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Standard Guide for Preparation of a Leak Testing Specification[1]

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1. Scope

1.1 This standard[2] is intended as a guide. It enumerates factors to be considered in preparing a definitive specification for maximum permissible gas leakage of a component, device, or system. The guide relates and provides examples of data for the preparation of leak testing specifications. It is primarily applicable for use in specifying halogen leak testing methods.

1.2 Two types of specifications are described:

1.2.1 Operational specifications (OS), and

1.2.2 Testing specifications (TS):

1.2.2.1 Total, and

1.2.2.2 Each leak.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 425 Terminology Relating to Leak Testing[3]

E 427 Practice for Testing for Leaks Using the Halogen Leak Detector (Alkali-Ion Diode)[3]

E 432 Guide for Selection of a Leak Testing Method[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *operational specification (OS)*—a specification from which the others are derived. The specification specifies and states the limits of the leakage rate of the fluid to be used for the product using criteria such as failure to operate, safety, or appearance.

3.1.2 *testing specification (TS)*—a specification for the detection, location, or measurement, or a combination thereof, of leakage. The operational fluid usually is not detectable with commercially available leak detectors. The leak test must be performed with a suitable test gas containing a tracer to which the detector is sensitive. The pressure magnitude and pressure direction may vary greatly from operational conditions. These and other factors are to be considered and evaluated when the leak testing performed to the requirements of the TS is to result in a product that meets most of the OS requirements. In addition, should a product be tested with a detector or tracer probe from point to point, allowance should be made for the possibility of two or more leaks, each causing less leakage than the total leakage maximum, but adding up to an amount greater than allowed.

4. Specification Content and Units

4.1 The content and units of the specification should relate the following data:

4.1.1 Mass flow per unit of time, preferably in moles per second (mol/s).

4.1.2 The pressure differential across the two sides of possible leaks, and the direction, in pounds per square inch (psi) or moles (mol).

4.1.3 Any special restrictions or statement of facts that might prohibit the use of a particular type of leak testing method.

4.1.4 The methods of the leakage specification shall not be limited to any one particular method unless it is the only one suitable. Specific leak testing methods can be selected when careful consideration of the facts is outlined (refer to Guide E 432 or the other applicable documents of Section 2).

5. Significance and Use

5.1 For any product to be tested the geometrical complexity will vary widely. However, the basic concept of determining an operative leakage specification regardless of geometries is much the same for all, whether it be simple, ordinary, or complex.

5.2 The data required for writing the OS, which is total leakage (moles), time(s), and pressure difference across the leak, are either available or can be determined by tests or measurements.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Guide SE-479 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 03.03.

5.3 A user who selects values to be used in a leakage specification as a result of someone else having used the value or simply because of prestige reasons, may find the value or values unsatisfactory for the product.

5.4 A specification that is too restrictive may result in excessive leak testing costs. A specification that is not restrictive enough may result in premature product failure, or increased warranty costs, or both.

5.5 A typical illustration for determining a leakage specification, using the complex geometry of a refrigerant system for an example, will be used throughout this recommended guide. It is well to point out that the user should realize that the values and test methods selected do not necessarily represent the best or typical ones for this application.

6. Procedure

6.1 The example that follows is to be construed as applicable to the equipment and testing method cited, and is not to be construed as setting up mandatory leakage rates for any other equipment or method of testing. The example used to illustrate the use of this guide is as follows: An automotive air-conditioning system using Refrigerant-12 (R-12, dichlorodifluoromethane) and consisting of a compressor, condensing coil, thermostatic expansion valve, evaporating coil, vacuum-operated hot gas bypass capacity control valve, and a sealed temperature control thermostat.

6.2 *OS, Refrigerant Circuit*—It is desirable that the rechargeable portions of the system operate three years before requiring additional refrigerant; for the sealed parts, 5 years. Tests show that 6 oz of the normal charge can be lost before serious operational inefficiency begins, and the neoprene connecting hoses have a basic permeation rate of 1 oz/year. Inspection of the system shows that the vacuum operator of the capacity valve and the thermostat are not directly connected to the refrigerant circuit, and can thus be considered separately.

