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Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production —

Part 1:
Thermoplastics

Industries du pétrole, de la pétrochimie et du gaz naturel — Matériaux non-métalliques en contact avec les fluides relatifs à la production d'huile et de gaz —

Partie 1: Matières thermoplastiques

Reference number
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Contents

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 23936-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

ISO 23936 consists of the following parts, under the general title *Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production*:

— *Part 1: Thermoplastics*

Elastomers, thermosets, fibre-reinforced composites, and other non-metallic materials are to form the subjects of future parts 2, 3, 4 and 5.

Introduction

Non-metallic materials are used in the petroleum and natural gas industries for pipelines, piping, liners, seals, gaskets and washers, among others. Specifically, the use of piping and liners will considerably increase in the future. The purpose of ISO 23936 is to establish requirements and guidelines for systematic and effective planning, for the reliable use of non-metallic materials to achieve cost effective technical solutions, taking into account possible constraints due to safety and/or environmental issues.

ISO 23936 will be of benefit to a broad industry group ranging from operators and suppliers to engineers and authorities. It covers relevant generic types of non-metallic material (thermoplastics, elastomers, thermosetting plastics) and includes the widest range of existing technical experience. This is particularly important because the subject has not been summarized before in a technical standard. Coatings are excluded from the scope of ISO 23936.

ISO 23936 was initiated during work on ISO 15156-1, ISO 15156-2 and ISO 15156-3, which give the requirements and recommendations for the selection and qualification of low-alloy steels, corrosion-resistant alloys and other alloys for service in equipment used in environments containing H_2S in oil and natural gas production and natural gas treatment plants, where failure of such materials could pose a risk to the health and safety of the public and personnel or to the environment. A fourth part of ISO 15156 was originally envisaged to cover, likewise, the selection and qualification of non-metallic materials in the same environment. However, at a later stage it was decided that due to the differences in the corrosion mechanisms of metallic and non-metallic materials it would be too limiting to solely consider hydrogen sulfide as the corrosive component for non-metallic materials, because in oil and gas production services other systems parameters must also be considered as being corrosive and deteriorating for non-metallic materials.

It was therefore decided to produce a stand-alone International Standard, covering all systems parameters that are considered relevant in the petroleum and natural gas industries to the avoidance of corrosion damages to non-metallic equipment. ISO 23936 supplements, but does not replace, the materials requirements of the appropriate design codes, standards or regulations.

ISO 23936 applies to the qualification and selection of materials for equipment designed and constructed using conventional design criteria for technical application of non-metallic materials. Designs utilizing other criteria are excluded from its scope. ISO 23936 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production —

Part 1: Thermoplastics

CAUTION — Non-metallic materials selected using the parts of ISO 23936 are resistant to the given environments in the petroleum and natural gas industries, but not necessarily immune under all service conditions. ISO 23936 allocates responsibility for suitability for the intended service in all cases to the equipment user.

1 Scope

ISO 23936 as a whole presents general principles and gives requirements and recommendations for the selection and qualification, and gives guidance for the quality assurance, of non-metallic materials for service in equipment used in oil and gas production environments, where the failure of such equipment could pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion failures of the equipment itself. It supplements, but does not replace, the material requirements given in the appropriate design codes, standards or regulations.

This part of ISO 23936 addresses the resistance of thermoplastics to the deterioration in properties that can be caused by physical or chemical interaction with produced and injected oil and gas-field media, and with production and chemical treatment. Interaction with sunlight is included; however, ionizing radiation is excluded from the scope of this part of ISO 23936.

Furthermore, this part of ISO 23936 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

The equipment considered includes, but is not limited to, non-metallic pipelines, piping, liners, seals, gaskets and washers.

2 Normative references

The following referenced documents are indispensable for the application 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 178, *Plastics — Determination of flexural properties*

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

ISO 306, *Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)*

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

ISO 868, *Plastics and ebonite — Determination of indentation hardness by means of a durometer (Shore hardness)*

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

ISO 2578, *Plastics — Determination of time-temperature limits after prolonged exposure to heat*

ISO 11357-6, *Plastics — Differential scanning calorimetry (DSC) — Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)*

ISO 15156–1, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156–2, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons*

ISO 15156–3, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D746, *Standard Test Method for Brittleness Temperature of Plastics and Elastomers By Impact*

ASTM D792, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms, definitions and abbreviated terms apply.

3.1 Terms and definitions

3.1.1
batch
discontinuously manufactured amount of thermoplastic material

3.1.2
certificate of compliance
⟨inspection⟩ document to be issued by the manufacturer in accordance with requirements stated in this standard or in the purchase order

3.1.3
end user
oil and/or gas operating company

3.1.4
fluid
liquid or gas

3.1.5
gasket
sealing component compressed in a joint

3.1.6
liner
thermoplastic material for protection of medium-contacted surfaces of pipes, piping, pipelines or equipment

3.1.7
lot
part of a batch or part of a continuously manufactured thermoplastic material

3.1.8
lot certificate
certificate of analysis issued by the manufacturer

3.1.9
manufacturer
producer of the thermoplastic material or semi-finished products made from thermoplastic materials

3.1.10
material specification
description of characteristics and test requirements for thermoplastic materials

3.1.11
operating temperature
temperature to which a component is subjected during normal operation

3.1.12
maximum operating temperature
maximum temperature to which a component is subjected, including deviations from normal operations, such as start-up/shutdown

3.1.13
minimum operating temperature
minimum temperature to which a component is subjected, including deviations from normal operations, such as start-up/shutdown

3.1.14
pipeline
those facilities through which fluids or gases are transported, including pipes, pig traps, components and equipment, including valves

NOTE Adapted from ISO 13623:2000, definition 3.12.

3.1.15
piping
pipe or system of pipes for the transport of fluids and gases

NOTE 1 A piping system can be regarded as one single system provided it conveys substances having the same properties and as a whole is designed for the same allowable pressure.

