FLEXPIPE®

Composite Technologies

TECHNICAL MANUAL

Flexpipe™
Flexpipe™ High Temperature
Flexcord™

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In an effort to provide useful product information, Flexpipe makes available three main documents:

Technical Manual
This document is mainly addressed to engineers, supervisors and procurement personnel. It is intended to present a general description of Flexpipe spoolable pipe products' materials, construction, qualification, performance, installation, operation and reliability.

Installation Guide
This document is mainly addressed to field personnel and is intended to provide general guidance on Flexpipe spoolable pipe products' handling, joining, installing and testing.

Operators Guide
This document is mainly addressed to pipeline operations and is intended to provide general guidance on the operation of Flexpipe spoolable pipe products.

Each of the three documents emphasizes particular aspects of the Flexpipe product application. Familiarity with the three documents is recommended for a broader perspective. Updated information is issued in bulletin form between main document revisions with the Engineering Bulletins being incorporated into the main documents at their next revision. Where conflicting information is found, the information contained in the bulletins supersedes the information in the three documents. Flexpipe TechTalk documents are marketing materials owned by the Flexpipe Sales and Marketing Team and are interpretations of the Flexpipe Engineering Manuals, Bulletins, and Testing documents.

This document is intended solely as a reference for use by persons of technical competence. It is the responsibility of the pipeline operator to ensure the suitability of Flexpipe products for any specific pipeline application. While the information contained in this document is believed to be correct as of the date of issue, under no circumstances will Flexpipe, or any of its subsidiaries, be liable in any way for any loss, damage or injury of any kind (whether direct, consequential, punitive or otherwise) incurred as a result of any omissions in this document or as a result of reliance on any information contained in this document. This document does not contain any warranty, express or implied.

1 Introduction

Flexpipe has designed, tested, and manufactured high pressure, corrosion resistant, spooled, continuous pipeline systems intended primarily for the Oil and Gas and Utility industries. Typical applications include oil and gas gathering; oilfield water transfer, disposal, and injection; gas distribution and transmission lines.

Flexpipe has also developed an innovative crimp fitting technology that allows efficient joining directly to steel lines, standard flanged connections, or other Flexpipe spoolable products pipelines. Flexpipe holds patents for its unique pipe and fitting designs[1].

No modifications to the pipe, fittings, or installation practices are allowed unless specifically approved in writing by Flexpipe Engineering.

2 Pipe

2.1 Product Lines

Flexpipe currently offers three spoolable composite pipe product lines:

- Flexpipe (FP)
- Flexpipe High Temperature (FP HT)
- Flexcord (FC)

The above products are each a type of reinforced thermoplastic pipe (RTP) and collectively referred to in this manual as Flexpipe Spoolable Products. FP and FP HT are intended for static or mild cyclic pressure applications with service temperatures up to 60°C and 82°C, respectively. FC is suited for severe cyclic pressure applications with service temperatures up to 60°C.

The product range for each product line is shown in Table 1:

[1] **Fiber reinforced pipe:** US patent number 6,889,716 (May 10, 2005); Canadian patent number 2,513,506 (August 3, 2010); Europe patent number 1592908 (April 7, 2010).
Crimp-style fitting: US patent numbers 7,946,629 B2 (May 24, 2011) and 8,042,252 B2 (October 25, 2011); Canadian patent number 2,562,823 (May 22, 2012).
High temperature pipe: US patent number 9,243,727 B2 (January 26, 2016); Canadian patent number 2,753,024 (May 1, 2018); Australian patent number 2010217166 (May 14, 2015).
Steel cord pipe: Canadian patent number 2,755,289 (February 20, 2018); China patent number 201,080,017,488.9 (December 3, 2014); GCC patent number GC0003910 (July 1, 2016).

Table 1: Product Lines

Pressure Rating	2,068 kPa (300 psi)	5,171 kPa (750 psi)	10,342 kPa (1,500 psi)	15,513 kPa (2,250 psi)
Flexpipe Grade	**150**	**301**	**601**	**901**
Product Line	**Nominal Size (inches)**			
FP	3”, 4”	2”, 3”, 4”	2”, 3”, 4”	
FP HT		2”, 3”, 4”, 5”	2”, 3”, 4”, 5”, 6”*	
FC				3”, 4”

*6” size product launched on June 2022.

Note: 2” FC901/FC901AB are not covered in this document. 2” FC901AB product is suitable for shallow water applications (e.g., 30 meters water depth) Please contact Flexpipe for more information.

Note: Flexpipe Grade is meant to coincide with typical ANSI flange ratings of the same class, e.g., 601 pipe is meant for 600 ANSI flanges.

FP and FC are manufactured with a standard white jacket, and FP HT is manufactured with a standard grey jacket. All product lines provide a minimum of 20 years protection against exposure to ultraviolet (UV) light.

All three product lines will hereafter be collectively referred to as Flexpipe Spoolable Products.

The product data sheets in the appendix list the Flexpipe Spoolable Products dimensions and parameters.

2.2 Design

Flexpipe Spoolable Products are manufactured at the advanced semi-automated Flexpipe production facility in Calgary, Alberta, Canada. Flexpipe Spoolable Products are patented three-layer designs constructed from a thermoplastic liner (liner), helically wrapped continuous high strength reinforcement, and an external thermoplastic jacket (jacket). FP and FP HT product lines are reinforced with high strength glass fibers, while the FC product line is reinforced with high strength galvanized steel cords.

The liner acts as a bladder, the reinforcement provides strength, and the jacket protects the load-bearing layer. This unique manufacturing process has the following advantages:

- The reinforcement is not encased in a thermosetting matrix and is therefore very flexible, as a result Flexpipe Spoolable Products are very rugged, durable and easy to handle.
- The simplicity of construction reduces the manufacturing costs.

- The high strength reinforcement enables design for high-pressure applications.
- The liner ensures that the pipeline system is highly resistant to corrosion.
- The continuous, long lengths facilitate fast and easy installation with fewer connections and less disturbance to impacted parties.
- Environmental impact and soil disturbance can be reduced since Flexpipe Spoolable Products can be trenched with a narrower trench and right of way than steel pipe or plowed in without trenching.
- Great Value: The combination of flexibility, ease of installation, and low weight per foot minimizes handling equipment requirements leading to lower installation costs when compared to stick and other spoolable products.

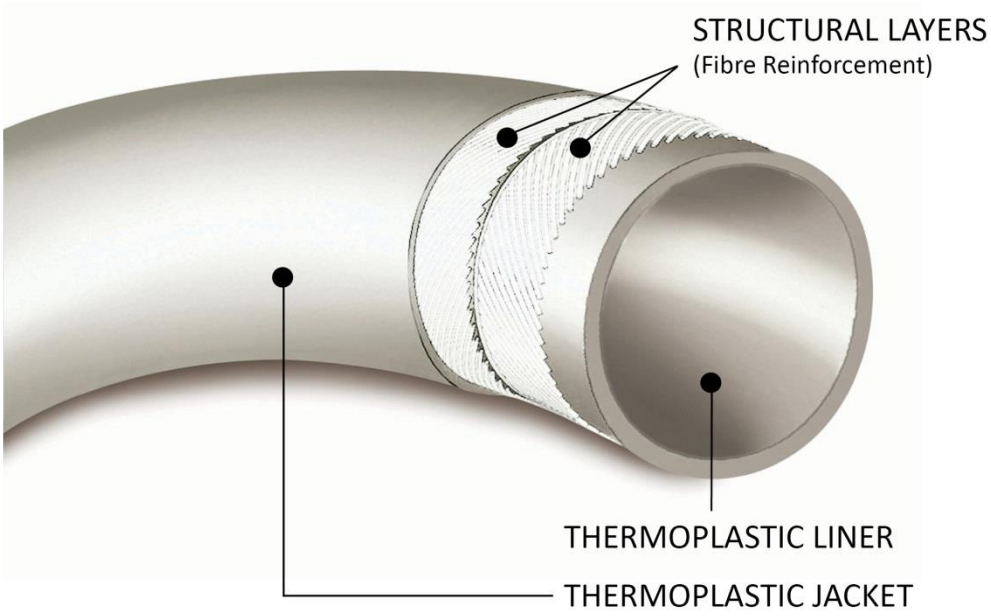


Figure 1: FP and FP HT Three-layer Design

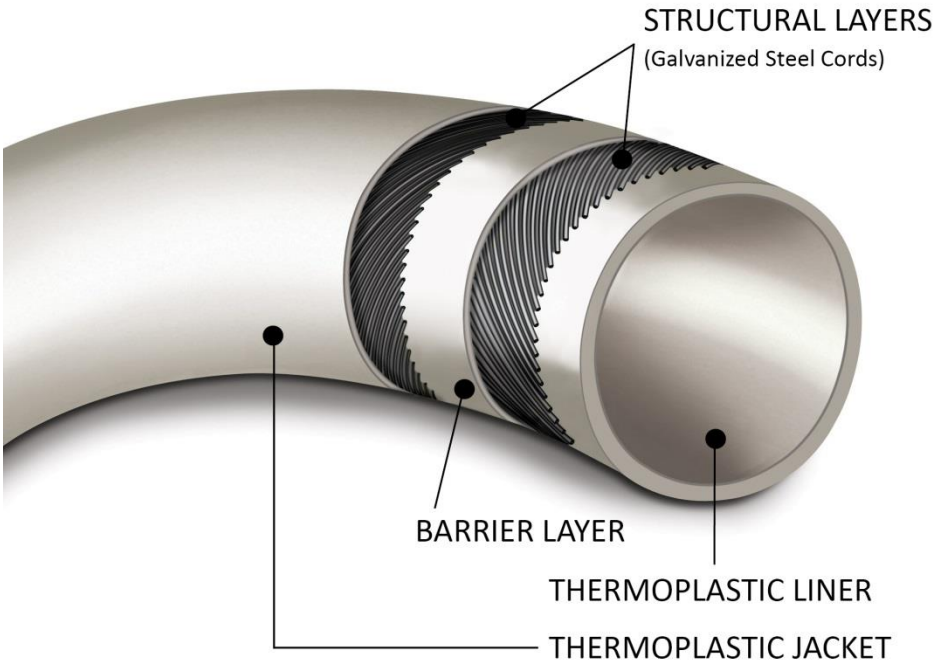


Figure 2: FC Design

Flexpipe Spoolable Products have been designed using a sophisticated mathematical model that was developed specifically for the unique construction of these products. The mathematical model was used to design the reinforcement configuration and optimize pressure capacity and strain. The validity of the mathematical model and the material properties used by this model has been validated through extensive physical testing.

The design and manufacturing of Flexpipe Spoolable Products are in accordance with standards and guidelines regarding qualification, quality control and testing of composite pipe and accessories. Please refer to Section 4 in this document for additional information on these standards, and Section 5.2 for a summary of the design methods and calculations.

2.3 Materials

The materials used in Flexpipe Spoolable Products have been widely used in the oil and gas industry for many years. The liner and jacket are manufactured using bimodal pressure-pipe-grade high density polyethylene (HDPE) thermoplastic resin. The reinforcement materials are either continuous glass fiber rovings for FP and FP HT or high strength steel cords for FC.

HDPE Liner – This material is designated PE4710 by PPI TR-3[2], in accordance with ASTM D3350[3]. The advancement in material properties of PE4710 increases resistance

[2] **PPI TR-3** *Policies and Procedures for Developing Hydrostatic Design Basis, Pressure Design Basis, Strength Design Basis, and Minimum Required Strength Ratings for Thermoplastic Piping Materials or Pipe.*

[3] **ASTM D3350** *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials.*

to crack growth while meeting rigorous standards for high strength. It also provides excellent wear resistance, reduced friction for decreased pressure losses, and increased impact toughness. A raised temperature (PE-RT) version of PE4710 is used for FP HT products.

Glass Fiber Reinforcement (FP and FP HT) – The glass fiber reinforcement utilized in FP and FP HT is constructed from a series of continuous glass fiber rovings. The fiber chemistry and coatings are specifically selected to optimize long-term performance.

High-Strength Steel Cords Reinforcement (FC) – The high-strength steel cords utilized in FC are constructed from a series of stranded galvanized wires for optimum performance.

HDPE Jacket – This PE4710 material has the same properties as the HDPE liner. Colorant and ultra-violet (UV) stabilizers are blended with the thermoplastic pellets during the extrusion process, providing resistance to weathering. The material properties of increased impact toughness and resistance to crack growth are especially important for the HDPE Jacket. A raised temperature (PE-RT) version of PE4710 is used for FP HT products.

Flexpipe is committed to maintaining high standards of quality and reliability. Each individual supplier is qualified by Flexpipe, in accordance with API Specification 15S (API 15S)[4] to ensure that quality inspections, physical testing, and material traceability meet Flexpipe quality standards. Each specific material is qualified by Flexpipe through rigorous physical testing, prior to use in manufacturing and in finished products.

2.4 Manufacturing

Raw materials required for manufacturing of Flexpipe Spoolable Products are approved by rigorous testing and closely monitored throughout the manufacturing process. Fittings are supplied by approved venders to Flexpipe specifications. All composite pipe is manufactured by Flexpipe utilizing our advanced manufacturing facilities in Calgary. Each step of the manufacturing process is closely monitored, resulting in direct control over the quality of the products.

2.4.1 Liner

The liner is manufactured and inspected by highly experienced operators using state-of-the art equipment, in accordance with stringent dimensional requirements defined by ASTM D2513[5]. Each liner run is continuously inspected for diameter, wall thickness, and concentricity by online ultrasonic measurement.

[4] **API Specification 15S** *Spoolable Reinforced Plastic Line Pipe.*

[5] **ASTM D2513** *Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings.*

2.4.2 Reinforcement

Glass Fiber Reinforcement

The fiber reinforcements for each product are constructed from a single type of input strand, purchased from qualified suppliers. Flexpipe has a proprietary multistep process to combine glass fibers into a package that ensures the glass fibers' strength is maximized at the correct helical angle to gain desired properties of flexibility, reinforcement strength, and redundancy. Flexpipe has developed extensive expertise in this area through critical evaluation and physical testing of various materials, coatings, and processing methods. State-of-the-art roving machines are used with tensioning systems designed in-house specifically for this process.

Galvanized Steel Cord Reinforcement

The galvanized steel cord reinforcements are applied directly as purchased from qualified suppliers. Similar to the glass fiber reinforcement, the helical angle to the pipe axis is controlled to maintain specific final product characteristics regarding flexibility, weight, and pressure rating.

2.4.3 Pipe

Each reel of pipe is manufactured in a single continuous production run that combines liner, reinforcement, and jacket into the finished product. The liner length is sufficient to complete an entire pipe production run without fusions.

The reinforcement is applied by sequential custom-designed winding machines, which wrap the reinforcement from multiple bobbins around the liner in a tightly controlled process. An automated control system measures the line speed and maintains the correct wrap angle by controlling the speed of each individual winding machine.

The jacket is applied over the reinforcement layer with a customized cross-head extrusion die, and immediately cooled. Computerized laser and ultrasonic measurement systems are used to ensure that strict quality standards are maintained as the protective jacket is applied. The jacket is marked with identifying information by an inline printer. Finally, the finished product is spooled onto a reel for transportation.

