Pressure and Leak Testing

Working Together for Safety Recommendation 028E/2016

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Table of contents

1 Introduction

Experience from the industry dictates that we should have a uniform method for conducting pressure and leak testing. This becomes particularly apparent when we know that much of this work is carried out by contractors who serve all the operating companies.

Experience also dictates that we should have uniform definitions and common terminology.

Pressure and leak testing involves operating with substantial amounts of energy, which in itself represents a major risk to personnel and equipment, unless there is complete control. We have therefore provided suggested methods in this document, particularly where standards and norms provide options.

2 Objective

The objective of this recommendation is to describe what we regard as best practice, and thereby help to reduce the risk of undesirable incidents occurring in connection with pressure and leak testing.

This document covers all pressure and leak testing that takes place within the area for which the Norwegian Petroleum Safety Authority is responsible, with the exception of subsea systems and pipelines (transport systems).

The recommendation may also be beneficial to suppliers who work with the pressure and leak testing of parts and equipment supplied to the petroleum industry.

A description of best practice concerning the preservation and handling of various materials with regard to the integrity of the equipment and systems has also been included.

The document covers both non-metallic and metallic materials within:

- Instrumentation / instrument piping
- Process and utility systems

3 Definition and purpose

Pressure testing is a verification of a piping system or equipment's mechanical integrity, and is performed by pressurising the piping system / equipment to a given factor of the design pressure. Pressure testing also equalises local material stresses and reduces the probability of brittle fractures. The most used factor for defining a pressure test is 1.5 x design pressure.[1, 2]

Pressure testing is performed on new piping systems / equipment, or after modifications/repairs involving welding or other work on permanent connections. In order to avoid premature fatigue, it is important that the pressure level is adapted to the design pressure.

Leak testing is verification of a piping system or equipment's mechanical integrity. The purpose of leak testing is to ensure that all mechanical connections (couplings, valves, conduit glands, etc.) can be put into operation without undesirable leaks occurring during normal operating conditions. For vacuum equipment, the purpose is also to ensure that the external atmosphere does not penetrate the equipment.

Golden welds / closure welds[3, 4] are welds that for various reasons cannot be pressure tested, and their mechanical integrity must therefore be verified using other methods. These may typically involve the use of x-rays, ultrasound, penetrant, MPI (magnetic powder) and visual inspection. A golden weld / closure weld entails a deviation from pressure testing requirements, and will usually require nonconformity handling and approval from the system owner.

4 Highlighting of changes

This recommendation has primarily been rewritten in accordance with Working Together for Safety's new template. Details in the text and the descriptions of the various tests, etc., remain largely unchanged, but much greater emphasis has been placed on managing the risks associated with pressure and leak testing. The difference between pressure and leak testing has been clarified, and the content has been reorganised in accordance with this. The figure in the appendix has been corrected (excess/incorrect arrows have been removed).

5 Pressure testing

5.1 Pressure testing criteria

This chapter provides a description of best practice for what shall be tested, and when.

5.1.1 New installations

During the construction of new installations, all piping systems and equipment shall be pressure tested so that their integrity can be verified. The exception is open draining and venting to the atmosphere, as well as instrument piping downstream of the first block valve.[2]

The test pressure shall be in accordance with the requirements of the design pressure class or rating used when designing the system and equipment. Here, it is recommended that the design pressure for the piping class / equipment is used to calculate the test pressure. This enables full flexibility in the event of any upgrades. The test pressure must be determined based on the system's weakest component, but it is recommended to divide the system into several tests if this is necessary in order to test all components.

Tests that shall be performed using inert gas shall be limited in volume. Where this is not possible due to a completely welded line, a risk assessment should be performed and the pressure test carried out in a period in which as few personnel as possible are present. When using inert gas (usually nitrogen) as the test medium, the test pressure shall not

exceed 1.1 x the design pressure. When using air as the test medium, the test pressure shall not exceed 7 barg.

5.1.2 Maintenance, modification and repair works

All maintenance work and repairs that involve modification/maintenance in the form of the welding of pipes, piping systems or other pressurised equipment will usually require a new integrity test. This integrity test shall be a pressure test wherever possible, and shall therefore be taken into account in the preparatory work.

