{ m} \end{aligned}$$

$$\begin{aligned} \ell_{0,C} &= \ell_C - L_C \\ &= 3.408641655 - 2.882 \\ &= 0.526148054 \text{ m} \end{aligned}$$

(c) Tap D

(U.S. Customary Units)

$$\begin{aligned} \ell_D &= \frac{K_D D}{4f} \\ &= \frac{2.5214688060 \times 0.085}{4 \times 0.003869699} \\ &= 13.84635139 \text{ ft} \end{aligned}$$

$$\begin{aligned} \ell_{0,D} &= \ell_D - L_D \\ &= 13.84635139 - 12.082 \\ &= 1.764350956 \text{ ft} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell_D &= \frac{K_D D}{4f} \\ &= \frac{2.5214688060 \times 0.025908}{4 \times 0.003869699} \\ &= 4.220367904 \text{ m} \end{aligned}$$

$$\begin{aligned} \ell_{0,D} &= \ell_D - L_D \\ &= 4.220367904 - 3.683 \\ &= 0.537774171 \text{ m} \end{aligned}$$

Step 5 (From Para. 3-9.2, Step 5). Average the estimates for the nozzle equivalent length:

(U.S. Customary Units)

$$\begin{aligned}\ell_0 &= \frac{\ell'_{0,A} + \ell'_{0,B} + \ell'_{0,C} + \ell'_{0,D}}{4} \\ &= \frac{1.744831578 + 1.706833414 + 1.726207527 + 1.764350956}{4} \\ &= 1.735555869 \text{ ft}\end{aligned}$$

(SI Units)

$$\begin{aligned}\ell_0 &= \frac{\ell'_{0,A} + \ell'_{0,B} + \ell'_{0,C} + \ell'_{0,D}}{4} \\ &= \frac{0.531824665 + 0.520242825 + 0.526148054 + 0.537774171}{4} \\ &= 0.528997429 \text{ m}\end{aligned}$$

Step 6 (From Para. 3-9.2, Step 6)

(a) Using the average nozzle equivalent length, ℓ_0, recalculate the equivalent length to tap A:

(U.S. Customary Units)

$$\begin{aligned}\ell'_A &= \ell_0 + L_A \\ &= 1.735555869 + 5.608 \\ &= 7.343555869 \text{ ft}\end{aligned}$$

(SI Units)

$$\begin{aligned}\ell'_A &= \ell_0 + L_A \\ &= 0.528997429 + 1.709 \\ &= 2.238315829 \text{ m}\end{aligned}$$

(b) Determine the corresponding total resistance to tap A:

(U.S. Customary Units)

$$\begin{aligned}K'_A &= \frac{4f\ell'_A}{D} \\ &= \frac{4 \times 0.003869699 \times 7.343555869}{0.085} \\ &= 1.337287097\end{aligned}$$

(SI Units)

$$\begin{aligned}K'_A &= \frac{4f\ell'_A}{D} \\ &= \frac{4 \times 0.003869699 \times 2.238315829}{0.025908} \\ &= 1.337287097\end{aligned}$$

(c) From the Lapple (1943) and Levenspiel (1977) model, for any of the four taps

$$K = \frac{Y_1}{kM_1^2}(1 - r^2) + \frac{k+1}{k}\ln r \tag{III-2-1}$$

$$P = P_1\left(\frac{1 - Y_1}{r} + Y_1 r\right) \tag{III-2-2}$$

where

K = total flow resistance to the tap

P = tap pressure, psia (kPa) (same units as P_1)

r = density ratio at the tap

Given the total resistance upstream of the tap, simultaneous solution of eqs. (III-2-1) and (III-2-2) will yield the theoretical tap pressure required in this step by para. 3-9.2.

NOTE: Equations (III-2-1) and (III-2-2) were reduced from eqs. 65 and 66 in Appendix I of Lapple (1943) with the following substitutions:

$$Y_1 = 1 + \frac{k-1}{2} M_1^2$$

$$r = \frac{v_1}{v_2}$$

Since $v_1/v_2 = \rho_2/\rho_1$, where ρ is the fluid density and subscripts are assigned as in Lapple, the parameter r is referred to here as the density ratio.

(d) Solve eq. (III-2-1) for the tap A density ratio, r_A, given the resistance, K'_A, from (b). Fixed-point iteration is used in this example by rearranging eq. (III-2-1) as shown in eq. (III-2-3); the first two iterations are provided for illustration.

$$r = \sqrt{1 + \frac{kM_1^2}{Y_1}\left(\frac{k+1}{k}\ln r - K\right)} \quad \text{(III-2-3)}$$

Initial approximation is $r_A = 1$.

