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PRESSURE AND LEAK TESTING

All piping systems used in ammonia refrigeration systems are required to undergo pressure testing following initial construction, modification, or repair prior to being placed back into service. In this issue of **THE**GOLD FRONT, we will explore the purpose of pressure testing and discuss key considerations for safely conducting pressure tests. Because pressure testing is performed on components and subsystems built by manufacturers, we will limit our discussion here to the pressure testing of the field-erected portion of piping and equipment commonly found in industrial refrigeration systems. Also, we will limit our discussion here to the technical aspects of pressure testing piping systems. In the next edition of **THE GOLD FRONT**, we will discuss recommended credentials of personnel involved in pressure testing.

BACKGROUND

As applied to a piping system, pressure testing is a process intended to demonstrate (1) the integrity of a piping system and (2) the piping system is free from leaks; prior to being placed into operation. The following definition of a pressure test is from ASME PCC-2 (2008).

IRC Staff

Director

Doug Reindl 608/265-3010

or 608/262-6381

dreindl@wisc.edu

Assistant Director

Todd Jekel 608/265-3008

tbjekel@wisc.edu

Research Staff

Dan Dettmers 608/262-8221

djdettme@wisc.edu

IRC Contact Information

Toll-free 1-866-635-4721 Phone 608/262-8220 FAX 608/262-6209

e-mail <u>info@irc.wisc.edu</u>

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Engineering Safety Relief
 Systems Webcourse

Mailing Address

1513 University Avenue

Suite 3184 Madison, WI 53706

Web Address www.irc.wisc.edu

<u>pressure test:</u> a test performed to ensure the gross integrity of the pressure component on new pressure equipment, or on previously manufactured pressure and piping equipment that has been or is in service and that has undergone an alteration or repair to a pressure boundary(s) to ensure the gross integrity of the pressure component to the original code of construction. A pressure test may be performed with liquid (hydrostatic test), with gas (pneumatic test), or a combination of both (hydro-pneumatic test).

In its simplest form, a pressure test on a piping system involves increasing the pressure within the piping system in a controlled manner to a target final test pressure in order to demonstrate or prove the piping system's integrity and to ensure it is free from leakage. It is important to realize that pressure testing is NOT intended to demonstrate the suitability of a piping system design or installation to operate without failing as a result of operational mechanisms such as cyclic fatigue, embrittlement, stress-related cracking, or loss of pipe wall thickness due to external corrosion.

In this article, we discuss general approaches for pressure and leak testing highlighting comparative advantages, disadvantages, and limitations of each given approach. We will also review pressure test requirements for industrial refrigeration piping systems that stem from related industry codes, standards, and guidelines. Let's begin by reviewing alternative approaches for conducting pressure tests along with their advantages and disadvantages.

HYDROSTATIC PRESSURE TEST

A hydrostatic test is a pressure test method that uses a <u>liquid</u> as a fluid medium in order to increase the pressure of a piping system to the desired target final test pressure. The most common liquid used for conducting a hydrostatic pressure test is water; however, other liquids can and have been used for hydrostatic pressure tests. Liquids that will react or otherwise be incompatible with the piping system's normal materials of construction or

UPCOMING AMMONIA COURSES

Intermediate Ammonia Refrigeration
Systems

December 7-9, 2011

Madison, WI

Engineering Safety Relief Systems

December 12-16, 2011

via the web

Process Safety Management Audits for Compliance and Continuous Safety Improvement

January 16-18, 2012

Madison, WI

Introduction to Ammonia Refrigeration Systems

March 7-9, 2012

Madison, WI

Ammonia Refrigeration System Safety
April 18-20, 2012 Madison, WI

Achieving Energy Cost Savings for Ammonia Refrigeration Systems

May 22-24, 2012

Madison, WI

Design of NH₃ Refrigeration Systems for Peak Performance and Efficiency September 17-21, 2012 Madison, WI

Introduction to Ammonia Refrigeration Systems

October 8-10, 2012

Madison, WI

Process Hazard Analysis (Emphasizing Ammonia Refrigeration Systems) October 19-21, 2012 Madison, WI

NOTEWORTHY

- Mark your calendars now for the 2012 IRC RESEARCH AND TECHNOLOGY
 FORUM May 2-3, 2012 at the Pyle Center in Madison, WI.
- Send items of note for next newsletter to **Todd Jekel**, **tbjekel@wisc.edu**.

the system's normal working fluid (refrigerant) should be avoided.