6.2.1 *Calculations*:

Leakage to be detected = 6 oz (total loss) − 1 oz $\times$ 3 years = 3 oz

Period = 3 years

Rate = 3 oz/3 years = 1 oz/year. Rate (standard units) = 1 oz/year $\times$ 1.8×10^{-4} (or 0.00018 = R-12 conversion factor) = 7.308×10^{-9} moles/s. See 6.6.3

Pressure—The maximum operating temperature of the system will be 77°C at which temperature the pressure of the refrigerant will be about 2.07 MPa. Pressure difference = 2.07 MPa (internal) − 0.10 MPa (atmosphere) = 1.97 MPa.

6.2.2 Therefore, the following would appear on the appropriate documents: Leakage Specification (Operational): 3.6×10^{-5} MPa max at 1.97 MPa pressure difference (7.308×10^{-9} moles/s excluding hose permeation).

6.3 *TS, Refrigerant Circuit*:

6.3.1 For a unit to be tested at the OS level, any inaccuracies in the test could cause possible unit acceptance when in fact the unit may leak in excess of the amount allowed. Most testing conditions cannot duplicate operating conditions. Should a point-by-point probing technique be used, a number of smaller leaks may allow a total leakage in excess of the value specified.

6.3.2 In addition, some portions of the system may be purchased as a completed operative component. Their potential contribution to the total system leakage must be limited. It is because of the requirements of the testing specification that these and other factors are considered, and that required leak testing at levels to ensure acceptable quality levels in the final product is made with the consideration for a lesser testing cost. Often it is necessary to divide the leakage allowance equitably among various components, taking into account the statistical probability of the largest allowable leakage occurring in a number of a given set of components.

6.3.2.1 *Division of Leakage Allowance Among System Components*—Assume in the previous example that the compressor, condensing and evaporating coils, the expansion valve, capacity control valve, and sealed thermostat all have to be considered. Also assume that the compressor and evaporating coil will both be tested separately before assembly into the system, as each has a number of fabricated joints more prone to leakage than the condensing coil. The condensing coil, considered a continuous length of tubing, can be tested at the final system test. All components except the thermostat make up some portion of the refrigerant circuit. How then should the leakage allowance be divided among them? The usually equitable way is to make the division on the basis of the number of joints in each, considering 25 mm of seam as one "joint." A tabulation example on this basis follows:

	No. of Joints	% of Total
Compressor	36	28
Condensing coil	78	60
Expansion	7	5
Capacity control valve	9	7
Total	130	100

6.4 *Factor of Safety for Leak Testing Accuracy*—When establishing the data for the factor of safety for leak testing accuracy and when performed by various people using different equipment, facilities, or operating standards, the resulting data usually will vary tremendously. Results of a round-robin test conducted by ASTM resulted in a spread of the test data of about one decade. This value is considered valid for leak tests using procedures and equipment described in Section 2. Therefore any operational specification may apply a factor of ⅓ or 0.3.

6.5 *Factor of Safety for Number of Leaks per System*—When a unit or device has a number of points that may leak, the leak test is to be performed by point-to-point probing. There is a possibility that the sum of all leaks smaller than the specification total may add up to an amount in excess of it. However, this is dependent upon the number of leak possibilities or on whether there is any distortion of the normal leak distribution curve, which covers many decades of sizes. The factor assigned here may depend upon a judgment of the probability of such an event occurring, the degree of confidence needed in the leak test, and the safety factor that can be afforded. In this example, assume that the condensing coil is of welded aluminum which has a strong tendency to have porosities that leak in the range of 4.06×10^{-10} moles/s. For this reason, the TS total will be divided by five for this item, and by three for the others, that is, a factor of 0.2 and 0.3 respectively.

