BRITISH STANDARD

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Cryogenic vessels — Methods for performance evaluation of thermal insulation

The European Standard EN 12213:1998 has the status of a British Standard

Confirmed
March 2008

ICS 23.020.30

National foreword

This British Standard is the English language version of EN 12213:1998.

The UK participation in its preparation was entrusted to Technical Committee PVE/18, Cryogenic vessels, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 10, an inside back cover and a back cover.

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Descriptors: pressure vessels, cryogeny, definitions, tests, estimation, characteristics, thermal insulation, testing conditions

English version

Cryogenic vessels — Methods for performance evaluation of thermal insulation

Récipients cryogéniques — Méthodes d'évaluation de la performance de l'isolation thermique

Kryo-Behälter — Verfahren zur Bewertung des Wärmedämmvermögens

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. EN 12213:1998 E

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 268, Cryogenic vessels, the Secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an indentical text or by endorsement, at the latest by May 1999, and conflicting national standards shall be withdrawn at the latest by May 1999.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association. This European Standard is considered to be a supporting standard to those application and product standards which in themselves support an essential safety requirement of a New Approach Directive and which make reference to this European Standard.

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Contents

Introduction

Traditionally in Europe, there have been different ways of defining the insulation performance. A requirement exists therefore to harmonize such methods of evaluating insulation performance for different cryogenic vessels.

To aid the understanding of this standard, see the logic diagram in Figure 1.

1 Scope

This standard defines a pratical method for determining the heat leak performance of cryogenic vessels. The methods include measurement on both open and closed systems.

This standard neither specifies the requirement levels for insulation performance nor when the methodology defined is applied. These requirements may be defined in design or operational standards/regulations.

2 Definitions

For the purpose of this standard, the following definitions apply.

2.1

open system

during test, a system is considered open when it is kept at a constant pressure (e.g. atmospheric pressure) and when the gas produced by the evaporation of the test fluid is continuously released to the atmosphere

2.2

closed system

during test, a system is considered closed when the mass of the contents is kept constant with no input or output of product

2.3

heat leak performance

the quantity of heat transferred per unit time from the ambient air to the contents of the inner vessel

NOTE In an open system the heat leak causes a loss of product. In a closed system it causes a rise in pressure.

2.4

holding time, open system

the time expected to elapse from initial filling level until the vessel is empty (no more liquid), calculated from heat leak data

2.5

holding time, closed system

the time elapsed from establishing the initial filling condition until the pressure has risen, due to heat leak, to the set pressure of the pressure limiting device

NOTE A pressure limiting device is either a safety valve or a rupture disc or a back pressure regulator or any other device installed to limit the system pressure under normal operating conditions.

2.5.1

equilibrium holding time

the holding time calculated from a specified heat leak assuming that liquid and vapour are constantly in equilibrium

2.5.2

optimum equilibrium holding time

the equilibrium holding time calculated from heat leak data for a vessel when filled with the quantity of product giving the longest holding time

2.5.3

static experimental holding time

a) when the critical pressure is greater than the set pressure of the limiting device, the holding time of a closed system measured on a stationary vessel filled with a quantity of product which is calculated to fill the tank to its gross volume without hydrostatic deformation, with saturated liquid at the set pressure of the pressure limiting device

b) when the critical pressure is less than the set pressure of the limiting device, the holding time of a closed system measured on a stationary vessel initially filled with the least mass of the specified product determined as follows:

— the maximum allowable mass of filling;

or

— the quantity of product which fills the vessel to its gross volume, without hydrostatic deformation, with liquid saturated to 99 % of its gross volume at the critical pressure.

3 General conditions for all methods

The measurements described in this standard shall be carried out under the following conditions.

3.1 The cryogenic fluid used for testing shall be chosen by the manufacturer. Liquid nitrogen should normally be used except in cases where the vessel to be tested is designed for a specific cryogenic fluid.

3.2 The liquid and gaseous phases shall be in equilibrium at the beginning of a test. When a test is carried out at a higher pressure than one bar gauge, it is important that the liquid equilibrium pressure is not lower than this test pressure.

