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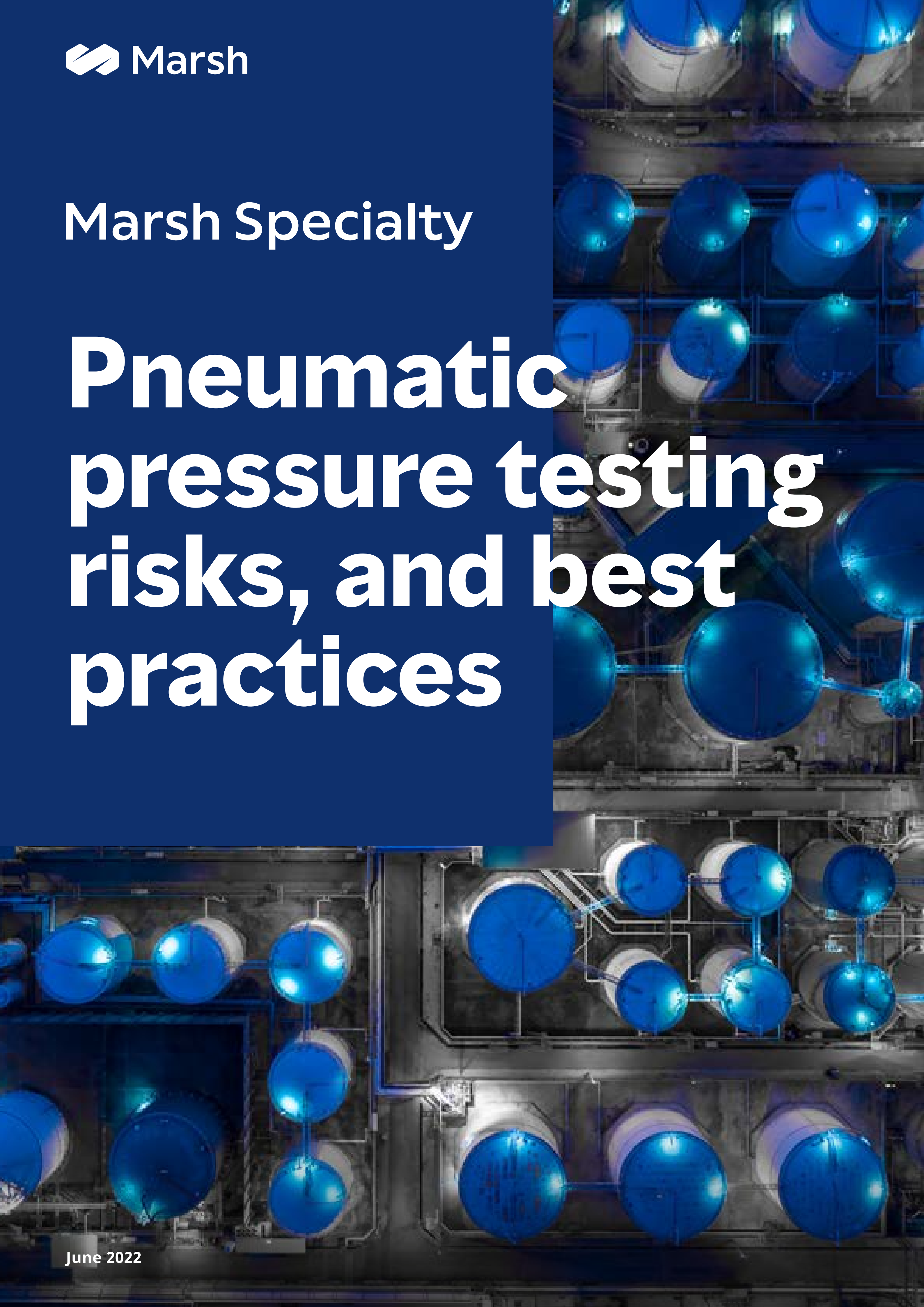
Pneumatic pressure testing risks, and best practices



