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Plastics piping systems for the supply of gaseous fuels — Unplasticized polyamide (PA-U) piping systems with fusion jointing and mechanical jointing —

Part 1: General

Systèmes de canalisations en matières plastiques pour la distribution de combustibles gazeux — Systèmes de canalisations en polyamide non plastifié (PA-U) avec assemblages par soudage et assemblages mécaniques —

Partie 1: Généralités

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 4, *Plastics pipes and fittings for the supply of gaseous fuels,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 155, *Plastics piping systems and ducting systems,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 16486-1:2020), which has been technically revised.

The main changes are as follows:

— in Table 1, the old requirement for "pigment or carbon black dispersion" has been substituted by new requirements with reference to ISO 18553 and no reference to Annex A. Footnote [a] has also been corrected;

— the former Annex A, “Assessment of degree of pigment or carbon black dispersion in unplasticized polyamide compounds,” has been deleted and reference is made to ISO 18553 instead;

— in Table D.2 and Figure D.2, permeation coefficients of methane for PA-U 11 are given;

— in Table D.4 and Figure D.4, permeation coefficients of hydrogen for PA-U 11 are given.

A list of all parts in the ISO 16486 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

This document specifies the general requirements for a piping system and its components made from unplasticized polyamide (PA-U), which is intended to be used for the supply of gaseous fuels.

Requirements and test methods for materials and components of the piping system are specified in this document and in ISO 16486-2, ISO 16486-3 and ISO 16486-4.

Characteristics for fitness for purpose of the system and generic fusion parameters as well as related requirements and test methods are covered in ISO 16486-5.

Recommended practice for installation is given in ISO 16486-6 which will not be implemented as a European Standard under the Vienna Agreement.

Assessment of conformity of the system forms the subject of ISO/TS 16486-7.

ISO/TS 16486-8 specifies the training and assessment of fusion operators.

NOTE 1 Recommended practice for installation is also given in CEN/TS 12007-6,[7] which has been prepared by Technical Committee CEN/TC 234, *Gas infrastructure*.

NOTE 2 EN 13067[8] also gives recommendations for the qualification of welders for thermoplastics welded assemblies.

NOTE 3 A list of ASTM standards related to polyamide pipes and fittings for the supply of gas is given in the Bibliography.[9], [10], [11], [12]

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Plastics piping systems for the supply of gaseous fuels — Unplasticized polyamide (PA-U) piping systems with fusion jointing and mechanical jointing —

Part 1: General

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1 Scope

This document specifies the general properties of unplasticized polyamide (PA-U) compounds for the manufacture of pipes, fittings and valves made from these compounds, intended to be buried and used for the supply of gaseous fuels. It also specifies the test parameters for the test methods to which it refers.

The ISO 16486 series is applicable to PA-U piping systems, the components of which are connected by fusion jointing and/or mechanical jointing.

This document establishes a calculation and design scheme on which to base the maximum operating pressure (MOP) of a PA-U piping system.

NOTE For the purpose of this document the term gaseous fuels includes, for example, natural gas, methane, butane, propane, hydrogen, manufactured gas, biogas, and mixtures of these gases.

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.

ISO 179-1, *Plastics — Determination of Charpy impact properties — Part 1: Non-instrumented impact test*

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 307, *Plastics — Polyamides — Determination of viscosity number*

ISO 472, *Plastics — Vocabulary*

ISO 527-1, *Plastics — Determination of tensile properties — Part 1: General principles*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 1043-1, *Plastics — Symbols and abbreviated terms — Part 1: Basic polymers and their special characteristics*

ISO 1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General method*

ISO 1167-2, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 2: Preparation of pipe test pieces*

ISO 1183-1, *Plastics — Methods for determining the density of non-cellular plastics — Part 1: Immersion method, liquid pycnometer method and titration method*

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ISO 1183-2, *Plastics — Methods for determining the density of non-cellular plastics — Part 2: Density gradient column method*

ISO 2505, *Thermoplastics pipes — Longitudinal reversion — Test method and parameters*

ISO 6259-1, *Thermoplastics pipes — Determination of tensile properties — Part 1: General test method*

