CHAPTER B14
PRESSURE AND LEAK TESTING

INTRODUCTION

Robert B. Adams
President and CEO
EST Group, Inc.
Harleysville, Pennsylvania

Pressure testing is required by most piping codes to verify that a new, modified, or repaired piping system is capable of safely withstanding its rated pressure and is leak tight. Compliance to piping codes may be mandated by regulatory and enforcement agencies, insurance carriers, or the terms of the contract for the construction of the system. Pressure testing, whether or not legally required, serves the useful purpose of protecting workers and the public.

Pressure testing may also be used to establish a pressure rating for a component or special system for which it is not possible to establish a safe rating by calculation. A prototype of the component or system is subjected to a gradually increasing pressure until measurable yielding first occurs or, alternatively, to the point of rupture. Then by using derating factors specified in the code, or the standard, appropriate to the component or system, it is possible to establish a design pressure rating from the experimental data.

PIPING CODES

There are a great many codes and standards relating to piping systems. Refer to Chap. A4 for a comprehensive listing and overview of codes and standards for piping systems, covering many different applications. Two codes of major importance for pressure and leak testing are the ASME B31 (previously called ANSI B31) Pressure Piping Code and the ASME Boiler and Pressure Vessel Code. While these two codes are applicable to many piping systems, other codes or standards may have to be met as required by the authorities, insurance companies, or the owner of the system. Examples might be AWWA standards for water transmission and distribution system piping.

The ASME B31 Pressure Piping Code has several sections. They are

- ASME B31.1 for Power Piping
- ASME B31.2 for Fuel Gas Piping
- ASME B31.3 for Process Piping
- ASME B31.4 for Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia, and Alcohols

- ASME B31.5 for Refrigeration Piping
- ASME B31.8 for Gas Transmission and Distribution Piping Systems
- ASME B31.9 for Building Services Piping
- ANSI/ASME B31.11 for Slurry Transportation Piping Systems

The ASME Boiler and Pressure Vessel Code also has several sections which contain pressure and leak testing requirements for piping systems, pressure vessels, and other pressure retaining items. These are

- Section I for Power Boilers
- Section III for Nuclear Power Plant Components
- Section V for Non Destructive Examination
- Section VIII for Pressure Vessels
- Section X for Fiberglass Reinforced Plastic Pressure Vessels
- Section XI for In Service Inspection of Nuclear Power Plant Components

There is great similarity with respect to the requirements and procedures for testing among the many codes. Various leak-testing methods, planning, preparation, execution, documentation, and acceptance standards for pressure testing will be discussed in this chapter. Equipment, useful for pressure testing, will also be included in the discussion. The material that follows should not be considered a substitute for a complete knowledge or careful study of the particular code requirement that must be used to test a particular piping system.

LEAK-TESTING METHODS

There are many different methods for pressure and leak testing in the field. Seven of these are

1. Hydrostatic testing, which uses water or another liquid under pressure
2. Pneumatic or gaseous-fluid testing, which uses air or another gas under pressure
3. A combination of pneumatic and hydrostatic testing, where low pressure air is first used to detect leaks
4. Initial service testing, which involves a leakage inspection when the system is first put into operation
5. Vacuum testing, which uses negative pressure to check for the existence of a leak
6. Static head testing, which is normally done for drain piping with water left in a standpipe for a set period of time
7. Halogen and helium leak detection

Hydrostatic Leak Testing

Hydrostatic testing is the preferred leak-testing method and perhaps the most often used. The most important reason for this is the relative safety of hydrostatic testing compared to pneumatic testing. Water is a much safer fluid test medium than air because it is nearly incompressible. Therefore, the amount of work required to compress water to a given pressure in a piping system is substantially less than the work required to compress air, or any other gas, to the same pressure. The work of compression is stored in the fluid as a potential energy, which could be released suddenly in the event of a failure during a pressure test. A calculation of the potential energy of air compressed to a pressure of 1000 psig (6900 kPa) compared to the potential energy of the same final volume of water at 1000 psig (6900 kPa) shows a ratio of over 2500 to 1. Therefore, the potential damage to surrounding equipment and personnel resulting from a failure during a pressure test is far more serious when using a gaseous test medium. That is not to say that there is no danger at all in a hydrostatic leak test. There can be substantial danger in a hydrostatic test due to air trapped in the piping. Even if all air is vented from the piping before pressurizing, workers are well advised to conduct any high-pressure test with safety in mind.

Hydrostatic testing may not be practical if during normal operation, the piping system cannot tolerate traces of water or its residue. An example would be a cryogenic system, which operates at a subfreezing temperature for water. The time required for removal of all traces of water prior to placing the system into operation could impede the startup process. Another example would be piping for a liquid sodium system. Traces of water left in the pipe would react violently with the liquid sodium. If another convenient-to-use liquid is not available, it may be more practical to use pneumatic testing.

Another disadvantage of hydrostatic testing may be the cost of disposal of the water if it has become environmentally contaminated from residue in the piping. In addition, it takes more time to fill and empty the system. Furthermore, if the system normally operates with a gaseous medium, the piping may not be strong enough to support the weight of a liquid test medium without additional temporary supports.

Inspection for leaks is a visual examination of all joints for signs of water. The leak-detecting capability of a hydrostatic test is not as good as a pneumatic test and is far less sensitive than a properly conducted halide or helium leak test. A hydrostatic test is sufficiently sensitive if the system normally operates with a liquid. However, if the system normally operates with a gaseous medium and slight leakage of this medium is unacceptable, a hydrostatic test may not be sufficiently sensitive to detect a slight gas leak. The reason for this is that the surface tension of water can act as a barrier to a leakage path that has a very small dimension. A gaseous-fluid test medium will leak through a small space that water will not pass through because of the surface tension of water. If it is sufficient that a system designed to operate a gaseous process is bubble tight, pneumatic testing is appropriate. However, if the leakage requirement is more stringent than bubble tight, halide or helium leak testing would be required. In either case the gaseous test is only more sensitive than the hydrostatic test if the system is completely dry at the time of the test.

Pneumatic Leak Testing

The fluid normally used for a pneumatic test is compressed air, or nitrogen if the source is bottled gas. Nitrogen should not be used in a closed area if the possibility exists that the escaping nitrogen could displace the air in the confined space. Persons have been known to become unconscious under such circumstances before realizing they were short of oxygen.

Because of the greater danger of injury with a gaseous test medium, the pressure that may be used for visual examination for leaks is lower for some piping codes than is the case for a hydrostatic test. For example, for pneumatic tests, ASME B31.1 permits the pressure to be reduced to the lower of 100 psig (690 kPa) or the design pressure during the examination for leakage. If the pressure required by the code is quite high, persons may be barred from the test area and sonic listening devices used to search for leaks. However, normally inspection for a leak is done with a soapy-water mixture that is applied to the joints and which produces bubbles when air is escaping. The applicable code may specify that pneumatic testing can only be done with the approval of the owner of the system (for example, ASME B31.1 section 137.5.1 and B31.3 section 345.5.1).

Combination Pneumatic and Hydrostatic Testing

A low air pressure, most often 25 psig, (175 kPa) is first used to see if there are major leaks. This low pressure reduces the danger of personal injury but still enables major leaks to be quickly located. Repairs, if needed, can then be done before the hydrostatic test. This method can be very effective in saving time, particularly if it takes a long time to fill a system with water only to find leaks on the first try. If leaks are found in a hydrostatic test, it will take longer to remove the water and dry the piping sufficiently to make repairs.

Hydrostatic-pneumatic leak testing is different from the two-step test in the preceding paragraph. In this case the pressure test is conducted with a combination of air and water. For example, a pressure vessel designed to contain a process liquid with a vapor phase or air above the liquid may have been designed to support the weight of liquid to a certain maximum-expected height of liquid. If the vessel was not designed to support the weight when completely filled with liquid, it would be possible to test this vessel only if it was partially filled with process fluid to a level duplicating the effect of the maximum-expected level.

Initial Service Leak Testing

This category of testing is limited by the codes to certain situations. For example, ASME B31.3 limits the use of this technique to category D fluid service. Category D fluid services are defined as nonhazardous to humans and must operate below 150 psi (1035 kPa) and at temperatures between −20 and 366°F (−29 and 185°C). ASME Code B31.1, section 137.7.1, does not allow initial service testing of boiler external piping. However, that same section of ASME B31.1 permits initial service testing of other piping systems if other types of leak testing are not practical. Initial service testing is also applicable to inspection of nuclear power plant components by Section XI of the ASME Boiler and Pressure Vessel Code.

As indicated, this test is usually run when the system is first put into operation. The system is gradually raised to normal operating pressure as required in ASME B31.1 or design pressure as required in ASME B31.3. It is then maintained at that pressure while an examination for leaks is conducted.

Vacuum Leak Testing

Vacuum leak testing is an effective way to determine whether or not there is a leak anywhere in the system. This is normally done by drawing a vacuum on the system and trapping the vacuum within the system. A leak is indicated if the trapped vacuum rises toward atmospheric pressure. A manufacturer of components quite often uses this type of leak test as a production leak test.

However, it is very difficult to determine the location or locations of a leak if one exists. Smoke generators have been used to determine the piping location where smoke is drawn into the piping. This is very difficult to utilize unless the leak is sufficiently great to draw all or most of the smoke into the pipe. If there is substantially more smoke generated than can be drawn into the pipe, the smoke that dissipates into the surrounding air can easily hide the leak location.

Obviously, this method is not suitable for testing the piping at or above the operating pressure unless the piping is to be operated at a vacuum.

Static-Head Leak Testing

This test method is sometimes called a drop test because a drop in the water level in the open standpipe, added to the system to create the required pressure, is an indication of a leak. Once the system and standpipe is filled with water, the standpipe level is measured and noted. After a required hold period, the height is rechecked and any decrease in level and the hold period are recorded. Any leak location is determined by visual inspection.

Halogen and Helium Leak Testing

These test methods use a tracer gas to identify leakage location and leakage quantity. In the case of halogen leak detection, the system is charged with halogen gas. A halogen detector probe is used to sense leakage of the tracer gas from any exposed joint. The halogen leak detector, or sniffer, consists of a tubular probe which sucks a mixture of leaking halogen gas and air into an instrument sensitive to small amounts of halogen gas. This instrument employs a diode to sense the presence of halogen gas. The leaking halogen gas is passed over a heated platinum element (the anode). The heated element ionizes the halogen gas. The ions flow to a collector plate (the cathode). Current proportional to ion formation rate, and thus to leakage flow rate, is indicated by a meter. The halogen detector probe is calibrated using an orifice that passes a known leakage flow. The detector probe is passed over the orifice at the same rate that will be used to examine the system for leakage. The preferred tracer gas is refrigerant 12, but refrigerants 11, 21, 22, 114, or methylene chloride may be used. Halogens should not be used with austenitic stainless steels.

Helium leak testing may also be done in the sniffer mode, as explained above for halogens. However, in addition, helium leak testing may be performed using two other methods that are more sensitive in detecting leakage. These are the tracer mode and the hood or closed system mode. In the tracer mode a vacuum is drawn on the system, and helium is sprayed onto the outside of joints to be inspected for leakage. The system vacuum draws helium through any leaking joint and delivers it to a helium mass spectrometer. In the hood mode, the system to be tested is surrounded by concentrated helium.