2.4.4 Quality Control

Quality Control (QC) is critical to the manufacturing process. Flexpipe is an ISO 9001:2015 certified manufacturing facility. Quality control data is diligently reviewed from supplier evaluation and approval all the way to the qualification of every finished product ready for delivery. Flexpipe is committed to using suppliers that provide material property

data and maintain certification and QC test results for all raw products. Material certification and traceability is critical to the Flexpipe quality assurance program that cohesively links raw materials with production records and serial markings on pipe and fittings. Flexpipe routinely verifies and audits the QC programs of its suppliers.

The manufacturing process is designed with many levels of quality monitoring. Sophisticated instrumentation systems, lasers, ultra-sonics, and production operators continually monitor the production line. Corrective action is implemented according to the established non-conformance reporting (NCR) system if design parameters are not within the specified tolerance limits.

Every finished product is tested in accordance with the Flexpipe Production Qualification Testing (PQT) Standards, and in accordance with API 15S. Samples are taken from the beginning and the end of every pipe run. The samples are subjected to destructive burst testing. The results from these tests must meet or exceed stringent QC requirements.

In addition, Flexpipe tests raw materials to ensure compliance with material specifications. Flexpipe testing equipment includes burst chambers, ovens, a cold chamber, a cyclic testing station, an Instron tensile testing machine, density test equipment, and numerous custom jigs and fixtures.

3 Fittings

Flexpipe has a series of metallic fittings to join composite pipe to steel pipe, steel fittings, or other composite pipe(s) to accommodate a wide range of field applications. For steel terminus situations, the fitting can terminate the composite pipe with a standard ASME B16.5[6] lap-joint flange or a weld neck transition to steel pipe, valves or facilities. The end of the Flexpipe product from one reel can be attached to the beginning of the Flexpipe product from a second reel with a pipe-to-pipe coupling, thus eliminating an underground flanged connection.

3.1 Fitting Configurations

The three types of fittings that are used with Flexpipe Spoolable Products are shown in Table 2. Each of these fittings is available for each pipe size and grade. For design and installation purposes, it is important to note that Flexpipe fittings are rated to match ASME and API flange ratings dimensionally and flange ratings are typically lower than the Flexpipe Spoolable Products pressure rating. As with all fittings and pipelines, pressure ratings of all components must be considered along with safety considerations and the weakest link will likely dictate system pressure rating (often referred to as Maximum Operating Pressure or Maximum Allowable Operating Pressure with appropriate pressure testing considerations). A thorough Engineering and Design review is required to ensure applicable pipeline regulations are met.

[6] **ASME B16.5** *Pipe Flanges and Flanged Fittings*.

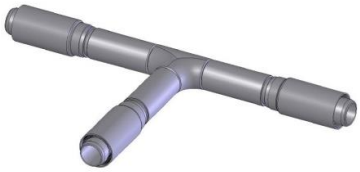
Refer to the installation manual document number 14-1096 for guidance on the installation of crimp fittings.

Flexpipe also offers pre-assembled flow joint fittings in the configurations shown in Table 3.

Table 2: Crimp Fittings

	Flanged End Fitting Compatible with standard raised face flanges. Slip-on flange is free to spin until bolts are tightened, allowing easy connection without stressing existing flanges.	*Dimensional drawings available upon request.*
	Coupling Fitting Used to connect two pieces of Flexpipe Spoolable Products together.	
	Weld Neck Fitting Used to connect Flexpipe Spoolable Products to steel pipe, using standard field welding procedures.	

Table 3: Custom Crimp Fittings

	90 Degree Elbow Flow Joint	*Dimensional drawings available upon request.* *See* Section 7.2 *for pigging guidance.*
	Tee Flow Joint	
	True Y Flow Joint	
	Y-Lateral Flow Joint	

3.2 Design

The fitting consists of a mandrel that is inserted into the pipe, and a sleeve that is crimped around the pipe. The mandrel and sleeve are both equipped with uni-directional teeth that securely grip the liner and jacket of the pipe. Crimping the sleeve creates very high permanent clamping pressure, which holds the reinforcement securely in place. The fitting system does not require the application of heat or adhesives in order to mechanically bond components together.

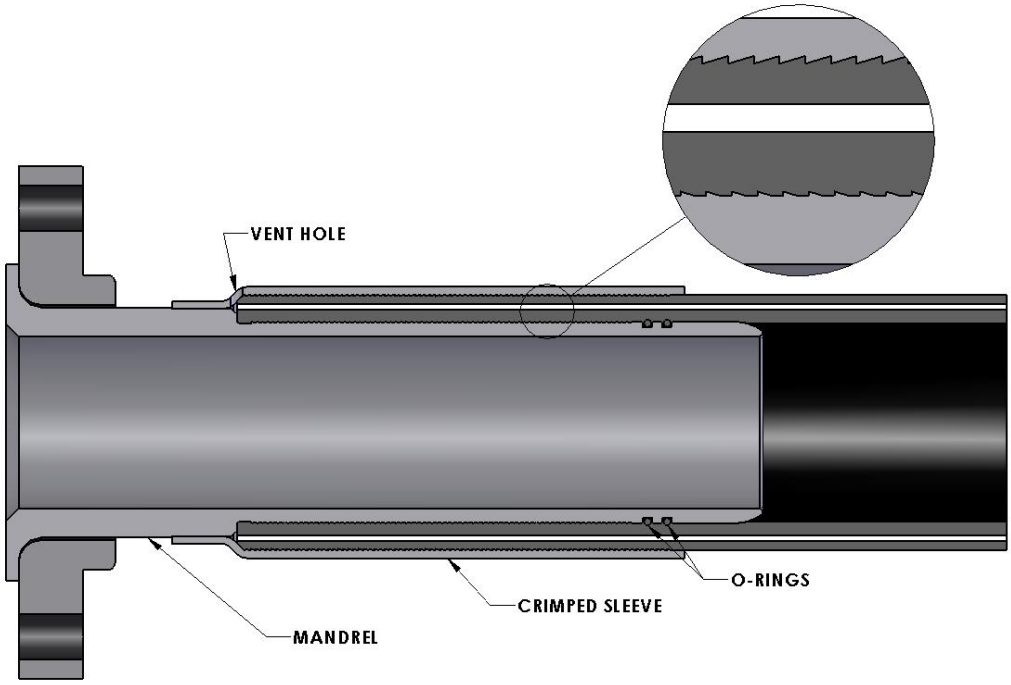


Figure 3: Cutaway View of Flexpipe Fitting

The mandrel is equipped with two O-rings that provide the primary seal.

The vent hole in the sleeve allows the annulus of the pipe (the space between the liner and jacket which contains the reinforcement layer) to vent freely at each fitting. This allows any gases that may have permeated through the liner to escape and prevents any pressure buildup in the annulus. It is important that the vent hole remains unobstructed. Water ingress through the vent hole must be prevented by using the proper fitting wrapping procedure. See the Installation Guide for more information.

Flexpipe fittings are installed in a two-step process, using portable installation equipment. In the first step, the mandrel is inserted into the liner. In the second step, the sleeve is crimped to the pipe. The fitting is supplied with the sleeve already welded to the mandrel to hold it in the correct position. To view a simulation of the fitting installation process, visit the Flexpipe website at www.flexpipesystems.com.

Flexpipe fittings have been tested together with our products as a complete system in long-term, high pressure tests, and have undergone rigorous testing to verify their performance in field conditions. More information on qualification testing is presented in Section 4.4.

The inside diameter of the mandrel in the fitting is smaller than the inner diameter of the pipeline. However, the restriction is minimal, and results in negligible pressure loss (see Section 5.4 for further information). Fittings are compatible with pigging programs as detailed in Section 7.2.

3.3 Materials

Standard Flexpipe fittings are manufactured from seamless steel that meets the requirements of NACE MR0175[7] for sour service. See Table 4 for a full list of materials used in Flexpipe fittings. Material certificates are reviewed by Flexpipe prior to manufacture of the fittings and are retained as part of Flexpipe's Quality Management System (Flexpipe QMS).

Weld neck fitting mandrels are manufactured using the same alloy steel material as flange and coupling fittings, with a short carbon steel pup welded to the end of the mandrel. This pup makes the weld neck fitting suitable for field-welding to standard carbon steel pipe and fittings of various pipe schedules.

The steel used in 4" and 5" Flexpipe fitting mandrels and flanges meet the low-temperature notch-toughness requirements of Category II of CSA Z662 with a minimum design temperature of -45°C. Whenever required, custom made mandrels and flanges in 2" and 3" sizes with proven low-temperature notch-toughness properties can also be supplied.

Custom made crimp fittings with a stainless steel mandrel can be specified. The end user is responsible for the material selection of the fittings.

Table 4: Flexpipe Fitting Material List

Part	Material type	Material grade(s)
Mandrel	Alloy steel[a] or Stainless Steel[a]	AISI 4130, 4140 or similar or Duplex 2205
Sleeve	Carbon steel[a]	ASTM A106, A333, A519, or similar
Flange	Carbon steel[a]	ASTM A105 or ASTM A350 LF2 Class 1
Weld neck fitting welding end	Carbon steel[a] or Stainless Steel[a]	ASTM A106, A333 or similar or Duplex 2205
Flow joints (tee, elbow, etc.)	Carbon steel[a]	ASTM A234 WPB or ASTM A420 WPL6
O-rings	FKM Fluorocarbon Elastomer	Viton A - 75 Durometer (for regular service) or High Performance FKM - 90 Durometer (Low Temperature & Rapid Decompression resistant)
Coatings	Electroless Nickel or uncoated. Weld neck and stainless steel fittings are not coated.	

[a] Meets requirements of NACE MR0175 for sour service

[7] **ANSI / NACE MR0175 / ISO 15156** *Petroleum and Natural Gas Industries—Materials for Use in H_2S-Containing Environments in Oil and Gas Production*

3.4 Manufacturing

Flexpipe fittings are manufactured, coated, assembled, and labeled according to Flexpipe specifications by suppliers whose processes have been qualified by Flexpipe. Flexpipe routinely verifies and audits the QC programs of these suppliers.

All welding required for the manufacture of Flexpipe fittings is performed in shop conditions, by suppliers with qualified weld procedures in accordance with CSA Z662 or equivalent. These procedures are specific to the materials used and include appropriate heat treatments and inspections.

3.5 Corrosion Protection

Flexpipe fittings are supplied with high-phosphorus Electroless Nickel Coating (ENC). This ENC coating protects the fitting wetted surfaces from corrosion and erosion for many applications. Additional information about ENC is available upon request. Weld neck fittings are not coated, since the coating would be damaged by the heat input during welding. Prefabricated flow joints can be coated, since no welding is required during installation.

ENC can typically provide an effective barrier against corrosion for many of the products transported in the oil and gas industry and in a wide range of applications, however ENC may not be appropriate for all applications. As with all protective coatings, coating failure or damage is possible for a variety of reasons. For those customers with low tolerance for coating failures, other materials may be considered. Bare steel or stainless steel (Duplex 2205) fittings are also available.

The end user is responsible for the final decision regarding material selection of the fittings, compatibility of materials with the product transported, and the adequacy of corrosion mitigative measures including the effectiveness of coatings. End users may select and install externally supplied alternative coatings; please consult Flexpipe Engineering regarding compatibility with Flexpipe fitting design.

During fitting transportation and installation, the coating must be protected from damage. It is recommended to keep the protective caps supplied with fittings in place until the time the fitting is installed.

Although the sleeves may be coated with ENC, it is not intended for corrosion protection as the crimping process will damage the surface of the nickel coating. Flash surface rust may occasionally be present on the sleeve surface or the flange ring.

After fitting installation, Flexpipe crimp fittings must be wrapped with tape to mitigate external corrosion, and to prohibit water ingress from reaching the pipe reinforcement. In both buried and surface installations, it is mandatory to apply the appropriate wrapping on all crimp fittings. Only materials and methods approved by Flexpipe may be used. See the Flexpipe Pipe Installation Guide for details.

To reduce the likelihood of water ingress past the fitting wrapping, a maximum of 1 meter (3 feet) of water depth above the vent hole is allowed. If the installation has more water depth than this, the vent hole must be eliminated. Discuss options to accomplish this with Flexpipe Engineering.

In jurisdictions requiring, or in applications deemed advantageous, an optional sacrificial anode can also be applied to the crimp fitting. Flexpipe has developed a sacrificial ribbon anode kit for buried steel fittings that provides external corrosion protection for a 50 year life in soil resistivities ranging between 1500 to 3000 ohm/cm. This is based on a fitting external wrapping efficiency of 95%. Please refer to the Flexpipe Pipe Installation Guide for more information.

4 Qualification

4.1 Introduction to Standards and Regulations

According to industry terminology, Flexpipe pipe is classified as a reinforced thermoplastic pipe (RTP). Various standards deal with this type of product, and cover topics such as materials, testing, manufacture, and installation. Standards are guidelines that are generally accepted throughout an industry as appropriate, usually on the basis of industry-wide experience. They are often referenced by regulations, which may adopt some or all of the guidelines, or even introduce more stringent requirements. Regulations are requirements that must be followed by law.

Standards that apply to Flexpipe products are primarily performance-based. This means that they emphasize the demonstration of a product's capabilities through repeated testing, rather than relying only on theoretical design calculations. A detailed theoretical design model serves as a starting point for Flexpipe product designs. The designs are validated through extensive testing in accordance with accepted test standards.

4.2 Standards

4.2.1 American Petroleum Institute (API)

API was the first North American standards body to develop a standard specific to the spoolable composite pipe industry. API 15S, *Spoolable Reinforced Plastic Line Pipe*, includes guidelines for determining material properties, pressure ratings, safety factors, and minimum performance requirements. It also includes guidelines for manufacturing, quality control tests, and typical installation methods. This specification applies to spoolable reinforced line pipe with both helically wrapped steel or non-metallic reinforcing elements.

API 15S is based on expert knowledge and experience with the materials involved. It uses proven ASTM testing methods, such as ASTM D2992[8], for establishing long-term performance.

All Flexpipe products meet or exceed the stringent qualification requirements established by API 15S. API 15S is the standard most recognized internationally for the qualification of spoolable reinforced plastic line pipe.

4.2.2 Canadian Standards Association (CSA)

CSA provides standards to which manufacturers should comply. CSA Z662, *Oil and Gas Pipeline Systems*, covers the design, construction, operation, and maintenance of oil and gas industry pipeline systems. Flexpipe Spoolable Products fall under Clause 13.1 of this standard, which specifically addresses design, manufacturing, and installation requirements for reinforced composite pipelines.

Flexpipe is fully compliant with CSA Z662 Clause 13.1. Some of the specific requirements are discussed below. Other requirements are discussed in more detail elsewhere in this document, as referenced in Table 5.

According to CSA Z662, reinforced composite pipelines may be used in low vapor pressure (LVP)[9], gas gathering, and oilfield water pipelines. High vapor pressure (HVP)[10] pipelines are excluded by this standard. Flexpipe Spoolable Products also meet the requirements of CSA Z662 Clause 12 for gas distribution systems[11].

Design pressure calculations for RTP are outlined in Clause 13.1. This clause refers to API 15S as the industry standard according to which Flexpipe Spoolable Products must be qualified. Design pressure calculations are shown in Section 5.2.3.