ISO 6259-3, *Thermoplastics pipes — Determination of tensile properties — Part 3: Polyolefin pipes*

ISO 6964, *Polyolefin pipes and fittings — Determination of carbon black content by calcination and pyrolysis — Test method*

ISO 9080, *Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation*

ISO 11413:2019, *Plastics pipes and fittings — Preparation of test piece assemblies between a polyethylene (PE) pipe and an electrofusion fitting*

ISO 12162, *Thermoplastics materials for pipes and fittings for pressure applications — Classification, designation and design coefficient*

ISO 13477, *Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Small-scale steady-state test (S4 test)*

ISO 13478, *Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Full-scale test (FST)*

ISO 13479, *Polyolefin pipes for the conveyance of fluids — Determination of resistance to crack propagation — Test method for slow crack growth on notched pipes*

ISO 13954, *Plastics pipes and fittings — Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm*

ISO 15512, *Plastics — Determination of water content*

ISO 16396-1, *Plastics — Polyamide (PA) moulding and extrusion materials — Part 1: Designation system and basis for specifications*

ISO 16396-2, *Plastics — Polyamide (PA) moulding and extrusion materials — Part 2: Preparation of test specimens and determination of properties*

ISO 16871, *Plastics piping and ducting systems — Plastics pipes and fittings — Method for exposure to direct (natural) weathering*

ISO 18553, *Method for the assessment of the degree of pigment or carbon black dispersion in polyolefin pipes, fittings and compounds*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472, ISO 1043-1 and ISO 16396-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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3.1 Terms related to geometrical characteristics

3.1.1
nominal outside diameter
d_n
specified outside diameter of a component, which is identical to the minimum mean outside diameter, $d_{em,min}$

Note 1 to entry: Expressed in millimetres.

3.1.2
mean outside diameter
d_{em}
measured length of the outer circumference of a pipe, or the spigot end of a fitting, divided by π (≈3,142), rounded up to the nearest 0,1 mm

3.1.3
wall thickness at any point
e
measured wall thickness at any point around the circumference of a component, rounded up to the nearest 0,1 mm

3.1.4
minimum wall thickness at any point
e_{min}
minimum value for the *wall thickness at any point* (3.1.3) around the circumference of a component, as specified

3.1.5
standard dimension ratio
SDR
ratio of the *nominal outside diameter* (3.1.1), d_n, of a pipe to its nominal wall thickness, e_n

3.2 Terms related to materials

3.2.1
compound
homogenous mixture of base polymer (PA-U) and additives, i.e. antioxidants, pigments, UV stabilisers, at a dosage level necessary for the processing and use of components conforming to the requirements of this document

3.2.2
virgin material
compound in the form of granules that has not been subjected to use or processing other than that required for its manufacture and to which no reprocessed or recycled materials have been added

3.2.3
own reprocessable material
material prepared from clean, rejected and unused pipes, fittings, or valves, including trimmings from the production of pipes, fittings, or valves, that is reprocessed in a manufacturer's plant after having been previously processed by the same manufacturer in the production of components by, for example, injection-moulding or extrusion

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3.3 Terms related to material characteristics

3.3.1
lower confidence limit of the predicted hydrostatic strength
σ_{LPL}
quantity, with the dimensions of stress, which represents the 97,5 % lower confidence limit of the predicted hydrostatic strength at a temperature θ and time t

Note 1 to entry: The quantity is expressed in megapascals (MPa).

Note 2 to entry: Temperature, θ, is expressed in degrees Celsius and time, t, is expressed in years.

3.3.2
minimum required strength
MRS
value of σ_{LPL} (3.3.1) at 20 °C and 50 years, rounded down to the next smaller value of the R10 series or the R20 series

Note 1 to entry: The R10 series conforms to ISO 3 and the R20 series conforms to ISO 497.

3.3.3
categorized required strength at temperature θ and time t
$CRS_{\theta,t}$
value of σ_{LPL} (3.3.1) at temperature θ and time t, rounded down to the next smaller value of the R10 series or the R20 series

Note 1 to entry: $CRS_{\theta,t}$ at 20 °C and 50 years equals *MRS* (3.3.2). Policies and procedures for developing CRS are given in PPI TR-3.[15]

Note 2 to entry: Temperature, θ, is expressed in degrees Celsius and time, t, is expressed in years.