6.6 *Factor of Safety for Test versus Operating Conditions*:

6.6.1 *Pressure*—As a recommendation, the leakage is assumed to be proportional to the difference of the squares of the pressures on each side of the leak. However, for this example, it is assumed that a 2.76 MPa pressure difference, high pressure internal, is needed. This would allow combining the leak test with the burst test which is fixed at 2.86 MPa, absolute internal − 0.10 MPa, absolute external = 2.76 MPa. This pressure will possibly reveal leaks that can only develop with higher stress. With the operating condition at 2.07 MPa, gage max, greater leakage can be expected at the higher test pressure. Calculate the Factor of Safety as follows:

$$\begin{aligned}\text{Factor of Safety} &= (P_2{}^2 - P_1{}^2)/(P_3{}^2 - P_1{}^2)\\ &= (2.76^2 - 0.1^2)/(2.07^2 - 0.1^2)\\ &= 1.8\end{aligned}$$

where:

P_1 = pressure, atmospheric,
P_2 = high pressure (internal), and
P_3 = pressure, operating.

Therefore, a factor of 1.8 can be applied to the operational specification.

6.6.2 *Test Gas*—Except at high ambient temperatures, most refrigerant gases normally used in a system will liquefy before the test pressure is reached. Nonetheless, other gases or mixture of gases, will be required for leak testing. The more suitable gases, such as helium, nitrogen, air, etc., have a viscosity of about 1.9×10^{-4} P, compared to 1.2×10^{-4} for most halogenated refrigerants, compared to 1×10^{0} for water and 1×10^{2} for lubricating oils. The leakage of a fluid is inversely proportional to its viscosity. Therefore, the correction for test fluid is extremely important, particularly when liquids are involved. In this example a factor of 1.2×10^{-4} divided by $1.9 \times 10^{-4} = 0.6$ will be used.

6.6.3 *Test Specifications*—From an operational specification of 7.308×10^{-9} moles/s. (excluding hoses) the testing specification for the completed system is derived (Note Appendix Table X1.1, Nos. 1–4). Test specification, total = $1.8 \times 10^{-5} \times 0.3$ (equipment accuracy) $\times$ 1.8 (gas pressure) $\times$ 0.6 (gas viscosity) = $1.8 \times 10^{-5} \times 0.32 = 5.8 \times 10^{-6}$. Round the coefficient to the nearest whole number. The total for all leaks will be: "Leakage specification, testing, total: 24.36×10^{-10} moles/s. max at 2.76 MPa pressure differential, pressure internal." Therefore, each leak = $24.36 \times 10^{-10} \times 0.3$ (selected by consideration of factors outlined in 6.5) = 7.308×10^{-10} moles/s. Rounded, each leak will be: "Leakage specification, testing, each leak: 8.12×10^{-10} moles/s at 2.76 MPa pressure differential, pressure internal."

6.6.4 *Testing Specification*, *Purchased Components*—When purchased components will be subject to receiving inspection for compliance with the leakage specification supplied to the vendor, these two specifications should not be the same; otherwise, parts tested at normal accuracies by the vendor may be rejected by the customer. Therefore, a typical factor of about 1⁄10 (0.1) should be applied to the vendor's specification.

6.6.4.1 *Expansion Valve*—This component has two leakage requirements. The part common with the refrigerant system must meet its requirements; the sealed operator assembly, a diaphragm, capillary tube, and bulb filled with R-12 gas has its own operation specification.

(*1*) *Refrigerant System Side Specifications: Test Specification*, *Total*—In the tabulation example in 6.3.2.1 an allowance of 5 % for the expansion valve compartment was established. Applying this to the similar system specification: $7.308 \times 10^{-9} \times 0.05 = 36.54 \times 10^{-11}$ moles/s. (This allowance might be increased on a statistical basis if desired.) Thus the specification for this component can be tabulated as follows:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal (Note Appendix Table X1.1, Nos. 5–8)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total		X	36.54×10^{-11}
Testing, total	X		36.54×10^{-12}
Testing, each leak		X	12.18×10^{-11}
Testing, each leak	X		12.18×10^{-12}

Observe that a factor of 1⁄3 has been applied for probe testing versus total leakage testing.

