



BSI Standards Publication

Leak detection systems

Part 2: Requirements and test/assessment methods
for pressure and vacuum systems

National foreword

This British Standard is the UK implementation of EN 13160-2:2016+A1:2024. It supersedes BS EN 13160-2:2016, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by A1 A1.

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Systèmes de détection de fuites - Partie 2 : Exigences et méthodes d'essai/d'évaluation des systèmes sous pression et à dépression

Leckanzeigesysteme - Teil 2: Anforderungen und Prüf-/Bewertungsmethoden für Über- und Unterdrucksysteme

This European Standard was approved by CEN on 8 April 2016 and includes Amendment 1 approved by CEN on 11 September 2024.

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European foreword

This document (EN 13160-2:2016+A1:2024) has been prepared by Technical Committee CEN/TC 393 “Equipment for tanks and filling stations”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2025, and conflicting national standards shall be withdrawn at the latest by August 2026.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document includes Amendment 1 approved by CEN on 11 September 2024.

This document supersedes A1 EN 13160-2:2016 A1.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1.

A1 *deleted text* A1

According to edition 2003 the following fundamental changes are given:

- requirements from EN 13160-1:2003 included, which are no longer contained in EN 13160-1:2016;
- new structure - technical requirements for the components divided; (pressure device, evaluation device, alarm device;
- technical requirements revised.

This European Standard *Leak detection systems* consists of 7 parts:

- *Part 1: General principles*
- *Part 2: Requirements and test/assessment methods for pressure and vacuum systems*
- *Part 3: Requirements and test/assessment methods for liquid systems for tanks*
- *Part 4: Requirements and test/assessment methods for sensor based leak detection systems*
- *Part 5: Requirements and test/assessment methods for in-tank gauge systems and pressurized pipework systems*
- *Part 6: Sensors in monitoring wells*
- *Part 7: Requirements and test/assessment methods for interstitial spaces, leak detection linings and leak detection jackets*

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1 Scope

This European Standard gives requirements and the corresponding test/assessment methods applicable to leak detection kits (leak detector) based on the measurement of pressure change. Leak detection kits are intended to be used with double skin, underground or above ground, pressurized or non-pressurized, tanks or pipework designed for water polluting liquids/fluids. The kits are usually composed of:

- measuring device;
- evaluation device;
- alarm device;
- pressure generator;
- pressure relief device;
- liquid stop device;
- condensate trap.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 228, *Automotive fuels — Unleaded petrol — Requirements and test methods*

EN 981:1996+A1:2008, *Safety of machinery — System of auditory and visual danger and information signals*

EN 12285-1, *Workshop fabricated steel tanks — Part 1: Horizontal cylindrical single skin and double skin tanks for the underground storage of flammable and non-flammable water polluting liquids*

EN 12285-2, *Workshop fabricated steel tanks — Part 2: Horizontal cylindrical single skin and double skin tanks for the aboveground storage of flammable and non-flammable water polluting liquids*

EN 13160-1:2016, *Leak detection systems — Part 1: General principles*

EN 13160-7, *Leak detection systems — Part 7: Requirements and test/assessment methods for interstitial spaces, leak detection linings and leak detection jackets*

EN 14879-4:2007, *Organic coating systems and linings for protection of industrial apparatus and plants against corrosion caused by aggressive media — Part 4: Linings on metallic components*

EN 61672-1, *Electroacoustic — Sound level meters — Part 1: Specifications (IEC 61672-1)*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 13160-1:2016 and the following apply.

3.1.1

design pressure

maximum pressure expected to be applied to a system component

3.1.2

pressure full scale

full scale pressure value of the measuring device

3.1.3

working pressure

maximum pressure which is generated by a pressure/vacuum generator in the interstitial space under normal operating conditions