The hood mode of helium leak testing is the most sensitive method for detecting leaks and the only method accepted by ASME Code Section V as quantitative. Manufacturers of components requiring a hermetic seal will use the hood method of helium leak detection as a production leak test. In these cases, the component may be surrounded by helium in a chamber. A connection to the component is made to a helium leak detector, which attempts to draw the internals of the component to a vacuum close to absolute zero. Any leakage of helium from the surrounding chamber into the component will de drawn into the helium leak detector by the vacuum it is producing. The helium leak detector contains a mass spectrometer configured to sense the presence of helium molecules. This closed-system testing method is capable of sensing leaks as small as 1×10^{-10}cc/sec (6.1×10^{-12} cubic in/sec), standard atmospheric air equivalent. The closed-system method is not appropriate to measuring a large leak that would flood the detector and render it useless for further measurement until every helium molecule could be withdrawn from the detector.

The closed-system method is not appropriate to a piping system in the field because of the large volumes. Also it does not show the location of the leak or leaks. Finally, the sensitivity of leak detection, using the closed system, is many orders of magnitude greater than normally required. The helium sniffer is the least sensitive method and is subject to false indications if helium from a large leak at one location in the system diffuses to other locations. A large leak can also flood the detector, temporarily rendering it useless until all the helium is removed from the mass spectrometer. The helium pressure used in all these methods is normally one or two atmospheres, which is sufficient to detect the presence of very small leaks. The low pressure also serves to reduce the amount of helium required for the test. Helium leak testing is rarely, if ever, used to demonstrate that the system can safely withstand the design pressure rating.

Helium leak detectors will not be successful in finding leaks unless the component or piping system is completely dry. Liquid contained in a small leakage path, due to capillary action, may seal the leak because of the low pressure of the helium and the surface tension of the liquid. Therefore great care is required to use this approach under completely dry conditions. Otherwise this system may be even less sensitive in detecting a leak than a high-pressure hydrostatic test. Furthermore, the helium leak detector is easily contaminated by oils and other compounds and rendered inaccurate. Field conditions are normally not free of the possibility for contamination of the leak detector.

Sensitivities of Leak-Testing Methods and Acceptance Standards

The order in which the various leak-testing methods indicate leak tightness, from least sensitive to most sensitive, are

1. Hydrostatic leak testing with visual observation
2. Pneumatic testing with visual observation of bubbles in soapy mixture
3. Gas lake testing
4. Helium-mass spectrometer sniffer
5. Halogen-diode sniffer
6. Helium-mass-spectrometer tracer technique
7. Helium-mass-spectrometer hood method

The gas lake method is similar to pneumatic testing, but instead of using a soapy mixture to detect leakage, all the pneumatic leakage is collected and passed through a water trap to permit a quantitative measurement of total leakage. Obviously the gas lake method is practical only with certain piping or vessel configurations that make it simple to conduct all the leakage to one location.

Pneumatic bubble testing should provide for a sensitivity of at least 10^{-3} std cc/sec (6.1×10^{-5} cu in/sec). Pneumatic testing is at least 57 times more sensitive than hydrostatic testing at the same pressure because of the ratio of viscosities. This ratio can be even larger when considering the barrier effects of surface tension in a hydrostatic test.

The maximum acceptable leak rate standards in ASME Code Section V for tracer gas methods are

1. Helium sniffer maximum acceptable leak rate of 1×10^{-4} std cc/sec (6.1×10^{-6} std cu in/sec)
2. Halogen sniffer maximum acceptable leak rate of 1×10^{-4} std cc/sec (6.1×10^{-6} std cu in/sec)
3. Helium-tracer-probe maximum acceptable leak rate of 1×10^{-5} std cc/sec (6.1×10^{-7} std cu in/sec)
4. Helium-hood-method maximum acceptable leak rate of 1×10^{-6} std cc/sec (6.1×10^{-8} std cu in/sec)

The maximum sensitivity of the helium-hood method can be increased in special cases from 10^{-10} std cc/sec (6.1×10^{-12} std cu in/sec) to 10^{-14} std cc/sec (6.1×10^{-16} std cu in/sec). This is done by allowing the leakage to accumulate in a known volume before a measurement of the leakage is made.

SELECTION OF A TEST METHOD AND FLUID TEST MEDIUM

The test method and fluid test medium to be used are most often known at the early stage of design of the piping system. The piping system contract will usually specify the applicable codes. Even if the applicable codes are not spelled out, the piping designers will know which codes will apply, based upon the piping system application and the jurisdiction. The codes in turn specify the allowable pressure and leak-testing methods. The designers will almost always know from experience which of the various testing methods permitted by the applicable code will be employed by the contractor. Based on this knowledge, the piping-system designers will provide the means required for running the tests, such as properly located connections for filling, venting, pressurizing, and measuring the test pressure of the system. They may even provide for additional temporary supports for the weight of a liquid test medium if the piping is for a gaseous-process medium.

They will also consider how portions of the system that are not to be tested may be isolated from the portions under test. This is usually done with isolating valves and flange blinds. In some cases field tests need to be conducted on subassemblies of process piping or equipment. In those cases the piping or vessels may have openings for later connection to the final system. If there are open ends of the piping or open connections to a vessel that must be sealed during the pressure test, hydrostatic test plugs may be more economically employed for this purpose than temporarily sealing these openings by welding. Cross-sectional views of hydrostatic test plugs, shown in Fig. B14.1 and B14.2, are discussed in greater detail in the later section titled Hydrostatic Test Plugs. The advance knowledge of a requirement for hydrostatic test plugs can be especially important for plug sizes larger than NPS 12 (DN300). Larger test plugs usually require longer delivery times.

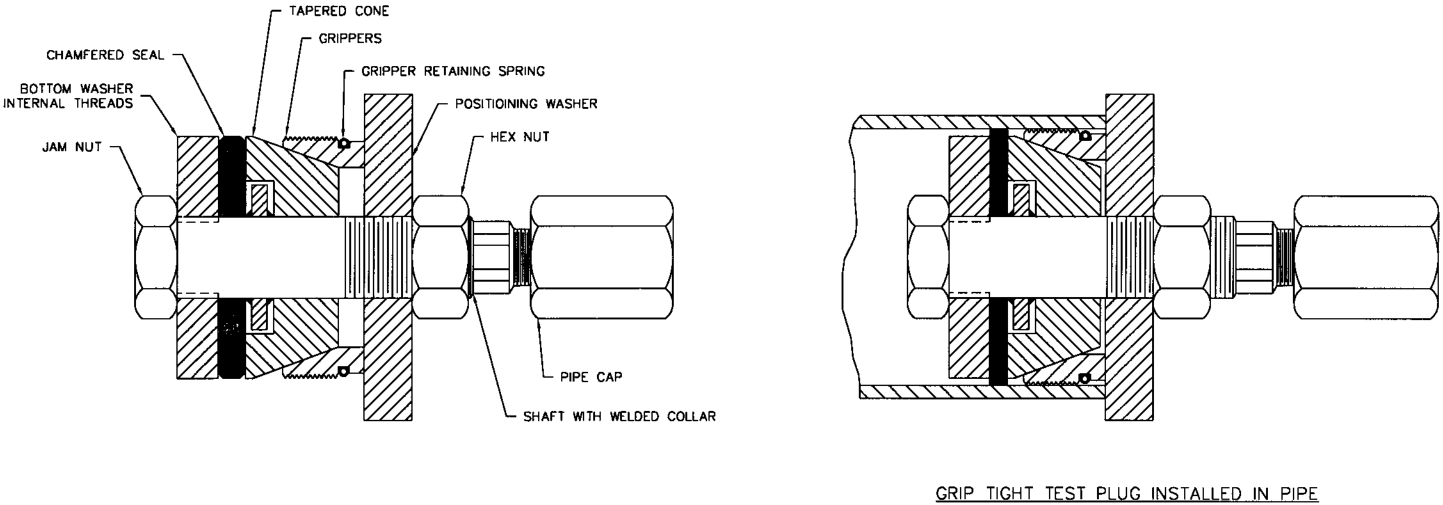

FIGURE B14.1 ID test plug. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

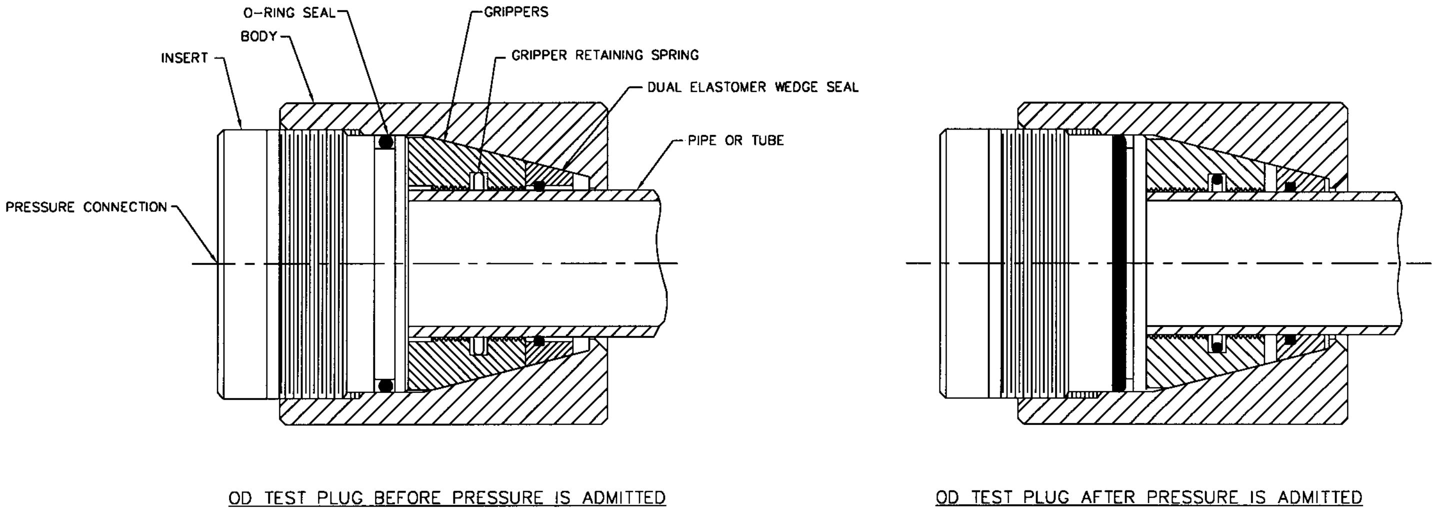

FIGURE B14.2 OD test plug. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

The chosen leak-testing method must be compatible with the piping-system requirements, in addition to meeting the code or standards requirements. Additionally the fluid test medium must be selected. These two choices are essential in establishing the test equipment required to fill or evacuate the piping, set and regulate the test pressure, and detect leaks by other than visual means. In addition, these two choices establish whether temporary additional supports may be required to support the weight of the test fluid medium. This entire test-related equipment must be arranged for far enough in advance to be available and in place prior to the starting date for the leak test.