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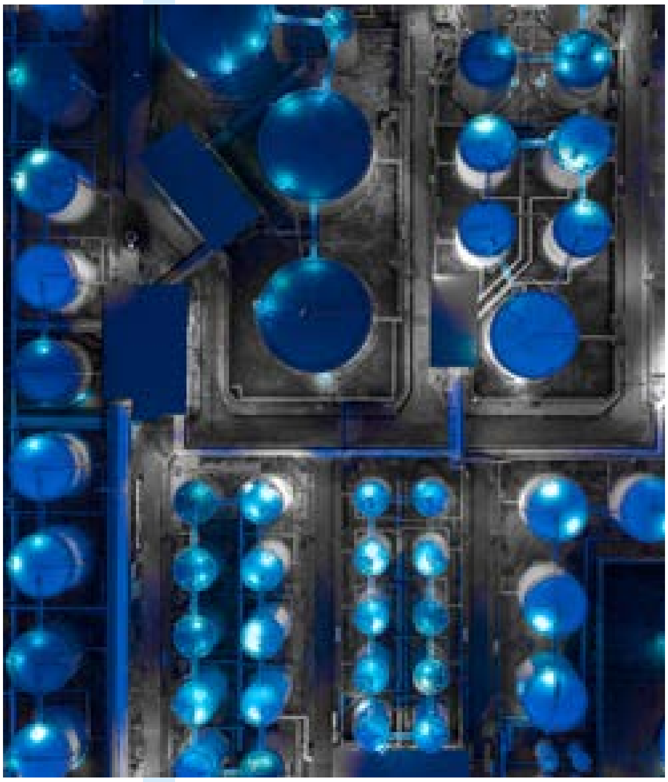

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Introduction

Pressure testing of process equipment is a common activity carried out in the energy and power industry. The inherent risk of pressure testing is associated with the release of stored energy when test equipment fails under pressure.

Critically, the test fluid used for these activities can be either a compressible gas, or much more commonly, an incompressible liquid. The difference in stored energy between a pressurized compressible gas and a pressurized non-compressible liquid is substantial, and failure of the equipment while pressurized can have catastrophic results, as shown in the image below.

