Materials System Specification

01-SAMSS-050 15 December 2012

Thermoplastic Tight Fit Grooved or
Perforated Liners for New and Existing Pipelines

Document Responsibility: Non-metallic Standards Committee

Saudi Aramco DeskTop Standards

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1 Scope

This document refers to the minimum technical requirements for thermoplastic material specification and manufacture of vented grooved or perforated tight fitting, non-bonded, liners in carbon steel pipelines. In addition to water injection, other aggressive fluids such as sour gas, three phase system, and sour crude oil shall also be included. The use of these liners is for rehabilitating existing carbon steel pipelines and flowlines as well as new pipelines and flowlines. Lining with thermoplastic liner is applicable to aboveground, buried and sub-sea pipelines.

This specification covers grooved, perforated and smooth liners. Grooved liner provides a path for any gases that may permeate the liner to be vented to avoid liner collapse due to process depressurization. In the case of perforated liners, metallic or plastic frit devices are installed through the perforated locations to provide a venting means that allows gas to flow from the micro-annulus into the center of the pipeline assembly but not in the opposing direction.

2 Conflicts and Deviations

2.1 Any conflicts between this specification and other applicable Saudi Aramco Materials System Specifications (SAMSSs), Engineering Standards (SAESs), Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this specification in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

The following references in force on the date of the Purchase Order form a supplementary part of this specification, as applicable:

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedure

SAEP-302 — *Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirements*

3.2 Industry Codes and Standards

American Petroleum Institute

API Spec 17J	*Specification for Unbounded Flexible Pipe*
API 15 LE	*Specification for Polyethylene Line Pipe (PE)*
API RP 5L1	*Recommended Practice for Railroad Transportation of Line Pipe*
API RP 5LW	*Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels*

American Society for Testing and Materials

ASTM A106	*Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*
ASTM A193	*Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
ASTM A194	*Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both*
ASTM D256	*Standard Test Methods for Determining the IZOD Pendulum Impact Resistance of Plastics*
ASTM D618	*Standard Practice for Conditioning Plastics for Testing*
ASTM D638	*Standard Test Method for Tensile Properties of Plastics*
ASTM D648	*Standard Test Method for Deflection Temperature of Plastics under Flexural Load*
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*
ASTM D1044	*Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion*
ASTM D1238	*Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer*

ASTM D1505	*Standard Test Method for Density of Plastics by the Density - Gradient Technique*
ASTM D1599	*Standard Test Method for Short-Time, Hydraulic Failure Pressure of Plastic Pipe, Tubing and Fittings*
ASTM D1603	*Standard Test Method for Carbon Black in Olefin Plastics*
ASTM D1693	*Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics*
ASTM D2122	*Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings*
ASTM D2240	*Standard Test Method for Rubber Property – Durometer Hardness*
ASTM D2513	*Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing and Fittings*
ASTM D2657	*Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings*
ASTM D2990	*Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep - Rupture of Plastics*
ASTM D3222	*Standard Specification for Unmodified Poly Vinylidene Fluoride (PVDF) Molding Extrusion and Coating Materials*
ASTM D3350	*Standard Specification for Polyethylene Plastic Pipe and Fitting Materials*
ASTM D3895	*Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry*
ASTM D4060	*Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*
ASTM D4066	*Standard Classification System for Nylon Injection and Extrusion Materials (PA)*
ASTM D4101	*Standard Specification for Propylene Plastic Injection and Extrusion Materials*
ASTM E328	*Standard Test Methods for Stress Relaxation Tests for Materials and Structures*

ASTM E831	*Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*
ASTM E1356	*Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry or Differential Thermal Analysis*
ASTM F491	*Standard Specification for Poly Vinylidene Fluoride (PVDF) Plastic-Lined Ferrous Metal Pipe and Fittings*
ASTM F492	*Standard Specification for Propylene and Polypropylene (PP) Plastic-Lined Ferrous Metal Pipe and Fittings*
ASTM F714	*Polyethylene Plastic Pipe Based on Outside Diameter*
ASTM F1733	*Standard Specification for Butt Heat Fusion Polyamide (PA) Plastic Fitting for Polyamide (PA) Plastic Pipe and Tubing*