NOTE 2 Interruption by different components such as pumps, machines, vessels, etc. does not preclude integration into one single piping system.

3.1.16
seal
deformable polymeric device designed to separate different environments

3.1.17
swelling
increase in volume due to absorption of fluids

3.1.18
thermoplastics
plastics that are capable of being repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastics and, in the softened state, of being repeatedly shaped by flow into articles by moulding, extrusion or forming

[ISO 15750-3:2002]

3.1.19
washer
flat plate of a material with a centralized hole used to seat bolt heads and nuts, among others

3.2 Abbreviated terms

COC	Certificate of compliance
COA	Certificate of analysis
DSC	Differential scanning calorimetry
DTMA/TMA	Dynamic thermo-mechanical analysis/Thermo-mechanical analysis
ECTFE	Polyethylene-chlorotrifluoroethylene
ETFE	Polyethylene-tetrafluoroethylene
HDPE	High density polyethylene
LDPE	Low density polyethylene
MDPE	Medium density polyethylene
PA	Polyamide
PAI	Polyamide-imides
PCTFE	Polychlorotrifluoro-ethylene
PE	Polyethylene
PEI	Polyether-imides
PEEK	Polyether-etherketones
PEX	Cross-linked polyethylene
PFA	Perfluoralkoxides
POM	Polyoximethylene
PP	Polypropylene
PP-B	Polypropylene heterophasic copolymers
PP-H	Polypropylene homopolymers
PP-R	Polypropylene random copolymers
PPS	Polyphenylene sulfide
PTFE	Polytetrafluoro-ethylene
PVDF	Polyvinylidene fluoride
QC	Quality control
RGD	Rapid gas decompression

4 Functional requirements

4.1 General

Materials selection shall be based on evaluation of compatibility with service environment, functionality under service and the design lifetime. The following shall be considered as appropriate to the requirements and evaluated when selecting a material for a specific application:

a) adequate physical and mechanical properties at maximum and minimum temperature (hardness, tensile strength, elongation at break, modulus of elasticity, etc.);

b) resistance to high pressure extrusion or creep at maximum temperature;

c) resistance against rapid gas decompression at maximum temperature;

d) resistance to thermal cycling and dynamic movement;

e) low temperature flexibility, as defined in ASTM D746 and ISO 178;

f) long-term behaviour;

g) gas permeation behaviour;

h) chemical resistance to service environment.

For load-carrying applications, special attention shall be paid on creep and cyclic mechanical loads.

Typical chemical resistances of the most commonly used thermoplastics are listed in Annex A.

4.2 Pipelines, piping and liners

4.2.1 General

The relevant thermoplastic materials in the field of pipelines, piping and liners for use in oil and gas production include Polyethylene (PE), Polypropylene (PP), Polyvinylidene fluoride (PVDF) and Polyamide (PA). Thermoplastic materials based on other monomers may also be used.

4.2.2 Polyethylene (PE)

Polyethylene (PE) is a semi-crystalline thermoplastic polymer. There are different types of PE used in the field of oil and gas production:

- LDPE (low density polyethylene);
- MDPE (medium density polyethylene);
- HDPE (high density polyethylene).

PEX is the abbreviation for cross-linked PE. Cross-linking is usually performed by peroxides (PEXa), silanes (PEXb) or irradiation (PEXc).

Table 1 gives the characteristic properties of the different types of PE and those of PEX, together with the related standards.

Table 1 — Characteristic properties of PE/PEX

Type	Property					
	Density g/cm^3	Melting point (DSC) °C	Vicat A softening temperature °C	Maximum operating temperature[d] °C	Brittleness temperature °C	Impact strength at –30 °C (Charpy) MPa
	Standard					
	ISO 1183-2	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
LDPE	0,910 to 0,925 > 0,932[a]	90 to 120	80 to 105	40	< –50	No break
MDPE	0,926 to 0,940	125 to 130	110 to 120	50	< –60	No break
HDPE	⩾ 0,941	130 to 135	125 to 130	60	< –60	No break
PEX	[b]	[b]	[b]	[c]	< –60	No break

NOTE Table A.1 (see Annex A) gives more details on service limitations in media encountered in oil and gas production.

[a] Density of LDPE copolymers.

[b] Similar to basic material (LDPE, MDPE or HDPE) used, depending on the cross-linking technique.

[c] Generally higher than the basic material (LDPE, MDPE or HDPE); however, depending on the cross-linking technique.

[d] Related to a long-term service life in benign environments.

Increasing the density of PE will increase the temperature limits and enhance the chemical resistance. Cross-linking will also improve the overall properties of the PE material.

NOTE Chemicals like methanol and aromatic hydrocarbons can extract additives from PE materials and thus accelerate the ageing behaviour. Contact the manufacturer in respect to the chemical resistance of the PE material.

The long-term maximum temperature for PE is related to the Vicat A softening temperature (ISO 306).

The low temperature limits of PE are in the order of –40 °C and relate to the brittleness of the material characterized by impact measurements as described in Table 1.

PE is generally accepted in aqueous environments. In the presence of aliphatic and aromatic hydrocarbons the use of PE can be limited due to permeation (specifically aliphatic hydrocarbons) and swelling (loss of mechanical properties and dimensional stability). The resistance to hydrocarbons can be improved by cross-linking (PEXa,b,c materials). The degree of cross-linking may be determined in accordance with EN 579.

UV light will degrade the PE material unless efficient stabilizers are added to the polymer.

PE may be sensitive to environmental cracking if contacted with surface-active compounds, such as detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors. Testing for susceptibility to environmental stress cracking can be performed in accordance with ISO 16770, ASTM D1693 or ISO 22088. The choice of the testing method should be agreed between end user and manufacturer.