3.2 Symbols and abbreviated terms

F_e	is the exhaust flow rate of the pressure relief valve at p_e , in litres per hour
g	is the force of gravity, in metres per second squared
h	is the maximum filling height of the tank, in metres
h_G	is the maximum height of the groundwater related to the lowest point of the tank, in metres
h_1	is the filling height of the interstitial space due to alarm pressure p_{AE} , in metres
l	is the length of the interconnecting line, in metres
m_1	is the mass of air at T_1 and p_4
m_2	is the mass of air at T_2 and p_4
m_a	is the mass of the absorbed water per kg dry pearls, in kilograms per kilogram
m_{sch}	is the bulk weight of the dry pearls, in kilograms per cubic metre
Δm	is the difference between m_1 and m_2
p_a	is the set pressure of the pressure relief valve, in Pascal
p_{am}	is the measured set pressure of the pressure relief valve, in Pascal
p_{AA}	is the relative pressure at control point “alarm off”, in Pascal
p_{AE}	is the relative pressure at control point “alarm on”, in Pascal
p_e	is the pressure of $p_{am} + 5\%$ of the pressure relief valve, in Pascal
p_{PA}	is the working pressure of the leak detection kit and corresponds to the relative pressure at control point “pump off”, in Pascal

p_{PE}	is the pressure of the leak detection kit and corresponds to the relative pressure at control point “pump on”, in Pascal
p_{t2}	pressure to which the interstitial space between the skins is subjected for testing, in Pascal
p_z	is the closing pressure of the pressure relief valve, in Pascal
p_{zm}	is the measured closing pressure of the pressure relief valve, in Pascal
p_0	is the operating pressure of the tanks and pipes, in Pascal
p_1	is $p_{PA} + 100\,000$, in Pascal
p_2	is $p_{PE} + 100\,000$, in Pascal
p_3	is $p_{AE} + 100\,000$, in Pascal
p_4	is $p_a + 100\,000$, in Pascal
Δp	is the difference between p_{AE} and p_{PA} , in Pascal
Q_L	is the flow rate of air due to leaks, in cubic metres per year
Q_S	is the flow rate of air due to temperature variation exceeding opening pressure of the over pressure device, in cubic metres per year
Q_{gas}	is the entire flow rate of air ($Q_S + Q_L$), in cubic metres per year
R	is the general gas constant (here for air) = $287\text{ J}/(\text{kgK})$
T_0	is $15\text{ °C} = 288\text{ K}$
T_1	is $T_0 + \Delta T_2$
T_2	is $T_1 + 7,5\text{ K}$
ΔT_1	is the temperature increase according to Formula (A.1), in Kelvins
ΔT_2	is the temperature increase according to Formula (A.2), in Kelvins
V	is the proportional reduction of the interstitial space caused by ingress of liquid for assurance of the alarm, in per cent
V_A	is the deflated air volume (by the pressure relief valve) in the leak detector), in cubic metres
V_k	is the volume of interstitial space = 1 m^3
V_{max}	is the max. volume of interstitial space, intended for this leak detector, in cubic metres
V_{TF}	is the contents (volume) of the dry filter, in litres
V_0	is the entire volume of the interstitial space, in cubic metres
V_1	is the volume of the interstitial space at filling height h_1 , in cubic metres

- p_m is $(p_1 + p_2)/2$ average working pressure (absolute), in Pascal
- ρ_G is the density of the groundwater, in kilograms per cubic metre
- ρ_P is the density of the stored product in the tank, in kilograms per cubic metre

4 Requirements

4.1 Effectiveness

4.1.1 General

This type of leak detection kit is classified according to EN 13160-1:2016 as class I.

The general requirements on leak detection systems according to Clause 5 of EN 13160-1:2016 shall be met.

The interstitial space shall fulfil the requirements according to EN 13160-7, EN 12285-1 or EN 12285-2. The leak detection kit is not effective with an interstitial space volume exceeding 10 m³.

NOTE To ensure the effectiveness of the system a vacuum leak detection kit can only serve one tank. Whereby a pipework may consist of several sections where the interstitial spaces are connected.

A complete documentation shall be provided by the manufacturer. The documentation shall contain the technical values according to 4.1.2 to 4.1.5, 4.2 and 4.3 as well as a statement about the reaction of the leak detection kit by over and under voltage and current.

The leak detection kit shall be equipped with an integrated test device for simulating a leak which shall result in an alarm.

4.1.2 Measure the pressure change

4.1.2.1 Measuring device for over pressure

Leak detection kit comprises of measuring device for over pressure to be connected to the interstitial space. The measuring device for over pressure shall fulfil the following requirements:

- pressure measuring range: given by the manufacturer;
- repeatability of the measurement according to manufacturer data;
- overload protection: at least 1,5 times of the working pressure (p_{PA});
- overpressure protection: at least 1,5 times of the pressure full scale.

