

THERMOPLASTIC LINED PIPELINES

DEP 31.40.30.34-Gen.

December 1999

(DEP Circulars 05/02 and 39/08 have been incorporated)

DESIGN AND ENGINEERING PRACTICE



This document is confidential. Neither the whole nor any part of this document may be disclosed to any third party without the prior written consent of Shell International Oil Products B.V. and Shell International Exploration and Production B.V., The Hague, The Netherlands. The copyright of this document is vested in these companies. All rights reserved. Neither the whole nor any part of this document may be reproduced, stored in any retrieval system or transmitted in any form or by any means (electronic, mechanical, reprographic, recording or otherwise) without the prior written consent of the copyright owners.

PREFACE

DEPs (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell Global Solutions International B.V. (Shell GSI)
and
Shell International Exploration and Production B.V. (SIEP)
and
Shell International Chemicals B.V. (SIC)
and
other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, international, regional, national and industry standards.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by Shell GSI, SIEP or SIC, in most cases under Service Agreements primarily with companies of the Royal Dutch/Shell Group and other companies receiving technical advice and services from Shell GSI, SIEP, SIC or another Group Service Company. Consequently, three categories of users of DEPs can be distinguished:

- 1) Operating companies having a Service Agreement with Shell GSI, SIEP, SIC or other Service Company. The use of DEPs by these operating companies is subject in all respects to the terms and conditions of the relevant Service Agreement.
- 2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements (whether as part of a Service Agreement or otherwise).
- 3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, Shell GSI, SIEP and SIC disclaim any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any DEP, combination of DEPs or any part thereof, even if it is wholly or partly caused by negligence on the part of Shell GSI, SIEP or other Service Company. The benefit of this disclaimer shall inure in all respects to Shell GSI, SIEP, SIC and/or any company affiliated to these companies that may issue DEPs or require the use of DEPs.

Without prejudice to any specific terms in respect of confidentiality under relevant contractual arrangements, DEPs shall not, without the prior written consent of Shell GSI and SIEP, be disclosed by users to any company or person whomsoever and the DEPs shall be used exclusively for the purpose for which they have been provided to the user. They shall be returned after use, including any copies which shall only be made by users with the express prior written consent of Shell GSI, SIEP or SIC. The copyright of DEPs vests in Shell GSI and SIEP. Users shall arrange for DEPs to be held in safe custody and Shell GSI, SIEP or SIC may at any time require information satisfactory to them in order to ascertain how users implement this requirement.

All administrative queries should be directed to the DEP Administrator in Shell GSI.

TABLE OF CONTENTS

1.	INTRODUCTION	5
1.1	SCOPE	5
1.2	DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS	5
1.3	DEFINITIONS	5
1.4	ABBREVIATIONS	8
1.5	CROSS-REFERENCES	8
2.	MATERIALS	9
2.1	GENERAL	9
2.2	THERMOPLASTIC LINER MATERIALS	10
2.3	MATERIAL SELECTION GUIDE	17
2.4	MATERIAL TESTING	18
2.5	END CONNECTORS	22
3.	DESIGN	23
3.1	INTRODUCTION	23
3.2	MINIMUM LINER THICKNESS	24
3.3	LINER DESIGN PROCEDURE	25
3.4	VENT POINT DESIGN	31
3.5	PULL-IN LOADS AND INSERTION LENGTH	33
3.6	DESIGN OF END CONNECTORS	35
4.	MANUFACTURE OF THE THERMOPLASTIC LINER	37
4.1	PROCESS OF MANUFACTURE	37
4.2	FINISH AND WORKMANSHIP	37
4.3	DIMENSIONS, WEIGHTS AND TOLERANCES	38
4.4	QUALITY PROGRAMME	38
4.5	EQUIPMENT MARKING	41
4.6	HANDLING AND STORAGE	42
5.	LINER INSTALLATION	43
5.1	GENERAL - INSTALLATION TECHNIQUES	43
5.2	PREPARATION PHASE	45
5.3	LINER FABRICATION PHASE	47
5.4	LINER INSTALLATION	49
5.5	END FLANGES AND IN-LINE FLANGED JOINTS	52
5.6	TESTING	53
6.	OPERATION	54
6.1	START-UP	54
6.2	DE-PRESSURISING	54
6.3	PIGGING	54
6.4	FLOW VELOCITY	54
6.5	VENTING	54
6.6	MAINTENANCE	55
6.7	REPAIR	55
6.8	OPERATIONAL PROCEDURE FOR A LINED PIPELINE	55
7.	DOCUMENTATION	56
7.1	INFORMATION TO BE SUBMITTED BY THE PRINCIPAL	56
7.2	INFORMATION TO BE SUBMITTED BY THE CONTRACTOR	56
8.	REFERENCES	57