In a hydrostatic pressure test, the test liquid is introduced at a low elevation point in the system undergoing pressure test. As the system fills, displaced air is vented out through a high point to avoid trapping air in the system. Once liquid-filled, the system is then pressurized in accordance with a stepwise pressure test protocol to the final test pressure. Thereafter, the system is inspected for liquid leaks. According to ASTM E1003, two procedures are used to assess system tightness under a hydrostatic pressure test: (1) pressure decrease over time and (2) visual indication of liquid loss from the system.

ADVANTAGES

 Relatively safe. Because liquids are nearly incompressible, the stored energy in the pressurized piping system is minimized. For this reason, hydrostatic pressure testing is considered the safest of the pressure test alternatives.

DISADVANTAGES

- Because of the relatively high surface tension of water, the leak detecting ability of hydrostatic pressure
 testing is relatively poor when small openings exist. Gaseous test fluids can penetrate through much
 smaller openings; thereby, increasing leak test sensitivity. It is also worthwhile to note that a
 hydrostatic pressure test should not sequentially precede a pressure test with a gaseous medium
 (ASTM E1003).
- Using water as a test liquid in a carbon steel piping system increases the probability of initial internal oxidation of the system following the test and prior to being placed into service.
- Because it is difficult to completely remove test liquid from the system following pressure testing and
 prior to placing the system into service, it is essential to ensure the presence of residual liquid will not
 cause other problems once refrigerant is introduced into the portion of the system hydrostatically
 tested. The presence of residual water makes subsequent vacuum testing for a piping system
 extremely difficult.
- Because of the density of test liquids like water, its introduction into a piping system for hydrostatic
 pressure testing will place significant stress on piping supports and structures. It is essential that the
 structural design and structural integrity of supports for any system planned to undergo hydrostatic
 pressure testing be verified prior to initiating liquid fill to the system.
- Common hydrostatic test liquids like water are susceptible to freezing when hydrostatic pressure testing in low ambient temperature conditions. Pressure tests with water should not be conducted at temperatures below 40°F (4°C).

PNEUMATIC PRESSURE TEST

A pneumatic pressure test is a pressure test method that uses a gaseous medium in order to increase the pressure of a piping system to the desired target final test pressure. Compressed air and nitrogen are two common gasses used for conducting pneumatic pressure tests, although other gases such as helium and mixtures of helium or other gases can theoretically be used but would be cost-prohibitive for testing large piping systems. In some cases, leak testing is performed with a mixture of ammonia and nitrogen to allow leak detection with refrigerant sensors or sulfur sticks. The use of air-ammonia mixtures for pressure testing is not recommended because the presence of oxygen with the ammonia creates an enabling environment for stress-corrosion cracking (IRC 2005).

PNEUMATIC TESTING HAZARDS

PNEUMATIC PRESSURE TESTING IS HAZARDOUS!

Did that get your attention?

The hazards of pneumatic pressure testing lie in the fact that a gas under pressure will store a tremendous amount of energy. If a vessel or piping system fails while undergoing a pneumatic pressure test, the consequences can be deadly. The following examples illustrate the extent of hazards associated with pneumatic pressure testing.

- Fragmented components resulting from component failure under pressure can create shrapnel that will be propelled at high velocity in unpredictable directions. Released shrapnel present personal injury risks as well as the potential for collateral damage to equipment or adjacent infrastructure.
- Portions of the piping system such as ungagged test plugs and other temporary connections are subject to ejection while under pressure creating risks similar to flying shrapnel.
- The pressure wave created by the sudden release of pressurized gas can cause injury or significant infrastructure damage. A pressure wave of 1 psi (6.9 kPa) has the potential to knock a person to the ground while a pressure wave of 2-3 psi (13.8-20.7 kPa) can shatter an 8" (20.3 cm) concrete or block wall.
- The catastrophic failure of equipment under pneumatic pressure can create an explosive noise with risk of hearing impairment or loss to nearby personnel.
- Reaction forces that result from gross failures on larger components can result in propelling the components from their supports like a missile.

Case studies of failures that have resulted during pneumatic and hydrostatic pressure tests can be found in BP (2009). With that being said, pneumatic pressure testing is a very common method for verifying the integrity of field-erected or modified industrial refrigeration piping systems. Further details on the code requirements and recommended practices for pneumatic pressure testing are provided below.

ADVANTAGES

- Unlike a hydrostatic pressure test, the gas used for pneumatic pressure testing does not impose the weight of test loads on the piping system and associated supports.
- Using gas in a pressure test offers enhanced sensitivity in leak detection compared to hydrostatic tests.
- The proper selection of a test gas eliminates possibility of latent damage caused by test gas used (no internal oxidation, etc.).
- Test gases are simple to bleed or vacate from system at the conclusion of a pressure test.
- When using air or nitrogen as the test gas, there is no practical risk of freezing.