Hydrostatic testing is most often preferred over pneumatic testing because of safety considerations. Water is the preferred fluid medium for hydrostatic testing. In addition to its relatively incompressible nature, it is also the safest fluid because it is nontoxic and nonflammable and it remains in liquid form down to atmospheric pressure unless heated above the boiling point. Water is readily and economically available. ASME B31.1, section 137.4.3, specifies water as the test fluid for hydrostatic tests unless otherwise specified. ASME B31.3, section 345.4.1, also specifies water as the test fluid for hydrostatic test unless there is the possibility of freezing or damage from adverse effects of water on the piping or the process for which the piping system is designed. This section provides for other uses of other nontoxic liquids as long as the flash point exceeds 120°F (49°C). If hydrostatic testing is being considered for a system that was designed for use of a gaseous medium as the process fluid, it must first be determined that the piping system will support the weight of the test liquid or that the piping can be safely supported during the hydrostatic test.

There are some cases where water cannot be employed as a fluid test medium. Traces of water left in the piping may react adversely with the process; for example, in piping for liquid sodium or a cryogenic process. If the test is to be run at temperature conditions which would make freezing likely, antifreeze may be added to the water as long as the antifreeze is not harmful to the piping or the process and the disposal of large amounts of antifreeze is not environmentally unacceptable. If water cannot be employed as the fluid test medium and another liquid is not practical, or if it is not practical to support the weight of a test liquid with piping supports, a pneumatic test may be the next best choice.

Testing of Piping Additions, Modifications, or Repairs

There is a lesser known technique for testing piping modifications or additions to older systems that can save considerable effort by testing only the new, modified, or repaired joints without the need for filling the entire piping system. This involves using a special device, called a flange test plug, shown in the cross-sectional view of Fig. B14.3, that will test only the weld between a weld-neck or slip-on flange and pipe. A modification of the flange test plug of Fig. B14.3 can be used to help make the weld between a weld-neck flange and a pipe in addition to also testing the weld. The modification adds a center port to sense any pressure in the pipe behind the plug and lengthens the plug to prevent seal damage from the heat of the weld. This device, called a flange weld plug, aligns the parts to be welded, provides for any gas purging requirements during the welding, and warns or protects the welder against any unexpected increase in pressure back in the pipe. Finally a special dumbbell test plug, shown in Fig. B14.4, may also be used to test only a single weld. The flange test plug, flange weld plug, and special dumbbell plugs are explained in greater detail in the later section titled Hydrostatic Test Plugs Suited

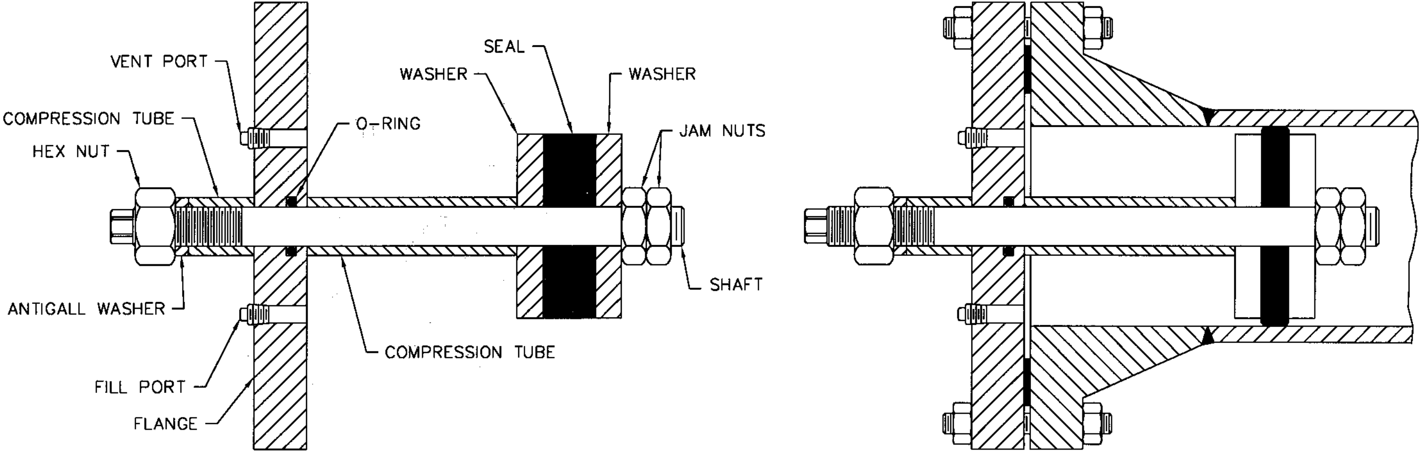

FIGURE B14.3 Flange test plug and flange weld plug. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

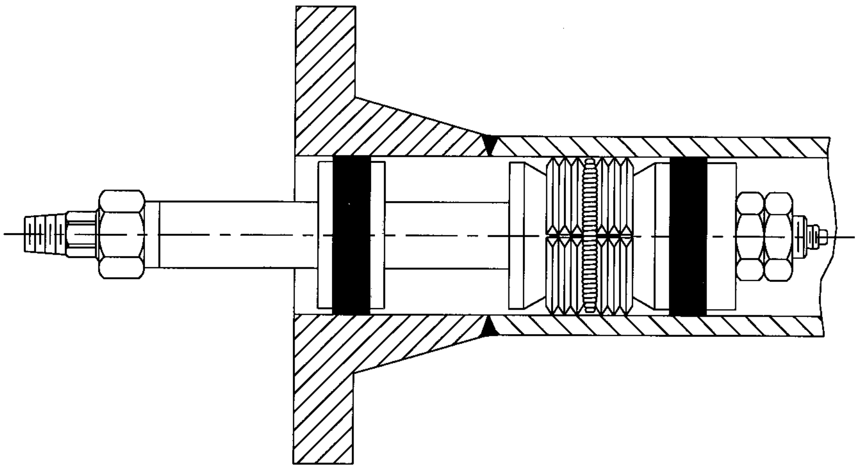

FIGURE B14.4 Special dumbbell plug. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

to Testing a Single Weld. All these devices save considerable time and money in testing plant expansions or modifications because it takes only moments to fill the small space surrounding the weld to be tested with the fluid test medium. There is also a substantial cost saving in the reduced amount of contaminated test liquid to be disposed of. It is always best to consider such options at the design stage because of the delivery time required for these special devices.

Test Pressures

The selected test method and fluid test medium, together with the applicable code, will also establish the rules to be followed in calculating the required test pressure. In most cases a pressure greater than the design pressure rating is applied for a short duration, say at least 10 minutes. The magnitude of this initial test pressure is often at least 1.5 times the design pressure rating for a hydrostatic test. However, it may be different, depending upon which code is applicable and whether the test is hydrostatic or pneumatic. Furthermore, the test pressure must never exceed a pressure that would cause yielding, or the maximum allowable test pressure of some component exposed to the test. In the case of ASME B31, section 137.1.4, and the Boiler and Pressure Vessel Codes, the maximum test pressure must not exceed 90 percent of yield for any component exposed to the test. The test pressure is needed to demonstrate that the system can safely withstand the rated pressure. Following this period of greater than design pressure, it is often permissible to reduce the pressure to a lower value for examination of leaks. The examination pressure is maintained for the length of time necessary to conduct a thorough

TABLE B14.1 Test and Examination Pressures

Code	Test type	Test pressure minimum	Test pressure maximum	Test pressure hold time	Examination pressure
ASME B31.1	Hydrostatic[1]	1.5 times design	Max allowable test pressure any component or 90 percent of yield	10 minutes	Design pressure
ASME B31.1	Pneumatic	1.2 times design	1.5 times design or max allowable test pressure any component	10 minutes	Lower of 100 psig or design pressure
ASME B31.1	Initial service	Normal operating pressure	Normal operating pressure	10 minutes or time to complete leak examination	Normal operating pressure
ASME B31.3	Hydrostatic	1.5 times design[2]	Not to exceed yield stress	Time to complete leak examination but at least 10 minutes	1.5 times design
ASME B31.3	Pneumatic	1.1 times design	1.1 times design plus the lesser of 50 psi or 10 percent of test pressure	10 minutes	Design pressure
ASME B31.3	Initial service[3]	Design pressure	Design pressure	Time to complete leak examination	Design pressure
ASME I	Hydrostatic	1.5 times max allowable working pressure[4]	Not to exceed 90 percent yield stress	Not specified, typically 1 hr	Max allowable working pressure[4]
ASME III Division 1 Subsection NB	Hydrostatic	1.25 times system design pressure[5]	Not to exceed stress limits of design section NB-3226 or maximum test pressure of any system component[5]	10 minutes	Greater of design pressure or .75 times test pressure
ASME III Division 1 Subsection NB	Pneumatic	1.2 times system design pressure[6]	Not to exceed stress limits of design section NB-3226 or maximum test pressure of any system component	10 minutes	Greater of design pressure or .75 times test pressure

TABLE B14.1 Test and Examination Pressures (*Continued*)

Code	Test type	Test pressure minimum	Test pressure maximum	Test pressure hold time	Examination pressure
ASME III Division 1 Subsection NC	Hydrostatic	1.5 times system design pressure	If minimum test pressure exceeded by 6 percent establish limit by the lower of analysis of all test loadings or maximum test pressure of any component	10 minutes or 15 minutes per inch of design minimum wall thickness for pumps and valves	Greater of design pressure or .75 times test pressure
ASME III Division 1 Subsection NC	Pneumatic	1.25 times system design pressure	If minimum test pressure exceeded by 6 percent establish limit by the lower of analysis of all test loadings or maximum test pressure of any component	10 minutes	Greater of design pressure or .75 times test pressure
ASME III Division 1 Subsection ND	Hydrostatic	1.5 times system design pressure for completed components, 1.25 times system design pressure for piping systems	If minimum test pressure exceeded by 6 percent establish limit by the lower of analysis of all test loadings or maximum test pressure of any component	10 minutes	Greater of design pressure or .75 times test pressure
ASME III Division 1 Subsection ND	Pneumatic	1.25 times system design pressure	If minimum test pressure exceeded by 6 percent establish limit by the lower of analysis of all test loadings or maximum test pressure of any component	10 minutes	Greater of design pressure or .75 times test pressure

Notes:

1. Boiler external piping must be hydrostatic tested in accordance with PG-99 of ASME Code Section I.
2. ASME B31.3 hydrostatic pressure must be raised above 1.5 times design pressure in proportion to yield strength at test temperature divided by strength at design temperature but not to exceed yield strength at test temperature. Where a vessel is involved whose design pressure is less than the piping and where vessel cannot be isolated, the piping and vessel can be tested together at vessel test pressure provided vessel test pressure is not less than 77 percent of piping test pressure.
3. ASME B31.3 initial service testing permitted only for piping in category D service.
4. ASME Code Section I hydrostatic test pressure at temperature of at least 70°F (21°C) and examination pressure at temperature less than 120°F (49°C). For a forced-flow steam generator with pressure parts designed for different pressure levels, the test pressure should be at least 1.5 times the maximum allowable working pressure at the superheater outlet but not less than 1.25 times the maximum allowable working pressure of any part of the boiler.
5. ASME Code Section III, Division 1, subsection NB, test pressure limits defined in section NB3226; also components containing brazed joints and valves to be tested at 1.5 times system-design pressure prior to installation.
6. ASME Code Section III, Division 1, subsection NB, pneumatic test pressure for components partially filled with water shall not be less than 1.25 times system-design pressure.

inspection for leakage. Again the examination pressure depends upon the particular code and the selected method of testing. Table B14.1 gives test and examination pressures for some of the ASME B31 and Boiler and Pressure Vessel codes.