3.3 The test environment shall be stable and constant during the test. It shall be as close as possible to the following reference conditions:

— ambient temperature: 15 °C;

— atmospheric pressure: 1 013 mbar.

For products except carbon dioxide and nitrous oxide:

— vessel reference pressure: 1 013 mbar.

For carbon dioxide and nitrous oxide:

— vessel reference pressure: 15 bar (gauge).

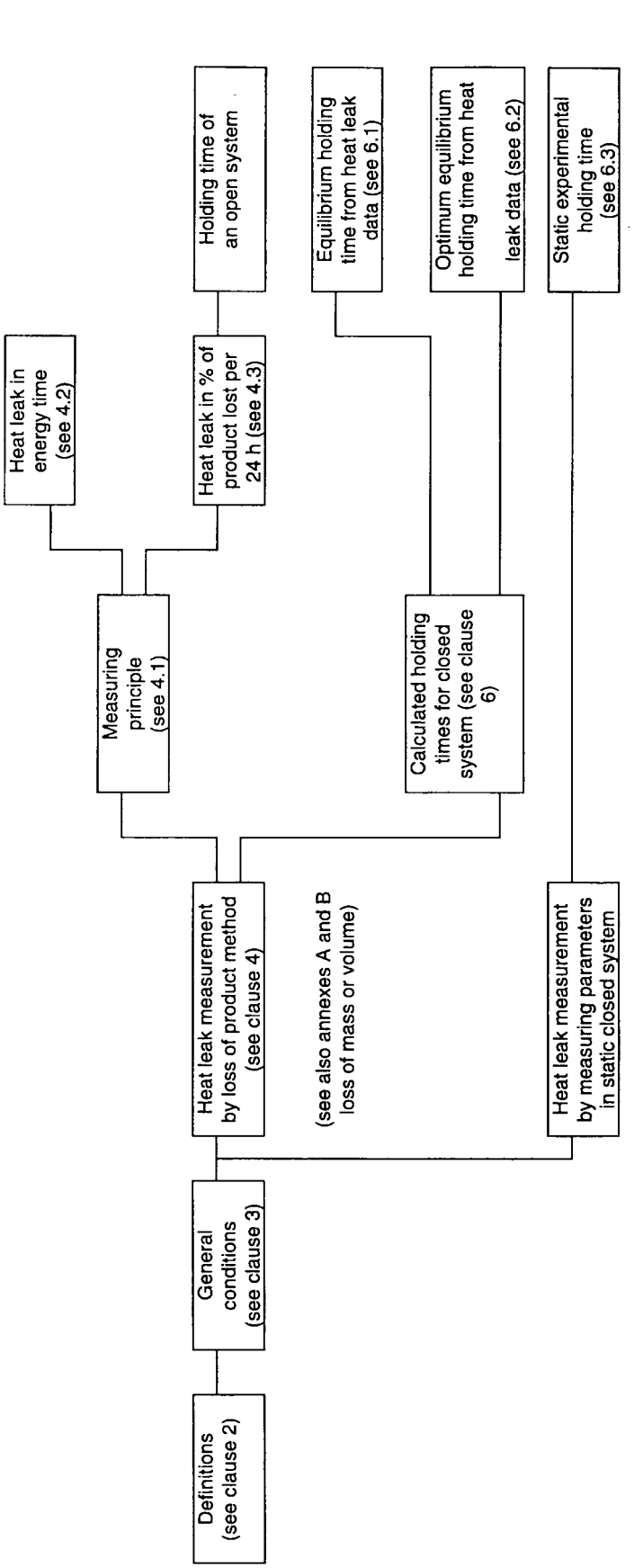


Figure 1 — Logic diagram

3.4 The vessel and its contents shall have reached a stable temperature before the beginning of the measuring period. Equilibrium conditions are obtained after a period of stabilization, the duration of which depends on the size of the vessel and the type and configuration of the insulation.

3.5 All accessories of the vessel which can have an influence on the result of the measurement shall be clearly defined and specified in the report.

3.6 All instrumentation used shall be periodically verified by calibration.

3.7 It is not necessary to use the method defined in this standard to evaluate the insulation performance resulting from small modifications (this evaluation can be obtained by simple extrapolation).