Note 3 to entry: The R10 series conforms to ISO 3 and the R20 series conforms to ISO 497.

3.3.4
design coefficient
C
coefficient with a value greater than 1, which takes into consideration service conditions as well as properties of the components of a piping system other than those represented in the lower confidence limit

Note 1 to entry: Recommended design factors and design coefficients for thermoplastic pressure pipes are given in PPI TR-9.[16]

3.3.5
design stress
σ_s
$\sigma_{s,\theta,t}$
stress derived by dividing the *MRS* (3.3.2) or $CRS_{\theta,t}$ (3.3.3) by the *design coefficient* (3.3.4), C, i.e. $\sigma_s = MRS/C$, or $\sigma_{s,\theta,t} = CRS_{\theta,t}/C$

3.4 Terms related to service conditions

3.4.1
gaseous fuel
any fuel which is in a gaseous state at a temperature of 15 °C, at a pressure of one bar (0,1 MPa)

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3.4.2
maximum operating pressure
MOP
maximum effective pressure of the gas in the piping system, expressed in bar, which is allowed in continuous use

Note 1 to entry: The MOP takes into account the physical and the mechanical characteristics of the components of a piping system and the influence of the gas on these characteristics.

4 Symbols and abbreviated terms

4.1 Symbols

a_{cN}	charpy notched impact strength
C	design coefficient
d_{em}	mean outside diameter
d_n	nominal outside diameter
e	wall thickness at any point
e_{min}	minimum wall thickness at any point
L	length
ln	natural logarithm
p	pressure at burst
p_c	critical pressure
t	time
θ	temperature
σ	hoop stress to be induced by the pressure at burst
σ_{LPL}	lower confidence limit of the predicted hydrostatic strength
σ_s	design stress

4.2 Abbreviated terms

$CRS_{\theta,t}$	categorized required strength at temperature, θ, and time, t
MOP	maximum operating pressure
MRS	minimum required strength
PA-U	unplasticized polyamide
R	series of preferred numbers, conforming to the Renard series
RT	room temperature
SDR	standard dimension ratio

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5 Material

5.1 Material of the components

The material from which the components, i.e. the pipes, fittings and valves, are made shall be unplasticized polyamide (PA-U) in accordance with ISO 16396-1.

5.2 Compound

5.2.1 Additives

The compound shall be made of the PA-U base polymer to which are added only those additives that are needed to facilitate the manufacture of pipes and fittings conforming to the applicable parts of ISO 16486.

5.2.2 Colour

The colour of the compound shall be yellow or black.

The carbon black used in the production of the black compound shall have an average (primary) particle size of 10 nm to 25 nm.

5.2.3 Identification compound

When applicable, the compound used for identification stripes shall be manufactured from a PA-U polymer manufactured from the same type of base polymer as used in the compound for pipe production.

When applicable, the compound used for an identification layer shall be of the same base polymer and of the same MRS as the compound used for pipe production.

5.2.4 Virgin material

The components of the piping system shall be made by virgin material. Own reprocessable material shall not be used.

5.2.5 Characteristics

The compounds from which the components are manufactured shall be in accordance with Tables 1 and 2.

Unless otherwise specified in the applicable test method, the test pieces shall be conditioned for at least 16 h at 23 °C and 50 % relative humidity in accordance with ISO 291 before testing in accordance with Table 2.

The test pieces shall not be tested within the period of 48 h after their manufacture.

Long-term hydrostatic strength data shall be generated on saturated polyamide pipe specimens representing the most severe case to prevent rising humidity content of the pipe over test duration and resulting effects on the analysis of time to failure test results. The saturation process in water can be accelerated according to ISO 1110. Data shall show the uptake of water until saturation over time according to ISO 15512.

NOTE In ISO 16486-2:2020, Annex B, information is given about the saturation performance of pipes in water.