The measuring device shall be connected to the interstitial space by a measuring line of the following minimum inside diameter:

- 6 mm for air based systems;
- 4 mm for inert gas based systems.

The colour of this measuring line shall be red or marked in red for indication.

4.1.2.2 Evaluation device for over pressure

The operating condition of the evaluation device shall be clearly indicated, i.e. by a “green” light.

The evaluation device shall be designed to be connected to an alarm device.

For leak detection kits with permanent connected pressure generator, the evaluation device shall provide a signal to the pressure generator that the pressure in the interstitial space does not exceed more than 90 % of p_{t2} and that a shut-off of the pressure generator is triggered.

— **For tanks**

The evaluation device shall evaluate the measuring device values. In case of a pressure drop in the interstitial space to the level before or at the value calculated in Formula (1) or Formula (2) a signal shall be sent to the alarm device.

$$p_{AE} = 3\,000 \text{ Pa} + \rho_P \cdot h \cdot g + p_0 \quad (1)$$

$$p_{AE} = 3\,000 \text{ Pa} + \rho_G \cdot h_G \cdot g \quad (2)$$

— **For pipes**

The evaluation device shall evaluate the measuring device values. In case of a pressure drop in the interstitial space to the level before or at the value calculated in Formula (3) a signal shall be sent to the alarm device.

$$p_{AE} = 0,1 \text{ MPa} + p_0 \quad (3)$$

4.1.2.3 Alarm device for over pressure

The alarm device shall generate an audible and visible alarm. The audible alarm shall have a sound level of $\geq 70 \text{ dB (A)}$ in a distance of minimum 1 m with a signal according to Table 1 of EN 981:1996+A1:2008 which shall be maintained for a minimum period of 36 h. The audible alarm may be able to be switched off, but the status off should be visible.

The visible alarm shall be clearly indicated i.e. by a “red” light. The visible alarm shall have no switch off option.

The alarm device should be designed for connecting an additional alarm device, e.g. signal horn. The output parameter shall be stated.

A test possibility shall be provided to test the functionality of the audible and visible alarm.

4.1.2.4 Measuring device for vacuum

Leak detection kit comprises of measuring device for vacuum to be connected to the interstitial space. The measuring device for vacuum shall fulfil the following requirements:

- vacuum measuring range: given by the manufacturer;
- repeatability of the measurement: according to manufacturer data;
- overload protection against vacuum: minimum 1,1 times of the working vacuum (p_{pA}), at least however 60 kPa (600 mbar);
- if the measuring device is designed to be used on pressurized tanks or pipes, the measuring device shall withstand an overpressure of at least 1,1 times of the design pressure given by the manufacturer.

A condensate trap shall be provided for all lowest points of the measuring line.

The measuring device shall be connected to the interstitial space by a measuring line of 6 mm minimum diameter. The colour of this measuring line shall be red or marked in red.

4.1.2.5 Evaluation device for vacuum

4.1.2.5.1 General

The operating condition of the evaluation device shall be clearly indicated, i.e. by a “green” light.

The evaluation device shall be designed to be connected to an alarm device.

For assurance of the alarm the volume of the interstitial space has to be reduced by increasing liquid, see Formula (4):

$$V = \left(1 - \frac{100000 \text{ Pa} - p_{\text{PA}}}{100000 \text{ Pa} - p_{\text{AE}}}\right) \cdot 100 \text{ in } \% \quad (4)$$

Due to the alarm pressure p_{AE} the interstitial space is filled (in the case of a leak) up to the height h_1 compared with the lowest point of the tank, see Formula (5):

$$h_1 = \frac{p_{\text{AE}}}{g \cdot \rho_{\text{P}}} \text{ or } h_1 = \frac{p_{\text{AE}}}{g \cdot \rho_{\text{G}}} \quad (5)$$

Under consideration of tank geometry or geodetic differences in the levels of the double wall pipe systems the volume of the interstitial space V_1 at filling height h_1 has to be determined by calculation (or by measurement in litres), see EN 13160-7.

The alarm is considered reliable, if the following condition is fulfilled, see Formula (6):

$$V < \frac{V_1}{V_0} \quad (6)$$

NOTE The above mentioned calculation would be carried out for tanks with a suction line down to the lowest point of the interstitial space. An analogue application is required for tanks without a suction line or for pipework, i.e. the line of reference for the height h_1 is the horizontal line through the lowest point, at which the suction line is connected with or ends in the interstitial space. For tanks with a suction line down to the lowest point of the interstitial space it is the end of the suction line on the lowest point and for tanks without a suction line down to the lowest point of the interstitial space it is the suction nozzle at the top of the tank.

