Qualification of Spoolable Reinforced Plastic Line Pipe

API RECOMMENDED PRACTICE 15S
FIRST EDITION, MARCH 2006

REAFFIRMED, OCTOBER 2013

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Qualification of Spoolable Reinforced Plastic Line Pipe

1 Scope

This Recommended Practice (RP) provides guidelines for the design, manufacture, qualification and application of spoolable reinforced plastic line pipe in oilfield flowline applications, including transport of multiphase fluids, hydrocarbon gases, hydrocarbon liquids and water. Such products typically consist of a continuous plastic liner reinforced with either glass reinforced epoxy—Spoolable Composite Pipe (SCP), or aramid fibers—Reinforced Thermoplastic Pipe (RTP). They are continuous flowline systems capable of being reeled for storage, transport and installation. For offshore use, additional requirements may apply.

This document contains recommendations on material selection, product qualification, and pressure rating. Quality control tests, hydrostatic tests, dimensions, material properties, physical properties, and minimum performance requirements are included.

The qualification tests in the RP are designed around non-metallic reinforcements, exhibiting time dependent mechanical properties characterized by regression analysis. Metallic reinforcement is, therefore, specifically excluded.

The RP applies typically to spoolable reinforced plastic flowline systems up to 6 in. (150 mm) diameter, pressures of up to 5000 psi (34.5 MPa) and maximum temperatures of 200°F (93°C), although the principles described in this document can be extended to apply to products outside this range.

The RP is confined to pipe and end fittings or couplers, and does not relate to other system components. Where other system components (elbows, tees, valves etc.) are of conventional construction they will be governed by applicable codes and practices.

The RP covers pipe systems where the pressure and thermal loading is static or cyclic, with loads resulting from typical installation methods. It does not cover systems that are subjected to other types of static or dynamic loads.

2 References

2.1 GENERAL

This specification includes by reference, either in total or in part, the most current issue of the following standards and industry documents:

API

Spec 15HR	*High Pressure Fiberglass Line Pipe*
Spec 15LE	*Polyethylene Line Pipe (PE)*
Spec 16C	*Choke and Kill Systems*
RP 17B	*Flexible Pipe*
Spec 17J	*Unbonded Flexible Pipe*
API 17TR2	*The Ageing of PA-11 in Flexible Pipes*

ASTM[1]

D1598	*Test Method for Time-To-Failure of Plastic Pipe under Constant Internal Pressure*
D1599	*Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings*
D2412	*Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*
D2657	*Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings*
D2992	*Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings*
D3350	*Specification for Polyethylene Pipe and Fittings Materials*

CEN[2]

EN 1555-2	*Plastics piping systems for the supply of gaseous fuels—Polyethylene (PE)—Part 2: Pipes*
EN 12201-2	*Plastic piping systems for water supply—Polyethylene (PE)—Part 2: Pipes*

[1]ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959, www.astm.org.
[2]CEN European Committee for Standardarization, 36 rue de Stassart, B-1050 Brussels, www.cenorm.be/cenorm/index.htm.

ISO[3]

3127	*Thermoplastic pipes—Determination of resistance to external blow by Round the Clock method.*
9080	*Plastic piping and ducting systems—Determination of the long term hydrostatic strength of thermoplastic materials in pipe form by extrapolation*
10931-2	*Plastic piping for industrial applications—Poly(vinylidene fluoride)—Part 2: Pipes*
11414	*Plastics pipes and fittings—Preparation of test piece assemblies between pipe/pipe or pipe/fitting in polyethylene (PE) by butt fusion.*
14531-1	*Plastic pipe and fittings—Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels—Part 1: Pipes*

NACE[4]

TM0298	*Evaluating the Compatibility of FRP Pipe and Tubulars with Oilfield Environments*

PPI[5]

TR-4	*PPI Listing of Ratings for Thermoplastic Piping Materials or Pipe*
TN-11	*Suggested Temperature Limits for the Operation and Installation of thermoplastic Piping in Non-Pressure Applications*
TR-19	*Thermoplastics Piping for the Transport of Chemicals*

2.2 REQUIREMENTS

Requirements of other standards included by reference in this specification are essential to the safety and interchangeability of the equipment produced. Only standards listed in 2.1 are considered part of this specification, and only specifically referenced sections of these standards are applicable. Documents (sub-tier) that are referenced by these standards are not considered part of this specification.