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Table 1 — Characteristics of the compound in the form of granules

Characteristic	Requirement	Test parameters		Test method
		Parameter	Value	
Density	PA-U 11 compound: (1 020 to 1 050) kg/m^3 PA-U 12 compound: (1 000 to 1 040) kg/m^3	Test temperature	23 °C	ISO 1183-1 ISO 1183-2
Viscosity number	≥ 180 ml/g	Solvent	*m*-Cresol	ISO 307
Water content	≤ 0,10 % (by mass)			ISO 15512, Method B or E
Carbon black content[a]	(1,0 to 2,5) % (by mass)			ISO 6964
Carbon black dispersion[a]	Grade ≤ 3 Rating of appearance A1, A2, A3 or B	Preparation of test pieces Number of test pieces[b]	Free[c] Shall conform to ISO 18553	ISO 18553
Pigment dispersion[d]	Grade ≤ 3 Rating of appearance A1, A2, A3 or B	Preparation of test pieces Number of test pieces[b]	Free[c] Shall conform to ISO 18553	ISO 18553

[a] Only for black compound.

[b] The numbers of test pieces given indicate the numbers required to establish a value for the characteristic described in the table. The numbers of test pieces required for factory production control and process control should be listed in the manufacturer's quality plan. For guidance, see ISO/TS 16486-7.

[c] In case of dispute, the test pieces shall be prepared by the microtome method.

[d] Only for yellow materials.

Table 2 — Characteristics of compound in form of pipe/bar

Characteristic	Requirement[a]	Test parameters		Test method
		Parameter	Value	
Chemical resistance	Change in mean hoop stress at burst between specimens tested in reagent and in the corresponding control fluid ≤ 20 % or Change in tensile strength at yield of injection moulded bar specimens tested in reagent and in the corresponding control fluid ≤ 20 %	In accordance with Annex A		In accordance with Annex A
Resistance to weathering	The weathered test pieces shall have the following characteristics:	Preconditioning (weathering): cumulative solar radiation	≥ 7,0 GJ/m^2	ISO 16871
a) Elongation at break after weathering	Elongation at break: ≥ 160 %	Testing speed	25 mm/min	a) ISO 6259-1, ISO 6259-3[a] or ISO 527-1, ISO 527-2[b]

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Table 2 *(continued)*

Characteristic	Requirement[a]	Test parameters		Test method
		Parameter	Value	
b) Hydrostatic strength after weathering	No failure during the test period of any test piece	End caps	Type A	b) ISO 1167-1, ISO 1167-2
		Orientation	Free	
		Conditioning time	16 h	
		Type of test	Water-in-water	
		Circumferential (hoop) stress:		
		PA-U 11 160 and PA-U 12 160[c]	10,0 MPa	
		PA-U 11 180 and PA-U 12 180[c]	11,5 MPa	
		Test period	165 h	
		Test temperature	80 °C	
c) Cohesive resistance for electrofusion joint after weathering of pipe	Length of initiation rupture ≤ L_2/3 in brittle failure	Test temperature	23 °C	c) ISO 13954 Joint: Condition 1, ISO 11413:2019 Table C.1
Resistance to rapid crack propagation (critical pressure, p_c)[d] ($e \geq 5$ mm) (Full-scale test)	$p_c \geq 1,5$ MOP	Test temperature	0 °C	In accordance with ISO 13478[e]
Resistance to rapid crack propagation (critical pressure, $p_{c,S4}$)[f] (S4 test)	[g]	Test temperature	0 °C	ISO 13477
Longitudinal reversion	≤ 3 % Pipe shall retain its original appearance	Heating fluid	Air	ISO 2505
		Test temperature	150 °C	
		Length of test piece	200 mm	
		Duration of exposure time	According to ISO 2505	
Resistance to slow crack growth for $e > 5$ mm (notch test)	No failure during the test period	Test temperature	80 °C	ISO 13479
		d_n	110 mm or 125 mm	
		SDR	11	
		Test pressure:		
		PA-U 11 160 and PA-U 12 160[c]	18 bar	
		PA-U 11 180 and PA-U 12 180[c]	20 bar	
		Test period	500 h	
		Type of test	Water-in-water	

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Table 2 *(continued)*

Characteristic	Requirement[a]	Test parameters		Test method
		Parameter	Value	
Charpy impact strength	a_{cN} ≥ 10 kJ/m^2 for PA-U 11 and PA-U 12 compounds	Test specimens	Notched injection moulded specimens prepared according to ISO 16396-2	ISO 179-1
		Test temperature	0 °C	

NOTE 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

[a] For test pieces taken from samples in the form of pipe/bar.