American Society of Mechanical Engineers

ASME B16.5	*Steel Pipe Flanges, Flanged Valves and Fittings*
ASME D2513	*Thermoplastic Gas Pressure Pipe*

British Standard

BS 4515	*Specification for Welding of Steel Pipelines on Land and Offshore*

Canadian Standards Association

CSA Z662-03	*Oil & Gas Pipeline Systems*

International Organization for Standardization

ISO 4427	*Polyethylene (PE) Pipes for Water Supply*
ISO 4437	*Buried Polyethylene (PE) Pipes for the Supply of Gaseous Fuels*
ISO 10931	*Plastic Piping Systems for Industrial Applications: Poly Vinylidene Fluoride Part 2 Pipes*
ISO 11414	*Preparation of Polyethylene Pipe/Pipe or Pipe/Fitting Test Pieces Assemblies by Butt Fusion*

ISO 11922 — *Thermoplastic Pipes for the Transport of Fluids-Dimensions and Tolerances, Part 1: Field Welding, Part 2: Shop Welding*

ISO 13628 — *Specification for Unbonded Flexible Pipe*

ISO 13953 — *Polyethylene Pipes and Fittings-Determination of Tensile Strength of Test Specimens from a Butt Fused Joint*

Manufacturers Standardization Society

MSS SP-44 — *Steel Pipe Line Flanges*

National Association of Corrosion Engineers

NACE RP0304 — *Design, Installation and Operation of Thermoplastic Liners for Oilfield Pipelines*

NACE 35101 — *Plastic Liners for Oilfield Pipelines*

4 Abbreviation and Definitions

SDR: Standard Dimension Ratio; Nominal outside diameter of liner/Nominal wall thickness

CRA: Corrosion Resistant Alloy

ESC: Environmental Stress Cracking

ID: Nominal internal diameter

OD: Nominal outside diameter

UV: Ultra violet light

Contractor: The party that conduct all or part of the project design, engineering, procurement, construction, commissioning or management of a project.

Principal: The party, in this case; Saudi Aramco, which initiates the project and pays for its design and construction. The Principal usually specify the technical requirements directly to the contractor or through an agent or consultant working or acting on his behalf.

Annulus: Space between thermoplastic liner and the host outside carbon steel pipe.

Bell hole: Excavations made at a section joints of a pipeline for the purpose of insertion of a section of thermoplastic liner.

Butt fusion welding: A method of joining plastic pipe, sheet, or other similar forms of a thermoplastic resin wherein the two ends to be joined are heated to the molten state and then 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.

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: ASME B16.5 code requires that the flange face (raised face and flat face) has a specific roughness to ensure that this surface be compatible with the gasket and provide a high quality seal.

Hot plate welding Technique: The process of hot plate welding uses a heated platen to melt the joining surfaces of the two halves of a thermoplastic pipe. The part halves are brought into contact with a precisely heated platen for a predetermined period.

In-line compression joint: System of terminating lined pipelines by compression of the liner between an internal ring and a CRA material.

Inspector: Professional assigned by the principal to ensure a project's compliance with its specifications and statutory requirements.

Modulus Elastic: The ratio of the stress applied on a body to the strain that results in the body in response to it. The modulus of elasticity of a material is a measure of its stiffness and for most materials remains constant over a range of stress.

Ovality: Ovality is the deviation from roundness as a result of extrusion, coiling, handling, or installation. 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.

Permeation: Diffusion of liquid and gas through a plastic layer under the influence of pressure and temperature. Permeation is a physicochemical mass transfer phenomenon involving diffusion of a solute through a porous medium. The driving force for mass transfer is the presence of an activity (e.g., concentration) gradient with respect to the solute.

Vent connection or point: Vent hole through the carbon steel outer pipe to allow the release of gas accumulated in the annulus between the liner and the host carbon steel pipe.