4.2.3 Polypropylene

Polypropylene (PP) is a semi-crystalline thermoplastic polymer. There are different types of PP used in the field of oil and gas production:

- PP-H (PP homopolymers);
- PP-R (PP random-copolymers);
- PP-B (PP heterophasic copolymers);
- PP-Elastomers (PP heterophasic copolymers with very high comonomer content).

Table 2 gives the characteristic properties of the different types of PP, together with the related standards.

Table 2 — Characteristic properties of PP

Type	Property				
	Melting point (DSC) °C	**Vicat A softening temperature** °C	**Maximum operating temperature**[a] °C	**Brittleness temperature** °C	**Impact strength at –30 °C (Charpy)** MPa
	Standard				
	ISO 1183-2	ISO 306	—	ASTM D746	ISO 179-1
PP-H	162	150	120	0	20 to 30
PP-R	130 to 150	90 to 130	100	–20	30 to 40
PP-B	160	110 to 135	80	–30	60 to 120
PP-Elastomer	130 to 150	50 to 90	60	–50	No break

NOTE Table A.2 (see Annex A) gives more details on service limitations in media encountered in oil and gas production.

[a] Related to a long-term service life in benign environments.

The chemical resistance of the different PP types is similar to that of the PE materials.

NOTE Chemicals like methanol and aromatic hydrocarbons can extract additives from PP materials and thus accelerate the ageing behaviour. Contact the manufacturer in respect to the chemical resistance of the PP material.

The long-term maximum allowable temperature for PP is related to the Vicat A softening temperature (ISO 306).

The low temperature limits of PP are in the order of –30 °C to 0 °C and relate to the composition of the PP material as described in Table 2.

PP is generally accepted in aqueous environments. In the presence of aliphatic and aromatic hydrocarbons, the use of PP may be limited due to permeation (specifically aliphatic hydrocarbons) and swelling (loss of mechanical properties and dimensional stability).

UV light will degrade the PP material unless efficient stabilizers are added to the polymer.

PP is less sensitive to environmental cracking compared to PE when contacted with surface-active compounds, such as detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors. Testing for susceptibility to environmental stress cracking can be performed according to ISO 16770, ASTM D1693 or ISO 22088. The choice of the testing method should be agreed between the end user and manufacturer.

4.2.4 Polyvinylidene fluoride

Table 3 gives the characteristic properties of Polyvinylidene fluoride (PVDF), together with the related standards.

Table 3 — Characteristic properties of PVDF

Property					
Density g/cm^3	**Melting point (DSC)** °C	**Vicat B softening temperature (50 K/h)** °C	**Maximum operating temperature** °C	**Brittleness temperature** °C	**Impact strength at −30 °C (Charpy)** MPa
Standard					
ISO 1183-2	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
1,75 to 1,78	170 to 180	140 to 145	130	−60	No break

Temperature limits are in the order of 130 °C.

PVDF is resistant to water and aliphatic or aromatic hydrocarbons up to the temperature limits. Basic environments (high pH, including amines) can cause degradation of PVDF. PVDF is sensitive to surface cracks which can grow when subjected to a number of thermally induced stresses. Appropriate testing for susceptibility to functional chemicals (detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors) is necessary. Stress cracking testing should be performed according to ISO 22088.

4.2.5 Polyamides

The most common polyamide (PA) used in oil and gas services (for more than 30 years) is Polyamide 11 (PA 11). There are other types of polyamides available. PA 12 has been approved according to ISO 13628-2 (based on API Spec 17J).

Engineering experiences with ageing of PA 11 in flexible pipes are summarized in API TR 17TR2. PA 12 meets the requirements of API Spec 17J:1999, sections 6.1 and 6.2, and ISO 13628-2.

Table 4 lists the characteristic properties of different types of PA, together with the related standards.

Table 4 — Characteristic properties of PA

Type	Property					
	Density	**Melting point (DSC)**	**Vicat B softening temperature (50 K/h)**	**Maximum operating temperature** [c]	**Brittleness temperature**	**Impact strength at –30 °C (Charpy)**
	g/cm^3	°C	°C	°C	°C	MPa
	Standard					
	ISO 1183-2	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
PA 11	1,03 to 1,04	183	160	70[a] 120[b]	–40	No break
PA 12	1,01 to 1,03	171 to 178	129 to 140	70[a] 120[b]	–40	No break

NOTE 1 The maximum operating temperature is application-related.

NOTE 2 Table A.3 (see Annex A) gives more details on service limitations in media encountered in oil and gas production.

[a] In water-containing systems.

[b] In non-aqueous hydrocarbon systems.

[c] For 20 years of service life at benign environmental conditions.

The high temperature limits are generally in the order of 80 °C in water-containing systems because above this temperature hydrolysis is starting to become a problem. Therefore, mineral acids and lower molecular weight organic acids will impair the properties of PA 11 and PA 12 in the case of prolonged contact, even at low concentrations. Likewise, prolonged contact should be avoided with

- lower molecular weight alcohols, aldehydes and ketones (specifically methanol, formaldehyde, acetone),
- phenols and cresols, anilines and pyridines, halogenated hydrocarbons (e.g. ethylene chloride),
- acetates (butylacetate, amylacetate),
- oxidizing agents (e.g. diluted chromic acid, hypochlorite, hydrogen peroxide and permanganate solutions),
- nitro compounds, and
- aqueous solutions of some inorganic salts (e.g. potassium or sodium carbonate, sodium nitrite, ammonium sulphate).

Aliphatic hydrocarbons are generally accepted in contact with PA 11 and PA 12 up to approx. 120 °C. However, lower molecular weight aromatic hydrocarbons (benzene, toluene, xylenes) can impair the properties of PA 11 and PA 12 at a temperature of 60 °C and above.

Leaching of plasticizer is specifically a problem in liners. Therefore, appropriate testing is necessary. This applies also for the susceptibility to functional chemicals (detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors).