DISADVANTAGES

- HAZARDOUS! Risks to personnel and infrastructure are elevated compared to a hydrostatic test due to the tremendous stored energy in the compressed test gas.
- The use of nitrogen as a test gas has the advantage of not supporting combustion but the disadvantage of being a potential asphyxiant to personnel if a leak were to occur in a closed or confined area.
- Air used for pneumatic testing should be dehumidified to at least a -20°F (-29°C) dew point temperature (lower is better) to avoid moisture from the compressed air condensing within the piping system.
- Whether hydrostatic or pneumatic, all pressure testing requires inspection of the piping system for signs of leaks.

Let's now move on to leak testing.

LEAK TESTING

Leak testing is the process of examining a piping system under pressure for the presence of leakage. The codes and standards that govern leak testing will require that all welds and joints where leaks can potentially arise be exposed and free of primer, paint, oil, grease, flux, slag, or other contaminants that might temporarily block or mask leakage points. With hydrostatic testing, the leak examination process involves inspecting each joint of connection to ensure the absence of seepage or flow of test fluid (liquid or vapor). With pneumatic testing, examination for leaks involves one or more of the following:

- The use of commercially-available leak detection liquids which produce visible bubbles at points of gas leakage.
- The use of ultrasonic leak detectors.
- The use of test gas-specific sensors for identifying leak sources. One example is the use of a mass spectrometer for leak identification when helium is used as the test gas.

TOOLS OF THE TRADE

Pneumatic or hydrostatic testing of piping systems often requires isolating only those portions of the system subject to pressure testing. This is accomplished by using isolation valves, temporary plugs, and blind flanges.

FIGURE 1 shows a test plug designed to be inserted into the inside diameter of a pipe in order to temporarily seal the connected piping system for pressure testing. This type of test plug eliminates the need for installing a temporary weld-end cap solely for the purpose of pressure testing the piping system. The plug includes a sealing surface as well as corrugated gripping surface to secure the plug against the inside surface of the pipe. They are available in both carbon steel and stainless steel construction with alternative seal materials and a test pressure range from 1,100 psi to 13,900 psi.

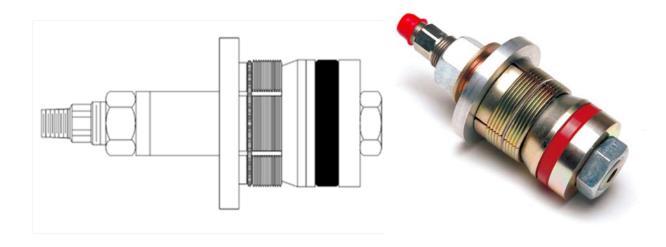


FIGURE 1: Inside diameter pressure test plug (photo courtesy of the EST Group).

In some cases, it may be desirable or necessary to seal from the pipe outside diameter. **FIGURE 2** shows an OD pressure test plug.

In certain situations, it may be desirable or necessary to pressure test an individual weld such as a single flange. In this case, a flange type pressure test plug as shown in **FIGURE 3** is used. A flange pressure test plug allows isolation of only the weld by the use of a long-reach seal inserted into the pipe to isolate seal the pipe as well as with a mating flange that is bolted to the flanged connection to seal the flange. Ports on the test side of the

flange allow for the introduction of gas or liquid to pneumatic or hydrostatic pressure test only that portion of the pipe that includes the weld.

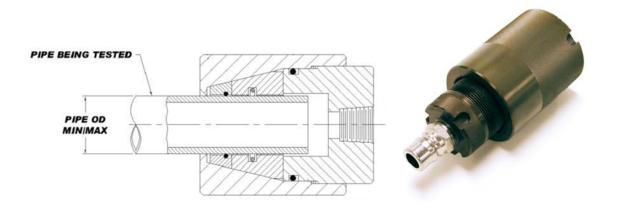


FIGURE 2: Outside diameter pressure test plug (photo and illustration courtesy of the EST Group).

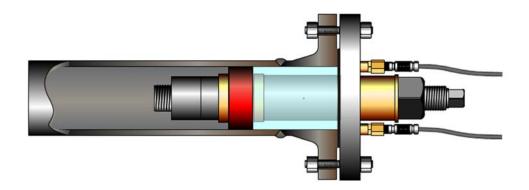


FIGURE 3: Flange pressure test plug (illustration courtesy of the EST Group).

These devices and other similar test devices allow portions of piping systems to be segregated and isolated for pressure testing. They can also be configured with gag cables or chains to guard against their inadvertent discharge while pressure testing. One end of the gag device is connected to the pressure test plug and the other secured to the piping undergoing testing.