4.1.2.5.2 Without integrated vacuum generator

For the application of these systems the following conditions shall be fulfilled:

- a suction line (for the vacuum pump to be installed outside) which shall be led down to the lowest point of the interstitial space;
- or
- at above-ground tanks, as an alternative, a control nozzle may be installed at the lowest point of the interstitial space.

The vacuum pressure (relative value) at p_{AE} shall be at least 35 kPa.

The vacuum pressure (relative value) of the working pressure shall be at least 70 kPa.

4.1.2.5.3 With integrated vacuum generator

The evaluation device with integrated vacuum generator for tanks and pipes shall evaluate the measuring device values. In case of a pressure rise in the interstitial space to the level before or at the value:

- a) as high as the pressure calculated according to Formula (7)

$$p_{AE} = 3\,000\text{ Pa} + \rho \cdot g \cdot h \quad (7)$$

or

- b) of 3 kPa, if the suction line in the interstitial space is led down to the lowest point

or

- c) of 25 kPa for flat-bottom tanks with double bottom

an appropriate signal shall be sent to the alarm device.

For leak detection kits with permanent connected vacuum generator, the evaluation device shall provide a signal to the vacuum generator that the vacuum in the interstitial space does not exceed more than 90 % of p_{t2} and that a shut-off of the vacuum generator is triggered.

4.1.2.6 Alarm device for vacuum

The alarm device shall generate an audible and visible alarm. The audible alarm shall have a sound level of ≥ 70 dB (A) in a distance of minimum 1 m with a signal according to Table 1 of EN 981:1996+A1:2008 which shall be maintained for a minimum period of 36 h. The audible alarm may be able to be switched off but the status off should be visible.

The alarm device should be designed for connecting an additional alarm device, e.g. signal horn. The output parameter shall be stated.

The visible alarm shall be clearly indicated i.e. by a “red” light. The visible alarm shall have no switch off option.

A test possibility shall be provided to test the functionality of the audible and visible alarm.

4.1.3 Replenishment rate of the medium (only if provided)

4.1.3.1 Vacuum and pressure generators with regulated flow rate

The volume flow at the alarm pressure shall be $(85 \pm 15) \text{ l} \cdot \text{h}^{-1}$ if a pressure/vacuum generator is used.

The pressure/vacuum generator shall be connected to the interstitial space by an interconnecting line of the following minimum inside diameter:

- 6 mm for air based systems;
- 4 mm for inert gas based systems.

The colour of this interconnecting line shall be white or clear or marked in white for indication.

The total flow resistance of the interconnecting line between the pressure generator and the double skin tank or pipe may be not more than 1 kPa (10 mbar) at $(85 \pm 15) \text{ l} \cdot \text{h}^{-1}$.

NOTE This requirement is fulfilled for air-based systems, when the length of the interconnecting line is ≤ 50 m for an inner diameter of the interconnecting line of 6 mm.

4.1.3.2 Pressure / vacuum generator with time regulated flow

The average volume flow (measured over a refill and a control period) at the alarm pressure shall be $(85 \pm 15) \text{ l} \cdot \text{h}^{-1}$ if a pressure/vacuum generator is used.

The pressure/vacuum generator shall be connected to the interstitial space by an interconnecting line of the following minimum inside diameter:

- 6 mm for air based systems;
- 4 mm for inert gas based systems.

The colour of this interconnecting line shall be white or clear or marked in white for indication.

The total flow resistance of the interconnecting line between the pressure generator and the double skin tank or pipe may be not more than 1 kPa (10 mbar) at $(85 \pm 15) \text{ l} \cdot \text{h}^{-1}$.

NOTE This requirement is fulfilled for air-based systems, when the length of the interconnecting line is $\leq 50 \text{ m}$ for an inner diameter of the interconnecting line of 6 mm.

4.1.4 Software (only if provided)

The software, where provided, shall have a facility for self-checking by fulfilling the following requirements:

- a self-diagnostic mode to test the integrity of the system at start up and periodically during use. A negative result of self-diagnostic mode shall result in an alarm condition;
- a facility to check the consistency of the input and output data, malfunction shall result in an alarm condition.