Flexpipe fittings are engineered for suitable low-temperature notch toughness. The material properties meet CSA Z662 Category II requirements with a minimum design temperature of -45°C.

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[8] **ASTM D2992** *Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe And Fittings*

[9] Includes oilfield water, multiphase fluids, or liquid hydrocarbon mixtures with a vapor pressure of 110 kPa (absolute) or less at 38˚C.

[10] Hydrocarbons or hydrocarbon mixtures in the liquid or quasi-liquid state with a vapor pressure greater than 110 kPa (absolute) at 38°C.

[11] Based on a design life of 50 years.

Table 5: Links for Specific CSA Z662 Requirements

Requirement	Reference in this manual
Gas service design pressure limit	Section 5.1.2
Sour gas limits	Section 5.1.5
Cyclic service	Section 5.3
Tracer wire	Section 6.6
Cathodic protection	Section 6.8
Pressure testing – new installations	Section 6.9
Static electricity	Section 7.5
Maximum external pressure	Section 5.12

4.3 Regulations

4.3.1 Canadian Provincial Regulatory Bodies

The Alberta Energy Regulator (AER) is a regulatory body that oversees the development of Alberta's energy resources, including oilfield pipelines. Any oilfield pipeline in Alberta must be approved by the AER before installation, in accordance with its regulations. Other provinces in Canada have regulatory bodies with a similar role. Cross provincial installations are licensed under the National Energy Board (NEB) in a similar manner.

The AER allows Flexpipe Spoolable Product applications to be processed as routine for fresh water, salt water, multiphase, crude oil/LVP, and natural gas service. Flexpipe has developed a positive history with the AER through provision of data on design, manufacturing, testing, installation, and in-service evaluations. More information on the results of these evaluations can be found in Section 8. Flexpipe has also established relationships with the corresponding regulatory bodies in British Columbia, Saskatchewan, and Manitoba, and installations have been completed in each of these provinces.

4.3.2 United States Regulatory Bodies

Flexpipe Spoolable Products are extensively used in class 1 areas in the United States. In United States Department of Transportation (DOT) regulated areas, the DOT considers the use of Flexpipe Spoolable Products through special permit applications submitted to the Office of Pipeline Safety. Currently, Flexpipe is working with the Department of Transportation to eventually include Reinforced Thermoplastic Pipes as an approved material in 49 CFR Part 192 "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards" and Part 195 "Transportation of Hazardous Liquids by Pipeline".

4.3.3 Other Regulatory Bodies

Australia:
Flexpipe Spoolable Products have been accepted by several regulatory bodies in Australia, in accordance with AS 2885.1 “Pipelines – Gas and liquid petroleum” for use as emulsion and oil pipe lines.

Mexico:
Flexpipe Spoolable Products have been certified by ABS Group Services de Mexico. FP and FP HT comply with NRF-185-PEMEX-2008 “Tubería Plástica Reforzada Enrollable para recolección y Transporte de Hidrocarburos Líquidos y Gaseosos” and FCLP complies with P.2.0730.01 “Tubería Plástica Reforzada Enrollable para recolección y Transporte de Hidrocarburos Líquidos y Gaseosos”.

Flexpipe also has qualified its product with several oil and gas operators in the Latin American Region.

4.4 Testing

Flexpipe is committed to ensuring that its products are rugged, reliable, and safe. Flexpipe Spoolable Products are tested together with fittings as a complete system. This system has undergone extensive testing to demonstrate that it meets and exceeds the strict requirements of API 15S.

Some of the specific tests in Flexpipe’s testing program are listed in Table 6. These tests have resulted in a comprehensive base of knowledge about product performance under a wide variety of service conditions.

Table 6: Pipe and Fitting Tests

Test description
Regression pressure testing
Elevated temperature pressure testing
Low temperature pressure testing
Minimum bend radius pressure testing
Short term burst pressure testing
Cyclic pressure testing
Respooling preconditioning
Axial load testing
Rapid gas depressurization
Impact resistance testing
Thermal expansion & pressure-expansion testing
Solar radiation resistance
Thermal cycle testing
External load testing
Corrosion testing - for steel cords

5 Performance

5.1 Applications & Chemical Compatibility

The information in this section is intended to provide an understanding of the suitability of the products for a wide range of common applications. For these or other applications, Flexpipe's engineering team will be pleased to evaluate the application and provide general guidance regarding compatibility of Flexpipe Spoolable Products.

5.1.1 Application Evaluations

Flexpipe has established a systematic process to evaluate proposed applications in order to compare conditions with the normal operational limits given in the following sections. These limits are intended to provide a consistent and conservative basis to potential applications.

Application evaluations are provided by the Flexpipe Engineering team as a service to clients. Each evaluation assesses the details of a proposed application to identify potential risks and determines specific measures that can be taken to eliminate or minimize them. Recommendations resulting from these evaluations have allowed many projects to successfully take advantage of the full capabilities of Flexpipe Spoolable Products. Flexpipe believes that this approach reflects its commitment to public safety and has contributed to its outstanding service record, while allowing it to meet the unique needs of its clients. In order to maintain the above commitments, Flexpipe reserves the right to not ship pipe until an application review has been approved and attached to the sales order.

5.1.2 Gas

Flexpipe has a strong historical record in gas applications. There is no requirement to further de-rate the Flexpipe MAOP in gas applications (see Section 5.2 for determination of pressure ratings). Suitable environments include natural gas, solution gas, and fuel gas. Flexpipe Spoolable Products can also be used in sour (H_2S) applications, but limits apply. Please refer to Section 5.1.5 for more details. See Section 5.1.6 for information on CO_2 applications.

For gas applications in which condensates can form, a suitable pigging program should be implemented to prevent condensate buildup at low points along the pipeline.

Clause 13.1 of CSA Z662 limits the allowable design pressure for RTP gas pipelines to a maximum of 9930 kPa (1440 psi).

5.1.3 Oil

Flexpipe Spoolable Products are suitable for oil emulsion or oil transfer applications and are fully piggable. For applications with high wax content, suitable pigging programs should be in place. Please refer to Section 7.2 for more information on pigging.

5.1.4 Water

Flexpipe Spoolable Products are an excellent option for oilfield water applications such as water transfer, frac water movement, disposal, and injection lines. However, these applications often involve cyclic pressure variations, and should be evaluated for compatibility. Please refer to Section 5.3 for more information on cyclic pressure applications.

5.1.5 H_2S

H_2S (hydrogen sulphide, also known as sour gas) is a toxic and potentially lethal substance commonly found in oilfield media. Accordingly, a greater risk exists in routine pipeline inspection or maintenance, or in the event of fluid release due to pipeline damage.

Non-metallic pipelines may allow some of the transported medium to absorb into and permeate through polymeric materials. The potential exists for this absorbed and permeated medium to accumulate to hazardous levels within the pipe material or fitting system. Accumulated H_2S may be released during pipeline work. Examples of work include external damage, tie-ins, repairs, and removal of external tape and insulation from fittings.

Flexpipe Spoolable Products are designed to vent gases that permeate through the liner. Permeated gases travel via the annulus reinforcement layer and are released at the fittings through a vent hole in each fitting. Permeated gases may also be released along the length of the pipeline (see Section 5.10).

Similar to other piping components in sour gas service (threaded fittings, gaskets, packing), due consideration should be given to the potential accumulation of H_2S around the vent hole of the Flexpipe fittings. Please refer to the *Flexpipe Sour Service Pipeline Bulletin*, available from the Flexpipe website, for more information.

Non-metallic pipelines may be more susceptible to external damage than metallic pipelines. Damage to or misuse of Flexpipe Spoolable Products may result in uncontrolled release of the H_2S containing medium being transported, which may result in serious injury or death. External forces, both during installation and during future disturbance or construction in the area, are potential causes of external damage to pipelines.

FP and FP HT are compatible with H_2S. Flexpipe chooses to limit H_2S content of up to 10% by mol in the gas phase of liquids (oil and/or water), gas, or multiphase. CSA Z 662 Clause 13.1 limits the partial pressure of H_2S in gas to 50 kPa (7.25 psi) for all composite pipe used in sour gas applications. Applications above 10% are evaluated on a case by case basis[12]. FC is suitable for the transport of liquids (oil and/or water), gas, or multiphase with up to 3000 ppm of H_2S. This limit has been established by extensive corrosion testing on the steel cord reinforcements of the FC product and has been approved by an independent third party engineering firm.

[12]The AER (Directive 71) requires calculation of H_2S release volumes for multi-phase pipelines.

5.1.6 CO_2

Flexpipe Spoolable Products can be used for gases or liquids containing up to 100% CO_2 by volume. The suitability for CO_2 service has been confirmed by rapid decompression testing. The standard 75 Durometer FKM O-rings are suited for a wide range of CO_2 applications. For applications having higher than 10% CO_2 and operating at pressures above 750 psi, Flexpipe recommends the use of special O-rings that provide superior performance for these conditions. Refer to Section 3.5 for further information on the fitting corrosion resistance.

5.1.7 Aromatic and Cycloalkane Hydrocarbons

Flexpipe Spoolable Products are compatible with aromatic and cycloalkane hydrocarbons (e.g., benzene, toluene, ethyl benzene, xylene, naphthalene, and cyclohexane) in gas or liquids. Table 7 lists the allowable aromatic and cycloalkane concentrations for normal operating pressures, based on Flexpipe test data.

Table 7: Allowable Aromatic and Cycloalkane Hydrocarbon Content

Product Line	Operating temperature	Maximum allowable aromatic and cycloalkane content (by volume)
FP and FC	60˚C (140˚F) or below	50%
FP HT	82˚C (180˚F) or below	50%

5.1.8 Chemical Injection

Common injection chemicals used in the oil gathering industry, such as corrosion inhibitors, biocides, paraffin dispersants, surfactants, scale inhibitors, defoamers, and demulsifiers, are not considered problematic to the HDPE liner. Flexpipe recommends that chemical injection programs use dilute concentrations or batch treatments, as per the standard practice for HDPE applications as set out by the chemical manufacturing company.

Injection chemicals which are made up from aromatic and cycloalkane hydrocarbons are acceptable for use with the HDPE liner provided the concentration of the injection chemicals is controlled such that the aromatic and cycloalkane concentration stays within the limits listed in Table 7 as applicable for the pipe service temperature. Any higher concentration batch treatment process should be of limited duration as recommended by the injection chemical manufacturer for use in HDPE pipe or Flexpipe fittings.

This section addresses only the more common injection chemicals used in the oil gathering industry. Due to the variety of injection chemicals available, however, Flexpipe recommends that the pipeline operating company develop an injection program in conjunction with the chemical manufacturing company to ensure there are no chemical compatibility concerns with HDPE or Flexpipe fittings.

5.1.9 Methanol and Ethylene Glycol

HDPE has good resistance to concentrated methanol and ethanol at temperatures up to 60˚C (140˚F). Alcohols may be used in Flexpipe Spoolable Products during hydrotests to prevent freezing. They may also be used in FP and FP HT in batch programs. Due to the possible introduction of oxygen with alcohols, continuous injection of alcohols in FC is not recommended. Continuous injection of alcohols with FP and FP HT should be evaluated by the end user for compatibility with the metallic fittings.

5.2 Pressure and Temperature Ratings

5.2.1 Maximum and Minimum Allowable Operating Temperature

The Maximum Allowable Operating Temperatures (MAOT) and minimum allowable operating temperatures for Flexpipe Spoolable Products are indicated in Table 8. These temperatures have been proven by the successful completion of the required qualification testing and the positive track record of field applications.

Table 8: Maximum and Minimum Allowable Operating Temperatures

Product Line	Maximum Allowable Operating Temperature		Minimum Allowable Operating Temperature (Standard O-rings)		Minimum Allowable Operating Temperature (Alternative LT O-rings, Standard for Canadian Applications)	
	(˚C)	(˚F)	(˚C)	(˚F)	(°C)	(˚F)
FP	60	140	-10	14	-29	-20
FP HT	82	180	-5	23		
FC	60	140	-10	14		

Note: LT O-rings are supplied as standard for all Canadian applications.

Flexpipe Spoolable Products have excellent impact resistance properties and do not become brittle at low temperatures. Flexpipe Spoolable Products can be installed at temperatures lower than 0˚C (32˚F). Refer to the Flexpipe Installation Guide for cold temperature installation limits, fittings materials selection, and starting up pipelines at low temperatures.

5.2.2 Maximum Allowable Operating Pressures

The Maximum Allowable Operating Pressures (MAOP) are shown in Table 9. These pressures have been established by performing the qualification testing at the MAOT of each product line.

Table 9: Maximum Allowable Operating Pressure

Maximum Allowable Operating Pressure*								
Product Line	**150**		**301**		**601**		**901**	
	(kPa)	**(psi)**	**(kPa)**	**(psi)**	**(kPa)**	**(psi)**	**(kPa)**	**(psi)**
FP	*2,068*	*300*	*5,171*	*750*	*10,342*	*1500*		
FP HT	*2,068*	*300*	*5,171*	*750*	*10,342*	*1500*		
FC							*15,513*	*2,250*

*Check if your local regulation has a limit on the maximum allowable operating pressure, as it may be lower than the Flexpipe Spoolable Products maximum allowable design pressure.

5.2.3 Calculations for Determining Maximum Allowable Operating Pressure

The MAOP listed in Table 9 for FP and FP HT has been determined by the following calculations as per API 15S:

$MPR = LCL_{RCRT} \times F_d$
$NPR \leq MPR$
$MAOP = NPR \times F_{fluid}$

Where:

MAOP = Maximum Allowable Operating Pressure
MPR = Maximum Pressure Rating
NPR = Nominal Pressure Rating
LCL_{RCRT} = Lower Confidence Limit, Regression Curve Reference Time
F_d = Design Factor
F_{fluid} = Service Fluid Factor

The Maximum Pressure Rating (MPR) has been determined at the qualification temperature and reference time (175,000 hours/20 years) for the pipeline in accordance with API 15S and includes the required Design Factor (F_d). The chosen Nominal Pressure Rating (NPR) must be equal to or less than the MPR.

The Service Fluid Factor (F_{fluid}) is the factor intended to provide additional protection based on consequence and not fluid compatibility. This factor is applied to the NPR to determine the MAOP at the qualification temperature.

The procedure utilized to establish the MAOP of FP and FP HT is illustrated in Figure 4, where data from multiple long-term pressure tests are plotted on a log-log graph. The

MPR is derived using statistical calculations and includes a Design Factor (F_d) which is the factor intended to account for normal variations in materials, manufacturing, and installation, to ensure that these variations do not cause the pipe's actual capabilities to be exceeded. Flexpipe uses an F_d = 0.67, as per API 15S.