Let's now look at some of the code and standard requirements related to pressure testing.

RELEVANT CODES AND STANDARDS

ASME B31.5 dictates pressure testing requirements for newly constructed refrigerant piping systems. ASME PCC-2 provides methods for repair of equipment and piping originally designed and constructed in accordance with ASME Pressure Technology Codes and Standards. Article 5.1 of PCC-2 covers pressure testing. IIAR 2 establishes requirements for testing and charging of ammonia refrigeration piping systems. A summary of the requirements for each of these codes and standards is provided below.

ASME B31.5

At a minimum, industrial refrigeration piping systems must be designed and constructed in accordance with ASME B31.5 – commonly referred to as "the code." ASME B31.5 requires pressure and leak testing of refrigerant

piping systems erected on-site after installation and before operation [538.4.1]. The code does exempt components that have been factory tested from subsequent pressure testing in the field [538.3.1]. Sections 538.4.2 and 538.4.3 of ASME B31.5 define more specific requirements for pressure and leak testing of piping systems designed and constructed within the scope of the code. Key excerpts from these two sections of the code are provided below.

538.4.2 Pressure Test

- (a) Piping shall be examined before pressure is applied to ensure that it is tightly connected. All items not subject to the pressure test shall be disconnected or isolated by valves, blanks, plugs, or other suitable means.
- (b) A preliminary test at a gauge pressure of up to 25 psig (170 kPa) may be applied, prior to other testing, as a means of locating major leaks.
- (c) The temperature of the piping system during testing shall be above the ductile-brittle transition temperature.
- (d) The means used to furnish the test pressure shall have either a pressure limiting device or a pressure reducing device and a pressure relief device and gage on the outlet side. The pressure relief device shall be set above the test pressure, but low enough to prevent permanent deformation of any of the system components.
- (e) The pneumatic test pressure used shall be at least 110% of the design pressure. The test pressure shall not exceed 130% of the design pressure of any component in the system.

538.4.3 Leak Test. After the pressure test in §538.4.2 is completed, a leak test shall be performed. (a) Examination for leaks shall be by the gas and bubble formation testing as detailed in Article 10, Section V of the ASME Boiler and Pressure Vessel Code, or by other methods of equal

EXCEPTION: Refrigerant vapor detection methods shall be used when refrigerant is used in the test medium. Comply with environmental regulations when venting refrigerants.

- (b) Examination shall be made of all joints and connections. The piping system shall show no evidence of leaking.
- (c) The pressure used for leak tests shall be either the design pressure or a pressure specified in the engineering design.

Discussion

sensitivity.

The initial test, conducted at pressures not greater than 25 psig (170 kPa), is intended to uncover gross piping system leaks prior to raising the piping system to the *final test pressure*. When using gas as the medium for the pressure test (pneumatic test), the code requires *the final test pressure* to be at least 110% but not more than 130% of the piping system's design pressure. Although ASME B31.5 does not prescribe a specific "hold" or "dwell" time at the final test pressure, both ASME B31.3 and ASME PCC-2 specify a minimum hold time 10 minutes at the *final test pressure*.

Once the hold period at the *final test pressure* can be maintained without loss of pressure, the system test pressure is reduced to a *leak test pressure*. The *leak test pressure* is equal to the *final test pressure* divided by 1.1. In other words if the *final test pressure* was 110% of the design pressure, the system leak test pressure would then be reduced to the design pressure. Once at the *leak test pressure*, the process of joint inspection to search for leaks commences.

ASME PCC-2

Article 5.1 of ASME PCC-2 provides recommended practices for determining the type of test, the test pressure, and the procedure for pressure and tightness testing of pressure equipment, including tubular heat exchangers, pressure vessels, and piping systems. PCC-2 recommends hydrostatic pressure testing unless one of the following conditions apply: (1) equipment or piping and associated supports are inadequate for the test loads anticipated; (2) test liquid cannot be completely removed from the system; (3) equipment has internal linings or otherwise

would sustain damage from test liquid.

PCC-2 provides good guidance on the general principles and practices for pressure testing that can be used as a reference but its focus is on repair and modification to existing piping systems. We will not review all aspects of the pressure testing provisions covered in PCC-2 here so if you are modifying or otherwise repairing an existing piping system, refer to Article 5.1 of ASME PCC-2 for examination and testing requirements.