Here it is especially important to look at opportunities to limit the scope of the test to a minimum, since it is highly probable that the system/equipment has been pressure tested several times before. This is important in order to avoid unnecessary weakening of the materials' strength.

In the first instance, opportunities to limit the test using blind flanges to isolate existing equipment, flange testers and weld testers (joint tests) should be considered, or if the criteria permit, a closure weld / golden weld may be used.

5.2 Managing risk during pressure testing

5.2.1 Hazards

The most significant hazard associated with pressure testing is uncontrolled release of the pressure medium and projectiles that may work loose from the test at high speed and with high energy.

Other hazards:

- Dropped objects (test equipment)
- Chemical exposure to system medium / test medium
- Injuries resulting from insufficient support of test object/system
- Exposure to noise (particularly during de-pressurisation)
- Prolonged vibration (from tools)
- Over-pressurisation
- Uncontrolled bleed-off
- When testing in cold surroundings: rupture as a result of the test medium freezing
- Uncontrolled pressurisation / insufficient stabilisation period during pressurisation
- Uncontrolled weight stress / insufficient support prior to filling of the test object
- Risk of asphyxiation in the event of uncontrolled release of inert gas in enclosed spaces

5.3 Risk-reducing measures – best practice

5.3.1 SJA – risk assessment[5]

Risk assessments should be conducted prior to all pressure testing – this is particularly important for large volumes and/or high pressures, since the potential for injury/damage increases with the test pressure and volume of the test.

5.3.2 Test equipment

Equipment used for pressure and leak testing shall be labelled, calibrated, approved and certified. The equipment to be used shall be checked for damage before use. Equipment with damage or defects shall not be used, but replaced.

All equipment used for pressure testing shall be designed for the specified test pressure. This applies to elements including fittings, valves, hoses and logging equipment. The pressure rating of all piping elements / fittings should be higher than the specified test pressure.

All flanges and threaded connections should be checked after installation and prior to pressurisation. This also applies to threaded hose connections. All hoses shall be secured with a whip-check cable and/or restraint. In addition, high-pressure hoses should be secured to the structure at a minimum of every 10 metres.

Failure of or damage to the equipment may occur when using a test pressure that is too high due to calculation errors, or faults on the pressure control equipment (e.g. PSVs). Testing at temperatures that are too low, or where local overpressure occurs due to freezing, may also result in damage to the equipment.

5.3.3 Access control

The size of the safety zone and access control measures must be assessed by the person responsible for executing the test – preferably in consultation with the safety responsible. The assessment must be based on the volume, pressure, test medium, number of potential leakage points and the location – including proximity to other work. It is particularly important to consider fittings, hoses and other components that may work loose from the piping system / test object when under pressure.

During pressure testing, the area shall be cordoned off in an appropriate manner.[7]

5.3.4 Preparations prior to pressurisation

The test object shall be released for pressure testing prior to all pressure testing. This entails a physical marking of the system which confirms that the system has been designed and assembled in accordance with drawings and specifications, that welds are approved, and that the system is sufficiently supported. All piping systems to be pressure tested shall be permanently installed and secured.

A test package with marked-up drawings and blind list shall be prepared and provide the necessary information: test pressure, medium and hold period.

The approved test procedure must be read and understood by all involved personnel. Personnel shall be familiar with the scope of work, as well as their designated tasks and areas of responsibility.
Experience dictates that it is important to focus on the pressure source, since this may deliver a higher pressure than that of the piping design. A secondary safety measure is therefore recommended, set in accordance with the system to be pressurised.

De-pressurisation, the establishment of barriers (spade / blind flange, etc.) towards adjacent systems, cleaning and draining must be undertaken before work is started on systems that have previously been in use.
All ball valves affected by the test must be placed in the half open position before pressurisation is started. Other valves must be set in the open position unless otherwise specified.

When pressure testing systems that are not designed for vacuum, precautions must be taken to ensure that a vacuum does not occur in the system when draining the test medium. Be particularly aware of thin-walled tanks and systems constructed of composite/plastic.

The preparations must also include the planning of ventilation at the highest level during filling, and emptying of the system at the lowest level.

Effective, continual communication between operators shall be established before testing starts. The operation shall be stopped immediately in the event of an interruption in communication. The work may only be resumed when communication has been re-established.