Venting: The release of gas accumulated in the annulus between the thermoplastic liner and the host carbon steel pipeline.

5 Materials

5.1 General

Typically, High Density Polyethylene (HDPE PE100) material is being used as grooved, perforated or smooth liner. However, there are other materials that have the potential to be used for highly aggressive fluids and these include; cross-linked Polyethylene (PEX), Unplasticised Polyvinylidene-fluoride (PVDF), Polypropylene (PP), and Polyamide (PA 11, PA 12 and PA6-12).

In this specification, emphasis will be made on HDPE (PE100), PEX and unplasticised PVDF materials as a liner due to their successful performance in many applications operated at their allowable service conditions in terms of maximum operating temperature and chemical resistance. The other materials, PP and PA, will also be considered in this specification.

The Lining contractor shall be responsible in selecting and supplying of all materials required to meet the specified service design conditions and installation requirements. The selection of materials shall be based on actual test data or documented methods for predicting the liner material properties for the specified service conditions. This document which includes test results and records shall be submitted by the Contractor for review by the Principal.
For gas service and services containing gas, the Contractor shall demonstrates by testing or documented evidence that the selected material will not fail during service start-up and continuous operation or shut-down and when the process undergoes rapid de-pressurization.

The mechanical, thermal, fluid compatibility and permeability properties of the selected material shall be documented by the Contractor for future references.

5.2 Thermoplastic Liner Materials

Plastic liners have been used for many years in areas of steel pipe construction. In most cases they are used for relining corroded steel pipes, but new pipes, such as subsea pipes for water injection lines used in oil production, are also provided with liners to prevent corrosion. Currently, there are many thermoplastic materials that are used for liners and these may include; HDPE, Cross-linked Polyethylene, Polypropylene (PP), Polyamide (PA) and Polyvinylidenefluoride (PVDF).

This specification provides more emphasis on HDPE (PE100), PEX and PVDF materials.

In general, the following guidelines shall be considered during the selection of the liner material:

- Effect of service fluid(s) on the chemical and physical long term performance of the liner material.
- Liner resistance to depressurization and collapse
- Effect of design and operating temperatures on the liner
- Suitability of the liner to pigging operations

The selected material shall only be utilized as the liner material after approval is granted by the Principal to ensure that it meets the required installation and service conditions.

5.2.1 High Density Polyethylene (PE100)

HDPE (PE 100), is also termed high performance polyethylene (HPPE) pipe material, and it differs from other grades of HDPE such as PE80 medium density polyethylene (MDPE) pipe material in that it demonstrates exceptional resistance to rapid crack propagation (60°C to -30°C) as well as long term stress crack resistance. The number classification refers to the strength of the material with PE100 being stronger than PE80. Pipe made from PE100 can withstand a greater pressure than pipe with the same diameter and wall thickness made from PE80 material.

HDPE grooved or perforated liner is formed from a number of HDPE pipe lengths heat fused together into sections currently up to 1 km long. After pressure testing, each section of the liner is inserted into a pre-welded carbon steel pipeline or flowline section. At the ends of the section the liner is terminated in an HDPE flange or other connection system, to enable sections to be joined together.

A summary of typical material properties of PE 100 at ambient conditions is presented in Table 5.2.1.1. This Table is for guidance only. Manufacturers/Contractors shall submit the relevant (minimum) material property specifications at the specific service conditions.

