Requirements for Static Pressure Testing Field Piping Systems

I. SCOPE

This document addresses static pressure tests of well-site piping and components and gathering system piping and components. The terminology and test requirements in this document are generally based on ASME B31.8 piping code. Requirements of pressure vessel inspection codes (NB-23 or API 510) and/or plant piping design or inspection codes (ASME B31.3 or API 570) must be followed in cases where they are applicable.

II. SPECIFIC REQUIREMENTS

Requirements and terminology in this section are defined in subsequent sections (terms in italics are defined in the definitions section).

A. Preparation for test

1. Calculations

a) Determine and document *maximum operating pressure* (MOP).

b) Calculate design pressure and set *maximum allowable working pressure (MAWP)* at the lower of MOP and design pressure. For pipe with threaded connections, pipe thickness (*t)* shall be measured from the inside diameter to pipe thread root. Pipe thickness (t) can be determined by deducting the pipe thread depth from the nominal thickness of the pipe.

c) Set nominal static test pressure and acceptable test-pressure range.

d) Calculate the *hoop stresses* in the piping at the top of the test pressure range.

e) Determine the *location classification* for the line being tested.

2. Isolation

a) Determine the isolation points and isolation methods (e.g., you can remove piping and install a blind flange, install an *insert blind*, or test against a closed valve, etc.).

b) Identify segments of piping that will not be tested and describe the non-destructive test requirements on that piping. These NDE requirements are to be defined as agreed upon by the Authorized Inspector and piping engineer (API 570 Par 8.2.6).

3. Selection of test medium

a) Hydrostatic test

(1) Select liquid source and verify water chemistry and any additives are compatible with both the piping and the disposal method.

(2) Verify that the terrain will allow the high points in the system to be tested to an acceptable pressure without exceeding stress limits at the low points in the system (e.g., bottom of hills).

(3) Verify that pipe supports on aboveground segments are adequate for the weight of the liquid.

(4) Determine a disposal method and ensure that disposal complies with federal, state, and local regulations.

(5) Select a monitoring point, fill point, and bleed point.

(6) Define degasification hold period and pressure.

b) Pneumatic test

(1) Verify that the location class and the applied stresses are compatible with a pneumatic test.

(2) Select a type of gas and a gas source.

(3) Select an injection point and a blowdown point.

(4) If the test will be result in hoop stresses above 72% of SMYS, define a minimum approach distance while the material stress is above 72% of SMYS.

c) Test

(1) Rate of pressurization

Pressure should be increased gradually to 50% of test pressure (a rule of thumb that has sometimes been applied is 100 psi/minute; however, high pressure systems may utilize a higher rate). At 50% of test pressure, a hold period (5-10 minutes is generally adequate) is recommended while the system is inspected for leaks. From the hold point at 50% of test pressure to the final test pressure, pressure should then be increased in increments of $1/10^{th}$ of test pressure with a hold period at the end of each increment

Note: If ambient temperature is below 60°F, rate of pressurization should be held to ½ the allowable pressurization rate for each step given above.

(2) Test duration

(a) The test procedure must specify conditions that must be satisfied prior to beginning the test (e.g., test liquid in line might be allowed 18 hours for temperature to reach ground temperature and to allow gas to evolve out of liquid).

(b) Absent local requirements to the contrary, tests should run for 2 hours after prerequisites are satisfied. During the test, no fluids may be added but venting to account for thermal expansion is acceptable.

(c) A successful test should sustain pressures within pre-defined pressure boundaries for the entire test period. Any deviation outside these boundaries will invalidate the test. A rule of thumb that is sometimes used has been to set the minimum pressure boundary at:

$$P_{\min} = MOP + \frac{P_{test} - MOP}{2}$$

(3) Test Media Removal

Remove test media per the plan.

III. BACKGROUND AND DISCUSSION

A. Philosophy

This document is intended to provide guidance as to necessary elements and options for local test procedures and it does not substitute for local procedures or local engineering review of those procedures. It assumes that selection of welding procedures, welder qualification tests, and selection of piping have been competently specified and rigorously followed. Adherence to applicable industry code/standards and governmental regulations is essential.