The test pressure for each test is calculated by multiplying the code requirements for the leak-test method by the design pressure of the weakest component or line within the test boundary. An exception to this occurs when the design rating is given for a higher temperature than the temperature at which the pressure and leak test will be conducted. In this case the test pressure must be increased by an amount reflecting the decrease in strength of the material between the test temperature and the operating temperature unless that would exceed code limitations regarding the maximum test pressure. Another exception occurs in ASME B31.3, where a vessel cannot be isolated from the system, and the allowable vessel pressure is less than calculated test pressure for the piping. In such a case it is acceptable to hydrostatic test the piping at the maximum allowable vessel–test pressure provided the owner approves and the reduced test pressure is at least 77 percent of the calculated test pressure per ASME B31.3, section 345.4.3.

PRESSURE TESTING PROCEDURES

The field engineer, responsible for the implementation of the field test program, must first be familiar with the testing provisions of the code or standards that are part of the contract. This person must assure coordination between the test supervisor, QA/QC, the contractor, and owner. The person responsible for the testing should begin preparation for the testing phase far enough ahead of piping system completion so that all the equipment needed to conduct the test is ready to be used and all preparations are completed before testing is scheduled to begin.

Preparation of Test-Package Documentation

A P&ID (piping and instrumentation diagram) marked with information concerning the pressure test, the piping isometrics, a valve line-up sheet, a test cover sheet, and a test data sheet make up the package of test documentation.

The P&ID should be marked with the scope of the leak test, showing boundary valves and test blind locations to isolate connections of the piping to the parts of the system which do not need to be pressure tested. If hydrostatic test plugs are required to seal any pipe or vessel openings, that requirement should be noted. The valve line-up sheet shown in Fig. B14.5 should be completed, showing the valve positions required for the test. Also identify any valves which must have the internals removed or must be blocked in position. Test blinds may be fabricated in accordance with the data given in Table B14.2. The ASME B31 codes do not require retesting of a flanged joint once the blinds are removed.

Determine the required test pressure by reviewing the P&ID drawings to obtain the lowest line index and lowest design pressure rating within the boundary of the test. Two checks are required for proper test pressure.

First, review the design documents and vendor information to ensure that the test pressure will not overpressurize any equipment or piping component within the pressure test boundary. In addition, verify that there will be no possibility of brittle fracture at the test pressure and temperature.

Second, determine the head loss between the lowest part of the piping and the gauge location. The head loss in psig is equal to the difference in elevation in feet

VALVE LINE-UP DATA SHEET

PRESSURE TEST NUMBER:	PROJECT NO.:	PAGE 1 OF
TYPE OF TEST: ☐HYDRO ☐PNEUMATIC ☐OTHER SPECIFY (OTHER):	PROJECT NAME:	
SYSTEM:		

VALVE NUMBER	DESCRIPTION	POSITION	TAG NUMBER

REMARKS:

RESPONSIBLE FIELD ENGINEER:	DATE:
CHECKER:	DATE:
APPROVAL:	DATE:

FIGURE B14.5 Valve line-up data sheet for pressure testing.

multiplied by 0.4327 psig/ft (9.7 kPa/m) for water as the test fluid. This will establish the required gauge readings during the test to avoid overpressure at the lowest point in the system. Determine also the pressures that the lowest parts of the system will experience.

The test cover sheet contains an identifying number for the test, test date, test pressure, fluid test-medium description, and all release and acceptance signatures. Test release authorizations depend upon the project. They may include the welding field engineer, instrumentation field engineer, mechanical field engineer, hanger field engineer, quality control inspector, superintendent, third party representative, and client representative. The piping or hanger field engineer will have to verify that the lines are supported to handle the hydraulic loads. The client may also walk down the package before the test can be performed.

The pressure-test data sheet of Fig. B14.6 is used to record the data taken during the test. It also contains provision for the sign-off required by the field engineer and the code inspector, if applicable, as is the case with boiler external piping (BEP).

TABLE B14.2 Test Blind Dimensions

Test blind fabrication data

A = Blind plate diameter
B = Paddle handle width
C = Handle height
D = Blind thickness
t = Required blind thickness
d = Nominal diameter of pipe
P = Line design pressure (psig)
S = allowable material stress

General notes:

1. Plate material types
   A-36, S = 12,600 PSI
   A-285 GR. C, S = 18,350 PSI
   A-570 GR. 36, S = 16,300 PSI

$$t = d\sqrt{\frac{3}{16} \times \frac{P}{S}}$$

Note: This will provide a safety factor of 1.7 of yield. These same values may be used for A36 plate, however, the safety factor will be reduced to 1.4

Test blind thickness schedule A285 Grade C

Pipe size	Test pressure			t, Test blind thickness						
	A	B	C	100	300	500	700	1000	1500	2000
1	2	1	4½							
1½	2⅞	1	5⅛							
2	3⅝	1	5¼							
3	5	1	6⅛	⅛	¼	½	¼	⅜	½	⅝
4	6³⁄₁₆	1	6¾	⅛	¼	⅜	⅜	½	⅝	¾
6	8½	1½	11½	¼	⅜	⅜	½	⅝	¾	1
8	10⅝	1½	12⅝	¼	½	⅝	¾	⅞	1⅛	1¼
10	12¾	1½	14	⅜	⅝	¾	1	1⅛	1¼	1½
12	15	1½	15½	½	¾	1	1⅛	1⅜	1⅝	1⅞
18	16¼	1½	16½	⅝	1	⅜	1⅝	1⅞	2¼	2⅝
20	23	1½	17¾	⅝	1⅛	1½	1¾	2⅛	2½	2⅞

A = Blind diameter
B = Grip width
C = Height from center of paddle to top of grip

Preparation

As the piping system nears completion, a check list should be made of items still requiring completion before testing can begin. This list must be pursued by the person(s) responsible for running the test until all remaining items are completed. Otherwise, it could be discovered that the system is not ready to be tested only when testing is ready to begin. Reviewing P&ID drawings is the best way to develop

PRESSURE TEST DATA SHEET

PRESSURE TEST NUMBER:	PROJECT NO.:	PAGE 1 OF
TYPE OF TEST:	PROJECT NAME:	

TEST INFORMATION		
SYSTEM:		
TEST BOUNDRIES:		
PIPE CLASS:	DESIGN TEMPERATURE:	DESIGN PRESSURE:
TEST METHOD: ☐ HYDROSTATIC ☐ PNEUMATIC ☐ OTHER SPECIFY (OTHER):		
TEST MEDIUM:	APPLICABLE CODE:	

TEST REQUIREMENTS			
TEST PRESSURE:	psi (kPa)	TEST TEMPERATURE:	°F (°C)
TEST DURATION:	_HR._MIN.	AMBIENT TEMPERATURE:	°F (°C)
EXAMINATION PRESSURE:	psi (kPa)	HOLD TIME:	Min.

GAUGE PRESSURE	
ELEVATION DIFFERENCE BETWEEN GAUGE AND HIGH POINT:	Ft. (m)
STATIC HEAD:	psi (kPa)
PLUS REQUIRED TEST PRESSURE:	psi (kPa)
EQUALS REQUIRED GAUGE PRESSURE:	psi (kPa)

PRE-TEST REVIEW	
FIELD ENGINEER:	DATE:
CODE INSPECTOR:	DATE:

TEST RESULTS			
TEST DATE:	START TIME: ☐ AM ☐ PM		
	FINISH TIME: ☐ AM ☐ PM		
ACTUAL GUAGE PRESSURE:	PRESSURE DROP:	IN:	min.

TEST EQUIPMENT			
TYPE:	RANGE:	CAL. DATE:	CAL. DUE:
TYPE:	RANGE:	CAL. DATE:	CAL. DUE:
TYPE:	RANGE:	CAL. DATE:	CAL. DUE:
TYPE:	RANGE:	CAL. DATE:	CAL. DUE:
REMARKS:			

TEST ACCEPTANCE	
FIELD ENGINEER:	DATE:
CODE INSPECTOR:	DATE:

FIGURE B14.6 Pressure test data sheet.

this checklist. A comparison of the P&ID drawings and the piping isometrics must be made to determine if there are any discrepancies. Review all valve types, flow directions, branch tie-ins, and any material changes. Recheck all in-line components to verify they can withstand the required test pressure.

After the crosscheck is complete conduct a physical inspection of the piping system using the P&IDs and piping isometrics. Typically systems are inspected for

- Completed and torqued flanges with no missing bolts or gaskets
- All gravity supports installed
- Proper pipe routing
- Correct valve type and orientation
- Vents and drains installed to allow proper filling and draining

- Proper material type verified using color codes or markings, and heat numbers recorded if required by the codes
- All required piping stress relief, weld examinations, and welding documentation completed and acceptable

Before the test is to be run, make certain, by reviewing the piping against the P&ID and valve line-up sheet, that

- All equipment not to be tested is disconnected from the test or isolated by closed valves or testing blinds
- Tagging and lockout of any valves used to isolate the test boundaries is in place to protect both the testing personnel and any others who may be on site
- All nonboundary valves in the test boundary are in the open position
- Expansion joints, if any, have required restraints to protect against damage from the test pressure
- All springs have travel stops to protect against the weight of the test medium
- All test equipment is checked and all test connections are tight

For gas systems, additional gravity supports may be required temporarily to support the weight of the test liquid.

Since requirements vary from project to project, the person responsible for the test will need to make a specific checklist of items for each project before testing can begin.

Hydrostatic Testing Preparation

All joints, including welds and flanges, of the portions of the system to be tested are left uninsulated and exposed for examination during the test. Some insulation may be installed on the straight runs or previously tested piping. If the system is to include jacketed piping, the leak tests should be run before any jacketing is installed.

A sample hydrostatic-test setup is shown in Fig. B14.7. A flow water pump is substituted for the pressurizing water pump during the filling of the piping. The water source should provide clean chloride-free water. The system is filled from the bottom to facilitate the venting of all air in the portion of the piping system under test. For sloped piping systems, filling should be done against the slope. Vents must be located at all high points in the piping and should be open during the filling stage. Once it is determined the system is completely liquid filled the vents may be closed and a pressurizing water pump connected to the system in place of the flow pump. The pressurizing pump must have a capacity greater than the allowable leakage of the system. Leakage at the packing glands of valves and pumps is permissible by the codes and is necessary to preserve the life of the packing. However, if this leakage is so great that the test pressure cannot be controlled by being trapped, there will be a problem in running the test. It is not very practical to turn the pressurizing pump on and off to maintain the pressure close to the required level. One solution is to temporarily tighten all the packings to a greater compression than is normally used during regular operation of the system. It may also be necessary to tighten flanges, screwed connections, and other mechanical or gland-type joints to eliminate leakage.