2.3 EQUIVALENT STANDARDS

Standards referenced in this specification may be replaced by other international or national standards that can be shown to meet or exceed the requirements of the referenced standard. Manufacturers who use other standards in lieu of standards referenced herein are responsible for documenting the equivalency of the standards. Referenced standards used by the manufacturer may be either the applicable revision shown in section 2.1, or the latest revision. When the latest edition is specificed it may be used on issue and shall become mandatory 6 months from the date of the revision.

3 Glossary

3.1 GENERAL DEFINITIONS

The **manufacturer** is the party that manufactures or supplies equipment and services to perform the duties specified by the purchaser.

The **purchaser** is the party that initiates the project and ultimately pays for its design and construction. The purchaser will generally specify the technical requirements. The purchaser may also appoint a third party to act on his behalf.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

3.2 ABBREVIATIONS

ASTM American Standard Test Method

API American Petroleum Institute

[3]International Organization for Standardization, ISO publications are available from the American National Standards Institute (ANSI), 25 West 43rd Street, 4th Floor, New York, New York 10036, www.iso.org, www.ansi.org.
[4]NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, P.O. Box 218340, Houston, Texas 77218-8340, www.nace.org.
[5]Plastic Pipe Institute, 1825 Connecticut Ave NW, Suite 600, Washington, DC 20009, www.plasticpip.org.

CEN	Comité Européen de Normalisation
FAT	Factory acceptance test
ISO	International Standard Organization
LCL	Lower confidence limit
LTHP	Long-term hydrostatic pressure
MBR	Minimum bend radius
MPR	Maximum Pressure Rating
NACE	National Association of Corrosion Engineers
MSP	Maximum service pressure
PA	Polyamide or Nylon
PE	Polyethylene
PEX	Cross-linked polyethylene (also referred to as XLPE).
PFR	Product family representative
PM	Principal mode of failure
PPI	Plastics Pipe Institute
PSF	Pressure service factor
PVDF	Polyvinylidene fluoride
QA	Quality assurance
RCP	Rapid crack propagation
RP	Recommended Practice
RTP	Reinforced thermoplastic pipe
SCP	Spoolable composite pipe
SLT	Standard laboratory temperature
STBP	Short-term burst pressure
UV	Ultraviolet

3.3 DEFINITIONS

3.3.1 aramid: Class of high strength organic fiber ('aromatic amide').

3.3.2 blistering: Damage in the form of gas filled pockets caused by the release of absorbed gas on depressurization and subsequent delamination either within a solid polymer layer, e.g. the polymeric liner, or at an interface between layers, e.g. under the cover.

3.3.3 carbon fiber: Class of high strength graphite-based reinforcing fiber.

3.3.4 collapse: Movement of the liner away from the structural layer on reduction of internal pressure.

3.3.5 connector: A device used to provide a leak tight structural connection between the end fitting and adjacent piping, e.g. bolted flanges, clamped hubs, and proprietary connectors.

3.3.6 couplers: A specific type of end fitting developed for RTP, typically joining pipe by electrofusion.

3.3.7 elevated temperature test: A survival test aimed at verifying that no undesirable failure mode occurs between the end of the qualification test period and the end of the design life.

3.3.8 end fitting: A mechanical device which forms the transition between the spoolable line pipe body and the connector. The different pipe layers are terminated in the end fitting in such a way as to transfer the load between the pipe and the connector. Note that this definition follows API Specification 17J rather than Specification 16C.

3.3.9 glass fiber: High strength reinforcement based on E-glass or S-glass.

3.3.10 lower confidence limit: The 97.5% lower confidence limit of the mean regression curve.

3.3.11 long term hydrostatic pressure: Pressure obtained by extrapolating the mean regression curve to the design life.

3.3.12 manufacturer's nominal pressure rating: The pressure rating of the pipe as defined by the manufacturer, which shall not exceed the maximum pressure rating.