4 Measuring the heat leak by the loss of product method

4.1 General

There are two methods of measuring the heat leak:

— by direct measurement of loss of mass;

— by indirect measurement of loss of mass by measuring the gaseous volumetric discharge rate.

The filling level shall be (50 ± 10) % of the maximum filling level at the start of measurement, unless otherwise stated.

The ambient temperature and the operating pressure at the top of the vessel shall be recorded throughout the test so as to be used for correction purposes. The temperature sensor(s) shall be placed in the immediate proximity of the test object, but sited such that they are unaffected directly by cold gas discharged from the vents.

The minimum measurement duration shall be 24 h after stable conditions have been reached.

During the test precautions shall be taken to avoid agitation of the liquid.

When measuring the rate of discharge of gas escaping from the vessel by a flow meter, it is essential that the entire gas flow passes through the meter. The gas flow rate shall be determined as a mass flow rate either by:

— using a mass flow meter;

or

— using a volumetric flow meter. An appropriate method is shown in annex A.

4.2 Test procedure

The test procedure shall be as follows:

step 1 : vessel precooling;

step 2 : stabilization;

step 3 : adjustment of the filling to the intended starting level (e.g. 50 % ± 10 %);

step 4 : connection of instrumentation (e.g. gas flow meter);

step 5 : second stabilization period;

step 6 : determination of mass of contents of vessel at start of measuring period;

step 7 : a sufficient number of readings shall be taken to establish an acceptable thermal equilibrium before the start of the measuring period;

step 8 : measuring period shall be at least 24 h;

step 9 : determination of the loss of product in mass units (when gaseous flow is measured) in accordance with annex A;

step 10 : reduction to reference conditions in accordance with annex B.

4.3 Determination of the heat leak in units of energy per unit time

The rate of product loss (kg/s) during the measurement period, corrected to the reference conditions in accordance with annexes A and B, shall be converted to an equivalent heat leak, Q, by multiplying it by the latent heat of evaporation (J/kg) of the product at the reference conditions.

To calculate the heat leak with a product other than the test product, compensation using linear extrapolation in accordance with annex C may be applied but only if the difference between the boiling temperature of these products at the reference conditions does not exceed 20 °C.

4.4 Determination of the heat leak as a percentage of product lost per 24 h

Based on the result obtained in accordance with **4.3**, the heat leak as a percentage of product lost per 24 h is calculated as follows:

a) correct the measured heat leak to reference condition for the test product by linear extrapolation as specified in **4.3**;

b) calculate the equivalent loss of the test product per day in accordance with the formula:

$$L = \frac{86\,400 \cdot Q}{h \cdot F} \cdot 100\,\%$$

where

F is the maximum allowable filling mass of the test product (kg);

L is the equivalent loss of product in % of F per day;

Q is the heat leak (W);

h is the latent heat of vaporisation (J/kg) at the vessel reference pressure (see **3.3**);

86 400 is the number of seconds per day.

All product related data shall be taken at correct reference conditions for the specified product. Annex C may be used to determine the equivalent loss of product in % of full tank content per day, for product other than the test product.

5 Determination of the holding time (open system) in days from heat leak data

The holding time in days is equal to $\frac{100}{L}$ for the specified product, which is equivalent to 100 times the reciprocal of the loss of product per 24 h in percent (as determined in **4.4**).

6 Holding times for closed systems

6.1 Determination of the equilibrium holding time from heat leak data

The following general rules shall be applied:

— the system is in thermal equilibrium, i.e. the liquid and gas phases are saturated and at a temperature corresponding to the saturation pressure at all times. The calculation process shall incorporate correctly the temperature and pressure dependence of the thermodynamic properties. The data source used for calculations shall be identified and the actual value shall be shown in the calculation. Thermodynamic data from reference [1] of clause **8** may be used. The influence of phase change in the system has to be accounted for in a proper manner;

— the thermal mass of the vessel shall be neglected in the calculation, which results in shorter holding times;

— for degree of filling above the optimum, the end of holding time period shall be defined as when the liquid phase fills the vessel to its gross volume;

— heat leak data may be used corrected in accordance with annex C when different products are concerned.