[b] For test pieces in the form of injection moulded bar prepared according to ISO 16396-2.

[c] For material classification and designation, see 5.4.

[d] The critical pressure, p_c, shall be determined for each new PA-U compound and for every pipe dimension with d_n > 90 mm.

[e] The temperature of cooling for the crack initiation groove shall be appropriate to produce a high-speed crack or cracks emanating from the initiation. For some PA-U compounds a crack initiation groove temperature between 0 °C and −60 °C has been found to be suitable.

[f] The critical pressure, $p_{c,S4}$, shall be determined on a pipe produced from the same batch of PA-U compound and the same lot of pipes, as the pipe submitted to the full-scale test.

[g] The value of $p_{c,S4}$ determined in this test is the reference value, $p_{c,S4,REF}$, to be referred to in the requirement of the S4 test specified in ISO 16486-2.

5.2.6 Change of compound formulation

Any change in dosage levels or manufacturing process of the compound affecting the performance can require a new qualification of the compound.

NOTE 1 Guidance for the assessment of conformity of the compound and the system is the subject of ISO/TS 16486-7.

NOTE 2 For further guidance, see Reference [8].

5.3 Fusion compatibility

Components made from PA-U 11 shall be heat fusion jointed only to components made from PA-U 11.

Components made from PA-U 12 shall be heat fusion jointed only to components made from PA-U 12.

Components made from PA-U are not fusion-compatible with components made from other polymers.

NOTE Test methods for assuring fusibility are given in ISO 16486-3 and ISO 16486-5.

5.4 Classification and designation

PA-U compounds shall be classified by MRS in accordance with Table 3.

The long-term hydrostatic strength of the compound shall be evaluated in accordance with ISO 9080, with pressure tests performed in accordance with ISO 1167-1 to find σ_{LPL}. The MRS value shall be determined from the σ_{LPL}.

The classification in accordance with ISO 12162 shall be given and demonstrated by the compound producer.

Where fittings are manufactured from the same compound as pipes, then the compound classification shall be the same as for pipes.

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Table 3 — Classification and designation of compounds

σ_{LPL} (20 °C, 50 years, 9,75 % lower confidence limit) MPa	**MRS** MPa	**Compound designation**
$16 \leq \sigma_{LPL} < 18$	16	PA-U 11 160 PA-U 12 160
$18 \leq \sigma_{LPL} < 20$	18	PA-U 11 180 PA-U 12 180

5.5 Maximum operating pressure (MOP)

The MOP is the lower value when calculated using Formula (1) and Formula (2):

$$MOP = \frac{20 * MRS}{C * (SDR - 1)} \quad (1)$$

NOTE MOP is measured in bar and MRS in MPa. Conversion is included in the Formula. 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

The minimum value of the design coefficient, C, for pipes, fittings and valves for the supply of gaseous fuels shall be 2.

$$MOP = \frac{p_c}{1,5} \quad (2)$$

where p_c is the full-scale critical pressure determined in accordance with ISO 13478 at 0 °C.

The critical pressure determined for a pipe with a given wall thickness may be used for pipes made from the same compound with a smaller wall thickness.

5.6 Effects of transport of liquid hydrocarbons and hydrogen

Annex C gives information about continuous liquid hydrocarbon exposure from transported fluid or soil contamination. Annex D shows the permeation resistance against different gases.

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Annex A
(normative)

Chemical resistance

A.1 Principle

Evaluation of chemical resistance is based on the determination either of the mean hoop stress at burst on a specimen in the form of a pipe, or the tensile strength at yield on a specimen in the form of an injection moulded bar between the corresponding specimens tested in reagent and in the relevant control fluid.

NOTE This test method is derived from AS 2943:1987, Annex H.[18]

A.2 Reagents

A.2.1 A solution of methanol in water, with a volume fraction of 10 %.