3.3.13 maximum pressure rating: The pressure obtained by multiplying the LCL pressure by the pressure service factor.

3.3.14 maximum service pressure: The pressure obtained by multiplying the maximum pressure rating by application-related design service factors.

3.3.15 principal mode: The only failure mode that shall be permitted in pressure testing.

3.3.16 product family: A group of pipe products having similar characteristics.

3.3.17 product family representative: The member of a product family chosen for full qualification.

3.3.18 product variant: A member of a product family, to which certain permissible changes have been made.

3.3.19 qualification test temperature: The temperature at which pressure tests are carried out to establish the Lower Confidence Limit. The design temperature may not exceed this temperature.

3.3.20 rapid crack propagation: An undesirable fracture mode, in which a crack propagates along a pipeline at very high speed.

3.3.21 regression analysis: Statistical procedure to establish a design rating from pressure test results carried out over a long period of time, typically greater than 10,000 hours.

3.3.22 short term burst pressure: Burst pressure measured in a short term test, where pressure is increased at a prescribed rate at SLT.

3.3.23 standard laboratory temperature: 73°F ± 3°F (23ºC ± 1.5°C).

3.3.24 stress rupture: Failure as a result of a period under steady stress or pressure. Also known as static fatigue.

3.3.25 survival test: Medium term, constant pressure test, to demonstrate that a product performs at least as well as a qualified product.

4 Product Description

4.1 PIPE LAYERS

SCPs and RTPs are non-metallic, multi-layer pipe products, capable of being made in long continuous lengths and reeled for storage, transport and installation. A “system” will comprise one or more runs of pipe, along with the end fittings and couplers connecting them to each other and to the other pipeline components.

All products employ a *polymeric liner* or barrier to contain the transported fluid.

A *structural layer* is used, over the liner, to provide the mechanical strength to withstand the loads applied during service and installation.

For SCPs, the structural layer typically consists of an even number of balanced helical windings of continuous glass or carbon fibers in an epoxy thermoset resin matrix. Other fibers and matrices are permissible. The manufacturing process is similar to filament winding. A bonding agent is typically employed to adhere the structural layer to the liner.

For RTPs, the structural layer typically consists of an even number of balanced helical windings of continuous aramid reinforcement, applied as helically wound yarns, or fiber reinforced preformed tapes in which the encapsulation is a thermoplastic resin. Other types of fibers are permissible.

An *outer polymeric cover* may be added on top of the structural layer. The cover protects the structure during installation and operation, and may help transfer mechanical loads within the end fitting.

The degree of bonding within and between the various layers of different RTP or SCP products can vary, and can influence several aspects of performance, including flexibility, response to permeated gas and load transfer in end fittings and couplers. No specific test of bond strength or efficiency is required by this RP. Rather pipe design and performance will be validated by the product successfully completing the suite of qualification tests in this document.

End fittings or couplers are used to terminate pipe ends or connect adjacent pipe sections. Termination is typically achieved through compression of the pipe structure between metallic components, with a load path going though various layers of the pipe structure depending on design. Some products employ electrofusion couplers. Standard connectors, e.g. flanges, are used to connect the pipe to adjacent sections of pipe in the process system.

4.2 MATERIALS SELECTION

The manufacturer shall be responsible for the selection and supply of all materials so that they meet the specified service and installation requirements.

4.2.1 Polymeric Liner

The liner shall maintain its integrity throughout the lifetime of the pipe for the specified fluids under the given service conditions. The manufacturer shall document materials properties, and the effects of service conditions on those properties, including: absorption of species from the carried fluid; leaching of low molecular weight material or plasticiser from the polymer; chemical changes to the molecular structure of the polymer; and environmental stress cracking. This RP qualifies the performance of the liner by a series of qualification tests based on current industry best practice.

Material qualification data shall be documented as agreed between the manufacturer and the purchaser. Guidance within Table 11 of API Specification 17J is useful in this respect, and the manufacturer should provide a summary of this test data for each liner material. For applications where gas or volatile components may be present under pressure, the liner polymer itself shall have adequate resistance to blistering.

The most common liner material is PE. Only established ‘pipeline’ grades shall be employed, namely PE 80 or PE 100 materials as defined by EN 12202 and EN 1555, or equivalents as defined by ASTM D3350.