APPENDICES

APPENDIX 1	CURRENT RANGE OF SERVICE EXPERIENCE	60
APPENDIX 2	EXAMPLE OF OPERATIONAL PROCEDURE	62
APPENDIX 3	LINER DESIGN DATA SHEET	64

APPENDIX 4 MATERIAL PROPERTIES.....66

APPENDIX 5 PURCHASE ORDER INFORMATION 67

1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the selection, design, manufacture, installation and operation of thermoplastic liners in carbon steel pipelines and flowlines. It covers both the retro-fitting of thermoplastic liners inside existing carbon steel pipelines and flowlines as well as new pipelines and flowlines.

In the context of this DEP, a liner consists of a number of thermoplastic pipe lengths which are fused together into sections of up to approximately 1 km. After pressure testing, the section of liner is inserted into a pre-welded carbon steel pipeline or flowline section. The carbon steel pipe provides the pressure containment and the liner the internal corrosion protection. At the ends of the section the liner is terminated in a thermoplastic flange or other (usually mechanical) connection system, to enable sections to be joined together.

Onshore, offshore, buried and above-ground applications are considered. Within certain limitations, thermoplastic lined pipelines and flowlines may be used in oil, gas or water service. Although the scope is directed towards thermoplastic liners for carbon steel pipelines and flowlines, much of the content is also relevant for liners inserted in flexible flowlines and risers.

The liners covered in this DEP are based both on currently applied thermoplastic materials and on those materials that have the potential to be applied in future, more demanding applications.

This DEP only gives requirements for the thermoplastic liner. It is assumed that the carbon steel pipeline or flowline into which the liner is to be inserted has been designed and constructed in accordance with DEP 31.40.00.10-Gen.

Amended per
Circular 05/02

Factory-applied liners inside steel pipe and fittings are covered by DEP 31.38.01.11-Gen. Hose lining techniques, using polyester materials with fibre tubes and epoxy to bond these to the pipe wall, are not covered by this DEP. Pipelines lined with thermoset materials such as GRE (Glass fibre Reinforced Epoxy) are not covered by this DEP either.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch /Shell group or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F" as described in DEP 00.00.05.05-Gen.).

This DEP is intended for use in the design, procurement, manufacturing, transport and installation of thermoplastic liners for pipelines for oil and gas production, oil refineries, chemical plants, gas plants and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or

maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Acceptance criteria	Defined limits placed on characteristics of materials, products or services.
Annulus	Space between thermoplastic liner and the carbon steel outer pipe.
Bell hole	Excavated area allowing access to a buried carbon steel pipeline e.g. for insertion of a section of thermoplastic liner.
Butt fusion welding	A process of fusing thermoplastic materials that entails squaring and aligning the pipe materials, heating the pipe ends, bringing the two aligned pipe ends together under pressure and a predetermined cooling time resulting in a fused joint having a hydrostatic strength equal to the parent pipe.
Crude oil service	Fluids in which the volume fraction of crude oil is at least 1%
End connector	A device used to provide a leak-tight structural connection between two sections of lined pipe. The lining is terminated inside the end connector.
Flanges	Face flanges with a bolt circle according to ASME B 16.5 or ASME B16.47, including thermoplastic flanges with metallic backup rings.
Grout porosity	Voids in grout, which allow the transport of gas through the grout to venting ports.
Hot plate welding	Technique whereby thermoplastic pipe is fused by smelting and re-solidification.
In-line compression joint	System of terminating lined pipelines by compression of the liner between an internal ring and a CRA material.
Inspectors	Individuals designated by the Principal to act on behalf of the Principal for monitoring Contractor's quality control testing and technical acceptance.
Lot number	Assignment of a unique code to each lot of pipes to maintain traceability. A 'lot' is defined as being all pipes produced from the same base polymer batch with the same diameter and wall thickness, up to a maximum number of 50 pipes.
Modulus	Elastic modulus: proportionality constant between applied stress and strain.
Ovality	This is a measurement of the deflected set in a cross-section of pipe and is expressed as a percentage. It is

measured by taking the maximum measured diameter minus the minimum measured diameter (the out-of-roundness value) and dividing that sum by the average measured diameter and multiplying that result by 100.