A.2.2 Undiluted pentane.

A.2.3 A mixture of 70 % (by mass) tetrahydrothiophene and 30 % (by mass) *t*-butyl mercaptan, in paraffin oil with a volume fraction of 5 %.

CAUTION — Tetrahydrothiophene and *t*-butyl mercaptan are extremely malodorous materials which should be handled with great care.

A.2.4 A mixture of liquid hydrocarbons, with the volume fractions as given in Table A.1 to which is added 0,5 g of phenol for 100 ml of the mixture.

Table A.1 — Volume fractions of liquid hydrocarbons

Liquid hydrocarbon	Volume fraction (%)
Benzene	10
Toluene	20
Xylene	25
Cyclohexane	25
Kerosene	10
Styrene	10

A.3 Control fluids

A.3.1 Water, for reagent A.2.1.

A.3.2 Undiluted paraffin oil, for reagent A.2.3.

A.3.3 Air, for reagents A.2.2 and A.2.4.

NOTE All reagents and control fluids are commercial grade.

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A.4 Test pieces

Test pieces shall be as follows:

a) 35 test pieces of (250 ± 10) mm long taken from a pipe of d_n 32, SDR 11 when the chemical resistance is based on the change in hoop stress at burst;

b) 35 test pieces prepared according to ISO 16396-2 when the chemical resistance is based on the change in tensile strength at yield.

A.5 Conditioning of test pieces and reagents

The test pieces and reagents shall be conditioned at (23 ± 2) °C for not less than 24 h immediately before testing.

A.6 Procedure

A.6.1 Determination of the hoop stress at burst

A.6.1.1 Determine and record the hoop stress at burst at (23 ± 2) °C for five test pieces in accordance with Annex B.

A.6.1.2 Subdivide the remaining 30 test pieces into six sets of five test pieces. Fully immerse each set in each of the four reagents and in each of the two control fluids, A.3.1 and A.3.2, making sure the test pieces do not touch each other or the walls of the container, for a minimum of 72 h at a temperature maintained at (23 ± 2) °C.

A.6.1.3 Remove each test piece from the reagent and wipe with a dry, clean cloth.

A.6.1.4 Within 5 min of removal from the reagent or control fluid, carry out the test in accordance with Annex B and determine the hoop stress at burst of each of the immersed test pieces.

A.6.1.5 Repeat steps A.6.1.3 and A.6.1.4 above until determinations have been carried out on all test pieces.

A.6.2 Determination of the tensile strength at yield

A.6.2.1 Determine and record the tensile strength at yield at (23 ± 2) °C for five test pieces prepared in accordance with ISO 16396-2 and tested in accordance with ISO 527-1 and ISO 527-2.

A.6.2.2 Subdivide the remaining 30 test pieces into six sets of five test pieces. Fully immerse each set in each of the four reagents and in each of the two control fluids A.3.1 and A.3.2, making sure the test pieces do not touch each other or the walls of the container, for a minimum of 72 h at a temperature maintained at (23 ± 2) °C.

A.6.2.3 Remove each test piece from the reagent and wipe with a dry, clean cloth.

A.6.2.4 Within 5 min of removal from the reagent or control fluid, carry out the test in accordance with ISO 527-1 and ISO 527-2 and determine the tensile strength at yield of each of the immersed test pieces.

A.6.2.5 Repeat steps A.6.2.3 and A.6.2.4 above until determinations have been carried out on all test pieces.

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A.7 Test report

The test report shall include the following information:

a) reference to this document (i.e. "ISO 16486-1:2023");

b) the procedure used for assessing the chemical resistance: hoop stress at burst or tensile strength at yield;

c) for the procedure based on hoop stress at burst:

   1) complete identification of the pipe, including manufacturer, nominal diameter, d_n, type of material and production date,

   2) mean outside diameter, d_{em}, of the pipe,

   3) minimum wall thickness, e_{min}, of the pipe,

   4) type of end caps,

   5) mean hoop stress at burst of non-immersed test pieces, and

   6) mean hoop stress at burst of immersed test pieces for each reagent and its associated control fluid;

d) for the procedure based on tensile strength at yield:

   1) mean tensile strength at yield of non-immersed test pieces, and

   2) mean tensile strength at yield of immersed test pieces for each reagent and its associated control fluid;

e) any factors which can have affected the results, such as any incidents or unusual features observed or any deviations from the procedure not specified in this document;

f) any unusual features observed;

g) date of the test.