(1) Iteration 1

$$\begin{aligned} r_A &= \sqrt{1 + \frac{kM_1^2}{Y_1}\left(\frac{k+1}{k}\ln r_A - K'_A\right)} \\ &= \sqrt{1 + \frac{1.405 \times 0.375094230450^2}{1.02849087555}\left(\frac{1.405+1}{1.405}\ln 1 - 1.337287097\right)} \\ &= 0.8619579381 \end{aligned}$$

(2) Iteration 2

$$\begin{aligned} r_A &= \sqrt{1 + \frac{1.405 \times 0.375094230450^2}{1.02849087555}\left(\frac{1.405+1}{1.405}\ln 0.8619579381 - 1.337287097\right)} \\ &= 0.8331260322 \end{aligned}$$

After 16 iterations, the solution converges within 10^{-10} to $r_A = 0.8242451311$.

(e) Evaluate eq. (III-2-2) to calculate the pressure predicted at tap A:

(U.S. Customary Units)

$$\begin{aligned} P'_A &= P_1\left(\frac{1-Y_1}{r_A} + Y_1 r_A\right) \\ &= 52.92760355\left(\frac{1-1.02849087555}{0.8242451311} + 1.02849087555 \times 0.8242451311\right) \\ &= 43.03874635 \text{ psia} \end{aligned}$$

(SI Units)

$$\begin{aligned} P'_A &= P_1\left(\frac{1 - Y_1}{r_A} + Y_1 r_A\right) \\ &= 364.923\left(\frac{1 - 1.02849087555}{0.8242451311} + 1.02849087555 \times 0.8242451311\right) \\ &= 296.7417 \text{ kPa} \end{aligned}$$

Step 7 (From Para. 3-9.2, Step 7). Repeat Step 6 for the remaining taps. The density ratio at each tap is found numerically as described above; the calculation steps are omitted here.

(a) Tap B

(U.S. Customary Units)

$$\begin{aligned} \ell'_B &= \ell_0 + L_B \\ &= 1.735555869 + 8.223 \\ &= 9.9585555869 \text{ ft} \end{aligned}$$

$$\begin{aligned} K'_B &= \frac{4f\ell'_B}{D} \\ &= \frac{4 \times 0.003869699 \times 9.9585555869}{0.085} \\ &= 1.813487652 \end{aligned}$$

$$r_B = 0.7445916279$$

$$\begin{aligned} P'_B &= P_1\left(\frac{1 - Y_1}{r_B} + Y_1 r_B\right) \\ &= 52.92760355\left(\frac{1 - 1.02849087555}{0.7445916279} + 1.02849087555 \times 0.7445916279\right) \\ &= 38.5070511 \text{ psia} \end{aligned}$$

(SI Units)

$$\begin{aligned} \ell'_B &= \ell_0 + L_B \\ &= 0.528997429 + 2.506 \\ &= 3.035367743 \text{ m} \end{aligned}$$

$$\begin{aligned} K'_B &= \frac{4f\ell'_B}{D} \\ &= \frac{4 \times 0.003869699 \times 3.035367743}{0.025908} \\ &= 1.813487652 \end{aligned}$$

$$r_B = 0.7445916279$$

$$\begin{aligned} P'_B &= P_1\left(\frac{1 - Y_1}{r_B} + Y_1 r_B\right) \\ &= 364.923\left(\frac{1 - 1.02849087555}{0.7445916279} + 1.02849087555 \times 0.7445916279\right) \\ &= 265.4968 \text{ kPa} \end{aligned}$$

(b) *Tap C*

(U.S. Customary Units)

$$\ell'_C = \ell_0 + L_C$$
$$= 1.735555869 + 9.457$$
$$= 11.19255587 \text{ ft}$$

$$K'_C = \frac{4f\ell'_C}{D} = \frac{4 \times 0.003869699 \times 11.19255587}{0.085}$$
$$= 2.0382034$$

$$r_C = 0.7009754472$$

$$P'_C = P_1\left(\frac{1 - Y_1}{r_C} + Y_1 r_C\right)$$
$$= 52.92760355\left(\frac{1 - 1.02849087555}{0.7009754472} + 1.02849087555 \times 0.7009754472\right)$$
$$= 36.01296771 \text{ psia}$$