PA liner	Liner based on Polyamide in combination with fillers and plasticisers.
PE liner	Liner based on Polyethylene in combination with fillers and plasticisers.
PK liner	Liner based on Polyketone in combination with fillers and plasticisers.
Point of fusion	The end of a liner which is available for trimming, heating and pressing together during the heat fusion process.
PP liner	Liner based on Polypropylene in combination with fillers and plasticisers.
PPS liner	Liner based on Polyphenylene Sulphide in combination with fillers and plasticisers.
PTFE liner	Liner based on Polytetrafluoroethylene in combination with fillers and plasticisers.
PVC liner	Liner based on Polyvinylchloride in combination with fillers and plasticisers.
PVDF liner	Liner based on Polyvinylidene fluoride in combination with fillers and plasticisers.
Permeation	Gradual diffusion of liquid and gas through a thermoplastic layer under the influence of pressure.
Records	Retrievable information.
Standard Dimension Ratio (SDR)	A specific ratio of the average specified outside diameter to the minimum specified wall thickness (OD/t) for outside diameter-controlled plastic pipe.
Thermoplastic materials	Plastic materials which retain their mechanical properties after heating and cooling.
Vent connection or point	Hole in the carbon steel outer pipe to allow the release of gas accumulated in the annulus between the liner and the carbon steel pipe.
Venting	The release of gas accumulated in the annulus between the thermoplastic liner and the carbon steel pipeline.
Water service	Fluids in which the volume fraction of crude oil is less than 1%

1.4 ABBREVIATIONS

CRA	Corrosion Resistant Alloy
ESC	Environmental Stress Cracking
ID	Nominal internal diameter
HDPE	High Density Polyethylene
MDPE	Medium Density Polyethylene
OD	Nominal outside diameter
PA	Polyamide
PE	Polyethylene
PK	Polyketone
PP	Polypropylene
PPS	Polyphenylene Sulphide
PTFE	Polytetrafluoroethylene
PVC	Polyvinylchloride
PVDF	Polyvinylidene fluoride
SDR	Standard Dimension Ratio
UV	Ultra violet light
XLPE or PEX	Cross-linked Polyethylene consisting of long polymer chains in a 3-dimensional structure.

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (8).

2. MATERIALS

2.1 GENERAL

The Contractor shall be responsible for the selection and supply of all materials required to meet the specified installation and service conditions (7). The Contractor shall have either measured test data (preferred) or documented methods for predicting the thermoplastic liner material properties for the specified service conditions. For the predictive methods, the Contractor shall have available, for review by the Principal, records of tests and evaluations, which demonstrate that the predictive method yields conservative results. If the conveyed fluid contains gas, it shall be demonstrated by testing or documented evidence of standard testing that the thermoplastic will not blister or degrade during service, i.e. start-up, continuous operation or shut-down (rapid de-pressurisation).

The Contractor shall also be responsible for documenting the mechanical, thermal, fluid compatibility and permeability properties of the thermoplastic liner material (2.4).

2.2 THERMOPLASTIC LINER MATERIALS

A liner is made from a mix of a thermoplastic polymer material, colouring agent, anti-oxidant and plasticiser. Currently there are several thermoplastic polymer materials that are used for liners in pipelines or for similar applications in flexible flowlines and risers: Polyethylene (PE), Polyamide (PA), and Polyvinylidene fluoride (PVDF). Other polymers such as Polypropylene (PP), Polyvinylchloride (PVC), Polytetrafluoroethylene (PTFE), Polyphenylene Sulphide (PPS) and Polyketone (PK) have the potential to be used but are not in use at present.

These thermoplastic polymer materials are produced in numerous grades and qualities. The differences in material properties between grades of the same polymer may be as great as the difference between different polymers.

The following presents a limited introduction to the generic thermoplastic material types and commonly applied grades. In particular, for each polymer, it specifies the:

- Application envelope (in terms of maximum operating temperature as a function of fluid composition);
- "Typical" material properties at ambient conditions;
- Appropriate testing standards.

The "typical" material properties (un-aged) are listed for guidance only, based on an assumed lifetime of twenty years. They should be considered as minimum values at ambient un-aged conditions. Specific material data relating to actual service conditions (temperature, life-time) and fluid composition shall always be used in design and installation requirement analyses.