4.1.5 Function and tightness of leak detection kit

All leak detection kits shall

- be equipped with a device for simulating a leak which shall result in an alarm;
- withstand the operation pressure/vacuum as well as the pressure of tanks or pipes or the hydrostatic pressure of tanks and shall be tight under these conditions;
- have an opening and closing pressure of the pressure relief device in the range given by the manufacturer.

The devices for simulating a leak shall have clearly identified operating position.

4.2 Durability of effectiveness

4.2.1 Durability of effectiveness against temperature

The temperature ranges for leak detection kits shall be as follows:

- Type 1: $-20 \text{ }^{\circ}\text{C}$ to $+60 \text{ }^{\circ}\text{C}$;
- Type 2: $0 \text{ }^{\circ}\text{C}$ to $+40 \text{ }^{\circ}\text{C}$;
- Type 3: $-40 \text{ }^{\circ}\text{C}$ to $+40 \text{ }^{\circ}\text{C}$.

4.2.2 Durability of effectiveness against chemical attack

Parts of leak detection kits which may come into contact with the liquid of the stored/conveyed product or its vapour shall be resistant.

4.2.3 Durability of effectiveness against fatigue through cycling of pressure

Leak detection kits shall withstand 10 000 cycles of pressure changes.

4.2.4 Humidity measurement of the leak detection medium (only if provided)

A dry filter shall be sized so that it has not to be exchanged within one year, provided a tight system.

A device shall indicate proper function.

4.3 Additional requirement

4.3.1 Over pressure change

Each pressure relief device shall have the following parameters given by the manufacturer:

- set pressure, p_a ;
- exhaust flow rate, F_e at a pressure p_e ;
- closing pressure p_z ;
- operational temperature range, i.e. underground, frost protected or open air.

NOTE The intention of a pressure relief device is to prevent a higher pressure in the interstitial space than p_{t2} . The higher pressure results from a temperature rise or a failure of the pump control.

4.3.2 Vacuum change

4.3.2.1 Liquid stop device

The liquid stop device shall stop the flow of liquid in the suction line of the vacuum generator under consideration of the pressures and the temperature ranges.

The liquid stop device can be

- 1) a mechanical device (usually called liquid stop valve), e.g. floater moving up in case of liquid. By floating up the suction line is closed;
- 2) a device combined of a sensor and a solenoid valve, e.g. the sensor detects the presence of liquid and by this the solenoid valve is closed.

If the sensor device is additionally connected to the evaluation device and the evaluation device is sending an alarm to the alarm device then 4.1.2.5.1 is no longer applicable.

The liquid stop device shall fulfil the following requirements:

- resist the working pressures of the evaluation device;
- resist the operating pressure of the tank or pipework;
- trigger an alarm when the sensor is wetted (only if applicable).

4.3.2.2 Condensate trap

The condensate trap shall be overpressure and vacuum tolerant.

If the condensate trap is designed to be used on pressurized tanks or pipes, the condensate trap shall withstand an overpressure of at least 1,5 times of the design pressure given by the manufacturer.

5 Testing, assessment and sampling methods

5.1 Effectiveness

5.1.1 General

For the tests minimum one sample shall be provided by the manufacturer.

For the tests the following documentation shall be provided by the manufacturer:

- instruction(s) according to Clause 7;
- datasheet of the parts of the leak detection kit including type of temperature range;
- electrical diagrams of the parts of the leak detection kit;
- design and application drawings;
- calculation of the dry filter according to Annex A, except a dry filter is monitored with a humidity sensor;
- parts lists of the used components including material data.

Leak detection kits shall be inspected visually to confirm that the sample complies with the documentation.