(SI Units)

$$\ell'_C = \ell_0 + L_C$$
$$= 0.528997429 + 2.882$$
$$= 3.411491029 \text{ m}$$

$$K'_C = \frac{4f\ell'_C}{D}$$
$$= \frac{4 \times 0.003869699 \times 3.411491029}{0.025908}$$
$$= 2.0382034$$

$$r_C = 0.7009754472$$

$$P'_C = P_1\left(\frac{1 - Y_1}{r_C} + Y_1 r_C\right)$$
$$= 364.923\left(\frac{1 - 1.02849087555}{0.7009754472} + 1.02849087555 \times 0.7009754472\right)$$
$$= 248.3007 \text{ kPa}$$

(c) *Tap D*

(U.S. Customary Units)

$$\ell'_D = \ell_0 + L_D$$
$$= 1.735555869 + 12.082$$
$$= 13.81755587 \text{ ft}$$

$$K'_D = \frac{4f\ell'_D}{D}$$
$$= \frac{4 \times 0.003869699 \times 13.81755587}{0.085}$$
$$= 2.516225041$$

$$r_D = 0.5812828536$$

$$
\begin{aligned}
P'_D &= P_1\left(\frac{1 - Y_1}{r_D} + Y_1 r_D\right) \\
&= 52.92706355\left(\frac{1 - 1.02849087555}{0.5812828536} + 1.02849087555 \times 0.5812828536\right) \\
&= 29.04827366 \text{ psia}
\end{aligned}
$$

(SI Units)

$$
\begin{aligned}
\ell'_D &= \ell_0 + L_D \\
&= 0.528997429 + 3.683 \\
&= 4.211591029\text{m}
\end{aligned}
$$

$$
\begin{aligned}
K'_D &= \frac{4f\ell'_D}{D} \\
&= \frac{4 \times 0.003869699 \times 4.211591029}{0.025908} \\
&= 2.516225041
\end{aligned}
$$

$$
r_D = 0.5812828536
$$

$$
\begin{aligned}
P'_D &= P_1\left(\frac{1 - Y_1}{r_D} + Y_1 r_D\right) \\
&= 364.923\left(\frac{1 - 1.02849087555}{0.5812828536} + 1.02849087555 \times 0.5812828536\right) \\
&= 200.2808 \text{ kPa}
\end{aligned}
$$

Step 8 (From Para. 3-9.2, Step 8). Find the error, ε, between the measured and calculated pressure at each tap as a percentage of the calculated pressure.

(U.S. Customary Units)

$$
\begin{aligned}
\varepsilon_A &= 100\% \times \frac{P_A - P'_A}{P'_A} \\
&= 100\% \times \frac{43.0240195 - 43.03874635}{43.03874635} \\
&= -0.043\%
\end{aligned}
$$

$$
\begin{aligned}
\varepsilon_B &= 100\% \times \frac{P_B - P'_B}{P'_B} \\
&= 100\% \times \frac{38.561844 - 38.5070511}{38.5070511} \\
&= 0.142\%
\end{aligned}
$$

$$
\begin{aligned}
\varepsilon_C &= 100\% \times \frac{P_C - P'_C}{P'_C} \\
&= 100\% \times \frac{36.0269315 - 36.01296771}{36.01296771} \\
&= 0.039\%
\end{aligned}
$$

$$
\begin{aligned}
\varepsilon_D &= 100\% \times \frac{P_D - P'_D}{P'_D} \\
&= 100\% \times \frac{28.9483255 - 29.04827366}{29.04827366} \\
&= -0.344\%
\end{aligned}
$$

(SI Units)

$$\begin{aligned}\varepsilon_A &= 100\% \times \frac{P_A - P'_A}{P'_A}\\ &= 100\% \times \frac{296.6402 - 296.7417}{296.7417}\\ &= -0.034\%\end{aligned}$$

$$\begin{aligned}\varepsilon_B &= 100\% \times \frac{P_B - P'_B}{P'_B}\\ &= 100\% \times \frac{265.8746 - 265.4968}{265.4968}\\ &= 0.142\%\end{aligned}$$

$$\begin{aligned}\varepsilon_C &= 100\% \times \frac{P_C - P'_C}{P'_C}\\ &= 100\% \times \frac{248.3969 - 248.3007}{248.3007}\\ &= 0.039\%\end{aligned}$$

$$\begin{aligned}\varepsilon_D &= 100\% \times \frac{P_D - P'_D}{P'_D}\\ &= 100\% \times \frac{199.5917 - 200.2808}{200.2808}\\ &= -0.344\%\end{aligned}$$

Since the percent error is within ±6% for all four taps, the test rig in this example is calibrated successfully by pressure tap profile comparison.

NONMANDATORY APPENDIX A
REFERENCES

The following is a list of publications referenced in this Code.

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