B. Background

Testing of pressure containing equipment is required by engineering standards, industry codes, and by law. These requirements are intended to verify that there were no gross errors in design or fabrication, and ensure that the system will contain necessary fluids (i.e., the system will not leak when placed in service).

C. Discussion

New piping or piping repairs/modifications downstream of the well-site separator shall be subject to static pressure strength test except as noted for the tie-in girth weld. Tie-in girth welds that are not included in a strength test shall be radiographically inspected. As an alternative, angle beam ultrasonic flaw detection may be used, provided the appropriate acceptance criteria have been established. If MOP of the piping results in material stresses greater than 72% of SMYS, a hydrostatic test is required for tie-in girth welds.

At the discretion of the Authorized Inspector and piping engineer, piping modifications (e.g., cutting in a tee for a valve setting, replacing a length of pipe after third-party damages, etc.) may not require a re-test. The cutoff is material stresses of 72% of SMYS. A line operating with material stresses above 72% of SMYS shall have a static test every time the line is cut.

For piping modifications on lines with material stresses below 72% of SMYS other methods of non-destructive testing may be used to verify fitness for purpose based on an engineering analysis. Radiographic examination should be used unless physically impractical due to piping configuration. Where radiography is not possible, other inspection methods as agreed upon by the Authorized Inspector and piping engineer should be conducted by a certified NDT examiner.

If the system test includes a pressure vessel, the allowable stress of the vessel must not be exceeded and adequate provisions shall be provided to remove test fluids from the vessel.

Some internal components are only designed for operating differential pressures, i.e., bellows, exchanger tube sheets, etc. These components must be identified and procedures used to prevent higher than design differential pressure on them when applying test pressure to only one side of the component.

During a strength pressure test, where the test pressure will exceed the set pressure of any pressure relief valve(s) and/or rupture disc(s) in the test system, the relief valve(s) and/or rupture disc(s) shall be removed and piping blinded or an insert blind shall be installed.

For hydrostatic tests, vents should be provided at system high points to purge possible pockets of air or other non-condensables before beginning the test.

Well-site piping ends and gathering-systems piping begins either at the outlet of the well-site separator, or at the inlet flange of the well-site sales meter. Good engineering judgment shall establish the demarcation between well-site piping and gathering systems, based on expected pressures, risks, and other considerations. This demarcation shall be documented and approved by local management.

Well-site piping is typically not required to have a static pressure strength test, except in areas with a "high" population density (see *Location Class* in the definitions below), operated at a high material stress (i.e., above 72% of SMYS), or the presence of toxic fluids. Wells shall be assigned the Location Class of the first mile of piping downstream from the well site.

If the line being tested falls under the explicit jurisdiction of a state, local, or federal regulatory agency local operating and engineering personnel shall be familiar with the specific records-retention regulations and shall conform to those regulations. While the overriding reason for testing is safety, the tests themselves pose inherent risk. As material stresses increase to a significant fraction of SMYS, brittle fracture can occur. Strength testing should not be performed if metal temperatures are below 60°F unless engineering evaluation is conducted on material to be tested.

Hydrostatic testing has some inherent risk. A line full of liquid will experience approximately 100 psi pressure increase for every °F temperature increase. The physical weight of water can crush pipe supports. The hydrostatic head of a water-filled pipe in hilly terrain can increase localized test pressure far beyond what was intended. Testing against a closed valve can over-stress adjacent piping if the valve should leak. The main advantage of hydrostatic testing is that if a pipe should rupture during a hydrostatic test, the energy is relieved very quickly with little risk that escaping liquid will carry high-velocity debris toward personnel or equipment. Each of these conditions requires the test designer to develop a plan to reduce their risk.

Use of a gaseous test medium carries a different set of inherent risks. While gases are light and don't add significantly to the load on pipe supports or increase test pressure at the bottom of hills, a gaseous test has potential for creating an explosive mixture and an oxygen deficient atmosphere. If a pipe should rupture during a static test with a gaseous medium, the stored energy release could be catastrophic, throwing high-velocity particles in unpredictable directions. Consequently, static tests using gas are limited to pressures that result in material stresses less than 72% of SMYS and are limited to Class 1 Division 2 and Class 2 locations.