5.3.5 Pressurisation of the test object

A gross leak test (see 6.4.3) shall be conducted prior to pressurisation. The entire test object shall be checked for audible/visible leaks.

The test object shall be pressurised in a calm and controlled manner as specified in this recommendation. The test shall be monitored during this period.

Personnel shall remain outside the test area during pressurisation. In the interest of safety, the pressure shall be reduced to 80-90% of the test pressure prior to the visual inspection of surfaces, welds and connections.**(8)**

No work shall be undertaken on pressurised equipment.

5.3.6 De-pressurisation

De-pressurisation must always be carried out in a calm and controlled manner, and to a safe area. Be aware of noise and the cooling effect during de-pressurisation. During the pressure

testing of piping systems that are not designed for vacuum, good ventilation is important at all peak points during the draining of the piping system.

If the de-pressurisation is undertaken via a temporary hose, this must be effectively secured prior to de-pressurisation. Be aware of trapped pressure if the system contains non-return valves. Non-return valves shall always be de-pressurised on both sides.

5.4 Pressure testing methods

5.4.1 Hydrostatic pressure testing

Hydrostatic pressure testing comprises an integrity test of welded joints using fluid, preferably fresh water. Here, there are requirements for calibrated equipment, pressure gauges, temperature control and pressure recorders for documentation.

The test object should be pressurised gradually. For test pressures over 100 barg, pressurisation up to the test pressure should be undertaken in three or more stages (e.g. 50%, 75%, 90% and 100% of the test pressure).

Checks for leaks should be carried out at the end of the hold period for each stage. The hold period for each stage should be ten minutes. The hold period for the pressure test is a minimum of 30 minutes.**(8)**

5.4.2 Pneumatic pressure testing

Pneumatic pressure testing comprises an integrity test of welded joints using inert gas.

Air shall never be used as the test medium for pressures over 7 barg due to the risk of spontaneous ignition of oily residues, etc., at higher pressures. In such cases, inert gas, preferably nitrogen, shall be used.

A leak test of the system at 0.2 barg should be performed before further pressurisation. Further pressurisation shall be undertaken in 10% intervals from 50% of the test pressure, with a hold period of ten minutes at each stage and 30 minutes at the maximum test pressure. At the end of the hold period the pressure shall be reduced to the design pressure before all welds are closely inspected visually.

Note: The maximum amount of calculated stored energy in a container or piping system to be pneumatically pressure tested shall be limited to 271 MJ.**(9)**

6 Leak testing

6.1 Leak testing criteria

This chapter provides a description of best practice for how and when leak testing shall be carried out. All normally pressurised systems shall be leak tested before they are operated.

6.1.1 New installations

A leak test is carried out as a final test of critical piping systems / equipment before the system is taken into use. The test method may be selected using the decision tree (see Appendix A), and will depend upon the criticality of the system. The test shall be documented.

6.1.2 Maintenance, modification and repair works

When testing systems that have previously been operational, the leak test's method and scope shall be determined via an overall risk assessment.

6.2 Managing risk during leak testing

6.2.1 Hazards

Like pressure testing, leak testing often involves large amounts of potential energy. The most significant hazard associated with leak testing is uncontrolled release out of the pressure medium and projectiles that may come loose from the test object at high speed and with high energy. The potential for injury/damage increases as the test pressure and volume increase.

There is also a risk of asphyxiation if gas, such as nitrogen, is released into poorly ventilated areas or enclosed spaces. The risk of asphyxiation increases with the amount of nitrogen that is released into a limited atmospheric volume.

When handling and using liquid nitrogen there is a risk of acute frost injury. Liquid nitrogen also causes damage to structures by reducing the material's tensile strength. Liquid nitrogen has a temperature of -196 °C.

6.3 Risk-reducing measures – best practice

6.3.1 SJA – risk assessment

A risk assessment should be undertaken prior to all leak testing – this is particularly important when risk factors that are not sufficiently highlighted in applicable procedures or work permits are present or may arise.

6.3.2 Personal protective equipment

In addition to the usual personal protective equipment, cold-resistant gloves and a visor / eye protection shall also be used when working with liquid nitrogen and chilled equipment.