4.3 Seals, washers and gaskets

4.3.1 General

Thermoplastics are used as seals and also for backup or support for seals. Due to their specific application, special types of thermoplastics, e.g. polyphenylene sulfide (PPS), polyether-etherketones (PEEK), polytetrafluoro-ethylene (PTFE), polyamide-imides (PAI), polyether-imides (PEI), polyoximethylene (POM), polychlorotrifluoro-ethylene (PCTFE), are used. These materials are often reinforced by glass powder, glass fibres or carbon fibres in order to enhance the mechanical properties.

Table 5 gives the characteristic properties of the unfilled polymers, together with the related standards.

Table 5 — Characteristic properties of selected unfilled polymers

Type	Property				
	Melting point (DSC) °C	**Vicat B softening temperature (50 K/h)** °C	**Maximum operating temperature** °C	**Brittleness temperature** °C	**Impact strength at −30 °C (Charpy)** MPa
	Standard				
	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
PPS	280	220	200	−50	No break
PEEK	335	259	250	−65	No break
PTFE	325	300	260	−200	No break
PAI	275	260	200	−65	No break
PEI	220	220	170	−60	No break
POM	165 to 175	115	80	−50	No break
PCTFE	210	160	130	−40	No break
The service temperature is strongly dependent on service stresses or pressure and sealing clearance. The ability to withstand stresses at applicable upper temperature shall be documented. PAI is susceptible to hydrolysis when exposed to water-containing fluids at 70 °C or 80 °C. The same chemicals that impair the properties of PA 11 and PA 12 will affect the PAI material. The maximum operating temperature shall be set at 70 °C when exposed to water containing fluids for long-term service life.					

4.3.2 Polyphenylensulfide (PPS)

PPS has good chemical resistance in aqueous and hydrocarbon media up to a temperature limit of 200 °C. This includes sour environments and functional chemicals (detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors). Stress corrosion cracking has not been observed with PPS.

4.3.3 Polyether-etherketones (PEEK)

The maximum allowable temperature is 250 °C for unfilled polymer grades.

PEEK is generally resistant to media used in oil and gas service up to the temperature limit. However, hydrogen sulfide can attack PEEK, specifically in the presence of amines and elemental sulfur and at high partial pressures and temperatures in the range of 200 °C. Limited chemical resistance exists also against halogenated hydrocarbons. Stress corrosion cracking has not been observed with PEEK. The mechanical properties are sensitive to the thermal treatment during the fabrication process, i.e. residual thermal stresses, especially for larger thicknesses.

4.3.4 Polytetrafluoro-ethylene (PTFE)

The temperature limit is 260 °C. At this temperature, the mechanical properties are very poor due to creep. Stress corrosion cracking has not been observed with PTFE.

No media used in oil and gas production, including functional chemicals (detergents, surfactants, emulsifiers, demulsifiers and corrosion inhibitors), have been reported to attack PTFE up to the temperature limit.

NOTE PTFE exhibits a high permeability for oxygen. Exclusion of oxygen is therefore not possible in the case of PTFE piping directly exposed to air.

4.3.5 Polyamide-imides (PAI)

The maximum allowable temperature is 200 °C for unfilled polymer grades.

PAI is virtually unaffected by aliphatic and aromatic hydrocarbons, chlorinated and fluorinated hydrocarbons, and most acids at moderate temperatures. The polymer, however, can be attacked by saturated steam, strong bases and amines (e.g. ethylene diamine, pyridine), and some high-temperature acid systems. Moderate attack must be expected by concentrated formic acid. Poor resistance exists against concentrated hydrofluoric acid. Proper post-cure of PAI components is necessary to achieve optimal chemical resistance.

4.3.6 Polyether-imides (PEI)

The maximum allowable temperature is 170 °C for unfilled polymer grades.

Polyether-imides (PEI) exhibit high strength and rigidity at elevated temperatures, long-term heat resistance, dimensional stability and good electrical properties, and they are inherently flame retardant. PEI resist chemicals such as hydrocarbons, alcohols and halogenated solvents. Creep resistance over the long term even allows PEI to replace metal and other materials in many structural applications. Electrical properties show excellent stability under variable temperature, humidity and frequency conditions. Chemical resistance is given against aliphatic hydrocarbons, hot water, strong organic acids, weak mineral acids and weak bases; however, aromatic hydrocarbons, fuels, strong bases, strong mineral and oxidizing acids, chlorinated hydrocarbons, alcohols, ketones like acetone, as well as lower molecular weight esters (e.g. ethyacetate), can impair the property profile of PEI.

4.3.7 Polyoximethylene (POM)

The maximum allowable temperature is only 80 °C for the unfilled polymer grades.

While good resistance exists against aliphatic and aromatic hydrocarbons, POM as a polyacetal is susceptible to hydrolysis by strong and weak acids and bases and only fairly resistant to low molecular weight alcohols.

4.3.8 Polychlorotrifluoro-ethylene (PCTFE)

The maximum allowable operating temperature is 130 °C for unfilled polymer grades. The low temperature limit of PCTFE is in the order of –240 °C. The shrinkage of PCTFE during cooling from 23 °C to –240 °C is only 0,01 %.

Polychlorotrifluoro-ethylene offers an excellent combination of physical and mechanical properties, chemical resistance, near-zero moisture absorption, non-flammability, and excellent electrical properties. It is used in valves for seats, stems and seals, in bearings, in compressors, in pumps and cryogenic applications, and as gaskets. The chemical resistance is comparable to that of PTFE, although some chlorinated hydrocarbons can cause swelling.

4.4 Encapsulations, electrical insulations, injection lines

4.4.1 General

Materials used for encapsulation, and electrical insulation of wires and cables and for injection or control lines include predominantly PP, PA 11, PA 12, PVDF, PTFE, PCTFE, ECTFE and ETFE. The characteristic properties of PP, PA 11, PA 12, PVDF, PTFE, and PCTFE are given in Tables 2, 3, 4, and 5. Characteristic properties of ECTFE and ETFE are collected in Table 6.