Other liner materials, such as crosslinked polyethylene (PEX), polyamide (PA), and polyvinylidene fluoride (PVDF), may be used provided that they conform to the material requirements of a relevant pipe standard, e.g. ISO 14531-1 for PEX and ISO 10931-2 for PVDF, and that fitness for purpose has been established. The manufacturer shall provide data, where applicable, relating to mechanical behavior, thermal behavior, permeability and fluid compatibility, following relevant national and international standards.

Fusion joints in a PE liner shall be acceptable so long as they are made according to the manufacturer’s written procedure, which shall be consistent with ISO 11414 or ASTM D2657. The manufacturer shall demonstrate that the properties of the joint are equal to those of the parent pipe. Suitable QA checks shall be included in manufacture to control the fusion process. The position of all fusion joints shall be recorded by the manufacturer.

4.2.2 Structural Layer

The structural layer, including any bonding agents, shall sustain its integrity throughout the lifetime of the pipe under the given service conditions. The manufacturer shall provide the test data that demonstrate the short term and long-term load-bearing capabilities of the layer, and the temperature capabilities, required fluid compatibility and aging characteristics of all materials employed. This RP qualifies the performance of the structural layer by a series of qualification tests based on current industry best practice. Where “dry” glass fibers are employed as the structural layer, the additional requirements of Appendix A shall apply.

4.2.3 Cover Materials

The cover shall sustain its function throughout the lifetime of the pipe for the specified service conditions. The resistance to installation loads and environmental conditions (UV, wear etc.) shall be documented if required by the application or by the purchaser.

4.3 APPLICATION ENVELOPES

4.3.1 Dimension and Pressure

SCPs are characteristically small diameter, higher pressure products, typically ranging from 2 in. (50 mm), 5000 psi (34.5 MPa) to 5 in. (125 mm), 2000 psi (13.8 MPa). RTPs have larger diameters but lower pressure capability, e.g. 6 in. (150 mm), 1000 psi (6.9 MPa).

Products outside this range are under development. As long as the principles of construction (design, materials and manufacturing process) are identical to previously qualified structures, this document shall be considered applicable.

4.3.2 Temperature

The upper temperature limit of any given pipe structure is to be defined by the comprehensive performance testing of the complete pipe structure, as detailed by this document. The maximum operating temperature for a given product shall be defined as the qualification test temperature used for the pipe and end fitting qualification tests described in Section 5.

Although pipe performance will ultimately depend on the complete structure, some guidance on likely application temperature ranges is possible based on the capabilities of individual layers. Testing of individual pipe layers may also be useful in defining some pipe capabilities, e.g. liner chemical compatibility and permeation.

With respect to the liner, it should be noted that upper temperature limits for polymers are application specific, being a complex derivative of the physical, chemical and mechanical interactions. In properly designed spoolable reinforced plastic line pipe and connectors, the liner should bear limited loads.

Most products are currently based on PE materials, and may ultimately be qualified for use up to 140ºF (60ºC), or higher. While high temperature performance in water based fluids is proven, experience in hydrocarbons is more limited. Low molecular weight, aromatic hydrocarbon liquids (and fluids with similar solubility co-efficients) are particularly limiting for these materials. Some experience with these materials is documented within PPI publications referenced in 2.1. Polyethylene based products will typically be limited to above –20ºF (–29ºC), based mainly on the requirement for handling and installation.

Alternative material options include PEX (160ºF (71ºC) or higher), PA (see API 17TR2 for capabilities) and PVDF (260ºF (127ºC) or higher).

For epoxy resins used in SCP, the glass transition temperature (Tg) will typically be in the range of 175ºF (79ºC) to 350ºF (177ºC), depending on curing agent and profile. Epoxy resins are typically limited to a maximum temperature of 35ºF (20ºC) lower than Tg. Other resins are permissible, and may be characterized by either Tg or heat deflection temperature (HDT).

The temperature capability of glass and carbon fibers will not normally come close to being exceeded by oilfield applications. The temperature capability of any other fiber reinforcement employed, including aramid, will be validated by the pipe product successfully completing the suite of qualification tests outlined in this RP.