Caution: Care must be taken to ensure that pressures during tests never cause pipe stress to exceed 80% of SMYS at any point. Particular attention should be paid to piping that is physically lower than the location of the pressure recorder/indicator during hydrostatic test.

Caution: Personnel shall not approach pipe while it is subjected to stresses greater than 72% of SMYS.

IV. DEFINITIONS

Note: Italicized words within a definition indicate that the italicized word is also defined in this section

A. Buildings Intended for Human Occupancy

Buildings intended for human occupancy are unique spaces that include rooms for human residence or rooms for a specific commercial enterprise. For example, an apartment building with 4 separate homes and 3 office suites would count as seven (7) *buildings intended for human occupancy*. A detached garage would not count as a separated building.

B. Design Factor(s)

Design Factors are factors used in the formula for *design pressure* address population, material, and structural issues. *Design factors* must be adjusted for special cases. For example, when a piping system in a *Location Class 1, Division 1* includes an aboveground fabrication, the *design factor (F)* is reduced from 0.80 to 0.60 (80% to 60%) for the fabricated assembly (see ASME B31.8 Table 841.114B). In all other cases, ASME B31.8 Table 841.114A shall be used.

C. Design Pressure

Design Pressure is the pressure that results in a given *hoop stress* adjusted by the *design factors.*

$$P = \frac{2St}{D} FET$$

D. Hoop Stress

Hoop stress is the stress in a pipe of wall thickness *t* acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe, produced by pressure *P* of the fluid in a pipe of diameter *D* and is determined by Barlow's Formula:

$$S_H = \frac{PD}{2t}$$

E. Hydrostatic Test

Hydrostatic Test is a *static test* using a non-compressible liquid as the test medium.

F. Leak Test

Leak test is a *static test* intended to verify that the piping will contain fluids at normal operating pressures.

G. Location Class

Location class designations are intended to assign an objective value to the risks of harm to the public from pipeline operations. Various organizations, regulatory agencies, and companies use different systems of classification. This document uses designations from ASME B31.8, which are consistent with most U.S. systems of risk assessment. In this designation, *buildings intended for human occupancy* within a ¼ mile wide region (1/8 mile on either side of the pipeline), are counted for a distance of one mile along the pipeline route. The five designations are:

Class I, Division 1—any one-mile section that has 10 or fewer buildings intended for human occupancy where the design factor of the pipe is greater than 0.72 but equal to or less than 0.80 and which has been hydrostatically tested to at least 1.25 times *maximum operating pressure*.

Class 1, Division 2—any one-mile section that has 10 or fewer buildings intended for human occupancy where the *design factor* of the pipe is equal to or less than 0.72, and which has been tested (either hydrostatically or pneumatically) to at least 1.1 times *maximum operating pressure*.

Class 2—any one-mile section that has more than 10 but fewer than 46 buildings intended for human occupancy.

Class 3—any one-mile section that has more than more than 46 or more buildings intended for human occupancy, except where Class 4 prevails.

Class 4—any section of pipe where multistory buildings are prevalent, where traffic is heavy or dense, and where there may be numerous other utilities underground. "Multistory" means 4 or more floors above ground including the ground floor. The depth of basements or number of basement levels is immaterial.

H. Maximum Operating Pressure

Maximum Operating Pressure (MOP) is the highest pressure at which a piping system is expected to be operated during a normal operating cycle. The expected source of maximum pressure (i.e., the "credible scenario") shall be documented during system design.

I. Maximum Allowable Working Pressure

Maximum Allowable Working Pressure (MAWP, also referred to as Maximum Allowable Operating Pressure, MAOP) is the maximum pressure at which a system can be operated. MAWP must be greater than or equal to MOP

J. Maximum Allowable Test Pressure

Maximum Allowable Test Pressure (MATP) is the maximum internal fluid pressure permitted for a pressure test based upon the material and location involved. See *design pressure.*

K. Nondestructive Examination

Nondestructive Examination (NDE), also referred to as *Nondestructive Testing (NDT), is* any of a family of tests that leave tested material in largely the same condition as it was in before the test. The most common forms of NDE include static pressure testing, radiographic examination, liquid-penetrant examination, ultrasonic examination, and magnetic particle examination.