SAMPLE HYDROSTATIC TEST SETUP

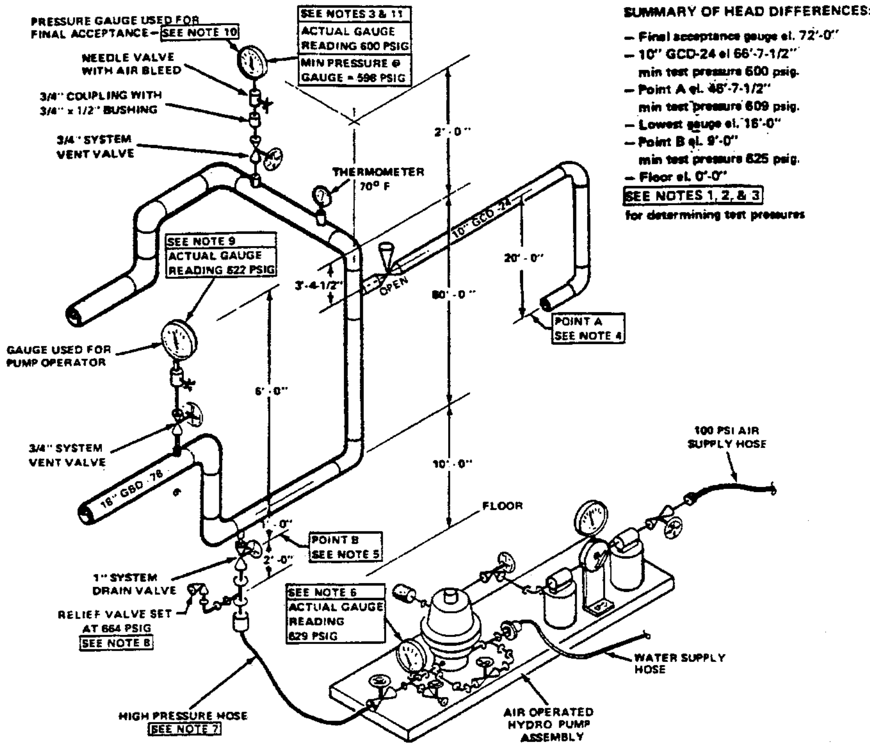

FIGURE B14.7 Hydrostatic test setup.

Calibrated relief valves should be installed as close as possible to the filling connection and to the low point of the system. The relief valves have two purposes. First they protect against an accidental overpressure during the pressurization process. To accomplish this they must have sufficient relief capacity to pass the full flow of the pressurizing pump (or filling pump if it is also used for pressurizing). Second they protect against an increase in pressure during the test that might result from an ambient temperature increase. The relief valve should be set to prevent the system pressure from exceeding

- The maximum allowable pressure of the lowest rated component in the test boundary
- The maximum allowable seat or backseat pressure of boundary valves
- The maximum allowable set pressures for gagged system-relief valves
- The maximum allowable pressures established by the applicable code or project specification

It is very important to eliminate all trapped air from the piping before pressurizing the piping. Trapped air poses at least three problems in hydrostatic tests. First, the danger of injury is greater if there is a failure with trapped air in the system. Second, if the air is trapped at a piping joint that is leaking, there may not be visible evidence of a water leak. Third, the presence of trapped air will lengthen the time required to pressurize the system. This last effect may be used as an indication of the presence of trapped air. It is also possible to test for trapped air in a piping system by tapping the pipe. A hollow sound indicates the presence of trapped air.

On the other hand there is a potential danger posed by a completely liquid-filled piping system. Normally pressure is trapped in the piping system after the pressurizing pump has raised it to the test level. With a trapped system, an overpressure condition can occur with an increase in ambient temperature. This is most likely to occur if the system is pressurized and trapped early in the day. Later in the day as the temperature increases the system pressure will rise unless controlled. This is because the thermal coefficient of expansion of water is an order of magnitude greater than that of the piping system metal. As the ambient temperature increases, the thermal expansion of the water is greater than that of the piping by at least an order of magnitude. Thus with an ambient temperature increase, the water is compressed by the piping, with a consequent increase in the water pressure that can be dramatic because of the relative incompressibility of water. Because of the potential dangers posed by this phenomenon, the ASME B31.1, section 137.2.6, and ASME B31.3, section 345.2.1, cite precautions to be taken against pressure rise during testing. This is usually done with a pressure-relief valve set as indicated above. Another means of preventing a thermally induced overpressure is not to leave the test unattended. The gauges must be continually monitored and pressure bled off at the vents as needed.

Information concerning the test gauges should be recorded on the test data sheet. Calibration of the test gauges should be performed prior to the start of the test against a master gauge or deadweight tester whose own calibration is traceable to the U. S. National Institute of Standards and Technology (NIST) standards. If the gauge employed is an analog device, the test pressure should ideally occur at midscale but never below 25 percent of full scale. A 1 percent of full scale accuracy device is generally acceptable. If the gauge is a digital gauge it may be used anywhere within the range that the accuracy is specified. This is because the accuracy of a digital gauge is generally a fixed percentage of the reading rather than full-scale reading. After the test is concluded, and the pressure reduced to zero, the zero reading of the gauge should be verified. If the gauge fails to repeat the zero reading by a significant amount, the test reading is not to be trusted.

Conducting the Pressure and Leak Test

Pressurization of the system should be done slowly and in stages only after all trapped air has been eliminated. Visual checks for leakage should be made during the pressurization process. If the system pressure for the examination of leakage is different than the maximum test pressure, the system should be held at the maximum test pressure for the prescribed period before it is reduced to the examination pressure. When examining the system for leakage, any condensation should be wiped away from the system parts to provide a clear and unmistakable view of leakage.

If there are any joints that cannot be visualized during the leak test and it is decided to use a trapped pressure for indication of leakage at the hidden joint, be aware of the following: First, there cannot be any significant leakage elsewhere in the system. Any leaking flanges or packings must be tightened to shut off their leakage. Any leaking joints must be repaired. The shutoff valves and blinds employed to isolate the system boundaries, including the valve to the pressure source, must be leak tight. If all the trapped air has been eliminated from the portion of the system under test, the trapped pressure will increase and decrease substantially as the ambient temperature increases and decreases. This occurs, as explained before, because of the greater thermal coefficient of expansion of the water as compared to the pipe material. A calculation using published values for the linear thermal coefficient and the bulk modulus of water estimates that the pressure will change approximately 40 psi/°F (497 kPa/°C). Any trapped air would reduce the magnitude of this effect. In order for the trapped-pressure test to successfully indicate a leak, the ambient temperature must remain reasonably constant. There is also another temperature-related effect to be aware of. When the piping is first pressurized, the liquid is heated by the compression. This heating immediately increases the liquid temperature above its surroundings. As heat transfer takes place to the surroundings there will be an exponential decline in liquid temperature and pressure. This effect can be recognized by its exponential nature. On the other hand a leak could be expected to cause a decrease in pressure at an approximate constant rate.

Normally the piping system, with the exception of possible leakage at pump or valve packings, should not show any visible sign of leakage. This is a requirement of ASME B31.1. Any sign of leakage at a permanent joint would be cause for repair to eliminate the leakage. However, in certain applications some leakage may be permitted if the consequences of small leakage amounts are not significant. This would have to be by permission of the owner or expressed in the piping system contract.

Draining the System

After the leakage test is completed the system may be drained. The piping may be drained and left to air dry or have hot air blown through it to dry it. Alternatively it may be left filled to prevent rust from forming until the system is put into operation. If the system is left filled after testing there should be warning tags on the valves to advise anyone of the wet layup condition. In draining the system, the following precautions should be observed:

- First make sure all system vents are open.
- Vents on tank-pressure vessels should be open and functional to avoid damage during draining.
- The rate of drainage should not exceed the allowable rate of the building or temporary drainage system.
- Disposal of test liquids containing surface preservatives or other water additives must meet local and project environmental requirements.
- Make certain that temporary piping and instrument connections are relieved of pressure before being disconnected.
- Make sure downstream pressure is relieved in systems containing check valves if the valves were not gagged open.

Cold Weather Testing

Hydrostatic testing with water should not be performed when there is chance for freezing. If the temperature is at or below 40°F, it is still possible to use water if one of the following options is employed to prevent freezing:

- Steam the line.
- Run warm water through the pipe.
- Use electric heat tracing on the line.
- Add antifreeze to the water.

The next to the last option may be a safety hazard and should be avoided unless the piping insulation is completed except for the area around the joints that need to be observed during the test. The last option may not be allowed because of environmental concerns about using and disposing of large amounts of antifreeze. Another liquid with a lower freezing point might also be considered.

Extra care should be used in draining systems in cold weather to ensure there are no remaining pockets of water that may freeze.

Pneumatic Testing

When hydrostatic testing cannot be employed, pneumatic testing may be employed with the approval of the owner of the system. Pneumatic testing may be performed with a gas as the only fluid or with a combination liquid and gas. The latter is called hydropneumatic testing and requires a smaller volume of gas, which reduces the danger associated with the test. However, the persons performing the examination for leakage must know whether each joint is exposed internally to the liquid test medium or the gaseous test medium. This is necessary because in the former case the examiner will look for signs of liquid escape whereas in the latter a soapy mixture must be applied to the joint to reveal signs of leakage.

A combination of pneumatic and hydrostatic testing may also be employed. The system is first tested with low pressure air, usually 25 psig (175 kPa), for major leaks. After any leaks are repaired, the system is hydrostaticly tested at the pressure required by the specified code.

Typically pneumatic tests are conducted with filtered, oil-free air, nitrogen, carbon dioxide, or other suitable nonflammable and nontoxic gas. Test temperatures are typically ambient. In pneumatic testing it is especially important to know that there will be no parts of the system under test that could have brittle failure at the test temperature.

Compressors or gas bottles with regulators may be used as the pressure source. The pressure source must have a capacity in excess of the expected leakage of the system. If the pressure cannot be regulated at the test-pressure levels, it must be trapped in the system. In this case the leakage must be reduced for the test by tightening flanges and packings so that the test pressure may be maintained. Again, a trapped gas system is subject to pressure changes due to variations in ambient temperature, but this change is much less than that for water. If the gas is presumed to behave as a perfect gas, the percentage change of the absolute pressure of the test gas would be the same as the percentage change of the absolute temperature of the gas. Assuming the test is run at 100 psig (670 kPa) and 65°F (18°C), a trapped pressure with no leakage would change 1 psi (6.9 kPa) for a 4.6°F (2.5°C) change in its temperature.

The following safety precautions must be taken when conducting pneumatic testing to reduce the possibility of injury due to rupture in the system or test equipment:

- Correctly sized and calibrated relief valves are installed.
- All persons in the area of the test are notified that the test will be performed.
- All unnecessary personnel are removed from the test area.
- The immediate test area is blocked off or roped off with warning signs so that no one can unknowingly enter the test area.
- The connecting line between the pressure source and the system must be capable of withstanding at least the test pressure and preferably the source maximum pressure.
- It is preferable to double regulate a bottled-pressure source so that if one regulator fails, the source is still regulated below the bottle pressure.
- A properly calibrated test gauge is installed in the system to monitor the pressure buildup.
- If leakage is discovered, the system must be vented before repairs or adjustments are made.
- Always check the test equipment before applying pressure.

During pneumatic testing, the test gauge(s) is normally installed at a remote location from the system undergoing the test. The pressure must be increased gradually to the test pressure and held for a period, usually 10 minutes. Before the examination for leakage is started, the pressure may be reduced to the design pressure, or even as low as 100 psig (690 kPa) for ASME B31.1 per section 137.5.5 if that is lower than design pressure.