IIAR 2

Section 15 of IIAR 2 (2008) establishes requirements for testing and charging newly installed or modified closed-circuit ammonia refrigeration systems. The intent of the field leak test prescribed in IIAR 2 is to "to assure a tight system which will operate without any appreciable loss of refrigerant" [15.1.1]. Section 15.1.2 of IIAR 2 identifies the basic requirements in preparing to conduct a pressure test of an ammonia system. Section 15.1.5 identifies fluids prohibited from use in leak testing ammonia refrigeration systems and they include: oxygen or any combustible gas/mixture, carbon dioxide, halocarbon refrigerants, and water or water solutions. Section 16.1.6 defines the test pressure for leak testing as well as some of the basic provisions for equipment used in leak testing.

In addition to a pressure/leak test, IIAR 2 requires a subsequent ammonia test [15.1.7]. The ammonia test involves purging of the test gas from the system followed by the introduction of gaseous ammonia (or ammonia-nitrogen mixture) to raise the system pressure to 100 psig (690 kPa) with subsequent inspection for leaks. Like other standards and codes, IIAR 2 is not intended to be a step-by-step guide for pressure testing. Plants are still required to develop and implement test procedures that meet the requirements of the code while protecting the safety of personnel on-site.

Let's look at some key safety considerations that arise in planning and executing successful pressure tests.

PNEUMATIC PRESSURE TESTING SAFETY CONSIDERATIONS

As we have already discussed, pneumatic testing carries with it inherent risks. Paulson (2009) reviews risks associated with pneumatic testing and identifies a number of specific recommendations to manage those risks. Paulson (2009) demonstrated that 1,000 ft-lb $_{\rm f}$ (1,356 J) of stored energy in a system under pressure test is a reasonable upper bound for stored energy and that limit provides a safe approach to manage the hazards present in pneumatic pressure testing.

ASME PCC-2 includes methods to calculate the stored energy as well as recommendations for establishing safe distances from a system undergoing a pneumatic pressure test. Applying the first law of thermodynamics and assuming ideal gas properties along with assuming the gas release process is reversible and adiabatic, the following relationship predicts the stored energy for air, *E*, (Paulson 2009).

$$E = \frac{P_{at} \cdot V}{(k-1)} \cdot \left[1 - \left(\frac{P_a}{P_{at}} \right)^{\frac{(k-1)}{k}} \right]$$
 Eq. 1

where

 $E = \text{stored energy, ft-lb}_f(J)$

k = ratio of constant pressure to constant volume specific heat for test gas

 P_a = absolute atmospheric pressure, 14.7 psia, (Pa)

 P_{at} = absolute test pressure, psia (Pa)

 $V = \text{total volume under test pressure, ft}^3 \text{ (m}^3\text{)}$

Assuming air is the test gas (k=1.4), the above relationship simplifies to the following:

$$E = 360 \cdot P_{at} \cdot V \left[1 - \left(\frac{P_a}{P_{at}} \right)^{0.286} \right]$$
 Eq. 2

Although somewhat fictitious, some have related the above stored energy, E, in terms of a trinitrotoluene (TNT) equivalent. The TNT equivalent (Ib_m) for stored energy expressed in ft- Ib_f is given by the following [ASME PCC-2]:

$$TNT = \frac{E}{1488617}$$
 Eq. 3

where

E = stored energy, ft-lb_f TNT = equivalent energy in a charge of TNT, lb_m

The blast effects associated with the stored energy will decrease as a cube of the distance from the origin. ASME PCC-2 establishes the following relationship for a safe set-back distance:

$$D = 30 \cdot (TNT)^{1/3}$$
 Eq. 4

where

D = minimum set back distance, ft TNT = equivalent TNT of stored energy, lb_m

The leading coefficient of 30 in Eq. 4 is a scaling factor included in PCC-2 that relates to the extent of biological and structural damage that could occur within the safe zone during the catastrophic failure of a system at the final test pressure. In this case, the biological impact that could lead to ear drum rupture and the potential for structural failure that could be damage to concrete block structures. The owner may choose other criteria.

EXAMPLE:

Determine the minimum safe set back distance for conducting a pneumatic test on a 20 cubic foot volume of a piping system using air to a final test pressure of 330 psig.

1. The first step is to determine the TNT equivalent using Eq. 2.

$$E = 360 \cdot P_{at} \cdot V \left[1 - \left(\frac{P_a}{P_{at}} \right)^{0.286} \right] = 360 \cdot (330 + 14.7) \cdot 20 \left[1 - \left(\frac{14.7}{344.7} \right)^{0.286} \right]$$

 $E=1,475,098\,ft-lb_f$ (2 MJ)

2. Next we determine the TNT equivalence using Eq. 3.

$$TNT = \frac{E}{1488617} = \frac{1,475,098}{1,488,617} = 0.99 \ lb_m \ (0.9 \ kg)$$