6.2 Determination of the optimum equilibrium holding time from heat leak data

The optimum equilibrium holding time for a specific product shall be calculated from heat leak data as follows:

a) correct the heat leak, Q, measured in accordance with clause **4**, to reference conditions for the specified product by linear extrapolation (see annex C);

b) determine the reference quantity of the specified product on the basis of either:

1) when the critical pressure is greater than the pressure of the pressure limiting device

the quantity of product which fills the vessel to its gross volume with saturated liquid at the set pressure of the pressure limiting device;

or

2) when the critical pressure is less than the pressure of the pressure limiting device

the quantity of product which fills the vessel to its gross volume with liquid saturated at 99 % of its critical pressure.

c) for the calculation the optimum equilibrium holding time shall be calculated in accordance with the following formula:

it is perhaps more convenient to consider the contents shall be considered as two separate systems, one containing the liquid and the other containing vapour, which do not have individually constant volumes and where mass transfer occurs between the two systems.

$$H = \frac{(h_{fg} \cdot m_{fg} - h_{sg} \cdot m_{sg} + h_{fl} \cdot m_{fl} - h_{sl} \cdot m_{sl})}{Q \cdot 3\,600}$$

and

$$m_{fg} = \frac{V - M \cdot v_{fl}}{(v_{fg} - v_{fl})}$$

$$m_{fl} = \frac{V - M \cdot v_{fg}}{(v_{fl} - v_{fg})}$$

$$m_{sg} = \frac{V - M \cdot v_{sl}}{(v_{sg} - v_{sl})}$$

$$m_{sl} = \frac{V - M \cdot v_{sg}}{(v_{sl} - v_{sg})}$$

where

H is the optimum equilibrium holding time (hours);
V is the container gross volume (m^3);
M is the mass of contents (kg) as defined in **6.2**b);
m_{fg} is the mass of vapour at final condition (kg);
m_{fl} is the mass of liquid at final condition (kg);
m_{sg} is the mass of vapour at starting condition (kg);
m_{sl} is the mass of liquid at starting condition (kg);
v_{fg} is the specific volume of vapour at final condition (m^3/kg);
v_{fl} is the specific volume of liquid at final condition (m^3/kg);
v_{sg} is the specific volume of vapour at starting condition (m^3/kg);
v_{sl} is the specific volume of liquid at starting condition (m^3/kg);
h_{fg} is the specific enthalpy of vapour at final condition (J/kg);
h_{fl} is the specific enthalpy of liquid at final condition (J/kg);
h_{sg} is the specific enthalpy of vapour at starting condition (J/kg);
h_{sl} is the specific enthalpy of liquid at starting condition (J/kg);
Q is the heat leak (W) determined in **4.3**.

The result can be given in hours or days as a matter of convenience and should always be accompanied by a specification of the product referred to and the reference quantity of filling in kg or as a percentage of full vessel capacity.

6.3 Static experimental holding time

The measurement shall be made with the product for which the result is required. Substitute products are not acceptable.

The vessel shall be filled to a level exceeding the intended starting level an amount to allow for a proper stabilization period to reference conditions for the product before the start of the measuring period. When the content level has reached the intended starting level, the system is closed and the recording of the pressure increase started.

The normal level of filling at the start of the measurement shall be as given in **6.2**.

During the measuring period the ambient temperature should be kept to 15 °C ± 10 °C. If the test object cannot be protected from exposure to sunshine during the measurement the result shall still be accepted as relevant provided a remark is made in the test report.

The test object shall be carefully inspected during the measuring period to ensure that there is no visible leakage of product ("bubble tight" -10^{-2} mbar l s^{-1}). If a leakage is observed, the measurement shall be regarded as failed unless the leakage can be measured and found to be less than 1 % of the product loss per unit time for the test object under open conditions. In this case provided the leak can be corrected, the measurement may be continued. A note shall be made in the test report.

During the measuring period the test object shall not be moved or otherwise disturbed so that the product is agitated.