Table 6 — Characteristic properties of selected unfilled polymers

Type	Property				
	Melting point (DSC) °C	**Vicat B softening temperature (50 K/h)** °C	**Maximum operating temperature** °C	**Brittleness temperature** °C	**Impact strength at −30 °C (Charpy)** MPa
	Standard				
	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
ECTFE	240	170	160	−75	No break
ETFE	255 to 280	180	150	−80	No break

4.4.2 ECTFE (Polyethylene-chlorotrifluoroethylene)

In aqueous systems ECTFE is acceptable up to 100 °C.

It can be attacked by high alkaline media, e.g. amines, at temperatures above 100 °C. Therefore, fitness-for-purpose testing according to ISO 175 is recommended.

The maximum operating temperature for non-aqueous media is about 160 °C. Stress corrosion cracking has not been reported within the application limits outlined above.

4.4.3 ETFE (Polyethylene-tetrafluoroethylene)

The maximum operating temperature is about 150 °C. The minimum operating temperature is about −100 °C.

ETFE is inert to many strong mineral acids, inorganic bases, halogens and metal salt solutions. Carboxylic acids, anhydrides, aromatic and aliphatic hydrocarbons, alcohols, aldehydes, ketones, ethers, esters, chlorohydrocarbons and classic polymer solvents have little effect on ETFE. Under highly stressed conditions, some very low surface tension solvents tend to reduce the stress-crack resistance of the lower molecular weight products of ETFE. Very strong oxidizing acids such as nitric acid, organic bases such as amines, and sulfonic acids at high concentrations and near their boiling points will affect ETFE to varying degrees.

5 Requirements for technical information

All materials used within the scope of this part of ISO 23936 shall be purchased in accordance with either a written material specification or an industry standard. The specification shall include measurable physical, mechanical and chemical characteristics.

All suppliers to the manufacturer shall have a documented quality assurance system.

The minimum requirements are valid for all applications. The following shall be documented for quality control:

a) specific gravity, in accordance with ASTM D792;

b) hardness in accordance with ISO 868 or ASTM D2240, Shore D;

c) tensile properties and elongation, in accordance with ASTM D638.

The following is a list of examples of material properties that may be documented for qualification of thermoplastic materials. Interested parties should agree on specifications and quality control parameters at the time of purchase. Test results shall be recorded on material test certificates. The standards are given for guidance:

- specific gravity (ASTM D792);
- hardness (ISO 868 or ASTM D2240, Shore D for seals);
- tensile properties and elongation (ASTM D638);
- impact strength (ISO 179-1);
- expansion coefficient;
- resistance to creep under permanent tensile and compressive loads at maximum temperatures (ASTM D2990);
- melting temperature;
- glass transition temperature;
- softening point (ISO 306);
- data for permeation of gases;
- ageing characteristics;
- resistance to media related to petroleum and natural gas production;
- stress cracking resistance in media related to petroleum and natural gas production.

6 Requirements for manufacturers

6.1 General requirements

A quality assurance system should be applied to ensure compliance with the requirements of this part of ISO 23936.

The intent of this part of ISO 23936 is to define requirements and recommendations for the selection and qualification of thermoplastic materials for service in equipment used in oil and gas production. It is important to note that various manufacturing procedures and practices can be used to make good quality thermoplastic products. However, qualification of the production process is outside the scope of this part of ISO 23936.

NOTE ISO 9001 gives guidance on the selection and use of quality systems and ISO 14001 on the selection and use of environmental management systems. ISO/TS 29001 gives guidance on the selection and use of quality management systems for the petroleum, petrochemical and natural gas industries.

The manufacturer shall be responsible for complying with all applicable requirements of this part of ISO 23936. It shall be permissible for the purchaser to make any investigations necessary in order to be assured of compliance by the manufacturer and to reject any material that does not comply.

This part of ISO 23936 specifies the required minimum testing that shall be performed in order to document the material suitability and compatibility with those test fluids specified in this part of ISO 23936 and applicable to the intended application. The qualification testing shall apply for the polymer material and the results shall be valid as long as the requirements stated in 6.4 are satisfied. For later supplies of identical material from the same manufacturer, a quality control certificate of each batch of material shall be sufficient. A copy of the original qualification test certificate should be included in the supply.

6.2 Raw material manufacturer

The testing shall be performed on standard test samples produced from specific polymer formulations and made as closely as possible to normal production procedures. The raw material manufacturer shall identify the details of the process used for producing standard test samples.

6.3 Component manufacturer

Component manufacturers shall ensure that materials are qualified to this part of ISO 23936. If a material has already been qualified by the raw material manufacturer and has not substantially been altered or formulated, then the material has been qualified. If the material is altered or formulated into a production compound, that new formulation shall also be qualified. For extruded products such as liners, it should be considered that the longitudinal and circumferential properties could be different. It is recommended that both properties be tested.

6.4 Validity of qualification

The qualification shall apply for each specific polymer material. The qualification shall be repeated if any changes have been made to the formulation of the product or the production route. This applies also for the changes in raw materials or for suppliers of specific raw materials or components.

If production is carried out at different plants/locations, a separate qualification is required for each plant.

7 Qualification of thermoplastic materials

7.1 General

The technical requirements for qualification of thermoplastic materials in oil and gas environments are described in Annex B. The different chemical resistance test regimes shall be decided based on analysis of service requirements for the different equipment components and the material in question. If possible, the standardized test fluids given in Annex B should be used. In the case of fitness-for-purpose testing, such assessment shall address all fluids that could come in contact with the polymer and the nature of these fluids, both on the high pressure and low pressure side.