Example layout of a high pressure piping spool being pressure tested

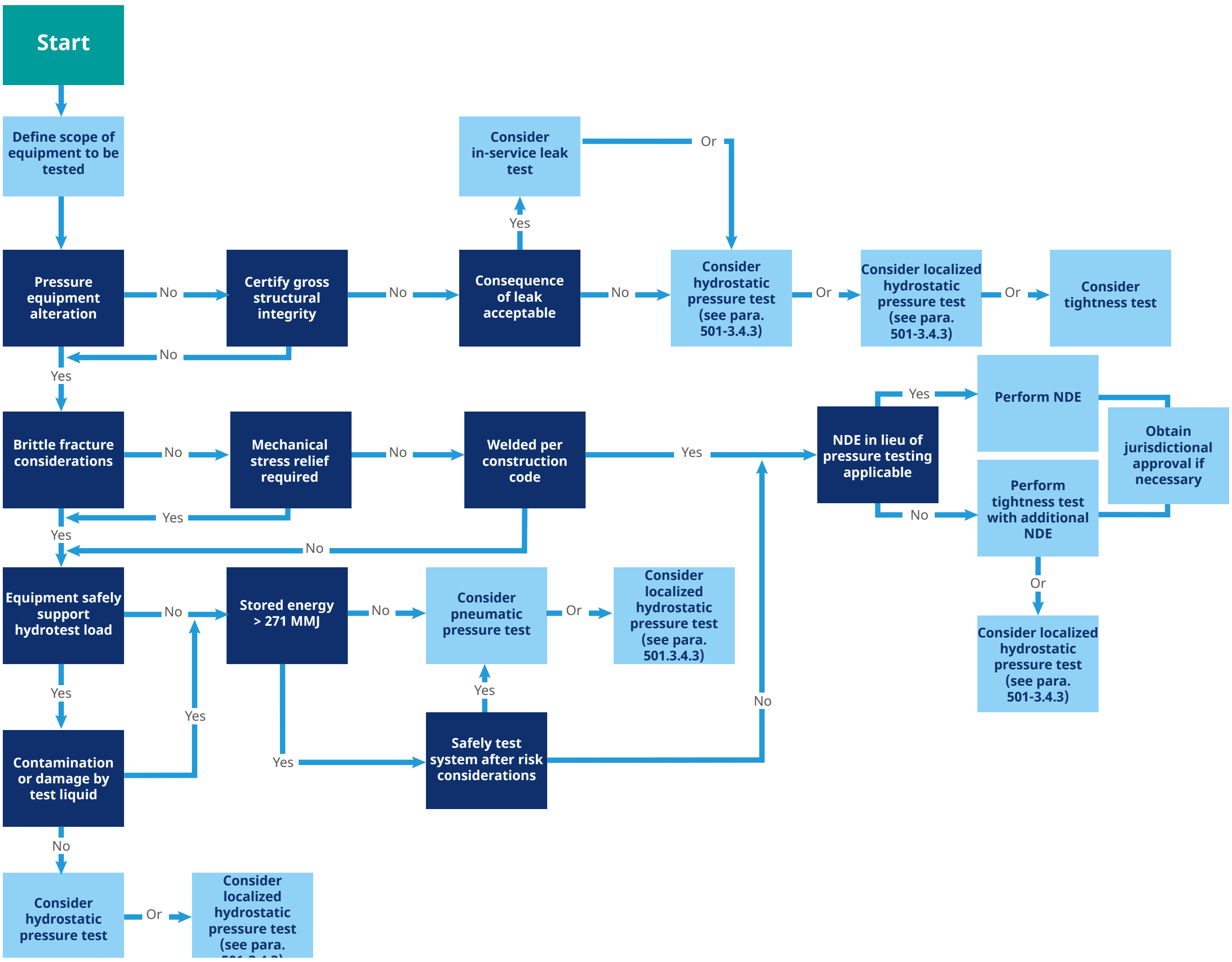
The requirement to pressure test process equipment is determined by the code of construction for new equipment, and post construction codes for re-rating equipment, or when carrying out a mechanical repair to the pressure envelope. In addition, local or regional regulatory requirements may apply.

Pressure testing of mechanical equipment, such as pressure vessels and process piping, is carried out as means of physically applying internal pressure to the pressure boundaries prior to commissioning or re-commissioning of process equipment. The test fluid used for pressure testing is most often water, which is defined as a hydrostatic test. In some instances, other test mediums may be used. When using a compressible fluid as the test medium, such as nitrogen, the test is defined as a pneumatic test. The most common reasons to conduct pneumatic rather than hydrostatic tests is to avoid introducing water to the system (and avoid internal degradation), and to protect the specification of the process fluid after commissioning because of limitations relating to dry-out procedures or draining low points. This report will explore some alternative options.

The reason for the substantial increase in stored energy is due to the volume of fluid within the equipment. Once equipment is filled with a non-compressible fluid such as water, at ambient pressure and temperature, the volume of additional water required to be added to the process equipment to increase the internal pressure is marginal. However, if the same equipment was filled with a compressible fluid such as nitrogen, the volume of additional nitrogen required to increase the internal pressure would be considerably more because the gas is able to compress from a large volume into a much smaller volume. For example, 1m3 of water can be vaporized into approximately 1600m3 of steam. The sudden release of the compressed gas (if the equipment being tested fails) has the energy to deform, and project steelwork, adjacent process equipment, and heavy obstacles with force. The amount of stored pneumatic energy can be calculated as equivalent weight in trinitrotoluene (TNT) using ASME PCC-2. The fact that this is a method used to understand the potential consequence of a test failure should indicate the significantly high risk for personnel carrying out the calculations.

The requirement for pressure testing will depend on the activity being conducted. In order to pressure test new process equipment prior to commissioning, the test pressure is based on the code of construction used for the design basis, such as ASME VIII Division 1. Alternatively, existing process equipment may require a pressure test to comply with post construction code, for example, following a mechanical repair in accordance with ASME PCC-2. In some instances the local regulations dictate the pressure test requirements, and these may overrule industry recommended practices and standards.