The minimum design temperature for all thermoplastic materials covered in this DEP is minus 20 °C. Lower temperatures may be tolerated but only provided that specific low temperature material data are available and the operating temperature does not fall below the brittleness temperature of the thermoplastic material.

For a more complete specification of polymer properties, refer to DEP 30.10.02.13-Gen.

2.2.1 Polyethylene (PE)

PE is the most commonly applied liner material. PE liners shall not be exposed to operating temperatures above 60 °C in water service. In hydrocarbon service (combined liquid and gas phases), the recommended maximum operating temperature is lower and depends on the fluid composition but shall not exceed 50 °C. If only a liquid phase or a dry gas phase is present, then a higher temperature (>50°C) can be tolerated, but the maximum operating temperature shall be specified and agreed by the Principal. This reduction in operating temperature results from small organic compounds diffusing into the PE, causing swelling and softening. (Table 2.2.1a) lists the recommended maximum operating temperature as a function of fluid composition.

Table 2.2.1a Maximum operating temperature for PE as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	50
Oil/water mixture	50
Gas and condensate	50
Dry gas	60
Water	60

Numerous PE grades are available. The differences between them primarily result from the polymerisation processes for the production of the base polymer, chemical modifications or enhancements with additives. Base polymer density is used to indicate PE type. Low, medium and high-density grades are distinguished as LDPE, MDPE and HDPE. This

characterisation applies to most vendor data. For lining applications, three types of PE are used; in increasing order of strength and chemical resistance, they are:

- MDPE, used in low-pressure water and gas distribution applications;
- HDPE, used in all types of service;
- Ultra High Molecular Weight (UHMW-HDPE) used in demanding applications.

MDPE (or PE 80) is a relatively soft grade and is used in (low) pressure applications at ambient conditions. It has good 50-year creep-rupture performance and is easy to manufacture (extrude) and install.

HDPE (or PE 100) is the basic engineering grade of PE. Compared to MDPE, it has a higher yield and ultimate strength, a higher modulus and better chemical resistance. These improved properties come with the penalty of slightly more difficult extrusion and installation. However, HDPE is more sensitive to notches and has a lower environmental stress cracking (ESC) resistance than MDPE.

UHMW-HDPE is developed for aggressive chemical environments and high toughness. Compared to HDPE it has a higher yield and ultimate strength, a higher modulus and better chemical resistance. This results in reduced swelling in crude oil and an increased capability of bridging pinhole leaks in the carbon steel outer pipe. However, these improved properties come with a penalty of considerably more difficult extrusion and installation.

The above description is for general information only. There is a general trend away from merely specifying PE grades, and it is recommended to specify the material properties of PE listed in (Table 2.2.1b) instead.

A summary of typical material properties of PE in ambient conditions is presented in (Table 2.2.1b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications at the specific service conditions.

Table 2.2.1b "Typical" material properties of PE

Typical properties	PE (MD)			PE (HD)			PE (UHMW)		
Density (g/cm ³)	0.926-0.94			0.941-0.965			0.989		
Tensile properties at 23 °C									
Yield strength (MPa)	18			25			32		
Stress at break (MPa)	20			20			25		
Elongation at break (%)	>400			>400			>400		
Modulus (MPa)	400			700			1100		
Thermal conductivity (W/m.K)	0.35			0.4			0.4		
Coefficient of thermal expansion (K ⁻¹)	200 x 10 ⁻⁶			200 x 10 ⁻⁶			200 x 10 ⁻⁶		
Mechanical properties (function of temperature)	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C
Modulus (MPa)	400	250	130	700	450	250	1100	600	400
Poisson ratio	0.35	0.38	0.4	0.35	0.38	0.4	0.35	0.38	0.4

All PE pipe and fittings supplied to this DEP shall be stabilised against degradation by UV-light in accordance with standard practices by a minimum of 2% (by mass) of Carbon Black (ASTM D 3350).

A UV stabiliser as specified by ASTM D 3350, code C or D shall be added.

2.2.2 Polyamide (PA)

PA is a commodity engineering plastic that is more expensive than PE. Therefore, it should only be considered for application outside the range of PE. PA has excellent resistance to hydrocarbons but limited resistance to water at elevated temperatures. (Table 2.2.2a) lists the recommended maximum operating temperature as a function of fluid composition.