6.3.3 Atmosphere

In all poorly ventilated areas and enclosed spaces where there is a risk of nitrogen emissions, personal oxygen meters shall be used. Ensure good ventilation if necessary.

Note: If a low oxygen level is suspected, the oxygen level shall always be measured prior to entry. Areas/rooms with an oxygen level lower than 20.9% shall not be entered. **(6)**

6.3.4 Handling liquid nitrogen

Tanks containing liquid nitrogen shall be placed in well-ventilated areas. In the event of a risk of contact between liquid nitrogen and non-cryogenic structures (steel deck), tanks should be placed in a water bath while in use. This can also be beneficial when storing the nitrogen tanks.

6.3.5 Test object

The test object shall be fully assembled, de-pressurised and completely drained before preparations for leak testing begin. This must be verified.

6.3.6 Test equipment

All rotating equipment that is used shall be function tested and approved before use.
All other equipment to be used shall also be checked for damage before use. Equipment with damage or defects shall not be used, but replaced.

All equipment used to handle liquid nitrogen shall be approved for cryogenic media.

All equipment used for leak testing shall be designed for the specified test pressure. This applies to elements including fittings, valves, hoses and logging equipment.

The pressure rating of all piping elements / fittings should be higher than the specified test pressure and a minimum of 10,000 psi. The following pressure ratings are usually used for leak testing:

- 10K: 0 – 689 barg
- 15K: 0 – 1034 barg
- 20K: 0 – 1378 barg

All flanges and threaded connections shall be checked after installation and prior to pressurisation. This also applies to threaded hose connections.

All hoses shall be secured with whip-check cables and/or restraints. High-pressure hoses should also be secured to the structure a minimum of every 10 metres.

6.3.7 Access control

The need for and scope of the safety zone and access control should be assessed, taking into account the test's volume, pressure, test medium, number of potential leak points and location – including proximity to other work. It is particularly important to consider fittings, hoses and

other components that may work loose from the piping system / test object when under pressure.

6.3.8 Technical barriers

The test object shall be secured against overpressure with a minimum of one technical barrier. If the system contains active/operative safety valves (PSV – Pressure Safety Valve), these may be used as long as this is approved by the system owner. In these cases, it must be ensured that the flare system is operational and that valves both upstream and downstream of the PSVs are secured in the open position.

In cases where the system does not feature PSVs, or these cannot be used, an OPS (Over Pressurisation Skid) or temporary PSVs shall be used. The set pressure for the OPS and temporary PSVs must never exceed the system's design pressure. The OPS shall be connected as close to the injection point for N_2He as possible (but not on the injection point itself).

The valve's blow-off capacity shall always be taken into consideration when selecting a PSV.

6.3.9 Preparations prior to pressurisation

The approved procedure must be read and understood by all involved personnel. Personnel shall be familiar with the scope of work, as well as their designated tasks and areas of responsibility.

Technical barriers shall be verified by both the system responsible and the executing contractor. Verify that the set pressure of the PSV/OPS corresponds to the test pressure.

Effective, continual radio communication shall be established between operators before testing starts. The operation shall be stopped immediately in the event of an interruption in communication. The work may only be resumed when communication has been re-established.

6.3.9.1 Verification of the system

Before leak testing can start, it must be verified that the system/equipment is fully assembled and released for the work to be carried out.

6.3.9.2 Test package / procedure

Adequate test packages and/or procedures for leak testing shall be in place. These shall specify/contain the following as a minimum:

- Test pressure
- Test limits
- Valve and blind lists

- Detailed mark-up
- Injection and bleed-off point
- Acceptance criteria
- Bleed-off sequence
- Detailed work description
- Necessary checklists

Test packages and/or procedures shall be quality assured and approved by the system responsible before being used.

6.3.9.3 System configuration

Before the system is configured, all relevant points on the system must be marked with tags corresponding to the tag numbers used in the valve and blind lists and in the system drawings.

After the system/equipment has been configured, the executing worker and system responsible shall perform a joint line walk. Both parties shall sign to confirm that each individual point on the system/equipment has been correctly set in accordance with the valve and blind list / mark-up. Any other checklists associated with preparatory work shall also be reviewed and signed.

6.3.10 Pressurisation of the test object

The test object shall be pressurised calmly and in stages, as specified in the applicable work description. During initial pressurisation (the first five minutes) the pressure from the pump/rack shall not exceed 30 barg.