It will not be necessary to perform qualification testing if well documented in-service experience and quality control documentation are available. Such documentation shall contain detailed information on service conditions such as time, temperature, pressure, fluid composition, chemicals added and flow conditions. An operating company may, for example, provide the documentation of satisfactory service, e.g. stating that no leaks and no failures occurred during service. The service temperature shall be in the same range as for the new application (maximum 10 °C below) and the service experience shall extend to cover at least 50 % of design life.

7.2 Requirements for chemical resistance tests

7.2.1 General

This part of ISO 23936 defines test procedures for the qualification of thermoplastic materials exposed to fluids at elevated pressures and temperatures over an extended period of time.

An initial pre-check test shall be performed if no previous knowledge about the behaviour of a thermoplastic material in a certain fluid exists. The test duration shall be sufficient to reach saturation of the fluid in the material at the test temperature.

The supplier shall, during accelerated testing for obtaining results for extrapolation to service life, limit the test temperature so that it can be ensured that the same chemical and/or physical processes will occur as during service.

When extrapolating data from the present procedures, appropriate statistical techniques shall be applied. For example, if progressive degradation is dependent on a single chemical ageing process, a method based on the Arrhenius equation/method may be used, as described in ASTM D3032.

When analysing the results for evidence of ageing, the Arrhenius principle is not always applicable. When such a linear relationship is not appropriate, alternative curve-fitting techniques will be investigated and the validity of the results justified.

Qualification test media, conditions, equipment, procedures and test report requirements are described in detail in Annex B. In addition to these qualification test media, it can be necessary to perform application-specific testing of materials in contact with other media, e.g. drilling fluids, scale-, hydrate-, wax- or asphalthene inhibitors, well stimulation fluids and corrosion inhibitors. However, fit-for-purpose testing is not covered by this part of ISO 23936.

Nevertheless, in fit-for-purpose testing, the methodology, test conditions and test procedure shall be documented.

The composition of all fluids to which the test specimens were exposed shall be detailed in the test report.

7.2.2 Acceptance criteria

The acceptance criteria shall be established prior to commencing the qualification test. Based on service experience, the criteria given in Table 7 have been established. The baseline data shall be determined according to B.3.2. The equipment manufacturer shall justify any changes to these requirements.

During visual inspection, the materials shall show no tendency towards dissolution, cracking, blistering or physical deformation. For electrical insulation purposes, the insulation resistance shall not drop below 100 GΩ after exposure testing.

Table 7 — General acceptance criteria

Component(s)	**Property change**						
	Length	**Mass**	**Volume**	**Tensile strength (Break)**	**Elongation**	**E-modulus**	**Thermo-stability (DSC test)** (ISO 11357-6)
	Length %	Mass %	Vol. %	MPa %	Length %	MPa %	Δ°C
Piping Liners	0–2	± 5	Not applicable	± 20	± 30	± 20	0–5
Seals Gaskets	Not applicable	Not applicable	$^{+5}_{-1}$	± 50	± 50	± 50	Not applicable
Encapsulation Electrical insulation	± 5	Not applicable	$^{+10}_{-5}$	± 50	± 50	± 50	0–5

Annex A
(informative)

Typical chemical properties of commonly used thermoplastic materials in media encountered in oil and gas production

A.1 Thermoplastic material performance

The following tables give guidance as to the general performance of thermoplastic materials in media encountered in oil and gas production. It is the interested parties' responsibility to determine the applicability of a material in a given environment.

Table A.1 — Polyethylenes (PE)

Medium/Media	Environmental condition(s)	
	Temperature [d] °C	Description
H_2S	0 to 60 [a]	No influence of H_2S on stability of PE in typical temperature range of oil and gas transport (0 °C to 60 °C).
CO_2	0 to 60 [a]	As for H_2S.
HC/crude aliphatics, aliphatic oils	0 to 60 [a, b]	Cross-linked PE exhibit better performance.
HC/crude aromatics, aromatic oils	0 to 20 [c]	Only cross-linked PE may be acceptable in special cases. Problem: swelling and permeation strongly influence the physical properties.
HC/crude naphthenics, HC/crude cycloaliphatics, cycloaliphatic oils	0 to 20 [c]	As for aromatics: dissolution at higher temperatures (e.g. $>$100 °C).
Brine	0 to 60 [a]	As for H_2S.
Acids, bases	0 to 60 [a]	No effect from inorganic non-oxidizing acids or bases. Formic and acetic acid have no effect up to 60 % concentration.
Surface-active compounds (inhibitors, emulsifiers, demulsifiers)	0 to 60 [c]	Stress corrosion cracking has to be considered and tested accordingly. Cross-linked PE types are more stable.
Sulfur solvents:		
amines	0 to 60 [a]	Cross-linked types are more stable.
spindle oil, diesel	0 to 60 [c]	Effects like the corresponding crudes.
disulfides	0 to 60 [c]	—

NOTE Cross-linking of PE generally improves the resistance to degradation by chemical interactions.

[a] Proven applicability.

[b] Limited applicability.

[c] Testing required.

[d] Temperature limitations relate to HDPE.

Table A.2 — Polypropylenes (PP)

Medium/Media	Environmental condition(s)	
	Temperature °C	Description
H_2S	0 to 80 [a]	No influence of H_2S on stability of PP in the temperature range of 0 °C to 110 °C.
CO_2	0 to 80 [a]	As for H_2S.
HC/crude aliphatics, aliphatic oils	0 to 60 [a, b]	—
HC/crude aromatics, aromatic oils	0 to 20 [c]	Swelling and permeation strongly influence the physical properties.
HC/crude naphthenics, HC/crude cycloaliphatics, cycloaliphatic oils	0 to 20 [c]	As for aromatics: dissolution at higher temperatures.
Brine	0 to 80 [a]	—
Acids, bases	0 to 80 [a]	No effect from inorganic non-oxidizing acids or bases. Formic and acetic acid have no effect up to 60 % concentration.
Surface-active compounds (inhibitors, emulsifiers, demulsifiers)	0 to 80 [a, b]	Stress corrosion cracking has to be considered and tested accordingly.
Sulfur solvents:		
amines	0 to 70 [a]	—
spindle oil, diesel	0 to 70 [c]	Effects like the corresponding crudes.
disulfides	0 to 60 [c]	—

[a] Proven applicability.