Table 5.2.1.1 – Typical PE 100 Material Properties

Property	Unit	Test Procedure	Typical Value
Material Designation	---	PPI-TR4	PE4710 PE100
Cell Classification	---	ASTM D3350	445574C 445576C
Pipe Properties			
Density	gms / cm^3	ASTM D1505	0.961 (black)
Melt Index (HLMI) Condition 190 / 21.6	gms/10 min	ASTM D1238	8.0
Hydrostatic Design Basis, 73°F (23°C)	psi	ASTM D2837	1,600
Hydrostatic Design Basis, 140°F (60°C)	psi	ASTM D2837	1,000
Minimum Required Strength	Mpa (psi)	ISO 9080	>10 (>145)
Rapid Crack Propagation Critical Pressure(Pc), 0°C (32°F)(2)	Bar (psi)	ISO 13477	>12 (>174)
Pipe Test Category	---	ASTM D2513	CEE
Material Properties			
Flexural Modulus at 2% strain	psi	ASTM D790	>150,000
Tensile Strength @ Yield (Type IV)	psi	ASTM D638	>3,500
Elongation at Break 2 in / min., Type IV Bar	%	ASTM D638	>800
Elastic Modulus @ Secant 2% strain (2 in/min., type IV bar)	psi	ASTM D638	>200,000
Hardness	Shore D	ASTM D2240	65
PENT	hrs	ASTM F1473	>5000
Thermal Properties			
Vicat Softening Temperature	°F (°C)	ASTM D1525	255 (124)
Brittleness Temperature	°F	ASTM D746	-180 (-118)
Thermal Expansion	in / in / °F	ASTM D696	1.0 x 10-4

All PE pipe and fittings shall be stabilized against UV degradation in accordance with ASTM D3350 using a minimum of 2% Carbon Black.

It is recommended to specify the material properties of PE listed in (Table 5.2.1.1) rather than specifying a grade.

PE 100 liners shall not be operated above 65°C in water service and 50°C in hydrocarbon service or three phase system. In a liquid phase or a dry gas phase, PE 100 may be used at slightly higher temperature than

50°C. However, the maximum operating temperature shall be specified and agreed by the Principal before approval of the material for lining. Utilization of PE100 in hydrocarbon service or three phase system is limited to 50°C due to the presence of organic compounds that easily diffuse into the PE100, causing swelling and softening of the material. (Table 5.2.1.2) lists the recommended maximum operating temperature as a function of fluid composition.

Table 5.2.1.2 – Maximum Operating Temperature for PE100 Liner as a Function of Fluid Composition

Fluid Composition	Temperature (°C)
Water injection service	65
Dry gas	65
Three phase system	50
Crude oil containing water	50
Gas and condensate	50

5.2.2 Cross-linked Polyethylene (PEX)

PEX is an engineering thermoplastic material manufactured by cross-linking polyethylene with either peroxide or silane coupling agents. PEX typical properties are displayed in Table 5.2.2.1. PEX has good resistance to hydrocarbons and water at temperatures up to 85°C. Table 5.2.2.2 shows the recommended maximum operating temperature as a function of fluid composition.

Table 5.2.2.1 – Typical PEX Material Properties

Physical Properties and Mechanical Properties	Test Method	Units	Values
Density at 23°C	ASTM D792	Kg/m^3	953
Melt flow index at 5 kg	ISO 1133	g/10 min	1.3
Gel content	EN 579	%	> 65
Yield strength at 23°C	ISO 527, Test Spec. ISO	MPa	47
Elongation at Yield at 23°C	1B, 50 mm/min	%	7
Yield strength at 100°C		MPa	26
Elongation at Yield at 100°C	25 mm/min	%	8
Elongation at Break at 23°C		%	390
Elongation at Break at 100°C	1 mm/min	%	170

Physical Properties and Mechanical Properties	Test Method	Units	Values
Tensile Modulus (Young)		MPa	
at 23°C			1250
at 100°C			130
	ISO 178		
Flexural Modulus		MPa	
at 23°C			1200
at 100°C			167
Charpy Impact Resistance	ISO 179 / 1A	kJ/m²	
at 23°C			partial break
at 100°C			No break
VICAT Point (5 kg)	ISO 306 / B 50	°C	88

This specification is provided as guidelines. The specifications for PEX liners shall be agreed upon between the Contractor and the Principal.

HDPE is cross-linked through the use of HDPE, silane grafting agent and catalyst and stabilizing masterbatch. This result of high mechanical and thermal properties liner is achieved once crosslinking is complete.
The crosslinking is brought about by post-treatment of the installed liner with hot water or steam.