A sonic detector may be used for detecting leakage at a safe distance from the system under test if it is considered unacceptable for personnel to be close to the piping under test. Otherwise, a leak detector solution may be applied to joints to see if bubbles develop at the joint, indicating a leak. Acceptable leak detector solutions include:

- A solution of liquid soap and water
- Linseed oil
- Any commercially available leak detection solution

If verification of a leak rate is required, flowmeters or totalizing meters may be used to monitor the test. These may be placed between the pressure source and the piping system.

After the test is completed, the pressure in the system is relieved. Exercise the following precautions when releasing the pressure:

- Make sure any residual downstream pressure is relieved in systems containing check valves that were not gagged open.
- Make sure temporary piping and instrumentation is relieved of pressure prior to disconnecting them from the system.
- Gases should be vented to the atmosphere outside any building

HYDROSTATIC TEST PLUGS

The region of the piping system that must be pressure tested can be isolated from other piping by valves or test blinds. However, in those cases where systems that need to be tested have open-ended pipes or open connections to pressure vessels, another means may be used to seal these openings. Such openings may be sealed temporarily by welding them closed. Alternatively, hydrostatic test plugs are also used to seal the open ends of pipe or pipe connections to vessels if required for a hydraulic test. They have the advantage of eliminating the time to weld a closure and the additional time to cut off the welded closure and repair the pipe end. They may also be used over and over again.

Although these plugs have been described as *hydrostatic* they can also be used with gases. However, the greater danger associated with using these plugs for testing with gas requires stricter adherence to safety rules to avoid any possibility of personal injury should failure occur. Some manufacturers of hydrostatic test plugs recommend the use of safety gags when testing with air. Safety gags are devices that are assembled over the pipe and secured by clamping them around the pipe. At the same time a cable or chain link extending from the safety gag is also secured to the test plug to prevent it from doing any damage should the plug be expelled from the pipe.

There are hydrostatic test plugs that seal against the inside diameter of a pipe or tube as well as those that seal against the outside diameter. Figure B14.1 illustrates the internal or ID (inside diameter) test plug and Fig. B14.2 illustrates the external or OD (outside diameter) test plug. Each cross-section view, and a view showing the installation of the test plug to the pipe. Both the ID test plug and the OD test plug have a seal, made of elastomeric material, which is expanded or contracted, respectively, to seal against the pipe. The plugs also have a positive gripping means to prevent expulsion from the pipe when pressure is applied. In addition, these plugs provide a center port for either filling the pipe with the fluid test medium or venting trapped air. This port may also be used as a connection for gauging the test pressure.

Inside-Diameter Hydrostatic Test Plugs

In the case of the ID test plug of Fig. B14.1, the hex nut on the center shaft is tightened to force the segmented grippers to slide up the conical support surface and expand outward in a radial direction. The gripper segments are constrained to contact the conical support surface by the gripper-retaining spring. The grippers have rows of sharp edges, which contact the inside diameter of the pipe. Once these sharp edges have been forced to contact the pipe, further tightening of the hex nut axially compresses the seal to expand the seal outwardly in a radial direction until the seal is also compressed against the pipe inside diameter. The seal is made of an elastomeric material, which can deform against the pipe surface to create a leak-tight seal. The best designs of hydrostatic test plugs for the inside diameters of pipes can seal at any pressure up to the limit of a pressure that will rupture a pipe of any wall thickness and strength. For example NPS 12 (DN300) inside-diameter plugs of the design of Fig. B14.1 have been tested at pressures as high as 12,000 psig (82,800 kPa) without failure. In this particular case the test fixture rather than the test plug limited the pressure. Smaller plugs have been tested to over 20,000 psi (138,000 kPa). ID test plugs can be made in sizes up to NPS 42 (DN1050). Larger sizes are possible, but the cost increases substantially.

Outside-Diameter Hydrostatic Test Plugs

The outside-diameter test plug of Fig. B14.2 works in the following manner: By rotating the insert piece it is advanced deeper into the body. The movement of the insert displaces the gripper segments toward the narrower end of the conical section of the body thus forcing the grippers inward in a radial direction against the pipe. When the gripper segments contact the pipe, the O-ring contained in the wedge-shaped annular seal also contacts the pipe but only with light contact force. Notice that, in the view illustrating the situation before pressure is applied, that the inside diameter of the wedge-shaped seal does not contact the pipe when the grippers first touch the pipe. From this point, if the pressure is admitted to the pipe, the pressure force will try to move the body away from the pipe end, but at the same time, this slight relative movement acts to further tighten the grippers against the pipe. Simultaneously, the pressure force acting on the wedge-shaped annular seal forces the seal to move away from contact with the narrow end of the grippers and deeper into the body cone. This movement continues until the inside diameter of the wedge-shaped seal is forced into contact with the outside diameter of the pipe. When the inner-diameter surface of the wedge-shaped seal touches the pipe, the O-ring is completely trapped in its groove. Because of this, very large pressures can be experienced without concern that the O-ring will extrude past the O-ring groove regardless of tolerances in the pipe outside diameter.

An advantage of the outside-diameter test plug shown in Fig. B14.2 is that a single plug for one pipe size may be used on any wall schedule. In comparison, a different inside-diameter test plug is most often required for each wall schedule. However, this advantage over an ID test plug is somewhat offset by the greater cost for the outside-diameter test plug.

The outside-diameter test plug of this design has another advantage over the inside-diameter test plug. Hand tightening will generally secure the gripper segments against the pipe, as in the case of a good inside-diameter test-plug design. However, as we have seen above, hand tightening is also sufficient to enable a leak-tight seal for the OD test plug whereas the ID test plug requires tightening with a wrench to make the seal leak tight.

The outside-diameter plug is also capable of having a larger center port for greater filling capacity if needed. Because of this feature, two OD test plugs with a hose connected between them can be effectively used as a jumper to temporarily repair a broken pipe.

Outside-diameter hydrostatic test plugs in this design are available in sizes up to NPS 4 (DN 100) for line pressures up to 10,000 psi (69,000 kPa) for the smallest plug, down to 5000 psi (34,500 kPA) for the largest. Outside-diameter plugs can be made for larger diameters, but the weight and cost become greater than desirable for most applications unless the pressure requirements are considerably lower.

Factors to Consider in Selecting a Hydrostatic Test Plug

A number of different designs of inside-diameter test plugs are available from different manufacturers. Some very inexpensive versions are made without grippers. Plugs, without grippers, rely on the friction force of the seal against the pipe to prevent expulsion of the plug by pressure. Test plugs without grippers are limited to lower pressures and even with lower pressure are unreliable, particularly when the inside surface of the pipe may be slippery. A slippery condition may result from moisture, oils, grease, loose material on the inside of the pipe, or a smooth coating applied to the pipe. The manufacturers pressure ratings for test plugs without grippers apply only for clean dry uncoated pipe and proper tightening. The actual pressure that test plugs without grippers can withstand in slippery conditions is drastically reduced. This is because the friction coefficient between the seal and a slippery pipe may be as much as one or two orders of magnitude lower. It is always safer, regardless of pressure, to use a hydrostatic test plug that has a positive gripping means in addition to the seal. Well-designed grippers eliminate any effect from lubricants that can easily be displaced. However, grippers cannot entirely overcome the bad effects of loose material or smooth and hard surface coatings.

There are only a few outer-diameter hydrostatic test plug designs that are commercially available. In choosing a hydrostatic test plug for pressure testing, whether it be an inside-diameter or outside-diameter plug, the selected plug must at the minimum meet the required pressure rating. In addition, there are a number of very important factors to consider beyond just the initial cost alone. For safety considerations, it is very important to use a design that has at a minimum the following features:

- The test plug should remain firmly in the pipe at any pressure even though it was only hand tightened.

Some plugs must be tightened to a specific torque to prevent expulsion from the pipe at rated pressure or even pressures below the rating. Often the user does not have a torque wrench and therefore has no way of knowing when he has tightened the test plug in accordance with instructions. Other manufacturers do not give a tightening torque but instruct the user to tighten the plug enough to make the grippers completely and firmly contact the pipe. Such an instruction does not provide the user with any means of knowing when he has tightened the plug sufficiently to meet the requirements of the instruction. This is an extremely important safety issue for a first-time user or someone who might have been distracted before tightening the plug completely and never completed the job before pressure was applied. If the user has inadvertently forgotten to tighten the plug securely or simply didn't have the experience to do it properly, the danger is that the plug will eject from the pipe when pressure is applied, unless it is of a design that has the following construction features:

The segmented grippers must grip the pipe completely along their length before the seal is compressed. Designs which employ the grippers to compress the seal cannot have the grippers contact the pipe before the seal does. If the seal contacts the pipe before the grippers, it is possible to have a perfect *pop gun* when pressure is applied.

In addition, a single support cone for the segmented grippers is required to obtain the hand-tightening gripping capability. With the single cone, the entire axial length of the gripper is always in contact with the pipe inside diameter. Furthermore, the applied pressure must be able to displace the cone without interference from the seal in a direction that will force the grippers outward, along their entire length, with a greater force as the pressure increases. Grippers that are supported at either end by separated twin-cone surfaces will experience loosening at one end as the pressure increases. Furthermore, if twin-cone supports are utilized in a design where the grippers are also used to compress the seal, only the gripper end that loosens with pressure will contact the pipe, except at very high-tightening torque. Therefore, at some high pressure, which depends on how tight the plug has been installed, the gripper, supported by twin cones, will start to loose its grip.

- The test plug should remain firmly gripped in the pipe even at pressures up to those which cause bursting of the pipe.

A dual cone support for the grippers cannot accomplish the above objective because, as pressure is applied, the displacement of the plug expands the gripper segments outward at one end of the grippers and allows the grippers to retract away from the pipe inside diameter at the other cone support. In such a design, increased pressure does not cause increased gripper force along the entire axial length of the gripper.

Another design feature necessary to accomplish this objective requires that the compression of the seal and expansion of the grippers must be independent of each other. Designs that use the grippers to compress the seal cannot accomplish this objective.

In the case of OD test plugs it is not always practical to meet this objective. This is because it is expensive and cumbersome to make the OD test-plug body large enough to withstand the combination of the gripper and pressure loading.

- The seal should never contact the pipe during installation or removal.

Some test-plug designs incorporate seals that interfere with the pipe even before installation and tightening. Sharp edges on the open end of the pipe can damage a seal that is already larger than the pipe before installation. In addition, if the seal interferes with the pipe during installation, a large force is required to push the plug into the pipe. Alternatively, some users of plugs that have seal interference lubricate the seal to make it easier to install the plug. A test-plug design which has a seal that initially interferes with the pipe is also less tolerant of a wide range of pipe tolerances. A preferred inside-diameter test-plug design always has a seal that is smaller than the pipe inside diameter when the plug is being installed and removed.

- A test-plug design should never employ a fixed O-ring to seal the plug against the pipe.

First, a fixed O-ring would have to interfere with the pipe before it was installed in order to work at all. Second, having pipe and tube tolerances means that the O-ring interference will vary, depending on the tolerance. In the worst cases, the O-ring will have major interference with the largest pipe and be difficult to install. On the other extreme, with the smallest pipe, the O-ring will have little interference. Furthermore, with the smallest pipe, there will be a large gap between the plug parts and the pipe, allowing the O-ring to extrude into this gap under high pressure and fail. O-ring manufacturers recommend that the gap between the male and female parts be limited to a few thousandths of an inch for the highest pressure ratings to avoid extrusion of the O-ring out of its groove, and consequent failure.