While the mandate to pressure test may be waived in some cases, it is most common to adapt the scope of the pressure test to ensure that one can be facilitated. The process for selecting the appropriate type of pressure test is described in ASME PCC-2, paragraph 501-3.3 as per the flowchart below.



Source: ASME PCC-2, 2018, Figure 501-3.3-1 Test Type Selection

Other types of process equipment pressure testing include tightness and leak testing however, these are not discussed in detail in this document. Such pressure tests are typically conducted at operating pressure in order to inspect for gasket leaks after re-jointing bolted flanges. Although the risk of stored energy release while pressure testing at operating pressure remains, the pressure testing activities above design pressure (typically driven by code following a repair or change) are a much higher risk.

Best practices

In this section, we summarize some of the key considerations when conducting a pressure test on process equipment. Common practical limitations, and respective solutions, are also considered.

1 BRITTLE FRACTURE

The key risk associated with conducting a pressure test on carbon and low-alloy steel process equipment is catastrophic failure due to brittle fracture. At lower temperatures, these steels transition from ductile to brittle and can rupture under pressure. The lower temperature limits of process equipment can be determined by reviewing the construction files, including drawings and material test certificates, which should include the impact strength test results (at specific temperatures). Alternatively, the minimum design metal temperature (MDMT), critical exposure temperatures (CET), and the test temperature can be calculated based on API 579 FFS-1. Pressure tests are typically conducted at ambient temperatures, although it is possible to use heated test fluids during turn-arounds or planned outages.

It should be noted that brittle fracture can occur during both hydrostatic and pneumatic pressure tests. While the latter is considerably more catastrophic, the failure mode associated with brittle fracture during a hydrostatic test is also a rupture scenario.

Service induced embrittlement can increase the risk of rupture scenarios for equipment that has experienced more severe services, such as operating in the creep temperature range or above the nelson curve.

For more information on brittle fracture, including calculations for the MDMT, CET, and minimum pressure test temperatures, refer to Section 3, API 579 FFS-1.

2 TEST FLUID SELECTION

For a helpful guide to test fluid selection, refer to ASME PCC-2 paragraph 216-6.4. Some of the common test fluids used in industry are:

- **Potable Water** – commonly used for lower criticality, less aggressive services such as category D fluids, as per ASME B31.3. Potable water may contain chlorides that can aggressively degrade process equipment - particularly alloy 300 stainless steels which would be susceptible to chloride stress corrosion cracking post-commissioning.
- **Demineralised water –** is a more commonly used test fluid. For larger vessel pressure tests or longer piping systems, demineralised water should be procured in advance of the test, with input on acceptable threshold of contaminants (typically defined in corporate standards). For example, an upper threshold of 50ppm of chloride is a typical threshold for testing stainless steel equipment.
- **Ethylene-glycol** – a mixture of ethylene-glycol and water solution can be used to conduct hydrostatic pressure tests at lower temperatures, down to -40oC (32oF). This allows pressure testing to be conducted in low temperature locations, without the risk of the test fluid freezing and causing damage to the equipment.
- **Light oil** – it is more common to use light oils when introduction of water presents a particularly high risk of degradation to the equipment, such as on hydrofluoric alkylation plants.
- **Air/nitrogen** – when conducting a pneumatic pressure test, it is recommended that an inert gas such as nitrogen is used. In the catastrophic event of a failure, the use of a hazardous or volatile gas would further exacerbate the incident. Nitrogen has an inherent asphyxiation risk, whereas the use of air may introduce contaminants.

3 REMOVING GAS POCKETS

The geometry of the process equipment being tested should be assessed by the pressure test technician and the pressure test inspector. High points without vents have the potential to collect gas pockets, which can then be compressed. In the event of pressure test failure, the scenario can be catastrophic, even if the test fluid is predominantly liquid.