5.1.2 Measure the pressure change

5.1.2.1 Measuring device for over pressure

5.1.2.1.1 Test equipment

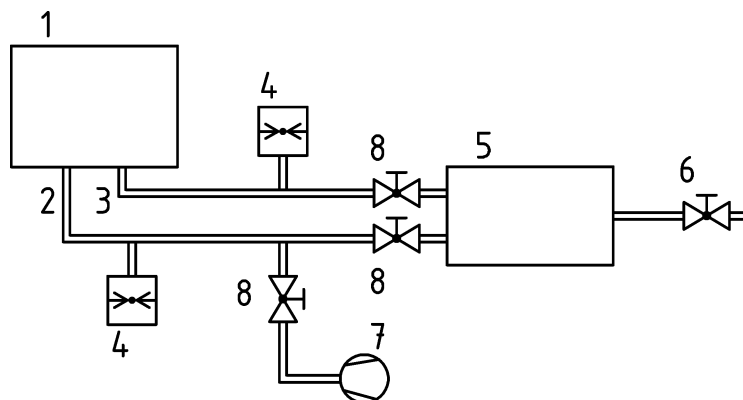
The testing shall be carried out with the following equipment:

- pressure generator for air;
- pressure regulator;
- valves;
- reference measuring device for pressure; with an accuracy of 0,6 % of the full scale range and a division of 0,5 %;
- temperature sensor/thermometer with an accuracy of 1 K;
- test sample (measuring device for pressure combined with a pressure vessel of a volume of 1 l);
- connection lines (tubing), length of $(1 \pm 0,01)$ m.

All measuring devices shall have a full scale, sensitivity, accuracy and repeatability in accordance with the acceptance criterion.

5.1.2.1.2 Preparation

The test set-up shall be according to Figure 1.



Key

1	test sample	5	pressure vessel 1 l
2	measure line	6	pressure regulator valve
3	pressure/suction line	7	pressure generator
4	measuring device for pressure	8	valves

Figure 1 — Measuring device for over pressure or vacuum

5.1.2.1.3 Procedure

The tests shall be carried out at a temperature of $(20 \pm 5) ^\circ\text{C}$.

- 1) Visual comparison of the data of the field of application compared with the data of the measuring device.
- 2) Test to check the repeatability.
 - The test sample shall be connected to the reference measuring device. With the pressure generator an overpressure shall be created until the switch value “Pump-off” is indicated. The corresponding value on the reference measuring device shall be noted. The test set-up shall be ventilated to until the switch value “Alarm-on” is indicated. The corresponding value on the reference measuring device shall be noted.
 - Then the test set-up shall be ventilated to atmospheric pressure.
 - The test procedure as described before needs be carried out once more. The noted values (set for pump-off and set for alarm-on) shall be compared.
- 3) Test to check the overload protection.
 - The openings of the test sample shall be closed with plugs. The test sample shall be pressurized with the overpressure generator to a pressure of 1,5 times of the working pressure of the measuring device (p_{PA}).

- Hold the pressure for (15 ± 1) min and then release to atmospheric condition.
 - The test sample shall be connected to the reference measuring device. With the pressure generator an overpressure shall be created until the switch value “Pump-off” is indicated. The corresponding value on the reference measuring device shall be noted. The test set-up shall be ventilated to until the switch value “Alarm-on” is indicated. The corresponding value on the reference measuring device shall be noted and compared with values of 2).
- 4) Test to check the overpressure protection.
- The test sample and the reference measuring device shall be pressurized to a pressure of 1,5 times of full-scale. Hold the pressure for (30 ± 1) min for pressure and temperature equalization.
 - Then the pressure generator is disconnected. The pressure on the reference measuring device shall be noted. Hold the pressure for another (30 ± 1) min and then note the pressure again.

Having the pressure difference, the test time and the volume of 1 l the calculation for the tightness requirement can be done.

5.1.2.1.4 Evaluation

The test deemed to be passed if

- 1) the data given by the manufacturer for the field of application of the measuring device for overpressure correspond with data for the measuring device;
- 2) the noted values according to 2) of 5.1.2.1.3 are within the tolerance given by the manufacturer;
- 3) the noted values according to 3) of 5.1.2.1.3 are within the tolerance given by the manufacturer;
- 4) the measuring device for overpressure fulfil the tightness requirement of maximum 1 Pa l s^{-1} according to 4) of 5.1.2.1.3.

5.1.2.2 Evaluation device for over pressure

5.1.2.2.1 Test equipment

The testing shall be carried out with the following equipment:

- pressure generator and pressure reducer, if applicable;
- regulating valve;
- pressure vessel (1 l);
- reference measuring device for pressure; with an accuracy of 0,6 % of the full scale range and a division of 0,5 %;
- test sample;
- connection lines (tubing), length of $(1 \pm 0,01)$ m;
- time measuring device with an accuracy of ± 1 s.