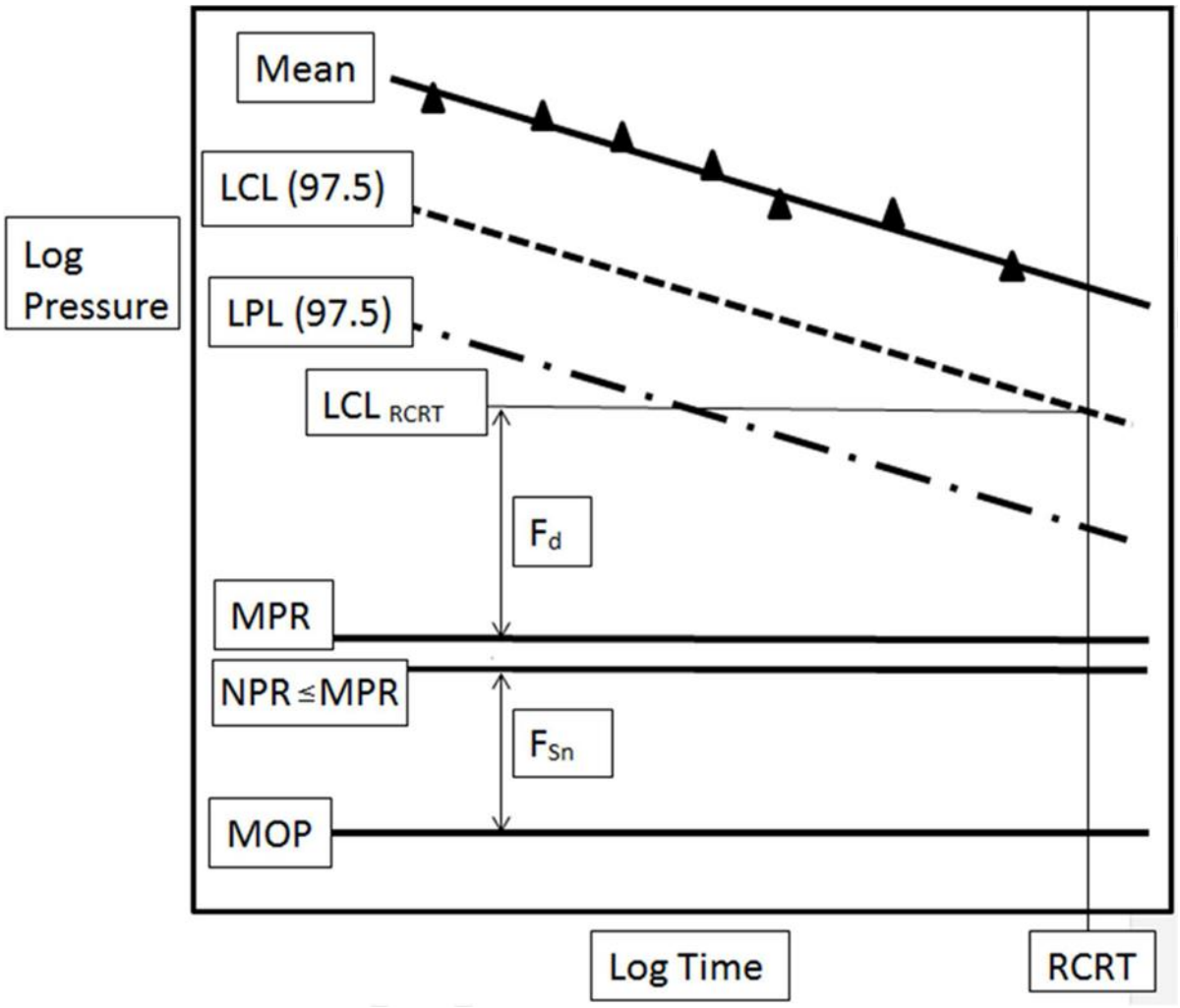

Figure 4: Illustration for Determining MPR and MOP[13]

Flexpipe FP and FP HT Products have been designed using an F_{fluid} = 0.67. This value allows a consistent MOP for all types of fluids. It meets the API 15S and CSA Z662 requirements for gas and is more conservative than these requirements for other services.

Flexpipe Spoolable Products are suitable for use in cyclic applications and have been tested using the test methodologies of API 15S.

[13] API SPEC 15S Spoolable Reinforced Plastic Line Pipe.

The FC Maximum Pressure Rating is determined in accordance with API 15S. Table 9, includes the use of the required design factors, and considers the effects of the transported medium on the material properties. Accordingly, and in line with CSA Z662, FC's MAOP has been determined using a Fluid Factor (F_{fluid}) of 1.0 for all service fluids shown in Table 13.1 of CSA Z662.

Because Flexpipe's MAOP already includes the required design and fluid factors, Flexpipe Spoolable Products can be operated in the field at pressures up to the MAOP published by Flexpipe.

The effect of pressure cycling (i.e., cyclic pressure service factor F_{cyclic} of CSA Z662) is taken into account during the application evaluation conducted by Flexpipe on a project by project basis. The amplitude of the pressure fluctuations that the system will see under typical operating conditions is compared to the cyclic test data generated by Flexpipe during laboratory testing, and a safe cycling frequency is determined. A Cyclic Pressure Service Factor (F_{cyclic}) of 1.0 has been used to determine the MAOP values shown in Table 9.

5.3 Cyclic Pressure

To ensure the optimal performance and reliability of Flexpipe Spoolable Products, consideration must be given to the cyclic pressure characteristics of the operating regime.

As part of Flexpipe's commitment to quality and customer satisfaction, an application evaluation process is required to ensure optimal performance of the product. The pipeline end user provides the operating parameters as per the Application Review Form for assessment. Flexpipe applications engineers provide project specific recommendations regarding selection of the best product and operational considerations for the intended application. The recommendations of an application review are based on a minimum 20 year service life. The end user is responsible for performing a thorough engineering and design review to ensure they are meeting applicable pipeline regulations.

The key parameters that influence the selection of the pipe type for a cyclic service application are:

- Type of pump: The pump type plays a major role in determining the cyclic characteristics of a pipeline system. Pumps can be generally divided into pulsating and non-pulsating types.
    - Most pulsating pumps are of the reciprocating positive displacement type, such as Triplex, Quintuplex, and Diaphragm pumps. These pumps generate a pulsating flow and pressure output as a result of their back and forth mechanical action. A peristaltic pump is also a pulsating pump. Standard industry practice estimates the working peak-to-peak amplitude of high-frequency pulsations to be 10% of the mean pressure value. To protect Flexpipe Spoolable Products from progressive damage, effective pulsation dampeners are required at the pump inlet and outlet, which are typically

designed to limit peak to peak amplitude to 3% of the operating pressure. In addition, a minimum of 100 feet of steel pipe between the pump and the pipe is required to assist with vibration dissipation.
    - Non-pulsating pumps such as centrifugal, progressive cavity, screw, and gear, are characterized by their rotating mechanical action resulting in a smooth flow and pressure output.
    - Pump Jacks are a unique type of positive displacement pump and are considered separately below.

- Pressure fluctuations:

    - Pump start/stop cycles where the pressure in the pipeline system cycles between the operating pressure and the shut off pressure
    - Typical pressure changes during operation
    - Modifications to the system operation or layout, such as operating an additional pump or injecting into a different well
    - Flexpipe Spoolable Products have the capability to handle infrequent pressure excursions up to the pipe MAOP as shown in Table 9.

Depending on their magnitude and frequency, pressure pulsations and fluctuations could be detrimental to the pipe performance. Contact your Flexpipe representative for a project specific application evaluation.

5.3.1 FP Cyclic Capabilities

Applications with non-pulsating pumps can be operated at the full FP pressure rating, as this type of pump provides a steady pressure output free of high frequency pressure pulsations or excessive vibration. Additionally, FP can handle mild pressure fluctuations and these applications need to be evaluated on a case-by-case basis using the Flexpipe application review process.

Applications with pulsating pumps can be detrimental to many pipeline materials. It is required to maintain the peak-to-peak amplitude of high-frequency pressure pulsations below 15 psi for FP301 and below 25 psi for FP601.

For all application types and in order to eliminate large amplitude pressure fluctuations resulting from pump on/off cycles, Flexpipe strongly recommends using a variable frequency drive (VFD) to regulate the flow rate while maintaining continuous operation of the pump, and to provide a soft start/stop whenever the pump shuts down.

5.3.2 FP HT Cyclic Capabilities

FP HT has reduced performance in cyclic applications but is otherwise similar to FP.

It is required to maintain the peak-to-peak amplitude of high-frequency pressure pulsations below 10 psi for FP301HT and below 20 psi for FP601HT.

5.3.3 FC Cyclic Capabilities

FC is suitable for service in systems subject to severe cyclic pressure conditions with either pulsating or non-pulsating pumps. FC is adequate for use with pulsating pumps operating at pressures up to 15,513 kPa (2,250 psi) and peak-to-peak pressure pulsations of up to 1,551 kPa (225 psi). Pulsating pumps can generate large peak-to-peak pulsations well in excess of 225 psi.

FC is also suitable for applications with large amplitude pressure cycles of up to 10 cycles per day of 0 – 10,342 kPa (0 - 1,500 psi), 1 cycle per day of 0 – 13,790 kPa (0 – 2,000 psi), or 4 cycles per week of 0 – 15,513 kPa (2,250 psi) based on a minimum service life of 20 years.

5.3.4 Pump Jacks

To ensure the optimal performance and reliability in pump jack applications, consideration must be given to the cyclic pressure characteristics of the system design and the operating regime.

In general, using sound system design and good industry operating practices will optimize the integrity and life of all production equipment. The pressure differential between the upstroke and downstroke pressures generated by the operation of the pump jack is of critical importance to the long-term integrity of the Flexpipe Spoolable Product.

Some of the design and operational factors that can affect the magnitude of the pressure differential in the flow line include:

- Length and diameter of the flow line
- Production volumes
- Production fluid properties
- Down hole pump integrity
- Wax build-up
- Flow line check valve integrity
- Hot oiling and pigging practices

For FP and FP HT applications with upstroke pressures below 150 psi, it is required to routinely monitor the pressure profile to ensure the upstroke and downstroke pressures stay within the allowable 100 psi differential pressure for FP601, 75 psi differential pressure for FP301 and FP601HT product, and 50 psi differential pressure for FP301HT. For example, if the normal upstroke pressure in an FP301 flow line is 150 psi, the

minimum pressure during the downstroke should be no less than 75 psi. Infrequent pressure excursions beyond these limits are generally acceptable.

For FP and FP HT applications with upstroke pressures between 150-250 psi, it is required to routinely monitor the pressure profile to ensure the upstroke and downstroke pressures stay within the allowable 75 psi differential pressure for FP601, 50 psi differential pressure for FP301 and FP601HT product, and 30 psi for FP301HT. Infrequent pressure excursions beyond these limits are generally acceptable.

Contact Flexpipe engineering for additional guidance regarding FP and FP HT applications with upstroke pressures above 250 psi.

FC is suitable for use in pump jack applications with severe pressure cycling parameters. It is required to routinely monitor the pressure profile to ensure the upstroke pressure stays within the allowable 500 psi differential pressure for FC901 product.

These recommendations are based on both qualification test results and field experience. They provide safe operating limits based on a minimum design life of 20 years. In order to ensure the long-term integrity of the piping system,

- Flexpipe recommends:
    - Installing and maintaining a pressure switch (such as a Presco switch) set at a maximum of 100 psi above the upstroke pressure to limit the possibility of subjecting the pipeline to excessive pressure swings for extended time durations.
    - Routinely monitoring the upstroke and downstroke pressure values using a calibrated pressure gauge mounted between the well head and the flow line.
- Flexpipe requires:
    - If wax or scale buildup is expected, to pig the line often enough, or use a wax dispersant program, to avoid having the normal operating pressures increase to the point of exceeding the guidance provided for the pressure differential between the upstroke and downstroke as a result of a reduced pipe cross section.
    - The use of properly maintained check valves to minimize the pressure fluctuation in the flow line.

5.4 Flow Characteristics

5.4.1 Pipe Flow

Relative to bare steel pipe, the smooth internal surface of Flexpipe Spoolable Products polyethylene liner provides favorable flow rates and reduced pressure losses as a result of reduced friction. Figure 5 and Figure 6 show representative pressure drops at various flow rates for salt water and methane @ 20°C (68°F), respectively. The results shown are based on calculation of the pressure drop for the given fluid in each size of the product using the Darcy-Weisbach method. The pressure drop for a given flow rate in the line will be significantly lower than for the similar ID steel pipe, as the surface of the steel can become rougher over time due to corrosion and scale buildup. Conversely, a higher flow rate can be attained for a given pressure drop using Flexpipe Spoolable Products.

For other flow scenarios, the pressure drop can be calculated using any of the flow coefficients listed in Table 10.

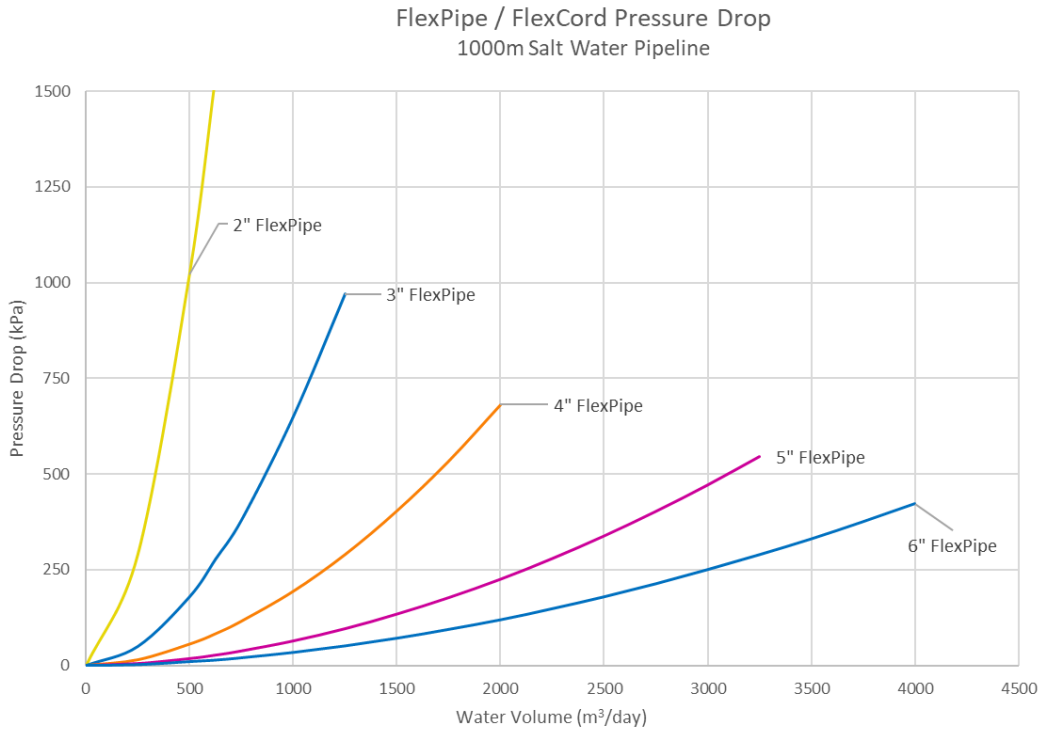

Figure 5: Flexpipe and Flexcord Pressure Drop Values for Sea Water
*Calculations based on 1000 meter of pipe length, with sea water at 20˚C (68˚F)