4.4 FUNCTIONAL REQUIREMENTS

The minimum overall functional requirements of the line pipe that shall be demonstrated by the manufacturer are as follows:

a. The pipe shall provide a leak-tight conduit;
b. The pipe shall perform its function for the specified service life;
c. The materials shall be compatible with the environment to which the material is exposed.

As a minimum, the end fittings and couplers shall be demonstrated as meeting the same functional requirements as the flexible pipe.

In any given application, the purchaser shall specify the functional requirements for the spoolable reinforced plastic line pipe.

The purchaser shall specify internal diameter, length of pipe and service life. The purchaser shall also specify the minimum, normal and maximum conditions for the internal fluid parameters, including: internal pressure; temperature; and fluid composition (produced fluids, injected fluids, and continual and occasional chemical treatments). External environmental parameters, such as location and routing, air temperature, soil data, sunlight exposure, corrosion protection requirements and thermal insulation requirements should also be provided. Connector and interface requirements, along with installation requirements, shall be fully defined.

Appendix B gives a sample format for the specification of the functional requirements. Functional requirements which are not specifically specified by the purchaser but which may affect the design, materials, manufacturing, and testing of the pipe shall be specified by the manufacturer.

The manufacturer shall inform the purchaser of any facets of product performance which may affect the operability of the pipe. This shall include requirements for gas venting, limitations for operations through the pipe, such as pigging and chemical treatments, limitations in fire resistance, the extent of permeation and diffusion of liquids and gases through the external pipe wall, the location and geometry of liner fusion welds, and requirements to implement specific condition monitoring procedures.

The purchaser must be aware that changes to operating conditions may affect pipe performance.

5 Qualification Program

Qualification requirements for the pipe bodies, end fittings, couplers and general characteristics are specified in this section.

In common with other related standards, such as API Spec 15HR and 15LE, the pressure rating of the pipe body shall be qualified using long-term rupture regression tests under constant pressure at a qualification test temperature, as described in 5.1. The regression procedure assumes that the applied pressure, P, and the failure time, t_f , are related by an equation of the form:

$$P = F \cdot t_f^G$$

where F and G are constants that describe the regression behavior.

In order to keep the total test burden within acceptable limits and to control the use of test data within their limits of applicability, the concept of a product family shall be used to establish the pressure rating of individual products. This pressure rating shall include appropriate design factors.

Integrity of the end fittings and couplers shall be qualified by an elevated temperature test, designed to demonstrate long term performance, as described in 5.2.

Other qualification tests, described in 5.3, shall verify other aspects of pipe performance.

The manufacturer is responsible for demonstrating compliance with the provisions of this RP. A qualification test report shall be kept on file by the manufacturer and a copy shall be available on request to the purchaser. Any purchaser may make any additional investigation deemed necessary to prove compliance by the manufacturer.

5.1 PRESSURE RATING OF PIPE

5.1.1 Definition of Product Family

Similar products shall be divided into product families, each product family being a range of product sizes and pressure ratings which have the same regression slope.

A product family representative with an internal diameter of at least 2 in. shall be tested in accordance with 5.1.2 to determine the regression slope for the product family. A product family size range may extend –2 in. (51 mm)/+4 in. (102 mm) from the family representative.

All products within a product family shall be termed product variants and qualified according to 5.1.3. Product variants shall be manufactured with the same material types, production process and process controls, and reinforcement architecture as the product family representative. Changes to any of these parameters will require re-qualification in accordance with 5.4.

5.1.2 Qualification of the Product Family Representative

5.1.2.1 Test Requirements

All qualification tests shall be carried out on spool pieces comprising the basic pipe body, together with one or more types of end fitting. The specimen length between end fittings or couplers shall be at least 6 times the nominal diameter. All tests shall be conducted with unrestrained ends. Re-useable test end fittings may be employed, although field end fittings or couplers are preferred. Where two or more lengths of pipe body are pressurized simultaneously, it is permissible, following the failure of one of the lengths of pipe body, to assemble a new spool piece and continue the test, at the same pressure, on the unfailed length(s). This is permissible provided that the failure of one spool piece does not result in visible external damage to the others.