It is important that Butt-welding of PEX is carried out by keeping the liner at a maximum critical degree of gel content, around 30%, before installation.

The maximum utilization temperatures of PEX in different services are given in Table 5.2.2.2 below.

Table 5.2.2.2 – Shows PEX Maximum Operating Temperature as a Function of Fluid Composition

Fluid Composition	Temperature (°C)
Oil/gas/water mixture (three phase system)	90
Oil/water mixture	90
Gas and condensate	85
Dry gas	85

5.2.3 Unplasticized Polyvinylidene Fluoride (PVDF)

Plasticized PVDF have been used in subsea flexible pipe as an internal sheath. Unfortunately, plasticized PVDF has experienced premature embrittlement due to leech out of the plasticizer during operation.

Unplasticized PVDF is accepted to be more stable material, since there is no plasticizer. However, unplasticized PVDF homopolymer has higher elastic modulus than plasticized PVDF, reducing the yield and ultimate strain and increasing the yield stress.

For liner applications unplasticized PVDF copolymer shall be based on vinylidene fluoride (VF_2) and chlorotrifluoroethylene (CTFE).
Other grades of copolymer or unplasticized PVDF shall be assessed by the Principal before acceptance. Table 5.2.3.1 shows the properties of one grades of unplasticized PVDF copolymer that may be considered for use as thermoplastic liners in new and existing corroded pipelines and flowlines in hydrocarbon services. Table 5.2.3.2 – Shows the fluid composition and the maximum allowable operating temperatures of PVDF Liners.

Table 5.2.3.1 – Typical PVDF Material Properties

Properties	Standards	Units	Values
Physical Properties			
Water absorption (24 h at 23°C)	ISO 62 (method 1)	%	<0.04
Density	ISO 1183	g/cm^3	1.77
Melt Flow Index	ASTM 1238		
	230°C, 10 kg	g/10 min	3
	230°C, 5 kg	g/10 min	1
	230°C, 2.16 kg	g/10 min	-
Mechanical Properties			
Tensile	ASTM D638		
Tensile stress at yield	23°C, 50 mm/min	MPa/psi	35-40/5075-5800
Tensile stress at break	23°C, 50 mm/min	MPa/psi	35-40/5075-5800
Elongation at yield	23°C, 50 mm/min	%	10-12
Elongation at break	23°C, 50 mm/min	%	100-350
Modulus	23°C, 1 mm/min	MPa/psi	1300/188500
Flexion	ASTM D790		
Maximum load	23°C	MPa/psi	-

Properties	Standards	Units	Values
Modulus	2 mm/min	MPa/psi	-
IZOD impact (notched V 10 mm – at 23°C – 4 mm thick)	ASTM D256	J/m	1000
Shore D Hardness (2 mm thick)	ASTM D2240	-	70
Abrasion resistance	TABER CS 10/1 kg	mg/1000 rev	5-10
Friction coefficient (static)	ASTM D1894	-	0.2-0.4
Friction coefficient (dynamic)		-	0.2-0.3
Thermal Properties			
Crystallinity by DSC	ASTM D3418		
Melting point		°C/F	173/343
Heat of fusion (80° to end of melting)		J/g	51
Crystallizing point		°C/F	140/284
Crystallization heat		J/g	41
VICAT point (4 mm thick)	ISO 306	-	0.2-0.4
Load 1 kg		°C/F	167/333
Deflection temperature (4 mm thick)	ASTM D 648		
Load 0.46 MPa	After annealing	°C/F	140/284
Load 1.82 MPa		°C/F	64/147
Glass transition (Tg)	DMTA	°C/F	-28/-18
Brittleness temperature (on 2 mm pressed sheet)	ASTM D746 A	°C/F	-31/-24
Molding shrinkage		%	2-3
Thermal stability	TGA beginning and at 1 % weight loss in air	°C/F	320-340/608-644
Linear thermal expansion coefficient	ASTM D699	10-6 K-1	130-180
Thermal conductance at 23°C	ASTM 177	W/m.K	0.2
Specific heat	23°C & 100°C	J/g.K	1.2-1.6
Electrical Properties			
Surface resistivity (Voltage< 1 V, after 2 min – 500 V at 23°C)	ASTM D257 / DIN 53483	Ohm/square	≥ 1.1014
Volume resistivity (Intensity = 10 mA, after 2 min at 23°C)	ASTM D257 / DIN 53483	Ohm.cm	≥ 1.1014
UL-94 Flammability test	UL-94	Class	-
Limiting Oxygen Index (sheet 3 mm thick)	ASTM D2863	%	-