The result can be given in hours or days as a matter of convenience and should always be accompanied by a specification of the product referred to and the reference quantity of filling in kg or as a percentage of full vessel capacity.

7 Test report

The test report shall describe all conditions of the tests and particularly:

a) reference to this standard;

b) full identification of the vessel tested and its accessories;

c) identification of the testing body responsible for the test;

d) date;

e) test parameters (particularly when they deviate from the conditions given in the standard):

1) cryogenic fluid used for the test;

2) the exact filling conditions;

3) recording of ambient pressure and temperature, noting any special conditions (e.g. exposure to sunshine);

4) full identification and calibration of the instruments used for the test results.

8 Bibliography

[1] Gas Encyclopaedia, Air Liquide, Elsevier 1976 (for product data tables).

Annex A (normative)

Conversion of measured volumetric gaseous flow to mass flow

To convert the measured volumetric gaseous flow to mass flow, it is necessary to take into account the difference between the measuring conditions and specified reference conditions (in accordance with **3.3**) of three parameters:

— the reference pressure as prescribed by the flow meter manufacturer or the pressure at the inlet of the flow meter;

— the temperature of gaseous flow at the inlet of the flow meter;

— the gas density at the reference conditions;

with the following formula:

$$Q_m = Q_v \frac{P_a}{1\,013} \cdot \frac{288}{T} \cdot \rho$$

where

Q_m is the average gaseous mass flow (kg/s);

Q_v is the average measured volumetric gaseous flow (m^3/s) at the measuring conditions;

T is the average temperature (K) of the measured volumetric gaseous volume during the measuring period;

P_a is the average flow meter reference absolute pressure or the absolute pressure of the gas at the inlet of the flow meter (mbar a) during the measuring period;

ρ is the mass density at 15 °C and 1 013 mbar abs (kg/m^3). Values of ρ for several gases addressed by this standard are shown in Table A.1.

Table A.1

Product gas	ρ kg/m^3
Nitrogen	1,185
Oxygen	1,354
Argon	1,691
Helium	0,169
Carbon dioxide	1,874
Nitrous oxide	1,877
Neon	0,853
Xenon	5,58
Krypton	3,55
Hydrogen	0,085

Annex B (normative)
Correction of measured mass flow rate with regard to deviation from reference conditions

It is necessary to correct the loss of product measured in accordance with clause **4** of the standard to take into account the influence of variations of:

— the ambient temperature;

— the vessel reference pressure.

B.1 Influence of the ambient temperature variations

B.1.1 *General*

The thermal insulation performance of a cryogenic vessel is given for reference conditions in accordance with **3.3**.

The rate of heat transfer to the cryogenic fluid is proportional to the temperature difference $(T_a - T_c)$

where

T_a is the absolute ambient temperature;

T_c is the absolute temperature of the vessel contents.

Variation of thermal equilibrium due to variations in T_a has a time constant (due to delay between the temperature variation and the heat leak variation) which may be measured. It depends on the vessel design.

B.1.2 *Practical measurements*

It is necessary to consider two cases.

B.1.2.1 *Variations of T_a with a 24 h periodicity*

To correct the measured loss of product in order to calculate the average loss during 24 h, the average temperature T_a is used.

Thus, it is sufficient to use 24 h or a multiple of 24 h as:

— the duration of the measurement by loss of volume;