Because of the molecular structure of PA, different grades e.g. PA-6 and PA-11, can essentially be considered as different materials. PA-11 is used as a liner in conventional flexible flowlines and risers transporting gas and crude with low water cuts. It has good material properties for liner applications, high modulus and strength, with relatively high strain to failure in its un-aged condition. It has been used to line carbon steel pipelines at temperatures up to 75 °C.

Table 2.2.2a Maximum operating temperature for PA-11 as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	65
Oil/water mixture	75
Gas and condensate	80
Dry gas	80
Water	75

A summary of typical material properties of PA is presented in (Table 2.2.2b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications at the specified service conditions.

Table 2.2.2b "Typical" material properties of PA-11

Typical properties	PA-11			
Density (g/cm ³)	1.04			
Tensile properties at 23 °C				
Yield strength (MPa)	40-60			
Stress at break (MPa)	80			
Elongation at break (%)	>30			
Modulus (MPa)	650-1400			
Thermal conductivity (W/m.K)	0.25			
Coefficient of thermal expansion (K ⁻¹)	100 x 10 ⁻⁶			
Mechanical properties (function of temperature)	23 °C	40 °C	60 °C	80 °C
Modulus (MPa)	650	500	400	300
Poisson ratio	0.35	0.36	0.37	0.38

PA liners shall comply with the requirements of ASTM D 4066 and ASTM F 1733.

2.2.3 Polyvinylidene fluoride (PVDF)

PVDF is a fluoropolymer that is more expensive than both PE and PA. Therefore it should only be considered for applications outside the range of PE and PA, i.e. for hydrocarbon applications above 80 °C and water applications above 60 °C. PVDF has excellent chemical resistance. Superior thermal stability implies that the application envelope in terms of temperature for PVDF extends well beyond that of PA, up to 120 °C for all applications. (Table 2.2.3a) lists the recommended maximum operating temperature as a function of fluid composition.

Table 2.2.3a Maximum operating temperature for PVDF as a function of fluid composition

Fluid composition	Temperature (°C)
Oil/gas/water mixture	120
Oil/water mixture	120
Gas and condensate	120
Dry gas	120
Water	120

PVDF has good mechanical properties. The modulus and yield strength are high but the yield strain is low. The pure polymer is difficult to extrude and to overcome this, plasticised grades (both homopolymer and co-polymer) are used, for example as pressure sheaths in flexible flowlines and risers. Only co-polymer grades of PVDF should be used to minimise problems associated with leaching out of the plasticiser.

A summary of typical material properties of PVDF is presented in (Table 2.2.3b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications at the specified service conditions.

Table 2.2.3b "Typical" material properties of PVDF

Typical properties	PVDF (homopolymer)					PVDF (co-polymer)				
Density (g/cm ³)	1.78					1.78				
Tensile properties at 23 °C										
Yield strength (MPa)	55					25				
Stress at break (MPa)	40					35				
Elongation at break (%)	>20					>50				
Modulus (MPa)	2200					1000				
Thermal conductivity (W/m.K)	0.19					0.18				
Coefficient of thermal expansion (K ⁻¹)	130 x 10 ⁻⁶					140 to 180 x 10 ⁻⁶				
Mechanical properties (function of temperature)	23 °C	40 °C	75 °C	90 °C	120°C	23 °C	40 °C	75 °C	90 °C	120°C
Modulus (MPa)	2200	1750	1000	750	400	1000	650	250	150	110
Poisson ratio	0.35	0.35	0.40	0.45	0.5	0.35	0.35	0.40	0.45	0.5

PVDF liners shall comply with the requirements of ASTM D 3222 and ASTM F 491.

2.2.4 Polypropylene (PP)

PP is a commodity engineering plastic. It is not currently used as a thermoplastic liner material but has the potential for such use in the future. Although chemically similar to PE, PP has important mechanical property differences. It can tolerate a higher operating temperature than PE, and it is not susceptible to ESC. PP has excellent resistance to water and liquid hydrocarbons, but limited resistance to aromatics. (Table 2.2.4a) lists the maximum recommended operating temperature as a function of fluid composition.

Table 2.2.4a Maximum operating temperature for PP as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	70
Oil/water mixture	70
Gas and condensate	70
Dry gas	85
Water	85

In general, the mechanical properties of PP, i.e. high modulus and high yield strength with sufficient strain to failure, are sufficient for liner installations. A summary of typical material

properties of PP is presented in (Table 2.2.4b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications at the specified service conditions.