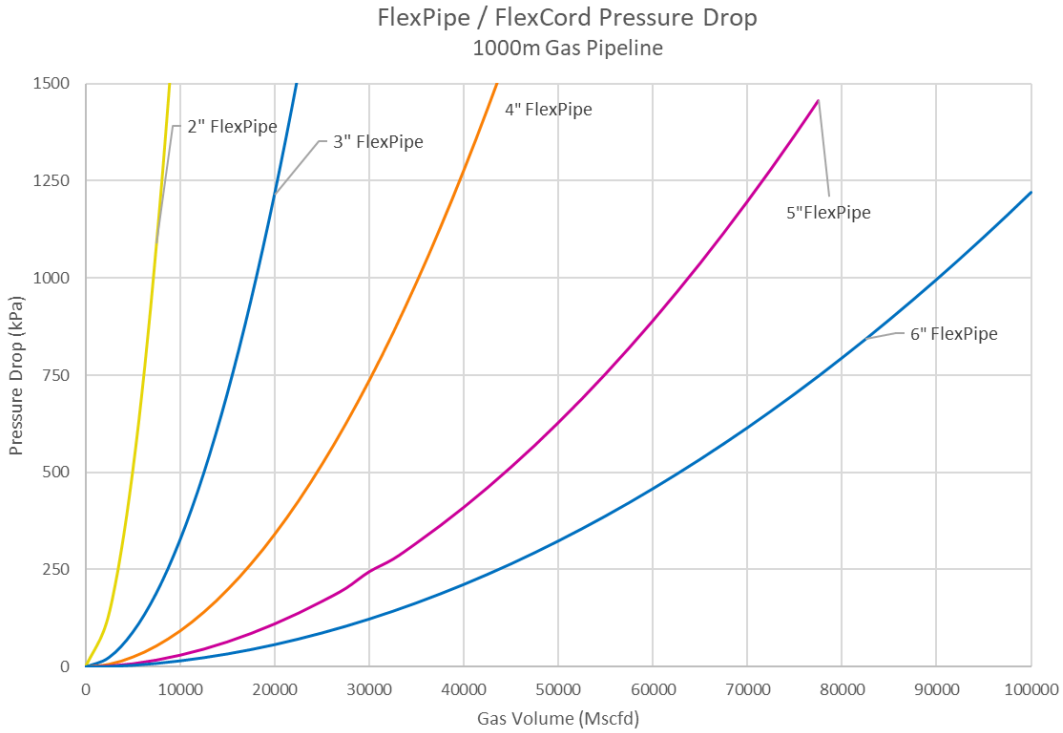

Figure 6: Flexpipe and Flexcord Pressure Drop Values for Gas
*Calculations based on 1000 meter of pipe length, with methane at 20˚C (68˚F) compressed to 1000 psi

Table 10: Flow Coefficients for Flexpipe Spoolable Products

Hazen & Williams	*150*
Darcy Weisbach	*0.0015 mm (0.000005 ft)*
Manning	*0.009*

5.4.2 Fittings

The inside diameter of the mandrel of the pipe fitting is smaller than the inner diameter of the pipeline (see Section 3.2). However, the restriction is minimal, and very few fittings are required even for very long lengths of pipe. The associated pressure loss is negligible compared to the pipe friction discussed above.

The following equations and K factors for Flexpipe coupling fittings can be used to calculate the loss in pressure or pressure head due to the flow constriction.

Pressure loss: $$\Delta P_{fitting} = K \frac{\rho V^2}{2}$$

Pressure head loss: $$h_{fitting} = K \frac{V^2}{2g}$$

Where:
ρ = fluid density
V = fluid velocity
g = acceleration due to gravity
K = factor from Table 11

Table 11: K Factor for Flexpipe Spoolable Products Coupling Fittings

Fitting size	K factor
2”	0.56
3”	0.55
4”	0.33
5”	0.34
6”	0.31

5.5 Durability

Flexpipe Spoolable Products are a durable, rugged product. The high-strength, pipe-grade thermoplastic used in the jacket protects the reinforcement from the environment. The jacket is highly resistant to cracking, and will not bruise, chip, or flake under normal handling. If the terrain is generally acceptable for steel pipelines it will be acceptable for Flexpipe Spoolable Products.

Impact testing according to API 15S at -25°C (-13° F) has demonstrated a high level of resistance to impact loading from normal handling and installation activities.

Flexpipe also tested a variety of its products to determine their ability to withstand exposure to an intense, fast moving brush wildfire. The test samples were exposed to a simulated intense, fast moving brush wildfire for three minutes and allowed to self-extinguish (burn until no flame was visible). FP601 and FP601 HT successfully held internal pressure until all flames self-extinguished. The FP601 and FP601 HT products were then pressurized to the 1,500 psi MAOP pressure and successfully passed this test. Finally, the FP601 and FP601 HT samples were burst at as much as 2.5 times MAOP.

5.6 Corrosion

Flexpipe Spoolable Products liner and jacket will not corrode. See Section 3.5 for a discussion on fitting corrosion protection.

FC is intended for applications where lined steel is typically specified and is expected to perform corrosion free.

5.7 Erosion

Flexpipe Spoolable Products will experience less erosion than steel in wet slurry applications (i.e., solid particles carried in a liquid) due to the elasticity and toughness of the liner material. However, a sufficient flow velocity should be maintained to prevent solid particles from settling out of the carrying liquid. Settled particles that slide along the bottom of the pipe may cause wear to the bottom surface.

To evaluate the erosion wear performance, the liner materials of Flexpipe Spoolable Products were subjected to Flexpipe’s internal slurry jet erosion testing. The test was conducted with a slurry (1:10 silica to water by weight) velocity of 10 m/s at a 90° impingement angle for 7 hours in room temperature on triplicate samples. The erosion

test results were then compared with similar test done on steel for two hours (See Figure 7).

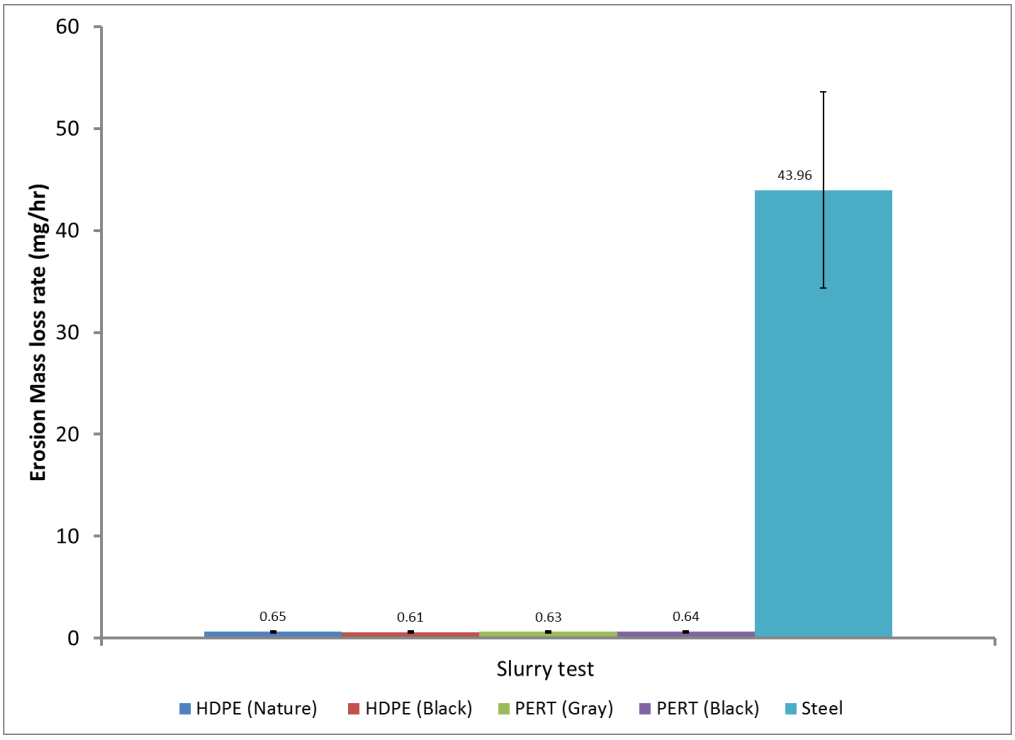

Figure 7: Erosion slurry test

Dry slurry applications (i.e., solid particles carried by a gas) may cause excessive static electricity build-up and/or heating due to dry particles sliding on the surface. Flexpipe Spoolable Products may not be suitable for dry slurry applications. Please contact your Flexpipe representative to conduct an application evaluation for your project in this case.

5.8 Ultra-Violet Protection

The outer jacket of Flexpipe Spoolable Products are designed to withstand weathering effects due to solar heating and ultraviolet (UV) radiation. The outer jackets of all Flexpipe Spoolable Products provide a minimum of 20 years protection against UV exposure.

To verify the UV life, samples were subjected to an accelerated weathering exposure according to the standard ASTM G155/ASTM D2565. The accelerated UV exposure test ran continuously to simulate 20 years of equivalent Florida conditions. The exposed specimens were removed for mechanical testing and the results were plotted in a semi-log scale to allow evaluation of the mechanical integrity of the polymer samples after 20 years of simulated service life. The results met the requirement criteria that the tensile samples when elongated, should retain 50% of original (i.e., unexposed) elongation at break after their anticipated design life.

5.9 Bend Radius

The minimum allowable bend radius of Flexpipe Spoolable Products differs in operation (pressurized) and transport/handling (un-pressurized) conditions, as shown in Table 12.

Table 12: Minimum Bend Radius for Operation, Transport and Handling

Flexpipe Spoolable Products	Minimum bend radius OPERATION		Minimum bend radius TRANSPORT & HANDLING	
	(m)	(ft)	(m)	(ft)
2”	1.2	4.0	0.8	2.5
3”	1.8	6.0	1.0	3.3
4”	2.1	7.0	1.3	4.2
5”	3.05	10	1.4	4.5
6”	3.4	11	1.6	5.2

Note: The minimum radius does not apply to fittings/couplings. These joints need to be kept straight to avoid point loading at the end of the fitting. Typically, there should be no bends within 1 meter (3 feet) from a fitting.

5.10 Permeation

Gas molecules are able to travel very slowly through pipe walls by moving through the spaces between the molecules of the pipe material. This is known as permeation. All piping materials allow gases to permeate to some extent, but composite materials allow more than steel pipes do. In rare cases permeation through the pipe can react with elements in the soil which can lead to discoloration of the surrounding soil or pipe jacket.

Flexpipe Spoolable Products have a self-venting design which allows permeated gases to vent at the fittings. This prevents or reduces the pressure from building up within the annulus (the space between the liner and jacket that contains the reinforcement layer), thereby lowering the risk of liner collapse during line depressurization. Wherever it is desired to avoid venting permeated gas above grade, Flexpipe offers fitting options where the vent hole can be connected to a venting system. In such installations, evaluation by Flexpipe Engineering will be needed to determine the optimal distance to a vent location from the vented fittings to provide the pipeline with adequate venting capability. See Section 7.4 for depressurization guidelines.

The following calculations are based on a conservative model, in which the gases in the pipe permeate through the liner and then permeate through the jacket or travel along the annulus to exit through the vent hole at the fitting. The calculations use the permeability coefficients given in Table 13, which are experimentally determined from testing conducted on unreinforced polyethylene. The following example provides a representative illustration of the extent of permeation in Flexpipe Spoolable Products.

Table 13: Permeability Coefficients

Permeant	HDPE Permeability coefficient at 60˚C (140˚F)		PERT Permeability coefficient at 82˚C (180˚F)	
	(cm^3/cm-sec-MPa)	($inch^3$/inch-sec-psi)	(cm^3/cm-sec-MPa)	($inch^3$/inch-sec-psi)
Methane	2.23×10^{-7}	2.38×10^{-10}	6.64×10^{-7}	7.10×10^{-10}
H_2S	2×10^{-6}	2.14×10^{-9}	4.91×10^{-6}	5.25×10^{-9}
CO_2	8.43×10^{-7}	9.01×10^{-10}	2.01×10^{-6}	2.15×10^{-9}

Flexpipe Spoolable Products liner has a similar DR (Dimension Ratio) in all sizes, which results in similar permeation rates for all sizes. Table 14 shows expected permeation rates for a gas mixture of 89% methane, 1% H_2S, and 10% CO_2. To obtain expected permeation rates at different temperatures, it can be approximated that a 5˚C (9˚F) decrease in temperature results in a 30% decrease in permeation rate. The values listed in Table 14 have been determined by the following equation:

$$q = \frac{PA(p' - p'')}{t}$$

Where:
q = Volume of gas permeating per unit length per unit time
P = Permeability coefficient from Table 13
A = Surface area per unit length of pipe
p' = Internal partial pressure
p" = External partial pressure
t = Wall thickness

Table 14: Representative Permeation Rates for Flexpipe Spoolable Products

		Permeation rate cm^3/m of pipe/day *(in^3/ft of pipe/day)*		
	Pipe pressure	**689 kPa (100 psi)**	**5171 kPa (750 psi)**	**10,342 kPa (1500 psi)**
FP/FC at 10°C (50°F)	89% methane	5 (0.1)	36 (0.7)	72 (1.3)
	1% H_2S	0.5 (0.009)	4 (0.07)	7 (0.14)
	10% CO_2	2 (0.04)	15 (0.3)	31 (0.6)
	Total mixture	7.5 (0.14)	55 (1.0)	110 (2.1)
FP/FC at 40°C (104°F)	89% methane	23 (0.4)	175 (3)	349 (6)
	1% H_2S	2 (0.04)	18 (0.3)	35 (0.7)
	10% CO_2	10 (0.2)	74 (1.4)	148 (3)
	Total mixture	36 (0.7)	266 (5)	533 (10)
FP/FC at 60°C (140°F)	89% methane	66 (1)	499 (9)	997 (19)
	1% H_2S	7 (0.1)	50 (0.9)	100 (2)
	10% CO_2	28 (0.5)	212 (4)	423 (8)
	Total mixture	101 (2)	760 (14)	1521 (28)
FP HT at 82°C (180°F)	89% methane	198 (4)	1484 (28)	2969 (55)
	1% H_2S	16 (0.3)	123 (2)	247 (5)
	10% CO_2	67 (1)	505 (9)	1010 (19)
	Total mixture	282 (5)	2113 (39)	4225 (79)

5.11 Expansion/Contraction and Axial Growth

Flexpipe Spoolable Products have been engineered to significantly minimize axial strain as a result of pressure or temperature changes in operation. Radial expansion will occur but will be far less than in unreinforced polyethylene.

When unpressurized, the product will display approximately the same amount of growth or contraction with temperature changes as unreinforced polyethylene. However, the low modulus and viscoelastic properties of the pipe allow it to shift and relax, thereby minimizing any loads exerted at end connections. Therefore, expansion loops and special consideration for end loads at termination points are not required*.

See Table 15 for expansion/contraction coefficients. The axial change can be expected to vary linearly with pressure.

Table 15: Axial Expansion/Contraction Coefficients

Product	Length Change at 1500 psi (%)	Pressurized[1] Linear Coefficient of Thermal Expansion ($m/m/°C x 10^{-6}$)	Unpressurized Linear Coefficient of Thermal Expansion ($m/m/°C x 10^{-6}$)
2” FP601	0.23	107	157
4” FP601	0.25	106	141
2”FP601HT	0.32	145	130
6” FP601HT	0.36	105	93

[1] *Pressurized to 2250 psi*

Sudden temperature and pressure changes should be avoided. Gradual or stepped flow increases should be used on very hot or very cold days to allow for gradual temperature and pressure changes in the system.