or

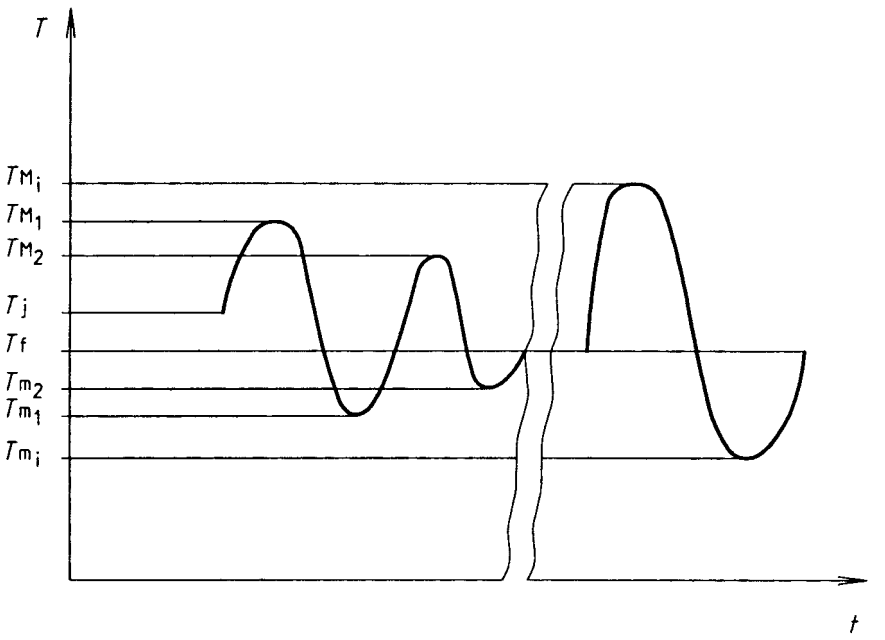
— the periodicity of the measurement by loss of mass;

in order to avoid making a correction in the time constant.

Temperature variations have the form given in Figure B.1.

A good approximation of the average T_a during the measuring period is:

$$T_a = \frac{T_j + T_f + \sum_{i=1}^{i=n} T_{M_i} + \sum_{i=1}^{i=n} T_{m_i}}{2 + 2n}$$



T_j is the initial temperature;
T_f is the final temperature;
T_{M_i} is the maximum temperature (extremes);
T_{m_i} is the minimum temperature (extremes);
n is the number of cycles

Figure B.1 — Temperature variations

B.1.2.2 *Variations of T_a that are not periodic*

This applies, for example, when a prolonged stop in heating of the premises occurs during the measuring period.

To avoid the need to take into account the time constant for thermal equilibrium variations, the loss of product value shall be validated as described in **B.1.2.1** only.

B.2 Influence of the pressure variations of the vessel contents

B.2.1 *General*

The variation of the pressure, P_v, of the vessel contents can cause:

B.2.1.1 A supplementary evaporation of liquid if P_v decreases. This is caused by a lowering of the equilibrium specific enthalpy of the test fluid. The resultant release of energy from the test fluid to achieve equilibrium is available as latent heat of evaporation. In addition, the equilibrium temperature of the liquid decreases, thus increasing the value of $(T_a - T_c)$ and the resultant heat leak to the liquid.

B.2.1.2 A reduction in evaporation of liquid if P_v increases. This is caused by an increase in the equilibrium specific enthalpy of the test fluid. The resultant energy absorption from the heat inleak to achieve equilibrium decreases the energy available for evaporation. In addition, the equilibrium temperature of the liquid increases, thus decreasing the value of $(T_a - T_c)$ and the resultant heat leak to the liquid.

B.2.1.3 The latent heat of evaporation of the vessel contents increases with falling pressure, thus decreasing the rate of evaporation. The opposite condition prevails if the pressure increases.

B.2.2 *Practical measurements*

The average value of P_v should be determined by a similar method as used for T_a in **B1.2.1** i.e.:

$$P_{va} = \frac{P_{vj} + P_{vf} + \sum_{i=1}^{i=n} P_{vM_i} + \sum_{i=1}^{i=n} P_{vm_i}}{2 + 2n}$$

where

P_{vj} is the equilibrium pressure of contents at start of test (bar abs);

P_{vf} is the equilibrium pressure of contents at end of test (bar abs).