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Annex B
(normative)

Hoop stress at burst

B.1 Principle

This test method determines the maximum internal stress that the material is able to withstand for a short time due to pressure surge.

B.2 Apparatus

This shall be in accordance with ISO 1167-1, except for pressurizing equipment, which shall be capable of producing a pressure in the pipe sufficient to result in bursting.

B.3 Test pieces

B.3.1 Preparation of test pieces

The preparation of test pieces shall be in accordance with the relevant clause of ISO 1167-2.

Before testing, each test specimen shall have its ends squared and cleaned. It shall have no burrs, notches or other markings which could cause premature failure.

Measure and record test piece component parameters (e.g. preparation conditions, dimensions) as necessary.

B.3.2 Number of test pieces

Prepare five test pieces.

B.4 Procedure

B.4.1 Connect a test piece to the apparatus and ensure that all air is excluded.

B.4.2 Pressurize the test piece at such a rate that failure will occur between 1 min and 3 min after applying pressure.

For a test series, all test pieces should be pressurized at the same rate.

B.4.3 Record the pressure required to burst the test piece and the time to failure. The test piece shall be considered to have failed when it leaks, weeps or ruptures. In the event of a failure at an end connection or within one diameter of an end connection up to a maximum of 75 mm, a further test piece shall be selected, and the test shall be repeated.

B.4.4 Calculate the hoop stress at burst using Formula (B.1):

$$\sigma = p\,(d_{em} - e_{min})/20e_{min} \tag{B.1}$$

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where

σ is the hoop stress to be induced by the pressure at burst, expressed in megapascals;

p is the pressure at burst, expressed in bar (1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2);

d_{em} is the mean outside diameter of the test piece, expressed in millimetres;

e_{min} is the minimum wall thickness of the free length of the test piece, expressed in millimetres.

B.5 Test report

The test report shall include the following information:

a) reference to this document (i.e. "ISO 16486-1:2020");

b) complete identification of the pipe, including manufacturer, nominal diameter (d_n), type of material and production date,

c) the test method used;

d) mean outside diameter, d_{em}, of the pipe,

e) minimum wall thickness, e_{min}, of the pipe,

f) type of end caps,

g) mean hoop stress at burst of non-immersed test pieces, and

h) mean hoop stress at burst of immersed test pieces for each reagent and its associated control fluid

i) any factors which can have affected the results, such as any incidents or unusual features observed or any deviations from the procedure not specified in this document;

j) any unusual features observed;

k) date of the test.

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Annex C
(informative)

Continuous liquid hydrocarbon exposure from transported fluid or soil contamination

When absorbed, internal fluids such as gases and condensates can have the effect of reducing the material strength upon which the design stress is based, the influence of gas being much less severe than condensate.

For continuous liquid hydrocarbon exposure from transported fluid or soil contamination, the *C* factor should be same as that of natural gases. This is in line with the design already in use by the gas industry in PPI TR-9.[16]

Therefore, no precautions have to be taken in this regard when using a PA-U piping system.

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Annex D
(informative)

Permeation of different gases

D.1 General

The injection of hydrogen in natural gas infrastructures demands considerations with regard to the integrity, safety and performance of the systems facing increasing hydrogen levels, its fluctuation and variation. CEN/TR 17797[19] provides guidance on how injection of hydrogen into the gas infrastructure can impact processes from the input of gas into the on-shore transmission network up to the inlet connection of gas appliances.

For PA-U permeation, values are given in the tables and figures of this annex.

NOTE Permeation characteristics of PA-U can also be found in CEN/TR 17797[19] and CEN/TS 17874.[20]

D.2 Release of methane from pressurized PA-U 11 and PA-U 12 Pipes

The values for the permeation coefficients of methane, CH_4, are calculated on the full-scale permeation measurement of PA-U 12 pipes (d_n 110 mm SDR 11) at room temperature (RT) and ambient outside pressure with an internal gas pressure of 10 bar1); see Table D.1 and Figure D.1.