3. Finally, we use Eq. 4 to determine the safe distance.

$$D = 30(TNT)^{1/3} = 30(0.99)^{1/3} = 29.9 ft (9.1 m)^{\dagger}$$

The *safe distance* is the recommended perimeter around all sides of a piping system undergoing pressure testing that should be established. Personnel or other susceptible

[†] Appendix III of Article 5.1 in ASME PCC-2 requires the safe distance to be as follows:

- for E < 1E8 ft-lb_f (135.6 MJ)
 - o Safe distance = max(D, 100 ft [30 m])
- for $1E8 \le E < 2E8$ ft-lb_f $(135.6 \le E < 271.2$ MJ)
 - Safe distance = max(D, 200 ft [60 m])

If E > 2E8 ft-lb_f the volume of system being tested should be reduced to reduce risk.

infrastructure that is movable should be removed from within safe distance boundary during the pressure test

process until the system pressure is reduced to the leak test pressure at which time only authorized personnel responsible for leak checking would be admitted. If maintaining this *safe distance* is not practical or feasible due to constraints within the facility, the volume of the system being pressure tested can be reduced until an achievable safe distance boundary is established. Keep in mind that the creation of a *safe distance* boundary or "test zone" with the above-calculated safe distance needs to be in all directions (think spherical) once pressure testing commences. The *safe distance* boundaries should be clearly marked with "do not cross" tape, barricades or other appropriate means to restricted access to only test personnel as-required. During the portion of pressure testing when the system is raised to the final test pressure, it is recommended that test personnel remain outside of the test zone as well.

PRESSURE TESTING

There are a number of other factors that need due consideration when planning and conducting a pressure test. The first step to a safe and successful pressure test is the development of a detailed pressure test plan. The pressure test plan is then followed by test personnel during pressure test execution. Finally, the test results need to be documented.

PRESSURE TEST PLAN

To be safe and successful, the development of a pressure test plan is essential. The plan needs to address a number of pre-test details including:

1. Pre-test inspection to verify all components in the piping system planned for testing have a pressure rating that meets or exceeds the intended/specified *final test pressure*. The design pressure needs to be documented as this establishes the basis for determining the final target test pressure (at least 110% of the design pressure but no greater than 130% of design pressure for pneumatic pressure testing).

Every component that <u>will be subjected to the test pressure</u> must have a design pressure equal to or greater than the piping system's design pressure. The following table provides typical design pressures for industrial ammonia refrigeration piping systems along with the minimum *final test pressure* (110% of design pressure) and the maximum *final test pressure* (130% of design pressure).

| Design Pressure | Final test pressure | Final test pressure |
|-----------------|---------------------|---------------------|
| | (minimum) | (maximum) |
| psig, [kPa] | psig, [kPa] | psig, [kPa] |
| 150 [1,034] | 165 [1,138] | 195 [1,344] |
| 200 [1,379] | 220 [1, 517] | 260 [1,793] |
| 250 [1,724] | 275 [1,896] | 325 [2,241] |
| 300 [2,068] | 330 [2,275] | 390 [2,689] |

The pressure test plan should prescribe a test protocol that requires the piping system to be continuously monitored while the system is under pressure during testing.

- Identification of all components connected to the piping system that will not be subject to the pressure test. For
 example, components that are manufactured units that have already undergone pressure testing may be
 excluded. The plan must also establish appropriate means for isolating those components or subsystems not
 subject to pressure testing such as those factory tested previously [exempt from pressure testing by ASME B31.5
 section 538.2.1].
- 3. Selection of the test gas that will be used and associated precautions (e.g. if nitrogen is to be used, are there risks of asphyxiation to test or other personnel?).
- 4. Determination of stored energy and associated safe distances along with plans for restricting access to the *test zone*.
- 5. Based on the stored energy and safe distance analysis, the test plan may require dividing the piping system into