L. Pneumatic Test

Pneumatic Test is a *static test* using a gaseous test medium.

M. Site Classifications

See *Location Class*.

N. Specified Minimum Yield Strength

Specified Minimum Yield Strength (SMYS) is a value specified by the pipe manufacturer of the stress that a given pipe would withstand indefinitely without permanent yielding. SMYS values for common grades of pipe are tabulated in ASME B.31.8 Appendix D, or are provided by the manufacturer of non-standard pipe descriptions. For example, API 5L X42 pipe has an SMYS of 42,000 psi. Dual-stamped pipe (e.g., stamping of API 5L Grade B pipe with an additional X42 designation is common) is certified to meet or exceed all physical and chemical characteristics of both pipe grades, including having the SMYS of the stronger pipe grade.

O. Static Test

Static test is an evaluation of the ability of pressure-containing equipment and piping to contain a specified pressure for a specified time. The test is performed with no-flow and at isothermal condition. Any *static test* must be of adequate duration to ensure that test results are not affected by test-media losing or gaining heat from the ground, sun, or other environmental conditions. A *static test* can be either a *strength test* or a *tightness test*.

P. Strength Test

Strength Test is a *static test* intended to verify that the system is capable of withstanding material stresses equal to a pre-determined fraction of *SMYS*.

Q. Tightness Test

See *Leak Test*

V. TESTING GUIDELINES

The following information is intended to provide a discussion of the issues that must be addressed when designing a test and is not intended to substitute for an engineering analysis of the system being evaluated.

A. Preparation for test

1. Prior to a test

Required NDE, heat treatment, repairs, etc., shall be successfully conducted. Adjacent equipment, vessels, and piping shall be isolated if they will not be included in test. Due to inherent leakage, block valves do not typically provide adequate isolation between a flowing stream and a system under test. Block valve leakage can result in process stream contamination and can give false indication of a leak.

The person controlling the pressurization for the test shall have immediate visible indication of current pressure and changes in pressure and temperature. Hydrostatic head at all elevations on the line shall have been considered in relation to the pressure readings. When dial pressure gauges are used in testing, they shall have dials graduated over their entire range for 1.5 to 2 times the intended maximum test pressure. The calibration on instrumentation used to indicate and document system test pressures and temperatures should be certified within 6 months of the test. Recording instruments shall be installed as closely as possible to the low point of the system being tested. Test results shall be documented. Other equipment used in the test setup (i.e., regulators, etc.) should be calibrated periodically.

For pneumatic air tests, non-lubricated air compressors are required.

An insert blind (also known as "skillet blind" or "line blank") is a flat plate of steel sized to fit between flange faces. Blinds provide maximum positive isolation, are not prone to accidental or unauthorized operation, and are readily identifiable where installed. Proper blinding techniques, to be developed locally, should be followed. Blinding locations are sometimes difficult to access (i.e., buried pipe flanges) and may require portions of existing systems to be included in the test.

If an insert blind is used, it is typically fabricated from mild steel plate (such as ASTM A515-70 or A516-70). Blind handle width should be 1 inch, minimum and handle length should be 6-inch, minimum beyond the outer flange face. Minimum blind thickness is specified in Table 1 (thicker stock can be used if it is more readily available):

Table 1
Minimum Insert Blind Thickness

	100 psid	285 psid	740 psid	1,000 psid	1,480 psid
2"	0.125	0.125	0.125	0.125	0.125
3"	0.125	0.125	0.125	0.126	0.139
4"	0.125	0.125	0.156	0.168	0.185
6"	0.142	0.184	0.233	0.252	0.278
8"	0.189	0.245	0.311	0.335	0.370
10"	0.236	0.306	0.388	0.419	0.462
12"	0.283	0.368	0.467	0.503	0.555

This table is based on using ASTM A515-70/516-70 plate material.

Note: Blind thickness specified in this table is intended for insert blinds that will be used to isolate piping during a static test only, and is not appropriate to determine required thickness for non-test applications (i.e., permanent insert blinds). Refer to the *BP Onshore U. S. BU Safety Standard, Section 4, Chapter 1*, if the insert blind will be required/used for any other reason.