Table D.1 — Permeation coefficients of methane[21],[22]

Pipe material	Permeation coefficients of CH_4 [(ml·mm) / (m²·bara·day)]
PA-U 12 Producer A	0,92
NOTE Bara (Absolute pressure) is a pressure mode where the reference pressure is absolute zero.	

1) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm².

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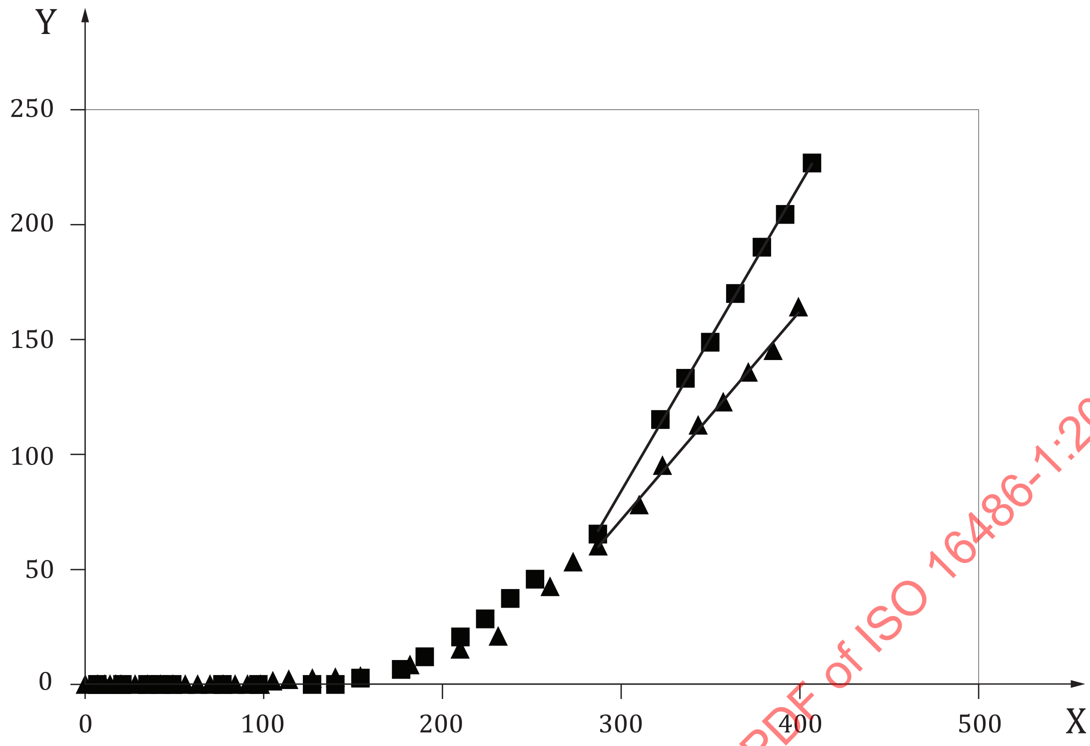

Key

X exposure time (days)

Y accumulated methane [(ml·mm)/(m^2·bara)]

▲ PA-U 12, producer A

■ PA-U 12, producer B

Figure D.1 — Accumulated permeation of methane gas by d_n 110 mm SDR11 pipe, internal pressure 10 bar at RT[21],[22]

In the literature,[23] permeation coefficients of methane through PA-U 11 are given for different pipe sections, both for the pure gases and mixtures at two pressures. The pipes used for the permeation tests are 8 mm outer diameter with 1 mm wall thickness; see Table D.2 and Figure D.2.

Table D.2 — Permeation coefficients of methane through PA-U 11[23]

Material, temperature (°C)	Value [(ml·mm) / (m^2·bara·day)]
PA-U11, 8	1,96[a]
PA-U11, 20	4,4[a]
PA-U11, 45	20,6
PA-U11, 60	39,8
PA-U11, 90	177
NOTE Bara (Absolute pressure) is a pressure mode where the reference pressure is absolute zero. [a] Calculated from Arrhénius approach.	

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