[b] Limited applicability.

[c] Testing required.

Table A.3 — Polyamide 11 (PA 11) and Polyamide 12 (PA 12)

Medium/Media	Environmental condition(s)	
	Temperature °C	**Description**
H_2S, CO_2	0 to 70 [a]	No influence of H_2S on stability of PA 11 or PA 12 in typical temperature range of oil and gas transport (0 °C to 90 °C). If presence of water cannot be excluded in all cases, PA 11 and PA 12 (which undergo hydrolysis at temperatures above 80 °C) cannot be recommended for higher temperatures.
HC/crude aliphatics, aliphatic oils	0 to 70 [a]	—
HC/crude aromatics, aromatic oils	0 to 70 [c]	—
HC/crude naphthenics, HC/crude cycloaliphatics, cycloaliphatic oils	0 to 70 [c]	—
Brine	0 to 70 [a]	At higher temperatures, hydrolysis occurs.
Acids	[b]	Acid degradation.
Bases	[b]	Degradation by hydrolysis.
Surface-active compounds (inhibitors, emulsifiers, demulsifiers)	0 to 70 [c]	—
Sulfur solvents:		
amines	[b]	Loss of mechanical properties.
spindle oil, diesel	0 to 70 [a]	—
disulfides	0 to 70 [c]	—

[a] Proven applicability.

[b] Not recommended.

[c] Testing required.

Table A.4 — Polyvinylidene fluoride (PVDF)

Medium/Media	Environmental condition(s)	
	Temperature °C	Description
H_2S, CO_2	0 to 90 [a]	No influence of H_2S on stability of PVDF in typical temperature range of oil and gas transport (0 °C to 90 °C).
HC/crude aliphatics, aliphatic oils	0 to 130 [a]	—
HC/crude aromatics, aromatic oils	0 to 130 [a]	—
HC/crude naphthenics, HC/crude cycloaliphatics, cycloaliphatic oils	0 to 130 [a]	—
Brine	0 to 130 [a]	—
Acids	0 to 80 [a]	—
Bases	[b]	—
Surface-active compounds (inhibitors, emulsifiers, demulsifiers)	0 to 60 [c]	Inhibitors like functional amines can degrade PVDF.
Sulfur solvents:		
amines	[b]	Cross-linked types are more stable.
spindle oil, diesel	0 to 130 [a]	Effects like the corresponding crudes.
disulfides	0 to 80 [c]	—

[a] Proven applicability.

[b] Not recommended.

[c] Testing required.

Annex B
(normative)

Test media, conditions, equipment, procedures and test report requirements

SAFETY PRECAUTIONS — The test procedures involve the use of pressurized fluids, which can be flammable and could have toxic effects. These media can be extremely hazardous if not handled correctly. The test operator shall ascertain and implement the appropriate safety precautions before commencing any test work.

B.1 Test requirements

The test vessel shall be resistant to the test environment at test temperature and test pressure, specifically to hydrogen sulfide. Reference is made to ISO 15156-1, ISO 15156-2 and ISO 15156-3.

B.1.1 Test media

Tests fluids shall be representative of the application environment. The fluid exposure of the material from both sides needs to be considered. The production fluids are defined as either sour or sweet, with composition as given in Tables B.1, B.2 and B.3. Testing in sour service conditions will qualify the polymer material for sweet service conditions as well. For wells with high H_2S levels ($>$ 0,6 % of total), separate tests with a higher H_2S level than required by Table B.1 shall be performed.

Table B.1 — Sour service conditions

Liquid phase (volume %)	**Gas phase** (volume %)	**Initial composition**
—	30	5 % CO_2, 10 % H_2S, 85 % CH_4
10	—	Distilled water (conductivity $<$ 5 μS)
60	—	70 % heptane, 20 % cyclohexane, 10 % toluene

Table B.2 — Sweet service conditions

Liquid phase (volume %)	**Gas phase** (volume %)	**Initial composition**
—	30	5 % CO_2, 95 % CH_4
10	—	Distilled water (conductivity $<$ 5 μS)
60	—	70 % heptane, 20 % cyclohexane, 10 % toluene

Table B.3 — Inhibited brine conditions

Liquid phase (volume %)	**Gas phase** (volume %)	**Composition**
—	30	Nitrogen (technical grade)
70	—	Brine (3 % NaCl + 0,5 % water-soluble or water-dispersible amine-based inhibitor, e.g. hexadecyl-trimethylammonium chloride/bromide)

The composition of all fluids to which the test coupon is exposed shall be detailed in the test report.

B.1.2 Test conditions

B.1.2.1 Test temperatures

Tests shall be run at three different temperatures with regard to the material and medium composition (see 4.2.2 to 4.2.5, 4.3 and 4.4). The temperature–time test conditions shall be established according to the criteria described in ISO 2578.

B.1.2.2 Test pressure

A pressure of (100 ± 10) bar[1] of the gas mixture or gas phase shall be applied at room temperature before heating the test media to the chosen temperature. The pressure versus time details of the test shall be fully described in the test report.

B.1.2.3 Exposure period

The exposure period shall be long enough to establish clear trends in the change of materials properties, typically up to three months. This generally implies taking intermediate time samples.

B.1.2.4 Specimens

The sample materials shall be of the same material quality as the finished component, and shall be obtained from the same manufacturer and preferably by the same manufacturing process. Where possible, these shall be in the form of test specimens for tensile properties and E-modulus measurements, in accordance with ISO 527-1.