Table 2.2.4b "Typical" material properties of PP

Typical properties	PP
Density (g/cm ³)	0.9
Tensile properties at 23 °C	
Yield strength (MPa)	35
Stress at break (Mpa)	40
Elongation at break (%)	>100
Modulus (MPa)	1200
Thermal conductivity (W/m.K)	0.22
Coefficient of thermal expansion (K ⁻¹)	180 x 10 ⁻⁶

PP liners shall comply with the requirements of the ASTM D 2657, ASTM D 4101 and ASTM F 492.

2.2.5 Polyphenylene Sulphide (PPS)

PPS is an engineering plastic with a price similar to that of PVDF. It is not currently used as a thermoplastic liner but has the potential for such use in the future. It has excellent high temperature properties and should only be considered for applications in the temperature range of PDVF and beyond. It has good chemical resistance to water, dry gas and most hydrocarbons, except aromatics. (Table 2.2.5a) lists the recommended maximum operating temperature as a function of fluid composition.

Table 2.2.5a Maximum operating temperature for PPS as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	150
Oil/water mixture	150
Gas and condensate	150
Dry gas	180
Water	180

There are many different grades of PPS available but because of its molecular structure PPS shall be plasticised to enable extrusion and to provide the flexibility required to enable insertion as a liner.

PPS has good mechanical properties, high modulus and strength but a limited strain to failure. A summary of typical material properties of PPS is presented in (Table 2.2.5b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications for the liner material at the specified service conditions.

Table 2.2.5b "Typical" material properties of PPS

Typical properties	PPS
Density (g/cm ³)	1.64
Tensile properties at 23 °C	
Yield strength (MPa)	90
Stress at break (MPa)	140
Elongation at break (%)	5
Modulus (MPa)	3800
Thermal conductivity (W/m.K)	0.2
Coefficient of thermal expansion (K ⁻¹)	90 x 10 ⁻⁶

Specifications for PPS liners shall be agreed between the Contractor and the Principal.

2.2.6 Cross-linked Polyethylene (PEX)

PEX is an engineering plastic manufactured by cross-linking PE. It is more expensive than PE. PEX has excellent resistance to hydrocarbons and water at elevated temperatures up to 85 °C. (Table 2.2.6a) lists the recommended maximum operating temperature as a function of fluid composition.

Table 2.2.6a Maximum operating temperature for PEX as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	85
Oil/water mixture	85
Gas and condensate	85
Dry gas	85
Water	85

The cross-linking of PE implies that PEX is stiffer than PE with a corresponding reduction in flexibility. For liner applications the material properties, modulus and yield strength are good, with a strain-to-failure strength sufficient for insertion.

A summary of typical material properties of PEX is presented in (Table 2.2.6b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications for the liner material at the specified service conditions.

Table 2.2.6b "Typical" material properties of PEX

Typical properties	PEX
Density (g/cm ³)	0.95
Tensile properties at 23 °C	
Yield strength (MPa)	25
Stress at break (MPa)	30
Elongation at break (%)	>50
Modulus (MPa)	800
Thermal conductivity (W/m.K)	0.35
Coefficient of thermal expansion (K ⁻¹)	120 x 10 ⁻⁶

Specifications for PEX liners shall be agreed between the Contractor and the Principal.

2.2.7 Polyketone (PK)

Polyketone (PK) is a relatively new thermoplastic polymer. It has good chemical resistance to both water and hydrocarbons. However, it is susceptible to oxidation and stabilisers shall

be used to limit degradation. (Table 2.2.7a) presents the recommended maximum operating temperature as a function of fluid composition.

Table 2.2.7a Maximum operating temperature for PK as a function of fluid composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture	105
Oil/water mixture	105
Gas and condensate	105
Dry gas	105
Water	105

A summary of typical material properties of PK is presented in (Table 2.2.7b). This Table is for comparison purposes only. Manufacturers shall submit the relevant (minimum) material property specifications at the specified service conditions.

Table 2.2.7b "Typical" material properties of PK

Typical properties	PK
Density (g/cm ³)	1.24
Tensile properties at 23 °C	
Yield strength (MPa)	55
Stress at break (MPa)	63
Elongation at break (%)	350
Modulus (MPa)	1600
Thermal conductivity (W/m.K)	0.25
Coefficient of thermal expansion (K ⁻¹)	110 x 10 ⁻⁶

Specifications for PK liners shall be agreed between the Contractor and the Principal.