(2) Operator Assembly Specifications—This is an independent system, and the operational specification must be established as before. Make the following calculations:

Maximum loss of R-12 before malfunction:	2 standard cm^3
Time limit:	5 years
Pressure (internal)	0.6 MPa

$$\text{Operational specification} = 2/(5 \times 3.15 \times 10^7) = 5.3 \times 10^{-13} \text{ moles/s}$$

Using factors previously discussed, the specifications may be tabulated as follows:

Maximum Leakage at 0.48 MPa Differential, Pressure Internal (Note Appendix Table X1.1, Nos. 9–13)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Operational		X	5.3×10^{-13}
Testing, total	X		16.24×10^{-14}
Testing, total		X	4.06×10^{-14}
Testing, each leak	X		12.18×10^{-14}
Testing, each leak			4.06×10^{-14}

Note that the factors used are larger than normal, as the sensitivity limit for the detection of halogen has been approached. (See Practice E 427).

6.6.4.2 *Control Valve*—There are two separate leakages to consider for this component: the refrigerant side and the operational side. Applying appropriate factors, the specifications may be tabulated as follows:

Refrigerant Circuit Side Specifications:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal (Note Appendix Table X1.1, Nos. 14–17)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total			8.12×10^{-10}
Testing, total	X		8.12×10^{-11}
Testing, each leak		X	24.36×10^{-11}
Testing, each leak	X		24.36×10^{-12}

Calculation, testing, total: $7.308 \times 10^{-9} \times 0.09$ (see the tabulation example in 6.3.2.1) = 6.5×10^{-10} moles/s.

Operator Specifications:

Maximum Leakage at 0.10 MPa Differential, Pressure External (Note Appendix Table X1.1, Nos. 18–20)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Testing, total		X	4.06×10^{-5}
Testing, total	X		4.06×10^{-4}

As this component is non-repairable, and because the diaphragm is accessible only through parts on each side of its enclosure, probe testing to locate points of leakage is neither possible nor desirable.

6.6.4.3 *Thermostat*—No parts are in contact with the refrigerant circuit. The unit components usually are sealed in an inert atmosphere at one atmosphere pressure, to prevent contaminants and oxidation. It is preferred to specify the tracer gas to be used, in order to control the electrical characteristics and contact life. As a rule, probing tests are difficult and not necessary, as defective units will be scrapped. Test data have revealed that a seal that leaks no more than 4.06×10^{-11} moles/s at 0.10 MPa differential will give adequate protection at the normally small operating differentials.

Maximum Leakage at 0.10 MPa Differential,
Pressure Internal (Note Appendix Table X1.1, Nos. 21–23)

Type of Specification	Seller	User	Maximum Leakage, moles/s
Operational			4.06×10^{-11}
Testing, total		X	12.18×10^{-14A}
Testing, total	X		12.18×10^{-14A}

[A] Fill to be 10 % helium in dry nitrogen. This value pertains to helium leakage only.

7. Summary of Requirements

7.1 A leakage specification should contain all the requirements for the qualifying procedure. It shall specify:

7.1.1 Mass flow, preferably in mol/s,

7.1.2 Time, preferably in seconds,

7.1.3 Pressure differential, preferably in mol/s,

7.1.4 Direction of pressure differential,

7.1.5 Other restrictions only when necessary, and

7.1.6 Intended use of specifications:

7.1.6.1 Operational.

7.1.6.2 Testing, total.

7.1.6.3 Testing, each leak (optional).

7.1.6.4 Testing, total, seller (optional).

7.1.6.5 Testing, each leak, seller (optional).

APPENDIX

(Nonmandatory Information)

X1. PRELIMINARY LEAK TESTS

X1.1 It should be noted that furnished specifications in no way prevent the manufacturer or seller from making his own interim leak tests. It should be determined, however, that such tests do not prejudice the required tests. For example, a preliminary bubble test under water might temporarily plug small leaks. As an example, consider line 11, Table X1.1, "Expansion valve operator assembly, seller, max leakage 1×10^{-9} standard cm^3/s at 70 psi (0.48 MPa) differential, pressure internal." The seller wishes to test the assembly before fitting and sealing. He elects to use the helium mass spectrometer with 100 % helium external test gas. He computes the expected difference in leak rate:

$$\text{Factor of Safety} = (P_2{}^2 - P^2)/(P_4{}^2 - P_3{}^2)$$
$$= (0.1^2 - 0^2)/(0.57^2 - 0.1^2) = 0.03$$