Table 5.2.3.2 – Shows the Fluid Composition and the Service Temperatures for PVDF Liners

Fluid Composition	Temperature (°C)
Oil/gas/water mixture (three phase system)	70
Oil/water mixture	70
Gas and condensate	75
Dry gas	80

5.2.4 Polypropylene (PP)

Random copolymer of polypropylene shall be used for liners due to its high molecular weight and excellent physical, mechanical and chemical properties. The grade selected for liner application shall be highly heat stabilized and especially formulated for extraction resistance.

PP is not commonly used as a thermoplastic liner material despite the fact that it has higher thermal properties than high density polyethylene.

Table 5.2.4.1, lists the maximum recommended operating temperature as a function of fluid composition.

Table 5.2.4.1 – Maximum Operating Temperature of PP as a Function of the Fluid Type

Fluid Composition	Temperature (°C)
Three phase system; Oil/gas/water mixture	75
Oil/water mixture	80
Gas and condensate	75
Dry gas	85

PP liners shall comply with the requirements of ASTM D2657, ASTM D4101 and ASTM F492.

5.2.5 Polyamide (PA)

Polyamide such as PA11, PA12, and PA6-12 shall be used as a liner for hydrocarbon services provided that the crude is free from water, or at very low levels, and within its limited maximum operating temperatures. Table 5.2.5.1 provides guidelines for the use of Polyamide as a function of fluid composition and operating temperatures.

Manufacturers shall submit the relevant PA (minimum) material specification at the specified operating conditions. This specification shall comply with the requirements of ASTM D4066 and ASTM F1733.

Table 5.2.5.1 – Shows the Polyamide Liner Use as a Function of Fluid Composition and Maximum Operating Temperature

Fluid Composition	Temperature (°C)
Oil/gas/water mixture (three phase system)	70
Oil/water mixture	70
Gas and condensate	75
Dry gas	80

5.3 Guidelines to Selecting Thermoplastic Liners

Liner material selection for pipelines shall consider the fluid(s) being carried; its chemical constituents and concentrations, abrasiveness, flow rates, the long term effect of the fluid(s) on the liner, resistance to pressure change that may lead to blistering and collapse of the liner, operating conditions (flow, temperature, pressure), compatibility with pigging operations and swelling.

5.3.1 Quality Control and Qualification Testing

Thermoplastic liner material shall be manufactured and qualified according to ISO 4427 or API SPEC 15 LE. These specifications provide standards for polyethylene (PE) line pipe suitable for use in conveying different types of fluid including; oil, gas and non-potable water in underground and above ground applications.

A qualification and quality control testing program for the selected thermoplastic liner shall be established. This program shall include the following properties.

5.3.1.1 Physical/Mechanical and Thermal Properties

Thermoplastic liner is chosen for its good range of physical, mechanical and thermal properties. In this application, designers are looking for a wide range of properties that have direct impact on the installation and performance of the liner. These properties are tabulated in Table 5.3.1.1 below.

Table 5.3.1.1 – Shows the Properties Required for Material Selection

Physical/Mechanical Properties	Standard	Implementation Requirements	QC Tests
Melt flow rate	ASTM D1238		B
Specific gravity	ASTM D792		B
Tensile Strength/elongation at break	ASTM D638	A	B
Yield strength/elongation at yield	ASTM D638	A	B
Hardness	ASTM D2240		B
Stress relaxation	ASTM D2990	A	
Modulus of elasticity	ASTM D790	A	
Flexural Creep and Creep-Rupture	ASTM D2990	A	
Thermal Properties			
Heat distortion temperatures (HDT) or Tg using DSC	ASTM D648	A	B
Coefficient of thermal expansion	ASTM E831	A	B

A: Implementation requirements include properties required before, during and after insertion of the liner.