*When Flexpipe Spoolable Products are used as free standing liners, it is required to terminate the liner pull underground and provide a minimum of 7 meters of uncased buried length before bringing the pipe to surface. This ensures any expansion or contraction concentrated inside the existing casing is restrained by ground friction before coming to surface.

5.12 External Load and Internal Vacuum Capability

When the pressure outside the pipe may exceed the pressure inside the pipe, the pipe’s ability to withstand collapse should be considered. External pressure arises from factors such as ground water pressure and the weight of soil above the pipe. Additional loads (such as the weight of water or live loads due to moving vehicles) must be considered if the pipe runs through a bore, through a casing, below a vehicle corridor, etc. Internal vacuums may result from liquid flow down a slope when the pipeline is unpressurized.

The ability of the products to withstand collapse is based on the total difference in pressure between the outside and inside of the pipe. The net external pressure can be calculated as follows:

$$P_{net,external} = P_{external} - P_{internal}$$

$Where\ P_{internal}\ is\ a\ negative\ number\ (for\ an\ internal\ vacuum), P_{net,external}\ is\ increased$

Flexpipe Spoolable Products external pressure resistance for buried applications has been measured according to ASTM D2412[14]. The maximum long term net external load that the pipe can withstand at 23°C (73°F) is 214 kPa (31 psi), when installed in backfill embedment material with a soil modulus of 1000 psi or greater and an internal pressure of 0 psi. This includes most soils, with the exception of very fine-grained or organic soils such as muskeg and clay. If the total combination of dead loads, live loads, and internal vacuum will exceed this, the pipe should be protected by a steel casing**.**

When on the surface, inside of a bore, or casing there is no support from surrounding soil. Under these conditions, the pipe can withstand a net vacuum pressure of 101 kPa (14.7 psi) at 23°C (73°F), the maximum vacuum pressure that will be created due to gravity flow down slopes.

When boring Flexpipe Spoolable Products beneath large roads and rivers, it is sometimes required for the bore to be significantly deeper than standard boring. These bores, both cased and uncased, are likely to be filled with drilling mud or filled with ground water over time. This fluid within the bore or casing will exert an external load on the pipeline. Contact Flexpipe Engineering for additional external collapse pressure guidance when the installations are deeper than 15 feet. If the deep bored pipeline will be left empty and unpressurized for extended periods of time (i.e., one year), contact Flexpipe Engineering.

Higher temperatures or long term exposure to liquid hydrocarbons may reduce the net external load that the pipe can withstand. Flexpipe Spoolable Products are not intended for subsea applications.

[14]**ASTM D2412** *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading.*

5.13 Thermal Conductivity

Flexpipe Spoolable Products thermal conductivity properties result from the properties of the polyethylene and the reinforcement materials. Accordingly, Flexpipe Spoolable Products is a good thermal insulator with higher resistivity than metallic pipes. Table 16 lists the approximate calculated thermal conductivity and resistivity values of the FP and FP HT products. FC will have somewhat higher conductivity values than listed below. Contact Flexpipe for additional guidance. Laboratory testing of these values has not been conducted or confirmed.

Table 16: FP and FP HT Thermal Conductivity and Resistivity

Pipe Size	Product	Wall Thickness		K_{eff} (W/m*K)	$Resist_{eff}$ ($1/K_{eff}$)	K_{eff} (1/Resist_eff)	$Resist_{eff}$ (hr*ft*F/Btu)
		mm	in				
2”	FP301/FP301HT	7.75	0.305	0.29	3.41	0.169	5.901
	FP601/FP601HT	9.40	0.370	0.25	4.05	0.143	7.005
3”	FP150	9.14	0.360	0.36	2.78	0.207	4.819
	FP301/FP301HT	9.91	0.390	0.30	3.35	0.173	5.795
	FP601/FP601HT	11.94	0.470	0.25	3.97	0.145	6.875
4”	FP150	11.30	0.445	0.36	2.80	0.206	4.844
	FP301/FP301HT	12.57	0.495	0.30	3.36	0.172	5.819
	FP601/FP601HT	15.37	0.605	0.25	4.02	0.144	6.965
5”	FP301HT	16.33	0.643	0.29	3.51	0.165	6.072
	FP601HT	20.42	0.804	0.24	4.16	0.139	7.208
6”	FP301HT	18.87	0.743	0.28	3.51	0.165	6.075
	FP601HT	23.60	0.929	0.24	4.21	0.137	7.280

6 Installation

Flexpipe Spoolable products can be installed in a variety of ways including conventional trenching, plowing, liner pull, etc. This section provides a general overview of the installation processes. Detail and additional guidance provided in various bulletins and Installation Guide should be reviewed by the end user at the time of pipe ordering.

6.1 Field Services Support

The Flexpipe Field Services Department provides support services for the installation of Flexpipe Spoolable Products, including training courses, project coordination services, equipment rentals, onsite inspectors, and installation supervisors. Experienced managers and project coordinators are on call 24 hours per day, 7 days per week. Flexpipe strives to ensure successful installation of its products on every project.

Fitting installation equipment is available from Flexpipe for rental. Information on this equipment can be found in the Flexpipe Installation Guide. In addition, Flexpipe offers a variety of specialized installation accessories, including A-frames for carrying pipe reels, riser support trays, pull tools, custom cleaning pigs, moisture resistant Denso products, Polyken tape and sacrificial anode kits for cathodic protection. For more information on these accessories, see the Flexpipe Installation Guide.

6.2 Liner Pull Considerations

For liner pull applications, multiple influencing factors can affect the pipelines performance and should be considered when planning the installation. Severe slugging, water hammer, high fluid velocities, impact forces, muskeg/swamp soil conditions and thermal expansion should all be considered.

• Emulsion pipelines that are prone to severe slugging can lead to impact forces at changes in direction (e.g., riser and pipeline bends) and misaligned transitions.

• High velocities (i.e., more than 1.5 m/s (5 ft/s)) can lead to significant fluid impact forces at changes in direction and water hammer during pump start/stops. Significant impact forces may lead to damaging the pipeline.

• For operating temperatures above 30°C, thermal expansion can create additional changes in direction or bends in the pipeline (snaking or lateral movement). Thermal expansion will be uncontrolled when there is inadequate restraint at pipeline transitions and can lead to damaging the pipeline.

• Muskeg/swamp conditions may not provide the same amount of restraint as in other soil conditions due to the low soil modulus of the backfill material. Preventing operating conditions that may lead to impact forces and impingement at transitions are more critical in muskeg conditions. Bell holes and risers with muskeg/swamp conditions typically require additional restraint to prevent floatation and movement of the pipeline.

Proper support and restraint is required to limit movement of the pipeline due to the above influencing factors. For liner pull applications that combine all of the influencing factors listed above,

- installed in muskeg/swamp conditions,
- operated at high velocities and
- operated at temperatures above 30°C.

It is strongly recommended to limit the liquid velocity to a maximum of 1.5 m/s (5 ft/s) and the installation must provide adequate restraint at bell holes and riser transitions. Additional information on restraint can be reviewed in the Liner Pull Bulletin and Flexpipe Installation Guide.

6.3 Support Spacing

For elevated support of Flexpipe Spoolable Products, a continuous tray which is wide enough to allow for the expected thermal expansion and snaking is recommended. Flexpipe Spoolable Products may also be supported using individual (non-continuous) pipe supports or hangers, as long as the expected thermal expansion can be accommodated. The pipe should be allowed to rest in a rounded cradle, with a length approximately equal to or greater than the nominal diameter of the pipe being supported. Supports should have rounded edges that will not cut into the pipe.

In order to prevent excessive sag between supports, Flexpipe recommends spacing the supports no farther than the distances given in Table 17.

Table 17: Recommended Pipe Support Spacing for Flexpipe Spoolable Products

Pipe Size	Recommended maximum support spacing			
	Liquid service		Gas service	
	(m)	(ft)	(m)	(ft)
2”	1.1	3.5	1.2	4
3”	1.2	4	1.5	5
4”	1.5	5	1.7	5.5
5”	1.5	5	1.8	6
6”	2.4	8	2.9	9.5

6.4 Buoyancy and Pipe Weights

Flexpipe Spoolable Products will float in water or muskeg if not weighted or buried in a clay base. If conditions are suitable, the pipeline may be plowed into muskeg without weighting. The suitability of the conditions may be evaluated based on existing pipelines in the area and consultation with Flexpipe Engineering.

If there is a concern that the pipe may float, the pipe can be weighted during installation. The weights should not have sharp edges that could point-load or cut the protective jacket of the product. Sand-filled saddlebag weights are recommended.

When weights are used t is preferable to place them while the pipe is in the ditch, if this is not possible, it is extremely important that the pipe is handled and lowered into the ditch by lifting on the weights directly. Lifting on the pipe may cause the pipe to kink or be damaged by the weights.

The following formulas can be used to calculate the pipe buoyancy per unit length (note that some unit conversions may be required). To keep the pipe submerged, the sand bag weight per unit length must be slightly more than the buoyancy force per unit length. Note that there will also be a buoyancy force on the sand bags themselves, which is compensated for in the formulas below.

$$\text{Pipe cross} - \text{sectional area} = \text{OD}^2 \times \frac{\pi}{4}$$

$$\text{Weight of fluid displaced per unit length of pipe} = \text{Pipe cross} - \text{sectional area} \times \text{Fluid density}$$

$$\text{Net buoyancy per unit length of pipe} = \text{Weight of fluid displaced per unit length} - \text{Pipe weight per unit length}$$

Note that the pipe will sink if the net buoyancy is less than 0.

$$\text{Submerged sand bag weight required per unit length of pipe} = \text{Net buoyancy per unit length of pipe} \times 1.1$$

Flexpipe recommends multiplying by 1.1 to ensure the pipeline is adequately weighted to remain submerged.

$$\text{Weight of fluid displaced by sand bag} = \text{Volume of fluid displaced by sandbag} \times \text{Fluid density}$$

$$\text{Submerged weight of sand bag} = \text{Weight of sand bag in air} - \text{Weight of fluid displaced by sand bag}$$

$$\text{Sand bag spacing} = \frac{\text{Submerged weight of sand bag}}{\text{Submerged sand bag weight required per unit length of pipe}}$$

Note: The sand bag spacing should be small enough to prevent the unrestrained pipe between sand bags from rising too far

The recommended dry sand bag weight can be found in the Installation Guide.

6.5 Riser Supports

Flexpipe Spoolable Products may be terminated underground with either a flange or weld neck fitting. Alternatively, it can be brought to surface and supported by a metal support tray (riser support) mounted onto pilings. The purpose of the riser support is to prevent unnecessary shear or tensile loads on the pipe that could be caused by settling of backfill and earth movement. In particular, riser supports are recommended in locations where differential settlement from ground freezing or frost heaving is seen. For further information regarding risers see the Installation Guide.

The aboveground portion of the riser must be covered with insulation or white Polyken tape. Flexpipe Spoolable Products should be protected from mechanical damage similar to other piping materials above ground, depending on expected hazards in the area. Flexpipe Spoolable Products is a ductile material and can withstand reasonable impact even at low temperatures.

6.6 Tracer Wire

Flexpipe Spoolable Products are non-metallic. Therefore, tracer wire is required for buried installations to allow for future location of the pipe. The tracer wire should be installed simultaneously with the pipe and checked for electrical continuity immediately after installation. The wire termination points should be secured and clearly marked at readily accessible locations above ground.

6.7 Heat Tracing

Flexpipe Spoolable Products may be heated by means of a heat tracer wire to prevent freezing. However, the heat tracer must be separated from the pipe by an insulation barrier to prevent concentrated hot spots or over-heating of the jacket.

Flexpipe recommends a sandwich type insulated barrier with an insulation/heat-trace/insulation configuration, as shown in Figure 8. Because the pipe jacket material is a very poor thermal conductor, concentrated hot spots will appear directly below the heat tracing wire if an insulated barrier is not used.

The maximum operating temperature of FP and FC is 60˚C (140˚F). Therefore, it is very important to select the insulation thickness and the amount of heat tracing per unit length of pipe accordingly.

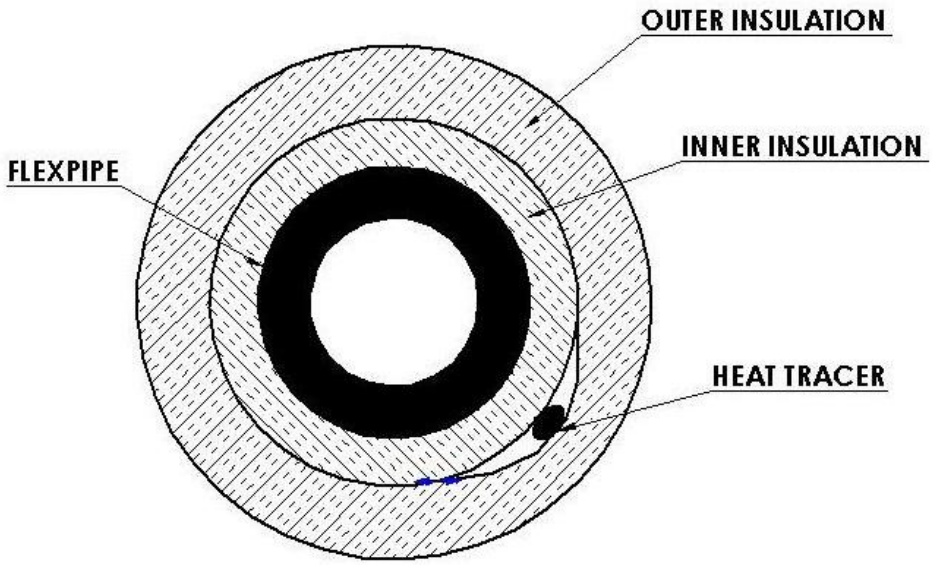

Figure 8: Sandwich Type Insulated Barrier Configuration

6.8 Cathodic Protection

Flexpipe Spoolable Products are corrosion resistant and do not require cathodic protection. Wherever regulations require cathodic protection for buried metallic fittings, Flexpipe can make available ribbon anode kits tailored for Flexpipe fittings. Further information is available in Section 3.5.

6.9 Field Pressure Testing of New Pipelines

Flexpipe Spoolable Products are designed to accommodate the pressure-testing requirements specified by regulatory standards and codes. Due to the safety factors built into the pipeline design, there is no need to upgrade to a higher pressure-rated pipe if testing is required above the stated MAOP. Field pressure testing requirements and recommendations for Flexpipe Spoolable Products depend on whether the pipeline is a new installation or a tie-in or repair job.

Flexpipe recommends that new pipelines that have not been placed in operation be subjected to a hydrostatic hold test at 1.25 x MAOP as shown in Table 19. Refer to Section 7.7 for hydrostatic testing of pipelines that have already been placed in operation.