2.2.8 Other materials

Other thermoplastic materials, e.g. PVC, PTFE or co-extruded liners, i.e. multiple layered liners made from more than one thermoplastic material, can be considered for liner applications. If such materials are proposed, the material data supplied by the Contractor shall at least comprise the data listed in (Tables 2.2.1a and 2.2.1b) and also satisfy the requirements of (2.4).

2.3 MATERIAL SELECTION GUIDE

Material selection is a procedure of matching system requirements to the property data of available materials. The loading conditions should be systemically identified and could comprise combinations of temperature, pressure, axial load and environment as a function of time. They are matched to materials property acceptance criteria in the design analysis.

The following strategy facilitates thermoplastic polymer material selection by identifying acceptance criteria in a structured manner:

1. Define pipeline function and requirements.
2. Identify fixed boundary conditions.
3. Design system and/or analyse design.
4. Define function of the individual components.
5. Identify service conditions of individual components.
6. Identify material requirements to maintain function throughout service life.
7. Identify acceptance criteria.

(Table 2.3) gives an example of the applied loads acting on a thermoplastic liner from transport from the manufacturing plant through to operation.

Table 2.3 Applied loads acting on the liner system

	Mechanical loading	Thermal loading	Environment	Duration
Transport	Handling	Ambient, - 40 °C /+ 50 °C	Ambient	Weeks
Storage	Stack weight	Ambient	Ambient	Weeks, months
Construction	Pull-in, reduction	Ambient + friction	Lubricant	Minutes, hours
Operation	Hydrostatic pressure	Fluid, operating temp.	Fluid, slugs	Years
Mis-operation	Vacuum	Rapid cool-down	Air	Days
Removal	Pull-out	Ambient	Residue	Hours, days

The material selection process involves matching the material properties of the candidate thermoplastic liner materials to the loads and boundary conditions listed in (Table 2.3) to provide the most appropriate material option.

2.4 MATERIAL TESTING

A full material qualification programme is required to the satisfaction of the Principal, before the Contractor can start production of the liner. Thermoplastic pipe material shall be qualified according to API Spec 15 LE. Thermoplastic pipe material qualified to ISO 4427 may also be supplied provided that the following requirements are met: equivalent strength grade to API Spec 15 LE and elevated temperature characteristics to ISO 4427, Section 4.4, Type A. Changes in the method of manufacture will require additional qualification tests.

NOTE: API Spec 15 LE and ISO 4427 are specific to PE. However, the general principles of material testing outlined in both API Spec 15 LE and ISO 4427 are also applicable to other thermoplastics. Specific temperatures for elevated temperature tests shall be proposed by the Contractor and agreed with the Principal.

The following list of tests (mechanical, thermal, permeation, compatibility and ageing tests) represents a complete material qualification programme (Table 2.4). For most applications only a restricted qualification programme will be required. Additional tests, specific to the unique operating conditions, shall be agreed between the Contractor and the Principal.

Other standard test procedures may replace those listed in (Table 2.4) on agreement between the Contractor and the Principal. (Table 2.4) also indicates for which applications the tests are required along with the purpose of the tests.

A chemical analysis of the compounds comprising the thermoplastic pipe material shall be available for review by the Principal.

Table 2.4 Standard test procedures required in the materials qualification procedure

Characteristic	Applications	Tests	Test procedure	Purpose	Comments
Mechanical/ physical properties	All applications	Creep modulus Yield strength/elongation Ultimate strength/elongation Stress relaxation properties Modulus of elasticity Hardness Impact strength Abrasion resistance Density Notch sensitivity	ASTM D2990 ASTM D 638 ASTM D 638 ASTM E 328 ASTM D 790 ASTM D 2240 ASTM D 256 ASTM D 4060 ASTM D 792 ASTM D 256	Collapse calculation Installation requirement Installation requirement Installation requirement Collapse calculation QA/QC QA/QC Flow conditions QA/QC Defect assessment and QA/QC	 or ISO 527 R or ISO 868 or ISO 180 or ASTM D 1044 or ASTM D 1505
Thermal properties	All applications	Coefficient of thermal expansion Melt flow index Heat distortion temperatures Brittleness temperature	ASTM E 831 ASTM D 1238 ASTM D 648 ASTM D 746	Installation requirement and collapse assessment QA/QC QA/QC – upper temperature limit QA/QC – lower temperature limit	 ISO 1133 Method A Or glass transition temperature (ASTM E 1356)
Permeation/ Characteristics	Only if gas phase present	Fluid permeability Blistering resistance	See (2.4.1) See (2.4.2)	Collapse calculation – venting rates No blistering for gas phase components	For gas phase components at design conditions At design conditions
Compatibility and ageing	Only if gas phase present	Ageing test	See (2.4.3)	Degradation in modulus – collapse calculation	
	All applications	Swelling test Environmental stress cracking Weathering resistance	See (2.4.4) ASTM D 1693 ISO 4427	Collapse calculation QA/QC – durability QA/QC – only if liner exposed	Method C. For PE only Effectiveness of UV stabiliser