- Any test plug should be able to function with only two gripper segments.

This is very important for cases where the pipe has a very out-of-round condition. In such a case it is likely that only two of the gripper segments will contact the pipe when pressure is first admitted.

- The test plug should be easily removable from the pipe after pressure is bled off.

Some gripper designs provide close to a locking angle, and, because of this, a severe impact is required to loosen them from the pipe after the test. In other cases the seal becomes wedged in the small space between the pipe and the test-plug parts, making it very difficult to remove the plug after the pressure is removed. This can be particularly true of test plugs that use low-durometer seals. However, some test-plug designs will work only if the seal is made from a low-durometer elastomer.

Care in the Use of Hydrostatic Test Plugs

Safety demands care in using any device to seal the open end of a pipe in order to run a pressure test. First verify that the pressure rating of the plug is greater than the test pressure to be used for the test. Next, the user must inspect the pipe end. It should be verified that the pipe diameter is within the range of dimensions that the plug is designed for. For example, if the plug seals against the inside diameter, that is the dimension that must be checked. Also, the surface against which the seal engages must be sufficiently free of defects for the seal to work. Finally, check the surface against which the grippers engage. This surface should be clean and dry. The pipe should not have a smooth and hard coating. Furthermore, there must not be any loose scale on this surface. If the grippers engage a loose surface scale as opposed to the pipe itself, the bond between the scale and pipe may break when pressure is applied, allowing the plug to slip.

Next examine the plug itself. It must be in good working condition. If there are signs of tearing of any of the gripper teeth they should be replaced. Also check that there is freedom of movement between the grippers and the supporting conical surfaces. Low friction between these two surfaces is essential to safe operation of the test plug. Sometimes users will find that a test plug was not cleaned and dried after the last use. If there are any signs of sticking, these parts should be cleaned and lubricated. Examine the hex nut and the threads on the shaft(s). They must be free of any damage or wear, and the hex nut must turn freely.

When installing the plug into the pipe always be sure to follow the manufacturer's recommended installation instructions. Always clean and properly store a test plug after each use.

HYDROSTATIC TEST PLUGS SUITED TO TESTING A SINGLE WELD

In those cases where a piping job is a repair, modification, or expansion of an existing system, it is very desirable not to have to fill and pressurize the entire piping system just to check the new welded joints. A device called a flange test plug shown in Fig. B14.3 can test a single weld between the pipe and a weld-neck flange or slip-on flange. Figure B14.3 shows cross-sectioned drawings of the plug before installation and the plug installed in piping. The flange test plug is inserted into the pipe after the weld is completed and bolted to the weld-neck flange. It is very important that the seal and mating parts are small enough to fit past any weld projection during the insertion and removal of the test plug. The seal, located behind the weld, is expanded in a radial direction to seal against the pipe by compressing the seal axially. The axial compression is accomplished by tightening the hex nut on the center shaft in order to squeeze the seal between the back washer and front washer. Flange test plugs larger than NPS 8 (DN200) have multiple shafts, which must all be tightened evenly to compress the seal.

Once the plug is installed, the fluid test medium can be admitted to the space between the flange and the seal against the pipe through ports located in the flange face. These ports also permit venting of the trapped gases for all positions but vertical up. In the latter case the trapped gas may be vented by temporarily relaxing the seal. Once the space surrounding the weld is completely filled with the test medium, it may be pressurized and the exposed weld joint visually examined for any signs of leakage. It is also possible to run a trapped pressure test with such a device. However, the same temperature effects as discussed before must be taken into account.

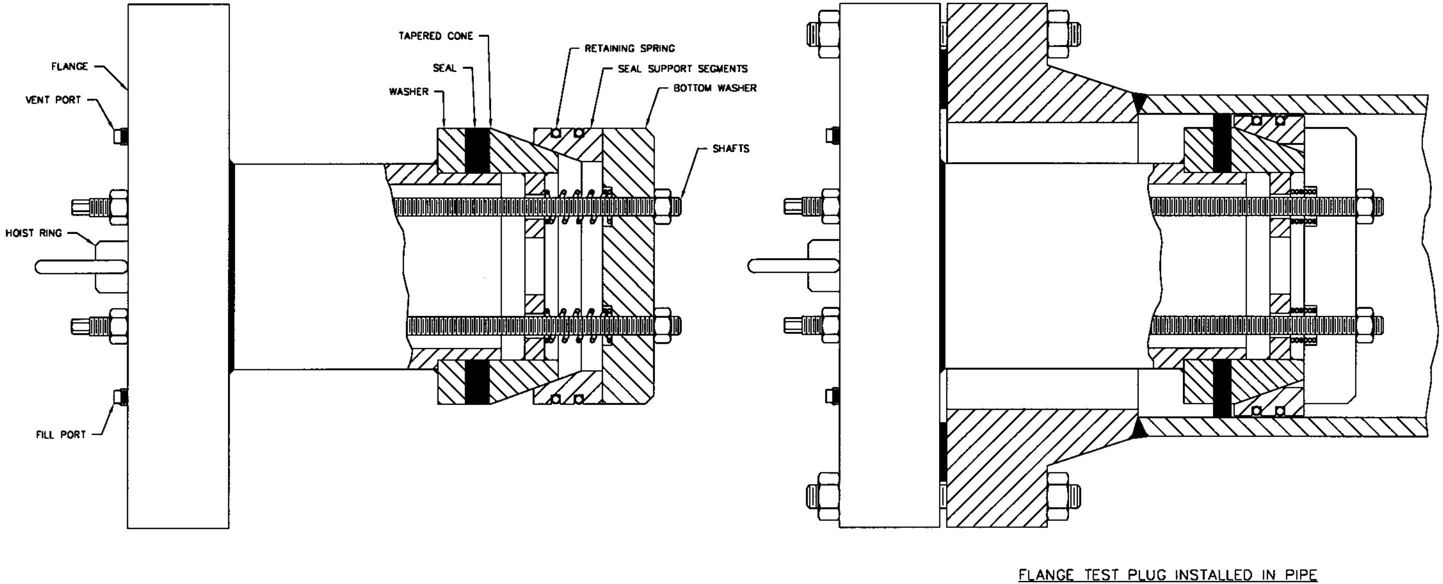

FIGURE B14.8a Special high lift flange test plug. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

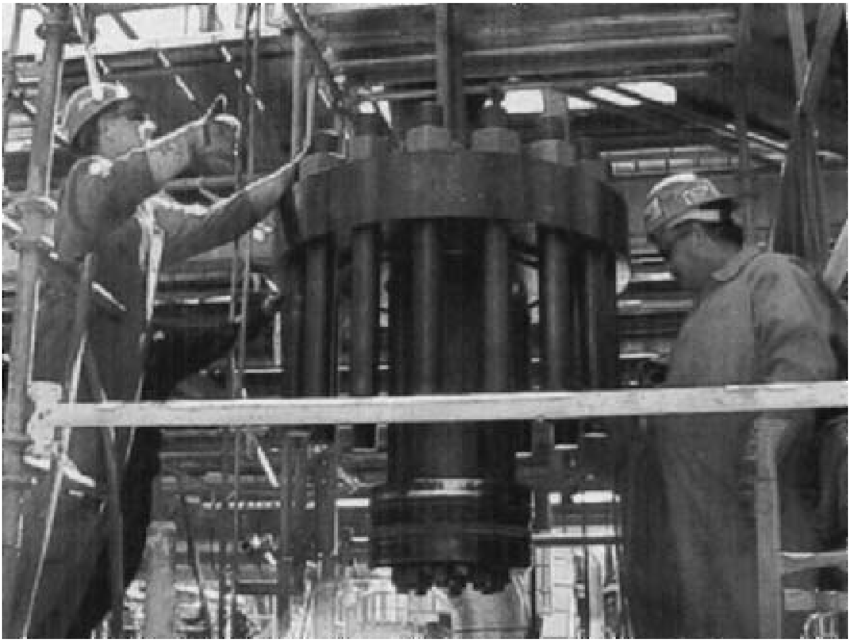

FIGURE B14.8b Special high lift flange test plug being installed. (*Courtesy of Expansion Seal Technologies, Harleysville, PA.*)

The flange test plug can substantially reduce the testing time and cost in a plant expansion or modification. In addition, if the test fluid is contaminated by residue in the piping, it is necessary only to dispose of a small amount of fluid test medium in an environmentally safe manner, as compared to filling the entire piping system. This capability also overcomes the argument sometimes advanced that a single weld should be subjected to a radiographic examination rather then be pressure tested as the code requires. This argument for taking a different approach than the code requires has often been made because of the inconvenience and cost of filling and pressurizing the entire system.

There have been some flange test plug applications where the opening in the weld-neck flange is smaller than the pipe on the other side of the weld. For example, this may occur when the flange rating is considerably higher than that for the pipe. There have also been applications for hydrostatic test plugs where these must fit through a narrow entrance and then seal against a larger diameter. Both of these applications can be accommodated with the special high lift design shown in Fig. B14.8a. Figure B14.8b shows a photograph of a 24 inch (DN 600) special high lift flange test plug being installed in a west coast refinery. Figure B14.8a shows cross-section views before and after the plug has been installed and adjusted so that the seal contacts the pipe. After the flange test plug has been inserted into the piping and the flanges have been bolted together, the hex nuts at the flange end are tightened gradually in sequence. Initially, during the tightening process, the segmented supports are urged to ride up the adjoining conical surface and expand outward in a radial direction. Once these segmented supporting surfaces expand to a diameter slightly less than the internal diameter of the pipe, further radial expansion of the segmented supports is prevented because the bottom washer engages the end of the cone. From this point, further tightening compresses the cone-shaped part against the seal to compress the seal axially and expand it outward until it seals against the pipe. The result is shown in Fig. B14.8a, identified as ''Flange test plug installed in pipe,'' and shows that the segmented pieces now act as back-up supports for the seal. The testing fluid medium may be admitted through one of the fill ports in the flange while the other serves to vent air from the space between the expanded seal and the flange. Once the liquid fill has been completed and is pressurized, any bending of the exposed portions of the seal due to pressure is resisted by the segmented supports. The use of this design has enabled a NPS 24 (DN 600) flange test plug to fit through an opening that was ⅞ in (22.23 mm) smaller than the diameter of the pipe against which the seal worked. In this application, the test pressure was over 2250 psi (15,525 kPa). Upon completion of the pressure test, the hex nuts are loosened, permitting both the seal and the seal-support segments to retract to their original size before installation. Removal of the flange bolts will now permit the flange test plug to be withdrawn through the smaller opening of the weld-neck flange.

A variation of the design of Fig. B14.3, called the flange-weld plug, may be used to align the weld-neck flange to the pipe and complete the weld prior to testing the weld. The fill ports may be used for inert-gas purging on the inside of the pipe during welding. The flange weld plug, unlike the flange test plug, has a center port for sensing pressure buildup back in the piping. If pressure were to build up behind the flange weld plug before the weld was completed, a dangerous condition wherein the plug might be ejected could occur. Gauges connected to the sensing port are used to warn the welder of any impending problem.