For larger sizes or different differential pressures, minimum plate thickness may be calculated by the following formulae (please refer to the note in Table 1):

$$f = \left(\frac{3}{8}\right)(3+\upsilon) * P\left(\frac{r}{t}\right)^2$$

$$y = \frac{(1-\upsilon)(5+\upsilon)fr^2}{2(3+\upsilon)Et}$$

To prevent distortion that inhibits blind removal, deflection (*y*) must be less than ½ *t*.

Note: Insert blinds thinner than 1/8 inch should not be used.

2. Before Applying Pressure

The system being tested should be visually inspected to ensure that new welds are complete (no undercuts, etc.), all vent and drain valves are closed with plugs installed, blinds of adequate thickness are installed, and all supports are in place.

The test apparatus and the system being tested should be examined to see that they are tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected or isolated.

B. Test Selection

Test type, test media, test pressure, and test duration define a test.

1. Test Type

a) Leak Test

A Leak test (also known as tightness test) is performed to ensure that equipment/systems are serviceable and leak-free prior to startup after being opened for cleaning or inspection with no structural repairs having been made to pressure parts.

For pneumatic tests, all flanged and screwed joints, connections, and closures should be swabbed with a soap or a similar solution to facilitate the detection of leaks.

b) Strength Test

A Strength Test is performed to ensure that the materials will perform to their specified levels and that no gross errors were made in engineering, fabrication, or construction.

2. Test media

Test media is the choice of liquid or gas for a test is crucial to a successful test.

a) Hydrostatic Testing

While the test liquid will typically be water, any non-toxic, non-hazardous, non-flammable liquid may be used. Appropriate additives may be used to protect against freezing, to scavenge oxygen, or to inhibit corrosion. Any additive should be compatible with the disposal method (e.g., if water is going to be released into a wetlands, then biocides may not be used). Personnel performing the test often have a choice between produced water and municipal water. In either case, the water chosen should minimize adding undesirable chemical or biological agents to the pipe (e.g., municipal water is usually treated with biocides that reduce the risk of Microbiological Influenced Corrosion, but it is also often oxygenated which increases the risk of several corrosion mechanisms).

(1) Disposal Considerations

An important component in a hydrostatic test plan is the dewatering and disposal procedures. When a line is tested with water, pigging facilities are required (either permanent or temporary) to remove the liquid. Multiple pigs will often have to be run to remove all the liquid. It is important that liquid be adequately removed to minimize future corrosion and operational risks. Disposal of hydrostatic test water is specifically addressed in several EPA regulations. Typically, water may not be surface-discharged, allowed to enter "Waters of the U.S.", allowed to accumulate where wildlife might ingest it, nor introduced into an underground injection well designated for Exploration and Production (E&P) exempt wastes. Exceptions allowing water discharge into one of these areas must be granted by explicit permit from applicable regulatory agencies before the disposal option is used. Therefore, disposal must be carefully planned and reviewed by a Field Environmental Coordinator before the pipe is filled.

(2) Weight Considerations

Liquid adds weight to the system. In standard piping greater than 12 inch, weight of test liquid is greater than the weight of the steel. Pipe supports (either permanent or temporary) must be designed to carry both weight of piping and weight of test liquid. As piping changes elevation, pressure at the bottom of an incline will equal pressure at the highest elevation plus 0.431 psi/ft, times the elevation drop from the highest point, times the liquid specific gravity. System design and establishment of an appropriate test pressure must take hydrostatic head into account.

(3) Conditioning Test Liquid

Hydrostatic test procedures treat test medium as incompressible. This approach is not valid if liquid is saturated with gas. Oxygenated water or recently produced water might contain enough dissolved gas to affect test results. To compensate, a line shall be filled and the pressure raised to some fraction of test pressure, then held at static pressure until a high-point vent stops discharging gas – this can take a full day, depending upon volume and length of line being tested.