- smaller pieces for pressure testing in order to stay within desired (or necessary) safe distance limits.
- 6. Consideration as to whether a hazard analysis is required prior to undertaking the pressure test process.
- 7. Training requirements and/or credentials of pressure and leak testing personnel.
- 8. Procedures to identify and remove all pressure relief devices permanently installed on those parts of the piping system subject to a pressure test and plugging or capping the openings as separate relief protection for the piping system being tested will be integrated into the pressure test system.
- 9. Inspection of all joints to make sure they are free and clear of primer, paint, oil, grease, flux, slag, or other contaminants that might interfere with leakage inspections prior to beginning the pressure test process.
- 10. Identification of methods and materials that will be used in leak testing (e.g. commercial bubble detection solutions, gas detection, etc.).
- 11. Locations for installation of test plugs (internal or external) and clearly marking those locations for personnel safety should a discharge occur. The plan should also consider whether or not gagging is required and associated tie points for the test plug gag(s).
- 12. Required positions for all valves (isolation, control valves, expansion, etc.) in the system planned for leak testing. The test plan/procedure should identify the valves by tag number and define the appropriate position before, during, and after the pressure test.
- 13. Care should be taken to ensure that check valves are not unintentionally isolating portions of the system undergoing testing.
- 14. Verification of pressure rating of hose, manifold, or other parts of the apparatus used for the temporary connections being made from the pressure source to the piping system being tested.
- 15. Verification of the pressure test gauge range and calibration.
- 16. Verification of suitable pressure test regulator and its proper function.
- 17. Verification of test system pressure relief device/valve including the valve's capacity, set pressure, and operability.
- 18. Verification that temperatures of the system undergoing test are above the ductile-brittle transition temperature for the components that will be subjected to the pressure test [per B31.5 538.4.2(c)]. As a margin of protection, it is recommended that the piping temperature be at least 30°F above the ductile-brittle transition during pressure testing.
- 19. Establishment of the specific protocol to be followed during the leak test (similar to that identified in the next section).
- 20. Identification of appropriate means for safely bleeding the pneumatic test gas from the system. This includes verifying adequate monitoring or ventilation where the test gas may reduce oxygen levels in confined areas (e.g. bleeding nitrogen from the system indoors). It also includes identification of appropriate personal protective equipment (hearing protection, eye protection, etc.) for test personnel.
- 21. Owner review and approval of the pressure test plan.

It is important to note that a credible pressure test plan cannot be developed unless current and accurate asbuilt P&IDs are available for the system planned to undergo pressure testing. In addition, a considerable amount other process safety information needs to be in-hand to ensure all of the requirements outlined in the pressure test can be safely met (such as material test reports, minimum design metal temperatures, etc.). Obtaining and reviewing this information is often overlooked in the rush to get systems tested for tightness to allow construction of the piping system to be promptly completed so painting, insulation, and system start-up can commence. DO NOT SHORT CUT PRESSURE TEST PLANNING!

PRESSURE TEST EXECUTION

The pressure test execution must adhere to the pressure test plan. A typical pressure test execution will involve the following:

- 1. Identifying the specific portion of the system that will be the subject of pressure testing.
- 2. Notifying and establishing the safe distance boundary referred to as the test zone and ensuring no personnel (or

- other sensitive infrastructure) are within the *test zone*. The use of barricades or other means is appropriate for preventing unauthorized access to the area.
- 3. Isolating all connected components and equipment that will not be subject to the pressure test.
- 4. Positioning all valves within the boundary of the system to be subject to pressure testing placed in their required position (open, closed). The use of a valve line-up form or checklist is useful to ensure that all valves are in their required position.
- 5. Verifying the ambient temperature is and will remain above the ductile-brittle transition temperature of the piping system components within the scope of the test plan.
- 6. Introducing the test fluid into the system from a pressure-regulated supply equipped with a safety relief valve along with a suitably spanned and calibrated master gauge for observing the system pressure.
 - a. As part of a preliminary pressure test, the system's gauge pressure is increased to a maximum of 25 psig (170 kPa) in order to determine if any major leaks exist. If leaks are found, the system is depressurized, repaired, and re-pressurized to a maximum of 25 psig and re-inspected until no leaks are apparent.
 - b. Following the preliminary pressure test, the full pressure test commences with the system pressure gradually increased to the greater of (1) 50 psig (340 kPa) or (2) 35% of the *final test pressure*. Once at the increased pressure increment, it is held for 3 minutes to allow strains to equalize. The pressure is then subsequently increased in 50 psi increments until 50% of the *final test pressure* is reached.
 - c. Once the system pressure increases to 50% of the *final test pressure*, that pressure level is held for 10 min. If the master pressure test gauge shows a decrease of 10% or more, the system pressure shall be lowered to 25% of the *final test pressure* and joints inspected for leaks and repaired.
 - d. With a successful hold at 50% of the *final test pressure*, the system pressure shall be increased in 10% increments with 5 minute holds at each pressure increment to observe the master pressure test gauge to determine whether any pressure loss is occurring.
 - e. Once the *final test pressure* is reached, the system test pressure should be held for 10 minutes (ASME PCC-2) and the master pressure test gauge observed to ensure any pressure decrease does not exceed 1% of the *final test pressure*.
 - f. If no leakage is apparent, the system pressure is reduced to the *design pressure* and leak test personnel then enter the safe distance perimeter to begin examining the piping system for leakage. The examination for pneumatic leakage at all joints is made by the proper application of commercially available leak detection solutions. In cases where a leak exists, bubbles will form and become readily visible to leak test personnel. If leaks are found, repairs shall commence **once the system is fully depressurized**. Following the repair, the pressure test sequence steps shall be repeated until the system passes.
- 7. Following a successful pressure test, the test fluid shall be safely bled from the system and the piping pulled into a vacuum to be held until charging commences. If the system being tested will normally run at sub-atmospheric pressure, a vacuum test shall be conducted. In a vacuum test, the system pressure is reduced to 10,000 microns initially. If that pressure is difficult to achieve or maintain, there may be water present in the system low points should be checked for cold spots which would indicate water is evaporating. Continue evacuating to 5,000 microns and hold the system for 1 hour. Pressure rise should not exceed 1,000 microns (IIAR 5). Some end-users may require a longer duration for their vacuum hold.
- 8. IIAR 2 then requires the introduction of ammonia <u>vapor</u> into the successfully completed pressure tested piping system. Sufficient ammonia is introduced into the system to raise the pressure to 100 psig [690 kPa]. Under low ambient temperature conditions that prevent the pressure from reaching 100 psig, dry nitrogen is introduced to increase pressure to 100 psig. The system pressure is then held for 24 hr to demonstrate leak tightness.
- 9. After completion of all pressure testing, the piping system construction can be completed including: priming, painting, insulating, etc.