A safer design than the flange weld plug would be to use grippers in conjunction with the seal, as shown in the dumbbell plug of Fig. B14.4. This plug, unlike the hydrostatic test plug, utilizes twin cones supporting the gripper segments to resist movement of the plug in either direction due to unbalanced pressure forces. In case of an unexpected pressure buildup behind the seal, the grippers would function to prevent the plug from being ejected before the weld was completed. However, because of the twin-cone construction, the assembly must first be tightened to the rated torque before pressure is admitted in order to be certain the plug will not move. A single cone gripper would be an improvement.

Flange test plugs and flange weld plugs are available in sizes from NPS 1 to 36 (DN 25 to 900) and with flange ratings up to class 600. Higher ratings and sizes are possible.

FREEZE PLUGS

Thomas J. Bowling, P.E.
Manager
Pipe Repairs, Inc.
Alvin, Texas

Cryogenic freezing is a cost-effective technique for solidifying liquid in a pipe to form a pressure-resistant plug so that maintenance and pressure testing can be performed without shutting down the whole system. This technique for creating a freeze plug has been used for over 30 years in process plants, cross-country pipelines, and nuclear submarines. Most applications are on water, although other liquids may be frozen effectively. Plugs as large as NPS 48 (DN 1200) have been used. Beyond this size, this method of isolation is not economical. Typical applications are

1. Piping repair
2. Valve replacement
3. Leakage and pressure testing
4. Secondary protection on water lines during nuclear fuel changes

The formation of a freeze plug is typically accomplished by circulating liquid nitrogen in a stainless, aluminum, or fiberglass jacket surrounding the pipe. See Fig. B14.9a, showing a typical installation for creating a freeze plug. The nitrogen inlet is located in the center of the jacket behind a centrally located thermocouple. There are two nitrogen vents as well as a drain connection shown. Also, shown in Fig. B14.9b, is an end view where the actual freeze plug can be seen. The liquid nitrogen extracts heat from the freeze-jacket walls, pipe walls, and the liquid within the pipe. The heat absorbed by the liquid nitrogen evaporates some of the nitrogen, and this heat is carried away from the jacket by the nitrogen-gas exhaust from the jacket. The nitrogen gas leaving the freeze jacket must be conducted away from any confined space where personnel are present. Nitrogen is heavier than air, and it is surprisingly easy to produce low-oxygen levels that can lead to asphyxiation. A few breaths of concentrated nitrogen can cause a loss of muscle function. Immediate

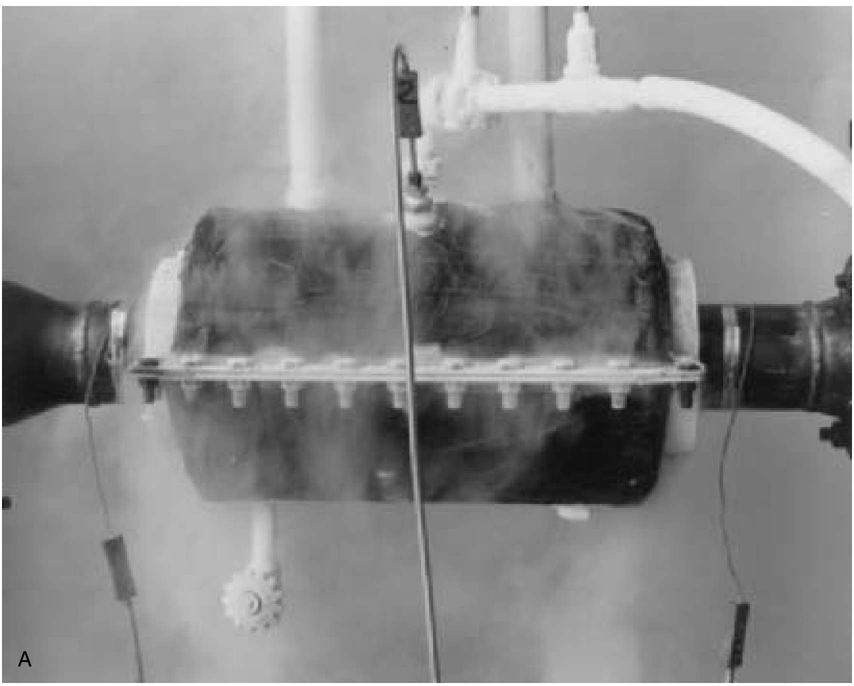

FIGURE B14.9a Typical installation for creating a freeze plug. (*Team, Inc., Alvin, TX*)

FIGURE B14.9b End view in which actual freeze plug can be seen. (*Team, Inc., Alvin, TX*)

cardio-pulmonary resuscitation is required to restore oxygen to the lungs and allow recovery.

The time required to form a freeze plug and the amount of liquid nitrogen required for a particular application may be estimated in advance using *Freeze Stop Tables* provided by the manufacturer of the freeze plug system. See Table B14.3 for an example. Several factors in addition to pipe size influence the amount of nitrogen needed. They are: starting liquid temperature, liquid convection currents and flow in a connected pipe, high ambient temperature and winds, flow in the pipe if any, and radiation from the sun or surroundings.

The primary indication of plug formation is the temperature of the pipe within the freeze jacket. For water, the temperature should be in the range of 0 to −20°F (−18 to −29°C). The secondary indication of success is a uniform band of frost formed completely around the pipe adjacent to the jacket. However, if a liner or process liquid sludge insulates the inside of the pipe, both may be false indications.

Because the liquid expands upon freezing, once the freeze plug isolates a volume of liquid, further freezing of liquid will serve to compress the remaining trapped liquid. The pressure in the trapped liquid can rise to a dangerous level unless relieved by opening a valve, cracking a flange, or other controllable means. On the other hand, as the temperature of the freeze plug drops below the freezing point, microcracks will form in the ice because the ice shrinks faster than the pipe. However, as soon as liquid enters the microcracks it will freeze and seal them.

The best way to test a freeze plug is to create a pressure difference across the plug, and monitor the pressure in the region trapped by the freeze plug for a change

TABLE B14.3 Liquid Nitrogen Requirements for Freeze Stop

	Column I		Column II		Column III		
	X		----------X		x		
Pipe diameter	Time to freeze, hour	Volume, gallons	Time to freeze, hour	Volume, gallons	Time to freeze, hour	Volume, gallons	Volume per hour to hold
1	.4	3	.3	2	.2	1.06	1.5
2	.8	9	.5	7	.3	3	1.5
3	1.5	19	.9	13	.5	7	1.5
4	2	57	1.3	39	.7	20	5
5	3	89	1.9	60	.9	30	6
6	4	124	2.5	83	1.3	42	7
8	6	340	4	225	2	114	9
10	9	525	6	350	3	175	15
12	12	961	8	641	4	320	25
14	14	1152	9	768	5	384	36
16	17	1924	12	1283	6	642	40
18	21	2425	14	1617	7	808	52
20	26	3652	17	2435	9	1217	68
22	31	4410	21	2940	10	1470	87
24	36	6188	24	4126	12	2063	127
26	42	7249	28	4832	14	2416	136
28	48	9690	32	6460	16	3230	145
30	55	11172	37	7448	19	3724	159
32	63	13607	42	9073	21	4536	171
		1 gallon = 3.785 liters					
		180 liters = 47.6 gallons					
Water at 68°F				Hold temperature −292°F			

that would indicate a leak. Freeze plugs have been tested to very high pressures. Generally the pipe will fail before the failure of a fully formed plug. This is due to the high strength of the bond between the ice and the pipe. However, in the interest of safety, any test pressure must be safely below any expected minimum value of brittle failure.

The liquid must wet the pipe to obtain a strong joint between the freeze plug and the pipe. Additionally, the plug strength increases with plug length. However, freeze jackets longer than three pipe diameters should not be employed due to the possibility of forming a double plug. A double plug can cause failure of the pipe within the jacket because of the very high pressure that is produced between two plugs that are close to each other.

In order to form a freeze plug that seals, the pipe must be full of liquid. An air bubble in the top of the pipe makes it impossible to form a freeze plug across the entire pipe diameter. Hydrocarbons with light ends that gas when depressurized can prevent the formation of a complete plug.

Also, hydrocarbon-based liquids, unlike water, do not have a specific freezing point temperature. Instead, they have a freeze range and become solid through a gradual increase in viscosity. Generally, if there is a question about the freeze point and characteristics of a fluid, a test sample may be frozen and evaluated.

The liquid should be stationary at the time of the freeze. There is a critical flow rate and pipe diameter above which it is impossible to achieve a fully closed plug. The critical flow rate is determined by several factors in addition to pipe size. These are pipe orientation, pipe material and thickness, pipe diameter, inlet fluid temperature, fluid freezing temperature, pressure-head-creating flow, and flow rate. Generally it is not possible to freeze plugs under flowing liquid conditions unless the pipe is small and the flow and water temperatures are both low.

It is sometimes difficult to know if there is flow in the line during a freeze unless there is an obvious leak. Undetected flow is probably the most common cause for an unsuccessful freeze. If freezing is taking longer than expected it may be possible to prove that this is due to flow in the pipe. Measuring the pipe wall temperature on both sides of the freeze plug does this. A difference in wall temperature on either side may indicate flow in a direction toward the lower temperature. Convection currents will delay the formation of a freeze plug and can sometimes prevent it from forming completely. Eddy currents generated in a branch line by flow in a main line can also interfere with the formation of a freeze plug in the branch line. Therefore it is best to locate a plug in a branch line as far away as possible from a flowing main line.

The pipe will contract in the longitudinal direction while the freeze plug is formed. This contraction will induce stress in any restrained section of pipe. The amount of contraction can easily be calculated to determine if resulting stresses will be too high to be safe. The freeze plug should not be located in any pipe fittings, valves, or other operating components. Although it is not recommended to locate freeze plugs at a pipe weld, freeze plugs have been successfully installed at pipe welds after adequate inspection and evaluation of the weld. The freeze area on the pipe should be inspected visually and nondestructively before a freeze. If significant flaws are detected, another section of the pipe should be chosen.

Once the freeze plug has been successfully formed and tested, the downstream side of the plug may be drained to remove the remaining liquid. It is best to maintain the freeze operation for another 15 to 30 minutes before opening the pipe and making repairs or changes. The freeze must continue to be monitored while piping revisions or repairs are made. This is done by watching the temperatures at the ends of the freeze jackets and making adjustments to the nitrogen flow to maintain the freeze plug until all work on the pipe is completed. No hammering or impact loads should be applied to the piping during a freeze. If it is necessary to unbolt a flange it should be *hot bolted* before freezing. Hot bolting consists of removing the studs and nuts one at a time and cleaning and lubricating them or replacing them with new studs and nuts. Pressure surges should also be avoided during the freeze.

When the required work on the piping is complete, and the revisions or repairs have been tested, the plug(s) may be thawed. The thawing must be done so that the plug does not move and cause damage to the piping. The pipe should be completely liquid filled on both sides of the plug and the pressure equalized across the plug(s) during the thawing operation. These two actions reduce the ability of the plug to move during thawing. The liquid nitrogen must be drained from the freeze jacket(s) and the jacket(s) removed from the pipe to allow the plug(s) to thaw naturally. There is risk involved in warming the pipe from the outside to speed up the thawing. External heating of the pipe at the freeze-plug location could melt the interface between the plug and pipe wall, allowing the plug to move. This is most dangerous if the pipe is vertical, as the buoyancy of the plug would cause it to move upwards.