(4) Leak considerations

Leaks under high pressure are potentially dangerous. A pinhole leak can cut flesh. Brittle fracture can throw debris. A significant sized leak during a hydrostatic test will rapidly lower the pressure in the line. Personnel should not approach piping while material stresses are above 72% of SMYS and until the pressure has been lowered to the MOP.

b) Pneumatic Tests

There are several reasonable choices of gas. Air, nitrogen (N_2), and sweet natural gas all have a place in testing. A comprehensive purge procedure shall be developed when flammable gas is used for the test media.

Air—For lines that have never been exposed to and are not currently connected to a line that has contained flammable fluids, compressed air has the advantage of being inexpensive while not increasing the risks over other gases.

N_2—Nitrogen may be used in situations where the line is connected to a line that has been exposed to or is currently connected to a line that has contained flammable fluids. If N2 is used, oxygen deficient atmospheres Immediately Dangerous to Life and Health (IDLH) can be created, so hazards of N2 must be addressed.

High-pressure sweet natural gas—This gas is sometimes available near low-pressure lines needing tests. As long as the line is properly purged (see Section 4 Chapter 16) this high-pressure gas can be safely used as a test media. Natural gas has the added advantage that it can be resold instead of vented.

Steam—Under no circumstances will steam be used as a test medium—steam can condense with a temperature change and collapse piping.

(1) Disposal

Testing with gas does not have the disposal complications that you have with a hydrostatic test. Air or N_2 can be vented to the atmosphere without any environmental concerns. If sweet natural gas must be vented, then personnel performing the test need to be sure that the vented gases are appropriately reported.

(2) Heat Transfer

Gases are compressible and have limited heat-transfer characteristics so only short periods are required to let a test stand before beginning the recording period.

(3) Explosion Risk

The greatest drawback with using gaseous media in a static test is the total energy stored in the system. To minimize risk to the public, ASME B31.8 limits gas tests to piping systems in Class 1 Division 2 and Class 2 locations. Personnel should not approach piping while material stresses are above 72% of SMYS and until the pressure has been lowered to the MOP.

(4) Auto-refrigeration

When a system is tested with gas, Joule-Thompson cooling can lead to very cold conditions at the vent piping during depressurization. Care must be taken to prevent this cooling from increasing the risk of brittle fracture. Typically, blowdown rate is controlled to a low enough rate to prevent the formation of ice near the vent.

3. Test pressure

When pressurizing a line, the rate of change of pressure is important. Pressure changes faster than 10 psi/minute can introduce localized stresses in excess of the average stresses calculated. It is prudent to allow a hold time of several minutes at MOP, at MAWP, and every 100 psi above MAWP to allow stresses to equalize. If ambient temperature is below 60°F, hold points should be added every 100 psi below *MAWP* and every 50 psi above *MAWP*.

Test pressure can only be determined after calculating design pressure, determining MOP, and setting a location class. ASME B31.8 sets forth the relationships in Table 841.322(f).

4. Test duration

Determining the length of a test, when a test should start, and if a test is successful has been the source of much discussion. Customs and regulations often specify test durations (e.g., static tests in several European countries are required to run for 24 hours after stabilizing). Sometimes local management sets the test duration (e.g., in some chemical plants, tests are required to be completed after 15 minutes). Absent regulation or local management requirements, ASME B31.8 specifies that tests should be held for 2 hours, but is silent on when the test actually starts. This is a critical omission because most procedures prohibit adding test media during the actual test. The test procedure should specify when the clock starts on the test. For hydrostatic tests, the start time should include an adequate delay for temperature to equilibrate and for dissolved gases to evolve from the water. For a gas test, a short time delay for temperature equilibration is necessary.

VI. NOMENCLATURE

D = *outside diameter of pipe (inches)*

E = *in Design Equation – longitudinal joint factor (ASME B31.8, Table 841.115A)*

E = *in Skillet Blind Equation – Young's modulus (psi)*

f = *force applied to a surface (lbf)*

F = *basic design factor (ASME B31.8, Table 841.114A)*

P = *design pressure (psig)*

r = *radius (inches)*

S = *specified minimum yield stress (SMYS, psi)*

S_H = *hoop stress (psi)*
t = *nominal thickness (inches)*
T = *temperature derating factor (ASME B31.8, Table 841.116A)*
y = *deflection (inches)*
ν = *Poisson's ratio*