Table 18: New Pipeline Hydrostatic Test Pressures and Durations

Pressure Rating	2,068 kPa (300 psi)	5,171 kPa (750 psi)	10,342 kPa (1,500 psi)	15,513 kPa (2,250 psi)
Flexpipe Grade	**150**	**301**	**601**	**901**
Product Line	**Hydrostatic test pressure and duration**			
FP	2,586 kPa (375 psi) / 8 hrs.	6,467 kPa (938 psi) / 8 hrs.	12,928 kPa (1,875 psi) / 8 hrs.	
FP HT		6,467 kPa (938 psi) / 8 hrs.	12,928 kPa (1,875 psi) / 8 hrs.	
FC				19,395 kPa (2,813 psi) / 8 hrs.

Check with local regulations to ensure required hydrostatic test pressures are met. **Flexpipe requires monitoring the system carefully to ensure that the pipeline does not exceed 1.5 x MAOP at any point along the pipeline including low points at any time during the hydrostatic test**.

Suggested procedures for pressure testing new pipelines are given in the Flexpipe Installation Guide and in the Field Pressure Testing of New and Existing Pipelines bulletin.

Pressure testing with a compressible or gas medium is acceptable however for safety reasons, the below conditions are strongly recommended for pressure testing with a gas medium up to 2900 kPa (420 psi). Pressure testing with air or gas above 2900 kPa (420 psi) is at the discretion of the engineering resources of the pipeline operating company, but must also consider the conditions listed below:

- It is not prohibited by local regulations or standards;
- Appropriate precautions are taken to protect the pipeline from damage and minimize the risks associated with a pressure test failure;
- Follow the company procedures and safety measures for air testing.

Pressure test failures involving compressible media such as air result in the sudden uncontrolled release of a great deal of energy, with the potential for property damage, personal injury, or death. Until a pipe line has successfully passed a pressure test it should be considered as high risk to have equipment and personnel near the pressurized pipe line.

Under no circumstances will Flexpipe be liable in any way for any loss, damage, or injury of any kind (whether direct, consequential, punitive, or otherwise) incurred as a result of the use of a gas medium for pressure testing.

To minimize the potential risk of injury or property damage in the unlikely event of a pressure test failure, a relatively incompressible liquid such as water is recommended as the pressurizing medium. Methanol is compatible with Flexpipe Spoolable Products and is commonly used as an additive to prevent water from freezing at low temperatures.

Where new Flexpipe pipelines have been hydrotested in sections or require repair after a successful hydrotest prior to operation, retesting of the entire pipeline system is not required after tying in provided:

- Pipe sections used for tie-ins, repairs, or replacement are pre-tested as per Table 19 where required by local regulations or standards.

- Joints of the tie-ins, repairs, or replacements are left exposed as the pipeline is brought into service and visually monitored for leaks for at least four hours, at the highest available operating pressure.

Note: Refer to Section 7.7 for hydrostatic testing of pipelines that have already been placed in operation.

7 Operations

7.1 Startup

In the case of large temperature differences between the pipeline and the conveyed fluid, startup procedures for Flexpipe Spoolable Products should include a gradual or stepped flow increase to allow for gradual temperature and pressure changes in the system. The system must be pressurized in a manner to prevent exceeding the MAOP, initiating water hammer, or creating uneven stress distributions due to rapidly changing pressures in the pipeline. It is recommended to pressurize the system at no more than 200 psi/minute. For depressurizations, line pressure should decrease at no more than 200 psi/minute in the case of a pump shut down or power loss.

There must be a mechanical protection device in place to prevent the line from being over pressured. A high-pressure shut-off should be installed and set to a pressure between the maximum typical operating pressure and the MAOP of the pipe. A pressure relief valve should be installed and set to relieve system pressure at no higher than the MAOP of the pipe. The set points of both devices should be inspected and recorded regularly (e.g., monthly). The devices should be function tested periodically (e.g., yearly).

Flexpipe recommends limiting the fluid velocity of liquids and gases to a maximum of 3 m/s (10 ft/s) and 30 m/s (100 ft/s), respectively. High liquid velocities (e.g., more than 1.5 m/s (5 ft/s)) can lead to water hammer and pressure spikes if there are changes in direction, rapid starts/stops, or valve open/close events. High gas velocities can lead to erosion and excessive pressure drop. To reduce the risk of flow related damage, it is recommended to:

- Monitor the flow so liguid velocities are below 1.5 m/s (5 ft/s).
- Reduce the severity of severe slugging and on/off cycles in general. The installation of a Variable Frequency Drive (VFD) is recommended to reduce the number of on/off cycles to as low as possible.
- Support and restrain the pipeline to reduce lateral and vertical movement.
- Terminate the pipeline below surface at each end and use steel pipe risers to bring the pipe to the facility. This removes a direction change within the composite pipeline (horizontal to vertical) and reduces the likelihood of damage caused by high liquid velocity (e.g., more than 1.5 m/s (5 ft/s)).
- Provide additional restraint for surface lines by adding dirt piles or sandbags at the entry and exit areas of any pipeline change of direction, and at each fitting.

7.2 Pigging

Flexpipe Spoolable Products are suitable for pigging. However, Flexpipe Spoolable Product fittings have an ID that is smaller than the ID of the pipe. To ensure proper pigging, the use of a medium-density foam bullet pig, or a Flexpipe disc (cleaning) pig is required. Any new pigging technology must be reviewed by Flexpipe Engineering prior to being used with Flexpipe Spoolable Products. Use of a pig not approved by Flexpipe could result in the pig becoming stuck in a fitting. Flexpipe supplies tags for installation on risers to warn operators of the temperature limitations of the pipe and pigging limitations.

Flexpipe recommends medium-density foam bullet pigs for dewatering and Flexpipe polyurethane disk pigs for removing wax build-up. The foam bullet pigs are also available with a polyurethane coated tip, which provides protection against damage during pigging operations. Ball pigs, brush pigs, or rigid pigs must not be used.

Flexpipe polyurethane disk pigs are designed specifically for Flexpipe Spoolable Products and offer more aggressive cleaning. However, a greater pressure differential is required to move them through fittings, and they require the presence of some liquid in the pipeline to provide lubrication. Polyurethane pigs are available from Flexpipe in a variety of durometers to suit different pigging requirements (see Table 19).

Table 19: Custom Polyurethane Disk Pigs

Size	Durometer	Color
2”	85	Yellow/Blue
	75	Green
3”	85	Yellow/Blue
	75	Green
	65	Purple
4”	75	Green
	65	Purple
5”	75	Green
	65	Purple
6”	75	Green

Note: Other pig styles having different durometers and lengths are also available. Check with your Flexpipe account manager.

Flexpipe polyurethane pigs cannot be used for threaded fittings and are not recommended for any T fittings or welded thin-wall elbows. They may be used with schedule 40 or 80 welded elbows (45° or 90°). If a pigging program is required on a Flexpipe line joining another line, Flexpipe recommends a y-lateral joint (see Section 3.1), oriented to allow the pig to enter the joint from one of the two arms and exit from the y-lateral. Bar-stops and long pigs should be used for custom flow joints that involve pigging. Pig launchers must be sized to accommodate the Flexpipe pig dimensions as indicated in Table 20.

Table 20: Flexpipe Pig Dimensions for Flexpipe Spoolable Products

Pipe Size (nominal)	Flexpipe Polyurethane Pig, Composite Pipe with Rear Cup (CPC) mm (in)		Flexpipe Polyurethane Pig, Composite Pipe (CP) mm (in)		Required pressure differential* kPa (psi)
(in)	Diameter	Length	Diameter	Length	Pressure
2”	N/A	N/A	57.15 (2.25)	95.25 (3.75)	138 (20)
3”	81.28 (3.2)	184.15 (7.25)	81.25 (3.2)	133.35 (5.25)	207 (30)
4”	104.14 (4.10)	228.60 (9.00)	104.14 (4.10)	165.10 (6.50)	276 (40)
5”	132.08 (5.20)	320.55 (12.62)	132.08 (5.20)	212.60 (8.37)	345 (50)
6”	154.94 (6.10)	327.66 (12.90)	154.94 (6.10)	218.44 (8.60)	414 (60)

Note: Required pressure differential is approximate and assumes the line is lubricated and pigged using a lower durometer pig. Higher durometers and wax build up may require higher pressure differentials.

7.3 Paraffin/Wax Removal

Flexpipe Spoolable Products can be hot oiled. For lines that operate above 700 kPa (100 psi), a minimum 700 kPa (100 psi) residual pressure must be maintained in the line during all stages of hot oiling. The bore pressure will prevent liner collapse due to pressure in the pipe annulus in gas or emulsion applications. If the line pressure will be dropped lower than 700 kPa (100 psi) use the depressurization guidelines noted below in Section 7.4.

For lines that operate below 700 kPa (100 psi) and 38°C (100°F), the line can be depressurized as needed during hot oiling. For applications with temperature above 38°C (100°F) follow the depressurization guidance noted below in Section 7.4

At the start of a hot oil treatment, use a maximum flow of 1.5 GPM for the first 10 minutes. After 10 minutes of operation hot oil flow can be increased as required.

Once hot oiling has been completed, pig the line with a Flexpipe urethane disk pig.

In addition, Flexpipe recommends limiting hot oiling temperatures to less than 60°C (140˚F) for FP Products, and 82°C (180°F) for FP HT Products. Contact Flexpipe Engineering to discuss the details of your hot oiling program.

For internal water jet cleaning of wax and deposits, Contact Flexpipe Engineering for additional guidance

7.4 Shutdown and Depressurization Procedures

Flexpipe Spoolable Products containing high pressure gas or CO_2 (including multiphase or liquid content, water, oil, CO_2 dense phase, etc) have the unique characteristic of having a high rate of gas permeation that is typical of a gas service.

Accordingly, in order to reduce the potential for liner collapse in these services at operating temperatures above 38 °C (100 °F), it is required to slowly depressurize the pipeline (i.e. no more than 500 psi per hour) to 100 psi and hold for a period of time as indicated below. This is to allow enough time for some of the gas in the annular space to vent out to the atmosphere, and to allow the pipeline to cool. For low pressure applications or where this hold period may be too operationally restrictive, contact Flexpipe for case-by-case guidance.

- 100 to 120 °F, hold at 100 psi for 1 hour
- 121 to 140 °F, hold at 100 psi for 2 hours
- 141 to 160 °F, hold at 100 psi for 8 hours
- 161 to 180 °F, hold at 100 psi for 24 hours

7.5 Static Electricity

Standard operating and maintenance procedures for handling non-conductive pipe and dissipation of static electricity apply when working with Flexpipe Spoolable Products. Static charge on a plastic pipe can be generated by friction during the physical handling of the pipe in storage, shipping, installation, and repairing operations. Also, flowing gas in an operational plastic pipe containing particulate matter in the form of scale, rust, or dirt, can generate static electricity. Other causes of static charge include gas flow disrupters such as pipe elbows, valves, reducers, and leaks.

Discharge of static electricity in the presence of a flammable gas-air mixture may cause an explosion or fire and result in property damage and/or personal injury. When conditions exist such that a flammable gas-air mixture may be encountered and static charges may be present, all company (pipeline operator, utility, contractor, etc.) procedures for static electricity safety and control should be followed, including procedures for discharging static electricity and personal protection. Information on handling static electricity in plastic pipelines is available in US Occupational Safety and Health Administration "Hazard Information Bulletin Static Electricity Buildup in Plastic Pipe"[15].

7.6 Secondary Excavations

Excavation near installed pipe is the most common risk to the integrity of Flexpipe Spoolable Products due to the potential for external damage. The preferred method for excavating buried pipe is hydro-excavation (hydrovac).

The following practices are recommended to minimize the risk of external damage to the pipe:

- Identify the location of the Flexpipe Spoolable Product using the tracer wire installed with the pipe.
- Where possible, depressurize the lines that will be excavated.
- Follow hydro-excavation procedures that comply with industry best practices for excavation of thermoplastic piping, including:
  - Use of protective tips (e.g., rubber, neoprene, etc.) on spray nozzles and suction hoses.
  - Use of multi-jet nozzles with diverging spray patterns; not oscillating, rotating, or converging pattern nozzles.
  - Continuous movement of the spray wand while excavating.
  - A distance of at least 12" between the spray nozzle and the pipe.
  - Spray pressures as low as practical and not above 1500 psi.
  - Water temperatures below 40˚C (104˚F).
- Inspect the exposed pipe thoroughly after the excavation is complete.
- Support the weight of exposed pipe at intervals of not greater than 3m (10 feet).
- Take appropriate precautions to avoid impact or sustained pressure from sharp or heavy objects.
- Exercise care during any mechanical excavation near Flexpipe Spoolable Products.

[15] https://www.osha.gov/dts/hib/hib_data/hib19880930.html

- Inspect all exposed Flexpipe Spoolable Products for external damage prior to backfilling.
- Replace any sections of Flexpipe Spoolable Products that are damaged during excavation.
- Use proper backfill procedures.

7.7 Field Pressure Testing of Existing Pipelines

When a cut out is replaced, a failure is repaired, or a tie-in is connected to a previously operating pipeline, the integrity of the new pipe section and the connections used to join or repair the pipeline is ensured by both of the following:

• The pipe section used for repairs, replacement or tie-ins is pre-tested as per Flexpipe Field Pressure Testing of New and Existing Pipelines Bulletin.

• The repaired, replaced, or connected section is left exposed as the pipeline is brought into service and visually monitored for leaks for at least four hours, at the highest available operating pressure.

Frequent hydrotesting of a pipeline after it has been commissioned into operation is not recommended. Hydro testing pipelines to a pressure greater than MAOP is generally only appropriate prior to a new pipeline being commissioned into operation, for infrequent integrity testing, or infrequent testing after repairs. Hydrotesting pipelines up to MAOP is typical after pipeline tie-ins, for frequent integrity testing, or when reactivating a shut-in pipeline. Contact Flexpipe Engineering for clarification as required.

8 Reliability

8.1 History

As of 2022, over 46,000 kilometers (28,500 miles) of Flexpipe Spoolable Products and 230,000 fittings have been installed throughout Western Canada, the United States, and internationally. Flexpipe Spoolable Products are currently in service carrying a wide range of liquid and gas media, at various operational temperatures and pressures up to and including the published limits. A number of different installation methods have been employed over a wide range of climate, soil, and terrain conditions.

Flexpipe Spoolable Products continuously meet the extensive challenges of operation in demanding applications and have earned an excellent record as high quality and dependable products in the field. This has been demonstrated through numerous evaluations of operating pipelines in a variety of applications.

8.2 Reliability Management

The reliability of Flexpipe Spoolable Products is dependent on the proper engineering, installation, and operation of the pipeline system. The end user is ultimately responsible for final design, material selection, installation, and operation of the pipeline system. Flexpipe provides guidance and recommendations to the end user for their evaluation regarding the design, material selection, installation, and operation of Flexpipe Spoolable Products.

8.3 Integrity Verification

Many operators elect to limit their integrity verification activities to an initial pressure test after installation. Some operating companies may choose to exceed normal industry practice by incorporating one or more of the activities listed below into their integrity verification activities, in line with their risk management strategies. It would typically be appropriate for an operating company to make use of the options below.