The pressure read-off point is used to verify that there is communication between the injection point and the entire system being tested. Only when this is confirmed is the injection rate gradually increased to the desired level.

A gross leak test (see 6.4.3) shall be conducted prior to further pressurisation. The entire test object shall be checked for audible/visible leaks.

Personnel shall remain outside the test area during further pressurisation. Personnel shall only inspect the system for audible/visible leaks when pressurisation has stopped at 25% of the test pressure. All personnel shall leave the designated test area before further pressurisation to 50% of the test pressure.

The process is repeated for the various steps up to 100% of the test pressure.
No work shall be undertaken on pressurised equipment.

6.3.11 De-pressurisation

Sufficient communication between all involved parties shall be established before de-pressurisation starts. Be aware of the risk of trapped pressure as a result of non-return valves in the system.

De-pressurisation must always be carried out in a calm and controlled manner. When de-pressurising the system to open air, this shall be done in a well-ventilated and secured area. De-pressurisation shall never be undertaken in poorly ventilated areas or enclosed spaces.

6.4 Leak testing methods

6.4.1 Sensitive leak test

Leak testing is usually carried out on piping systems or equipment that contain flammable and potentially explosive substances that are also hazardous to health. Leak testing is also used if a vacuum is a critical factor for the piping system / equipment's functionality. The test is performed on new systems and after renovations and repair work.

For hydrocarbon systems, this test is usually performed using an N_2 / He mixture (1 to 2% He), where He is used as a tracer gas. Soapy water (bubble test) is also used to find leaks. This method is not very quantifiable and is weather dependent.

The test pressure is determined by the system responsible, but should not exceed 90% of the PSV set point for the system. If PSVs are not installed on the system, the maximum test pressure should not exceed 90% of the system's design pressure. A lower pressure, e.g. normal operating pressure, is most often used as the test pressure on the Norwegian Continental Shelf. Using a pressure that is almost equal to the system's normal operating pressure ensures that flanges and other connections are tested as close to actual operating conditions as possible.

6.4.2 Vacuum test

A vacuum is created on the outside or inside of equipment, and the opposite side is filled with gas / tracer gas. This is an extremely precise test that is used for critical applications, e.g. subsea equipment.

6.4.3 Gross leak test

This type of test is generally performed as a part of leak testing in order to ensure early detection of larger leaks. The test is performed using air or nitrogen at low pressure, generally between 1 and 2 bar. Leaks are detected visually or audibly.

6.4.4 Initial service test (re-installation test)

This leak test is usually used as an alternative to N_2He leak testing. It is performed using pressurisation up to the maximum operating pressure in stages, by visually checking for leaks when using the system's usual "process medium".

7 Tested components/systems

Tested piping systems and equipment shall be drained and dried in accordance with requirements. Unless otherwise is specified, Table 1 annex B of Norsok L-004 shall be followed. Equipment, piping and piping systems that shall not be immediately put into operation shall be preserved internally.

Open ends shall not remain after pressure testing has been completed. Flanges shall be protected with a gasket and blind flange / gasket and steel plate or gasket and wooden plate. For carbon flanges, the contact surface shall also be preserved using a suitable medium. It is important that the flange surfaces of compact flanges are protected against damage and corrosion.
Smooth piping ends shall be preserved using plastic plugs/caps. Components should be stored in a dry location with a stable temperature. Piping systems and equipment shall be stored on a solid foundation, off the ground on wooden planks or similar. A preservation follow-up programme should be implemented in the event of long-term storage (over three months).

8 References

1) ASME B31.3 paragraph 345.4.2
2) NORSOK L-004 chapters 8 and 9
3) ASME B 31.3 paragraph 345.1 (a).
4) NORSOK L-004 annex 3.
5) Norwegian Oil and Gas Guideline 090 Safe Job Analysis (SJA)
6) Norwegian Oil and Gas Guideline 088 Work Permits (WP)
7) Working Together for Safety Recommendation 026E Access Control
8) NORSOK L-004 chapter 9.4
9) ASME PCC-2
10) NORSOK L-004 annex B, table 1

9 Appendix A: Decision tree, pressure and leak testing