B: QA/QC Properties are required to ensure that the measured properties are in line with specified properties. These properties are required to be documented by the Contractor and the Principal.

5.3.1.2 Chemical Resistance Aging Test

Aging test shall represent the liner operating conditions and be conducted according to ISO 23936-1 to provide experimental data about the changes of the liner mechanical properties with time.

An initial pre-check test shall be performed if no previous knowledge about the behavior of a liner 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 contractor 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 it does 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 aging process, a method based on Arrhenius equation may be used, as described in ASTM D3032.

When analyzing the results for evidence of aging, 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. All test results shall be evaluated by the Principal to evaluate the long term performance of the liner. Rapid or significant decay in critical mechanical/physical properties shall not be accepted and the liner material should be either modified to enhance performance or rejected and new liner material shall be selected.

Table 5.3.1.2 – Liner Acceptance Criteria after Chemical Aging Test

Length (%)	**Mass (%)**	**TS at Break**	**Elongation (%)**	**E-Modulus** (MPa %)	**Thermostability*** Δ°C
0–2	± 5	± 20	± 30	± 20	0–5

***DSC test – ISO 11357-6**

5.3.1.3 Swelling Test

Swelling is the increase in volume due to absorption of fluids. The following conditions shall apply for the swell test procedure:

- Actual sample from the liner shall be cut for the test.
- Specimen weight shall be recorded to the nearest 0.001 g.

The cut samples shall be immersed in fluid(s) similar to those used in the pipeline for 500 hours at the design pressure and temperature in a sealed container.

After exposure, the dimensions and weights shall be measured and recorded.

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

% mass change = (mass prior to exposure - mass after exposure) x100/ mass prior to exposure

% volume change = (volume prior to exposure - volume after exposure) x 100/volume prior to exposure

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.

5.3.1.4 Blistering Resistance Test

Thermoplastic liner swells when exposed to oil particularly at high temperature and pressure. If the liner is exposed to sudden variations in pressure, the liner may blister, tear or crack.

Blistering resistance test shall replicate the design requirements of liner materials in fluid(s) containing gas under a given environmental conditions of temperature, pressure and operating at certain numbers of depressurization and depressurization rate. For this test the following conditions shall be followed.

- The test shall be only conducted on the gas component of the fluid.
- The sample thickness shall be the same as that of the selected liner.
- The design pressure of the liner shall be used during the test
- The sample conditioning time shall be sufficient to ensure full saturation.
- The number of depressurizations (decompressions) shall be a minimum of 20 cycles or the number expected during the actual operating conditions.
- The depressurization rate (decompression rate) shall be the expected rate or a minimum of 1000 psi/ minute.
- The actual service operating temperature shall be used throughout the test.

Optical stereomicroscope shall be used at a magnification of 20 times to detect signs of blisters and cracks. The liner shall only be acceptable when no blister or crack is seen.

5.3.1.5 Permeability Tests

Permeability is the penetration of permeates (such as liquid, gas, or vapor) through thermoplastic materials such as PE100, PEX, PP, etc. Permeability of the liner can be measured with any gas or liquid provided that the test sample is cut from an

extruded liner having wall thickness and diameter corresponding with the size of the testing machine. The test conditions shall be per the operating temperature of the liner and to as much as possible to the operating pressure.
A sufficient number of tests shall be performed to allow for linear interpolation of the results as a function of temperature.

The test will provide an indication on the gas/liquid permeation rate into the annulus between the host carbon steel pipe and the liner. The result should help designer to account for correct venting to eliminate potential collapse of the liner.

This test shall be conducted only if gas phase is present. However, it may not be necessary to conduct the test if the contractor provides tests results certified by a competent third party testing laboratory.