B.2 Equipment

B.2.1 Test vessel

The test vessel shall be rated for the appropriate test pressures and temperatures, and the metallic materials shall be compatible with the test fluid. The fluid capacity shall be such that the ratio of the fluid volume in cm^3 to the total sample surface area, in cm^2, is greater than 25:1. The vessel shall be capable of being purged with inert gas (e.g. purified nitrogen or argon) to remove air prior to testing. This is specifically important in the case of sour environments. Samples shall be exposed from all sides.

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1) 1 bar = 0,1 MPa = 0,1 N/mm^2 = 10^5 N/m^2.

B.2.2 Exposure

The material shall be exposed in the liquid phase. In the case of two-phase fluid mixtures, provisions for stirring shall be taken. If tests are performed in unstirred liquids, tests may be performed with each liquid phase in two separate experiments maintaining the volume ratio of gas to liquid as described in Tables B.1 and B.2.

B.3 Test procedure

B.3.1 Introduction

The following specifies the test procedure to be used in the qualification of thermoplastic materials for oil and gas applications. The test procedure provides for the determination of the change of various physical properties of the test material.

B.3.1.1 Measurements

All property measurements shall be made at room temperature as soon as possible and not more than 4 h after the end of the exposure period. The measurements described in B.3.2 shall be performed prior to exposure, whilst those in B.3.4 to B.3.6 shall be made after exposure. All measurements/observations shall be recorded in the test report.

B.3.1.2 Reproducibility

In order to test the reproducibility, five specimens of each material should be included in the same test run.

B.3.2 Measurements prior to test

B.3.2.1 Sample dimensions, volume and weight

The cross-section dimensions shall be measured for all samples, with an accuracy of ± 0,05 mm. The volume and weight of all exposure samples shall be determined according to the displacement method in a suitable fluid prior to exposure. A balance with an accuracy of 1 mg shall be used.

B.3.2.2 Tensile properties

The tensile properties including the E-modulus of the test material shall be determined in accordance with ISO 527-1, using five specimens for the baseline tensile test and five specimens for the baseline E-modulus test. The measured individual and mean values shall be reported.

B.3.2.3 Thermal stability

Material properties measurable with the differential scanning calorimetry [glass transition temperature, temperature and enthalpy of melting and crystallization, specific heat capacity, characteristic reactivation-curve temperatures and times, enthalpy of reaction and degree of conversion, oxidation induction time (isothermal OIT) or temperature (dynamic OIT)] shall be determined according to ISO 11357. The measured individual and mean values shall be reported.

B.3.3 Main test protocol

The following list details the main test protocol.

- Clean the test vessel.
- Install the test samples in the vessel. Only one type of material and cross-link system shall be used in the same experiment. Samples should not contact each other.
- Fill the vessel with the test liquid.
- Purge the vessel with an inert gas through the test liquid to remove oxygen. Leave a positive pressure of 0,5 bar.
- Fill the vessel with the specified gas mixture to make a total pressure of 100 bar ± 10 bar (cold pressure).
- Heat the vessel to the specified temperature.
- After stabilizing of the temperature and the pressure, record the final test temperature and pressure; maintain the temperature (± 3 °C) and pressure ($\geqslant$ 100 bar) for the required test duration.
- Cool down the vessel to ambient temperature (recorded as the final date of ageing).
- Depressurize the vessel at a rate of 5 bar or less per minute to atmospheric pressure.
- In the case of sour gas, purge with inert gas to remove H_2S before opening the autoclave.
- Retrieve the samples.
- Carry out the test procedures specified in B.3.4 to B.3.6.

B.3.4 Visual inspection for physical damage

The test specimens shall be visually inspected for external damage. The nature of any physical damage, internal delamination, swelling, blistering etc., and its location, shall be included in the test report. For detection of internal delamination, sectioning of the specimens at three evenly distributed locations is necessary.

A photographic record (10 × magnification) of the specific features shall be included in the test report.

B.3.5 Sample volume and mass

The volume and mass[2] of each sample tested shall be measured in a suitable liquid by the displacement method. A balance with an accuracy of 1 mg shall be used.

The percentage mass change as a result of exposure shall be calculated for each sample from:

$$\%\ \text{mass change} = \frac{\text{mass prior to exposure} - \text{mass after exposure}}{\text{mass prior to exposure}} \times 100$$

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[2] Mass is the ISO-approved term for weight.

The percentage volume change as a result of exposure shall be calculated for each sample from:

$$\% \text{ volume change} = \frac{\text{volume prior to exposure} - \text{volume after exposure}}{\text{volume prior to exposure}} \times 100$$

The mass and volume changes measured for each set of specimens shall be reported in the test report together with the average values used for qualification purposes.

B.3.6 Tensile properties

The tensile properties, including E-modulus, shall be measured for all five specimens within 4 h after retrieval of each specimen. The measured values shall be averaged for each set of specimens and the average reported in the test report.

B.4 Test report

B.4.1 Details of the test material

Material identification: manufacturer designation, polymer type, batch/lot number and production date, sample dimensions.

B.4.2 Test conditions

The following lists the test conditions to be documented in the test report:

a) test medium identification with detailed composition;

b) test temperature (degrees Celsius) and temperature history;

c) test pressure (bar) and pressure history;

d) test duration (hours);

e) date and time for start and end of test.

B.4.3 Pre-test measurement

The following lists the pre-test measurements to be documented in the test report:

a) volume (cubic centimetres) and mass (grams) for all samples;

b) E-Modulus (megapascals);

c) tensile strength (megapascals) and elongation (percent).

B.4.4 Post-test examination

The following lists the post-test examinations to be reported in the test report:

a) visual examination of the test specimen after test, e.g. dissolution, cracking or physical deformation;

b) volume and weight change (percent) for each sample, and mean value for the set of specimens;

c) E-Modulus (megapascals) for each sample and mean value for the set of specimens.

d) Tensile strength (megapascals) and elongation (percent) for each sample, and mean value for the set of specimens.

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