B.3 Correction factors

$$Q_o = (Q_m - Q_c) \cdot \frac{(288 - T_{co})}{(T_a - T_{cm})} \cdot \frac{(h_{gm} - h_{lm})}{(h_{go} - h_{lo})}$$

where

Q_o is the rate of product loss at reference conditions (kg/s);

Q_m is the average measured rate of product loss (kg/s) (see annex A);

T_{co} is the equilibrium temperature of contents at reference conditions (K);

T_{cm} is the equilibrium temperature of contents at pressure P_{va} (K);

h_{gm} is the specific enthalpy of vapour at an equilibrium pressure of P_{va} (J/kg);

h_{lm} is the specific enthalpy of liquid at an equilibrium pressure of P_{va} (J/kg);

h_{go} is the specific enthalpy of vapour at the vessel reference pressure (J/kg);

h_{lo} is the specific enthalpy of liquid at the vessel reference pressure (J/kg);

Q_c is a factor to correct for the supplementary or lesser evaporation losses described in **B.2.1.1** and **B.2.1.2** (kg/s).

$$Q_c = \frac{(M_{il} \cdot h_{il} + M_{ig} \cdot h_{ig} - M_{fl} \cdot h_{fl} - M_{fg} \cdot h_{fg})}{(h_{gm} - h_{lm}) \cdot t}$$

where

$$M_{il} = \frac{V - M_i \cdot v_{ig}}{(v_{il} - v_{ig})} \text{ (kg)};$$

$$M_{ig} = \frac{V - M_i \cdot v_{ig}}{(v_{il} - v_{il})} \text{ (kg)};$$

$$M_{fl} = \frac{V - M_f \cdot v_{fg}}{(v_{fl} - v_{fg})} \text{ (kg)};$$

$$M_{fg} = \frac{V - M_f \cdot v_{fl}}{(v_{fg} - v_{fl})} \text{ (kg)}.$$

t is the duration of test;

V is the container gross volume (m^3);

M_i is the measured mass of contents at the start of the test (kg). Where this cannot be determined by direct measurement, it may be estimated by use of calibrated contents gauges, such as differential pressure indicators, and the measured equilibrium pressure of the contents;

$M_f = M_i - Q_m \cdot t$ (kg);

v_{ig} is the specific volume of vapour contents at the start of the test (m^3/kg);

v_{il} is the specific volume of liquid contents at the start of the test (m^3/kg);

v_{fg} is the specific volume of vapour contents at the end of the test (m^3/kg);

v_{fl} is the specific volume of liquid contents at the end of the test (m^3/kg);

h_{ig} is the specific enthalpy of vapour contents at an equilibrium pressure P_{vi} (J/kg);

h_{il} is the specific enthalpy of liquid contents at an equilibrium pressure P_{vi} (J/kg);

h_{fg} is the specific enthalpy of vapour contents at an equilibrium pressure P_{vf} (J/kg);

h_{fl} is the specific enthalpy of liquid contents at an equilibrium pressure P_{vf} (J/kg).

Annex C (normative)

Equivalent loss determination, for product other than the test product

C.1 Determination of the heat leak in units of watts, of fluids other than the test fluid

$$Q_s = Q_t \frac{(288 - T_{cos})}{(288 - T_{cot})}$$

C.2 Determination of the heat leak, in units of percent product loss per 24 h, of fluids other than the test fluid

$$L_s = \frac{L_t(288 - T_{cos})\cdot(h_{got} - h_{sot})\, F_t}{(288 - T_{cot})\cdot(h_{gos} - h_{sos})\, F_s}$$

C.3 Symbols

Q_s is the heat leak to the specified fluid (W);

Q_t is the heat leak to the test fluid (W);

L_t is the equivalent loss of the test fluid in % of full vessel contents per day;

L_s is the equivalent loss of the specified fluid in % of full vessel contents per day;

T_{cot} is the equilibrium temperature of the test fluid at the vessel reference pressure (K);

T_{cos} is the equilibrium temperature of the specified fluid at the vessel reference pressure (K);

h_{got} is the specific enthalpy of vapour of the test fluid at the vessel reference pressure (J/kg);

h_{gos} is the specific enthalpy of vapour of the specified fluid at the vessel reference pressure (J/kg);

h_{sot} is the specific enthalpy of the test fluid at the vessel reference pressure (J/kg);

h_{sos} is the specific enthalpy of liquid of the specified fluid at the vessel reference pressure (J/kg);

F_t is the maximum allowable filling mass of the test fluid (kg);

F_s is the maximum allowable filling mass of the specified fluid (kg).

NOTE The modulus of $(T_{cot} - T_{cos})$ shall be less than 20 °C (see **4.3**).

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