5.4 End Connectors

The material of the thermoplastic flange shall be the same as the liner material to avoid incompatibility and failure at the joint.

The retaining rings shall be per ASTM A106 or equivalent material while bolts and nuts shall be per ASTM A193 B7 and ASTM A194 Grade 2-H respectively.

6 Manufacture of Thermoplastic Liner

6.1 Manufacturing of the Liner

The manufacturing of thermoplastic liner shall be similar to pipe manufacturing using extrusion machines.

Only 100% prime virgin materials shall be used for the production of the liner, with a maximum of 0.2% wt of additives. Conductive additives such as special grade of conductive carbon black may be added if electrically conductive liners are required.

The Contractor shall be responsible for the manufacturing of the liner.

6.2 Flange Material

The flanges material shall be the same materials used in the manufacture of the thermoplastic liner. The wall thickness of the flanges shall be equal to the wall thickness of the liner. Flared flanges are only permitted for limited lengths, which cannot be fitted with fused flanges and only after approval of the Principal.

6.3 Rotationally Molded Spools

Rotationally molded spools are acceptable after agreement by the Principal. The material used shall have minimum material properties provided by the Contractor unless otherwise agreed with the Principal.

The wall thickness of the liner in the spools should be equal to the minimum wall thickness.

6.4 Dimensions, Weights and Tolerances

6.4.1 Size, Tolerances

Liner, manufactured to this specification shall comply with the dimensions and tolerances given in ISO 4427 Tables 3 – 6 or API SPEC 15 LE Table 3.

The tolerance on the liner wall thickness shall be -0%/+5% of the specified value.

6.4.2 Ovality

The ovality of the pipe shall not exceed 5% when measured in accordance with ASTM D2513.

During liner manufacturing, ovality / out-of-roundness shall be monitored and recorded.

7 Quality Program

7.1 Quality Manual

The Manufacturer shall maintain a Quality Manual which describes the quality program. All prior revisions shall be retained for a period of not less than five years.

The Quality Manual shall address a documentation program to assure communication of approved manufacturing and inspection procedures to qualified receiving, manufacturing and quality control personnel. The Quality Manual shall be submitted to the Principal for review and approval, and shall cover at least the following aspects:

- raw material acceptance;
- extrusion procedures;
- pipe manufacturing practices;

- welding procedures and qualifications;
- inspection and test procedures;
- acceptance criteria;
- repair procedures.

7.2 Hydro-testing

The hydrotest pressure shall be 1.5 times the "rated" pressure for the stand-alone thermoplastic pipe. The hydrostatic test pressure shall be maintained for at least 3 minutes. Liner pipe sections undergoing hydrostatic pressure test shall not show any sign of leakage, weepage or ballooning.

7.3 Storage and Handling

Straight lengths shall be stored on horizontal racks and given support to prevent damage. Coils shall be stored stacked flat one on top of another.

Pipe shall be protected from environmental contamination and damage by third party.

Covers shall be used to prevent ingress of moisture or dirt inside the grooves or perforations of the liner.

Liner can be susceptible to damage by abrasion and by sharp objects. Dragging pipe sections or coils over rough ground shall not be permitted. If, due to unsatisfactory storage or handling, a liner is damaged it shall be rejected.

8 Documentation

➢ **Information to be submitted by the Contractor**

The Contractor shall submit information on the liner system to be used. This information shall contain as a minimum:

- Liner system identification.
- Manufacturer's material data.
- Material pre-qualification information.
- Type and thickness of liner material.
- Expected short-term and long-term volumetric swelling or shrinkage for the range of operating conditions.
- Expected thermal deformations due to operating temperatures.
- Liner manufacturing procedure.

- Liner installation procedure.
- Anticipated insertion forces for each liner section in relation to the liner strength capabilities.
- Bend limitations for the steel pipe.
- Maximum allowable weld penetration of carbon steel pipeline girth welds.
- Vent connection details and spacing.

Revision Summary

15 December 2012 New Saudi Aramco Materials System Specification.