DOCUMENTATION

At the conclusion of a successful execution of a pressure test, the results shall be documented as evidence that the piping system has been pressure tested, and found to be tight. At a minimum, the documentation or test record needs to include: the test date; identification of piping tested; testing fluid used; final test pressure obtained; leak detection media and method; pressure held during leak test; and the name and business address of person(s) performing the pressure test. See Appendix I of Article 5.1 in the ASME PCC 2 standard for an example pressure test record form.

CONCLUSIONS

All industrial refrigeration piping systems designed and constructed in accordance with ASME B31.5 are subject to a post-construction pressure test regimen. In this issue of **THE COLD FRONT**, we reviewed methods of pressure testing as well as risks associated with pneumatic pressure testing. Methods for determining the stored energy in a system undergoing pneumatic testing were presented along with recommendations of establishing safe test zones. Safe and successful pressure testing requires careful planning and execution of test procedures in accordance with the plan. See the listed sources below for additional sources of information on pressure testing.

REFERENCES

ASME B31.3, "Process Piping", American Society of Mechanical Engineers, (2010).

ASME B31.5, "Refrigeration Piping and Heat Transfer Components", American Society of Mechanical Engineers, (2010).

ASME Section VIII Div. 1, "Boiler and Pressure Vessel Code – Rules for Construction of Pressure Vessels", American Society of Mechanical Engineers, (2010).

ASME PCC-2, "Repair of Pressure Equipment and Piping," American Society of Mechanical Engineers, (2008).

ASTM E1003, "Standard Test Method for Hydrostatic Leak Testing", ASTM International, (2005).

BP, "BP Process Safety Series - Hazards of Trapped Pressure and Vacuum" 3rd Edition, Institution of Chemical Engineers (2009).

IIAR 5, "Start-up and Commissioning of Closed-Circuit Ammonia Mechanical Refrigerating Systems", International Institute of Ammonia Refrigeration, draft standard for trial use (2008).

ANSI/IIAR 2, "Equipment, Design, and Installation of Closed-Circuit Ammonia Mechanical Refrigerating Systems", including Addendum A, International Institute of Ammonia Refrigeration, (2008).

IRC, "Stress Corrosion Cracking: Defining & Diagnosing", IRC Cold Front Newsletter, Vol. 5 No. 1, (2005)

Paulson, S. S., "Pressure Systems Stored-Energy Threshold Risk Analysis", Pacific Northwest National Laboratory report PNNL-18696, Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830, (2009).

Sources for Additional Information

Ellenberger, J. Phillip., Piping and Pipeline Calculations Manual - Construction, Design, Fabrication, and Examination, Elsevier, (2010).

Lees, F.P., Loss Prevention in the Process Industries, 2nd Edition, Elsevier, (1996).

Matthews, Clifford, Engineers Guide to Pressure Equipment - The Pocket Reference, John Wiley & Sons. (2001).

NASA, "Glenn Research Center, Glenn Safety Manual", Chapter 7—Pressure Systems Safety, GLM-QS-1700.1, (2010).

Nayyar Mohinder L., Piping Handbook, 7th Edition, McGraw-Hill, [Chapter B14], (2000).

Smith, Peter, Process Piping Design Handbook, Volume 1 - The Fundamentals of Piping Design, Gulf Publishing Company, (2007).

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