2.4.1 Fluid permeability test

The following conditions shall apply as a minimum for the fluid permeability test:

- a) Test sample shall be taken from the extruded polymer.
- b) Minimum sample thickness is 1 mm.
- c) Minimum sample diameter is 50 mm.
- d) A sufficient number of tests shall be performed to allow for linear interpolation of the results as a function of temperature.

The procedure for the fluid permeability test may be to pressurise one side of the specimen and measure fluid flow at the other side when steady state flow conditions are reached. Alternatively, the test can be performed with the same absolute pressure on both sides using the partial pressure of the component gas as the driving force.

The purpose of the permeability test is to provide an estimate of the gas permeation rate into the annulus and is for information only. Therefore this test is only necessary if a gas phase is present.

2.4.2 Blistering resistance test

Blistering resistance tests shall reflect the design requirements along with fluid conditions, pressure, temperature, and number of decompressions and decompression rate. As a minimum, the following conditions shall apply:

- a) Only gas components of the specified environment shall be used.
- b) Conditioning time shall be sufficient to ensure full saturation.
- c) Number of decompressions should be a minimum of 20 cycles or the number expected in practice.
- d) The decompression rate should be the expected rate, otherwise a minimum 70 bar per minute should be used (from design pressure to zero).
- e) Sample thickness shall be the same as the wall thickness of the liner.
- f) The expected decompression temperature shall be used.
- g) The design pressure shall be used as a minimum.

The test procedure is that after each depressurisation the sample shall be examined at a magnification of 20 times for signs of blistering, swelling and slitting. The acceptance criterion is that no blister formation or slitting is observed.

2.4.3 Ageing test

The Contractor shall have either documented test data of the samples aged in the service environment according to ASTM C 581, or ageing prediction models for the thermoplastic polymer. The fluid used in ageing tests shall be representative of the service conditions fluid. Materials that will be subjected to tensile or compressive loads in service shall be tested under equivalent stress conditions.

The ageing model shall be based on testing and experience and shall predict the ageing or deterioration of the polymer under the influence of environmental and load conditions that represent the service conditions. As a minimum, polymer-ageing models shall consider temperature, chemical environment and mechanical load. Special attention should be given to de-plasticisation, fluid adsorption and changes in dimensions. Creep and stress relaxation shall be investigated on aged and un-aged samples.

Ageing may be determined from changes in either specified mechanical properties or in specified physico-chemical characteristics which includes reduction in the plasticiser (if relevant) content of the material.

The purpose of the ageing test to provide the elastic modulus and yield strength and strain for the material aged in the flow conditions.

2.4.4 Swelling test

The following conditions shall apply for the swell test procedure:

- 5 cubic specimens, each approximately 125 mm³, shall be machined from a sample of the actual thermoplastic liner.
- Specimen dimensions shall be recorded to the nearest 0.01 mm.
- Specimen weight shall be recorded to the nearest 0.001 g.

The samples shall be exposed to 500 cm³ of the liquid hydrocarbon mixture of the pipeline fluid for 500 h and at the design temperature in a sealed container.

After exposure, the dimensions and weights shall be recorded to the same accuracy as the pre-expose samples.

Linear swell of the liner, ϵ_{swell} (%), is related to the volumetric swell and shall be calculated as follows;

$$\epsilon_{\text{swell}} = \frac{\Delta V_{\text{swell}}}{2} * 100$$

where the volumetric swell of the sample, ΔV_{swell} , is defined as:

$$\Delta V_{\text{swell}} = \frac{V_{\text{exposed}} - V_{\text{pre-exposed}}}{V_{\text{pre-exposed}}}$$