Integrity verification options for Flexpipe Spoolable Products include:

- Visual inspection of jacket. Where pipe is exposed above surface the jacket can be inspected for discoloration that may indicate UV degradation. Exposed pipe can also be inspected for damage and jacket breach.
- Visual inspection for corrosion of metallic fittings. The external condition of a fitting can be inspected by removing the petrolatum and pipeline tape. The condition of the interior coating of a flanged fitting can be inspected visually after unbolting the flanged connection. It is recommended that new gaskets and protective wrappings be used during reassembly. Visual inspection of the fittings should include installation quality such as open vent holes, proper crimping, etc.
- Gas detection testing. Fittings can be checked for leaks during operation using gas detection equipment.
- Integrity Pressure Testing. To verify the integrity of the pipe after a period of operation a pressure test may be conducted.
- Cut-out testing. A method for confirming pipe integrity is to remove a minimum of 3 samples of pipe, each approximately 8 feet in length and have these tested. Flexpipe offers integrity assessment testing and analysis of such samples.

The extent and frequency of the integrity testing program is to be determined by the end user.

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- Midland, TX
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9 Appendix

Product Data Sheets

Linepipe Designed to Withstand High Pressures and Corrosion

Constructed from a winning combination of high-density polyethylene, helically wound epoxy-free dry fiberglass and a protective outer jacket, Flexpipe products are safe to install thanks to smaller crew sizes and less heavy equipment requirements.

60°C - 82°F

(140°F - 180°F) Maximum Continuous Operating Temperature

1,500 psi

(ANSI 600) Maximum Operating Temperature

Applications:
Oil, gas, water H2S and CO2 (up to 100%)

Pipe Sizes:
2, 3, 4, 5 and 6”

Length Per Reel:
325 - 1,100 meters (1,066 - 3,610 feet)

Installation:
Trenching, plowing, chain ditching, surface lines, horizontal directional drilling (HDD), liner pulls (remediation)

Quick Installation & Total Life Cycle Costs

- ·Approximately a 50% reduction in installation crew size and up to 35% installation cost savings compared to a steel pipeline
- ·Impact-resistant design eliminates the need for sand packing
- 20-year UV life protects pipe while in service or storage

Expanded Operating Envelope

- Lower operating costs due to corrosion-resistant design
- Maximum operating temperature of 60° (140°F) or 82° (180°F)
- Flexpipe products are suitable for sour service applications
- Compatible with up to 50% aromatic and cycloalkane hydrocarbons
- HDPE liner provides excellent chemical resistance

Product Reliability & Safety

- Built to exceed the industry requirements of API, ASTM and CSA standards
- Connections are made with robust leak-free fittings, available in two corrosion-resistant material options
- Flexpipe products are abrasian-resistant, low friction and have higher flow rates compared to steel alternatives

Flexpipe® & Flexpipe HT™

The Mattr Difference

- In-house engineers dedicated to ensuring Flexpipe is suitable for your application to maximize service life
- Project planning, technical and field services support to ensure on-time delivery and world-class installation
- Contractor installation training allows customers better control over project timing, costs and completion

		FP301 / FP301HT					FP601 / FP601 HT				
		2”	3”	4”	5”	6”	2”	3”	4”	5”	6”
Pressure	*psi* *kPa*	750 5,171					1,500 10,342				
Temperature	*°C* *°F*	60 or 82 140 or 180				82 180	60 or 82 140 or 180				82 180
Outside Diameter	*mm* *in*	69 2.7	97 3.8	124 4.9	157 6.2	179 7.1	73 2,9	101 4.0	130 5.1	165 6.5	191 7.5
Inside Diameter	*mm* *in*	54 2.1	77 3.0	99 3.9	125 4.9	142 5.6	54 2.1	77 3.0	99 3.9	125 4.9	142 5.6
Pipe Weight	*kg/m* *lb/ft*	1.7 1.1	3.0 2.0	4.9 3.3	8.3 5.6	10.8 7	2.4 1.6	4.3 2.9	6.9 4.6	11.8 7.9	15.6 10.5
Weight - Full of Water	*kg/m* *lb/ft*	4.0 2.7	7.7 5.1	12.6 8.4	20.4 13.7	26.6 17.9	4.7 3.1	9.0 6.0	14.6 9.8	20.4 16.1	31.4 21.1
Operational MBR	*m* *ft*	1.2 4	1.8 6	2.1 7	3 10	3.4 11	1.2 4	1.8 6	2.1 7	3 10	3.4 11
Length/reel*	*m* *ft*	1,100 3,610	760 2,495	735 2,410	365 1,198	350 1,150	1,100 3,610	700 2,300	570 1,870	325 1,066	350 1,115
Reel Diameter	*m* *ft*	3.7 12				4.3 14	3.7 12				4.3 14
Reel Width	*m* *ft*	1.2 4		2.4 8			1.2 4		2.4 8		
Reel Weight - Full	*kg* *lbs*	2,520 5,550	2,945 6,490	4,735 10,435	4,170 9,190	5,590 12,323	3,355 7,405	3,710 8,180	5,085 11,200	4,985 10,980	6,920 15,255
Reel Weight - Empty	*kg* *lbs*	680 1,500		1,150 2,530		1,497 3,300	680 1,500		1,150 2,530		1,500 3,300
Fitting OD**	*mm* *in*	82 3.2	111 4.4	140 5.5	178 7.0	203 8	85 3.4	116 4.6	144 5.7	186 7.3	213 8.4
Fitting ID**	*mm* *in*	45 1.8	64 2.5	86 3.4	108 4.2	124 4.9	45 1.8	64 2.5	86 3.4	108 4.2	124 4.9

*Lengths and reel weights are approximate as they may vary depending on the manufacturing run.

**Fitting dimensions do not include O.D. of flange provided for flanged end fittings. Fitting O.D. and I.D apply to flanged end, weld-neck and pipe-to-pipe coupling fittings.

Product data is subject to change without notice. Flexpipe's products are patented by US Patents 6,889,716, 6,902,205, 7,946,629 B2 and 8,042,252 B2 by Canada Patents 2,513,506, 2,513,468 and 2,562,823 and by European Patent 1592908. Additional patents are pending. Flexpipe products comply with API RP 15S, API 17J, CSA Z662-15, ASTM F2686 and ASTM D2992.

Mattr Ltd. is a global energy services company specializing in products and services for the pipeline and pipe services segment of the oil and gas industry and related products for petrochemical and industrial markets. The Company operates through a network of fixed and mobile manufacturing and service facilities located around the world and is valued for its integrity, technology, and proven capability to execute the most complex projects in our industry.

FLEXPIPE®

FP 150

FLEXPIPE®

Designed to Withstand High Pressures and Corrosion

Constructed from a winning combination of high-density polyethylene, helically wound epoxy-free dry fiberglass and a protective outer jacket, Flexpipe products are safe to install thanks to smaller crew sizes and less heavy equipment requirements.

60°C

(140°F) MAXIMUM CONTINUOUS OPERATING TEMPERATURE

300 psi

ANSI (150) MAXIMUM OPERATING PRESSURE

Applications:
Oil, gas, water, H_2S (up to 100,000ppm), CO_2 (up to 100%)

Length Per Reel:
750-760 meters (2,460-2,495 feet)

Installation
Trenching, plowing, chain ditching, surface lines, horizontal directional drilling (HDD), liner pulls (remediation)

Quick Installation & Total Life Cycle Costs

- Approximately a 50% reduction in installation crew size and up to 35% installation costs savings compared to a steel pipeline
- Eliminate the need for sand packing
- 20 year UV protection

Expanded Operating Envelope

- Lower operating costs due to corrosion resistant design
- Maximum operating temperature of 60°C (140°F)
- Suitable for sour service applications up to 100,000 ppm H_2S compared to other composites which are limited to sweet service applications due to steel plate reinforcement design

Product Reliability & Safety

- Higher flower rates, robust leak free fitting connections and corrosive resistance sets our products apart from other composite pipe on the market
- Flexpipe products are epoxy-free which eliminates micro-cracking
- Our products also have high abrasion resistance and fire resistant properties

FP 150

The Mattr Difference

- In-house engineers dedicated to ensuring Flexpipe is suitable for your application to maximize service life
- Project planning, technical and field services support to ensure on-time delivery and world-class installation
- Contractor installation training allows customers better control over project timing, costs and completion

		FP 150	
		3”	4”
Pressure	*psi* *kPa*	300 2,068	
Temperature	°C °F	60 140	
Outside Diameter	*mm* *in*	95 3.75	122 4.80
Inside Diameter	*mm* *in*	77 3.02	99 3.90
Pipe Weight	*kg/m* *lb/ft*	2.6 1.7	4.0 7.2
Weight - Full of Water	*kg/m* *lb/ft*	7.3 4.9	11.7 7.8
Operational MBR	*m* *ft*	1.8 6	2.1 7
Lenght/reel*	*m* *ft*	760 2,495	750 2,460
Reel Diameter	*m* *ft*	3.7 12	
Reel Width	*m* *ft*	1.2 4	2.4 8
Reel Weight - Full	*kg* *lbs*	2,660 5,855	4,150 9,150
Reel Weight - Empty	*kg* *lbs*	680 1,500	1,150 2,530
Fitting OD**	*mm* *in*	110.7 4.36	139.7 5.50
Fitting ID**	*mm* *in*	63.5 2.50	85.9 3.38

*Lengths and reel weights are approximate as they may vary depending on the manufacturing run.
**Fitting dimensions do not include O.D. of flange provided for flanged end fittings. Fitting O.D. and I.D apply to flanged end, weld-neck and pipe-to-pipe coupling fittings.

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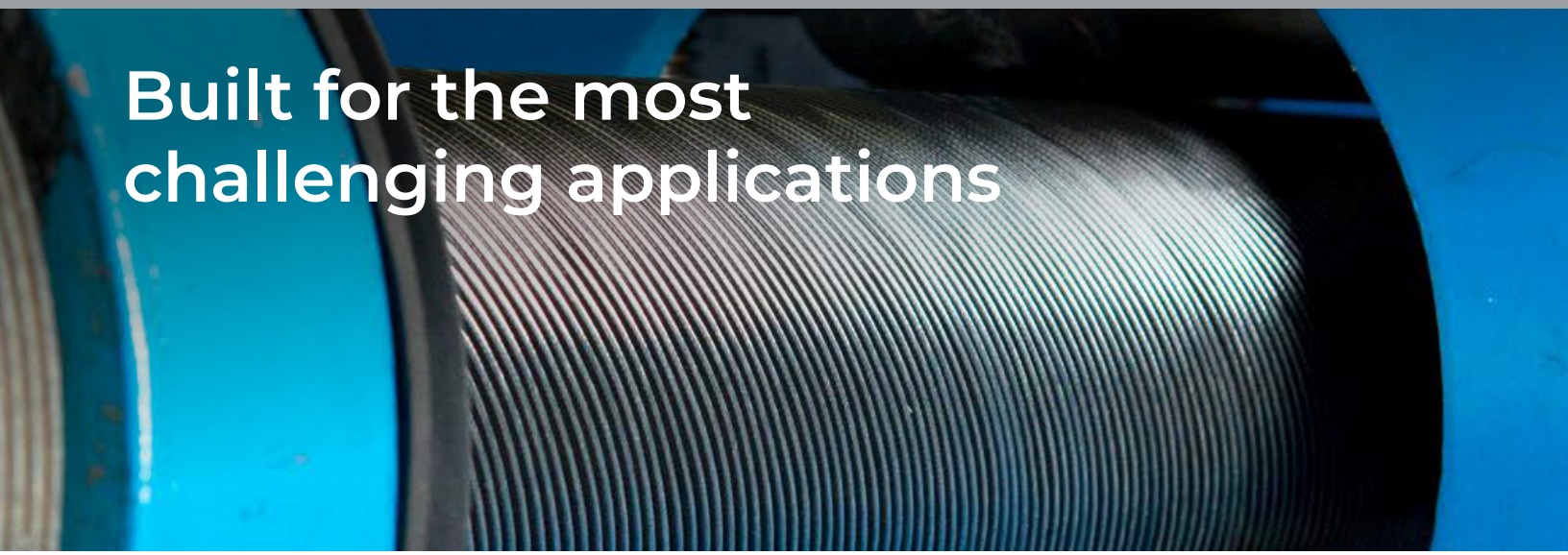
FLEXPIPE®

FLEXPIPE®



Built for the most challenging applications

Engineered for high freqeuency 225 psi peak-to-peak pressure pulsations, combined with 10 full pressure on-off cycles of 0-1,500 psi per day with a 10x safety factor eliminating the need for de-rating in most cyclic applications.

60°C

(140°) Maximum Continuous Operating Temperature

2,250 psi

(ANSI 900) Maximum Operating Temperature

Applications:
Oil, gas, water, EOR, H_2S 0up to 3,000 ppm), and CO_2 (up to 100%)

ID Sizes:
3 and 4 Inch

Length Per Reel:
525 - 615 meters (1,722 - 2,018 feet)

Installation:
Trenching, plowing, chain ditching, surface lines, horizontal directional drilling (HDD), liner pulls (remediation), shallow water applications

Quick Installation & Total Life Cycle Costs

- Reinforced with high strength galvanized steel cords to handle pressure cycles and pulsations during cyclic applications
- Approximately a 50% reduction in installation crew size and up tp 35% installation cost savings compared to steel pipeline

Expanded Operating Envelope

- Rigorous internal testing confirms no blistering or collapse after repeated cycles of rapid decompression at 1,000 psi/minute
- Steel cord design allows for enhanced venting of gasses that permeate through the liner allowing for rapid decompression

Product Reliability & Safety

- Built to exceed the industry requirements of CSA, API and ASTM standards
- Designed with an industry accepted safety factor which does not require de-rating

Flexcord™ Linepipe

The Mattr Difference

- In-house engineers dedicated to ensuring our product is suitable for your application to maximize service life
- Project planning, technical and field services support to ensure on-time delivery and execution
- Contractor installation training allows customers better control over project timing, costs and completion

		FC901	
MAXIMUM OPERATING PRESSURE @ 60°C OR 140°F		**15,510 KPA / 2,250 PSI**	
Nominal Size		**3”**	**4”**
Outside Diameter	*mm* *inches*	100 3.95	129 5.07
Inside Diameter	*mm* *inches*	77 3.02	99 3.90
Weight	*kg/m* *lbs/ft*	5.1 3.4	8.4 5.6
Weight - Full of Water	*kg/m* *lbs/ft*	9.8 6.5	16.1 10.8
Min. Bend Radius (Operational)	*m* *ft*	1.8 6	2.1 7
Length / Reel	*m* *ft*	615 2,018	525 1,722
Reel Diameter	*m* *ft*	3.7 12	3.7 12
Reel Width	*m* *ft*	1.2 4	2.4 8
Reel Weight - Full	*kg* *lbs*	3,820 8,415	5,560 12,260
Reel Weight - Empty	*kg* *lbs*	680 1,500	1,150 2,530
Fitting Outside Diameter*	*mm* *inches*	115.6 4.55	144.3 5.68
Fitting Inside Diameter	*mm* *inches*	63.5 2.50	85.9 3.38
Length / Coil*	*m* *ft*	–	–
Coil Weight**	*kg* *lbs*	–	–

Lengths and weights are approximate as they may vary depending on the manufacturing run.

*Fitting dimensions do not include O.D. of flange provided for flanged end fittingsFitting O.D. and I.D. apply to flanged end, weld-neck and pipe-to-pipe coupling fittings.

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