Therefore he will get a value of $1 \times 10^{-10} \times 0.03 = 12.18 \times 10^{-16}$ moles/s. However, in leaks of this size, helium leaks about 7 times faster than R-12. Therefore, he may desire to use the specification value of $3 \times 10^{-12} \times 7 = 8.12 \times 10^{-15}$ moles/s as a preliminary test.

TABLE X1.1 Leakage Specification Developed in Example, Automotive Air Conditioner

No.	Component	Type of Specification	Seller	User	Pressure Internal	Pressure External	Differential, MPa (psi)	Max, Leakage, moles/s	Methods Considered[A]
1.	Hoses	operational			X		2.07 (300)	7.308×10^{-9}	A1
2.	Refrigerant system except hoses	operational			X		2.07 (300)	7.308×10^{-9}	A1
3.	Refrigerant system except hoses	testing total		X	X		2.76 (400)	24.36×10^{-10}	A, B
4.	Refrigerant system except hoses	testing, each leak		X	X		2.76 (400)	8.12×10^{-10}	A, B
5.	Expansion valve refrigeration system	testing total		X	X		2.76 (400)	36.54×10^{-11}	A, B
6.	Expansion valve refrigeration system	testing total	X		X		2.76 (400)	36.54×10^{-12}	A, B
7.	Expansion valve refrigeration system	testing, each leak		X	X		2.76 (400)	12.18×10^{-11}	A2
8.	Expansion valve refrigeration system	testing, each leak	X		X		2.76 (400)	12.18×10^{-13}	A2
9.	Expansion valve operator assembly	operational			X		0.48 (70)	5.3×10^{-13}	A1
10.	Expansion valve operator assembly	testing total		X	X		0.48 (70)	16.24×10^{-14}	A1
11.	Expansion valve operator assembly	testing total	X		X		0.48 (70)	4.06×10^{-14}	A1
12.	Expansion valve operator assembly	testing, each leak		X	X		0.48 (70)	12.18×10^{-14}	A1
13.	Expansion valve operator assembly	testing, each leak	X		X		0.48 (70)	4.06×10^{-14}	A1
14.	Control valve refrigeration system	testing total		X	X		2.76 (400)	8.12×10^{-10}	A, B
15.	Control valve refrigeration system	testing total	X		X		2.76 (400)	8.12×10^{-11}	A, B
16.	Control valve refrigeration system	testing, each leak		X	X		2.76 (400)	24.36×10^{-11}	A2
17.	Control valve refrigeration system	testing, each leak	X		X		2.76 (400)	24.36×10^{-12}	A2
18.	Control valve operator system	operational				X	0.10 (15)	4.06×10^{1}	A
19.	Control valve operator system	testing total		X		X	0.10 (15)	4.06×10^{-5}	C3
20.	Control valve operator system	testing total	X			X	0.10 (15)	4.06×10^{-6}	C3
21.	Thermostat	operational			X		0.10 (15)	4.06×10^{-11}	B1
22.	Thermostat	testing total		X	X		0.10 (15)	12.18×10^{-13}[B]	B1
23.	Thermostat	testing total	X		X		0.10 (15)	12.18×10^{-14}[B]	B1

[A] The last column, "Methods Considered," is not a proper part of the specifications. It and the footnotes were appended to show test methods that were considered.

Methods Considered	Reasons for Suitability
A. Halogen, alkali-diode	1. Inherent tracer
B. Helium mass spectrometer, tracer internal	2. Adequate sensitivity
C. Sensitive flowmeter	3. Quantitative measurement of large leaks[B]

[B] Fill to be 10% helium in dry nitrogen. This value is for helium leakage only.

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