4 TESTING PROCESS

Consider using the following practices to conduct pressure tests safely:

- **Pressure relief valve:** should be calibrated in the workshop and installed onto the process equipment undergoing the pressure test. Calibration certificates should be reviewed by the pressure test inspector. The valves must be checked prior to pressure testing, to ensure the relief device is not isolated from the equipment, particularly when quarter-turn ball valves are being used.
- **Pressure gauge**: should be calibrated in the workshop and installed to provide the inspector and pressure test technician visibility of the test pressure. Calibration certificates should be reviewed by the pressure test inspector. It is common practice to install a minimum of two test gauges. The pressure gauge limit should be approximately twice the test pressure to allow a suitable range to see the live test pressure clearly.
- **Keeping personnel safe:** risk awareness training for all site personnel should be included in the process safety on-boarding training. Specialist personnel from operations, maintenance and inspection departments should have a higher level of understanding, and be formally authorized to participate in pressure testing activities. Training should include awareness of exclusion zone safety barriers and appropriate personal protection equipment (PPE).
- **Flange-to-weld test plug:** Flange-to-weld test plugs can be used to test the weld between the flange and the piping system. These are typically used when installing a new flange(s) in the field to allow a spool piece to be installed. A blind flange with test equipment is bolted onto the flange and an internal component protrudes into the pipe, expands against the internal pipe wall, and seals the equipment for testing.

Example layout of a high pressure piping spool being pressure tested

NEAR MISS

Am I unknowingly pneumatically testing?

Air cooled heat exchangers

The design pressure of some equipment can be lower than instrument air and nitrogen supplies.

During a turnaround at a European refinery, inspection personnel were asked to support the recommissioning stage of an air-cooled heat exchanger (fin fan), following an IRIS inspection. After re-installing the channel box doors, the operations team conducted a soapy bubble leak test using plant nitrogen, and identified a weep. The equipment design pressure was less than 2barg, whereas the plant nitrogen supply was more than double that. The weep, which was due to a gasket issue, was resolved and a near-miss incident investigation carried out.

Definitions

- **Design conditions:** Maximum upper and lower operating parameters of the process fluid during operation. Note that these limits are typically more extreme than panel alarms and pressure relief set pressures.
- **Hydrostatic testing:** Pressure testing of process equipment using water as the test fluid, typically at ambient temperature and above the design pressure, in accordance with the code of construction or the post construction code associated with the work activity (construction or repair).
- **Materials of constructions:** Specification of metallic components used to construct the pressure envelope, for example ASTM A-516 grade 70 carbon steel.
- **Pneumatic testing:** Pressure testing of process equipment using a compressible gas such as nitrogen as the test fluid, typically at ambient temperature and above the design pressure, in accordance with the code of construction or the post construction code associated with the work activity (construction or repair).
- **Process equipment:** Process equipment is the hardware used to contain and transport process fluids, for example, piping systems, pressure vessels or heat exchangers.
- **Test Fluid:** A fluid can either be a liquid or a gas. The test fluid is the gas or liquid used to fill the equipment and be pressurized to facilitate testing of the equipment pressure envelope.
- **Pressure envelope/pressure boundary:** The components of pressurized equipment designed to hold the internal pressure and ensure there is no loss of containment of process fluid, for example, pressure vessel shell wall or shell and tube heat exchanger channel door.
- **Process fluid:** A fluid can either be a liquid or a gas. The process fluid is the gas or liquid that is contained within the equipment under normal operation.
- **Re-rate:** A process carried out to modify the design conditions of the equipment.
- **Spool piece:** A flange-to-flange piping section, typically installed in a workshop to replace a piping section in the field, where flange connection can be achieved.

Reference materials

ASME, Repair of Pressure Equipment and Piping, PCC-2 – 2018

API RP 579-1 / ASME FFS-1, Fitness-For-Service, 2021

HSE, Safety requirements for pressure testing, Edition 4

Pneumatic Test of Pressurised Equipment: Its Hazards and Alternatives

Pneumatic Testing of Piping Assemblies: Criteria for Stored Energy and Pinhole Leak Detectability

Comparative Risks of Hydrostatic and Pneumatic Pipeline Testing

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