Pressure tests shall be conducted with potable water as the pressurizing fluid. Addition of additives for boiling point suppression is acceptable if required. The qualification test temperature shall be selected by the manufacturer, and shall be greater than or equal to the design temperature in any application for which the product is employed. The preference shall be for all tests to be conducted in a thermostat controlled water bath. For products with thermoset resin based outer layers, with no thermoplastic cover, regression data collected in air should be supplemented by proof of the longevity of the reinforced thermoset resin in an external wet environment, using a 1000 hr survival test similar to that described in 5.1.3.

Test specimens may be taken either from straight pipe or from pipe that has been coiled. If straight pipe samples are employed, then the effect of reeling and unreeling on pipe performance during manufacture, installation and service can be proven with 1000 hour survival tests on two samples conditioned with 10 fully reversed cycles at the minimum storage bend radius. If this test is unsuccessful, or if the manufacturer prefers, pipe samples for full qualification shall be conditioned with 10 fully reversed cycles.

Where it is necessary to introduce discontinuities or joints of any type into the manufactured pipe, samples containing discontinuities shall either be employed in the full qualification procedure, or be treated as a product variant. Examples of discontinuities are joints in the reinforcing tape. PE liner butt welds are exempt from this, provided the appropriate procedures are followed to ensure consistent high weld quality, as described in 4.2.1, and that they are subjected to the elevated temperature test.

Appropriate safety precautions should be observed during the pressure testing of plastic pipe. There are hazards on failure due to high-pressure fluid jets and the release of significant levels of strain energy.

5.1.2.2 Permissible Failure Modes

The manufacturer shall specify the principal mode (PM) of failure. For products reinforced with glass, carbon, aramid or other non-metallic fibers, tensile (hoop) or mixed mode (bi-axial) failure the structural reinforcement shall be the only acceptable failure modes under hydrostatic pressure testing. These lead to loss of integrity by a combination of structural layer failure, localized leaking / weeping, and / or rupture of the liner and outer cover.

Any failure mode other than the PM invalidates the test. Any such failures shall be thoroughly investigated by the manufacturer to determine the cause, and the necessary steps shall be taken to prevent recurrence. Examples of non-permissible failure modes include failure of the liner (leading to pressurization of the structural layer), and failure involving an end fitting or coupler, especially the ejection of the pipe from the fitting or coupler.

5.1.2.3 Qualification Procedure

The pressure rating of the product family representative shall be determined by a series of stress rupture tests under constant pressure at the qualification test temperature. The procedure as described in ASTM D 2992—Procedure B shall be used. At least 18 failure points are required for this procedure, with not more than 2 samples below 100 hours, at least three samples 1000 to 6000 hours, and at least one over 10,000 hours.

As illustrated in Figure 1, test data is used to determine the mean regression line of the long term hydrostatic pressure, LTHP, and its Lower Confidence Limit for the product family representative, LCL_{PFR}. The LCL shall be taken as the value above which 97.5% of results can be expected to lie. The LCL_{PFR} is obtained by extrapolating this confidence limit on the regression relationship until it meets the design life. In common with other composite pipe standards, a design life of 20 years should be assumed, unless otherwise requested by the purchaser. For transmission applications a 50 year life may also be quoted. Manufacturers may choose to express LCLs in terms of either hoop stress or pressure – stress units are typically more relevant to SCPs, while pressure units are more useful for RTP manufacturers. Figure 1 also shows the use of service factors for determining the maximum pressure rating and the maximum service pressure as described in 5.1.4 and 5.1.5.

A manufacturer may choose to carry out additional regression tests at a temperature lower than the qualification test temperature. Pressure ratings at temperatures between two test temperatures shall be based on a linear interpolation.

In addition to the regression measurements, the short-term burst pressure (STBP) of the product family representative should be determined following the ASTM 1599—Procedure A. The STBP shall be determined by testing at least five samples. Samples shall be taken from the same production batch. The lower confidence limit of STBP may be required for use as the baseline for the Batch Test, described in 6.3.1.1. The LCL of the STBP shall be taken as the value above which 97.5% of results can be expected to lie.

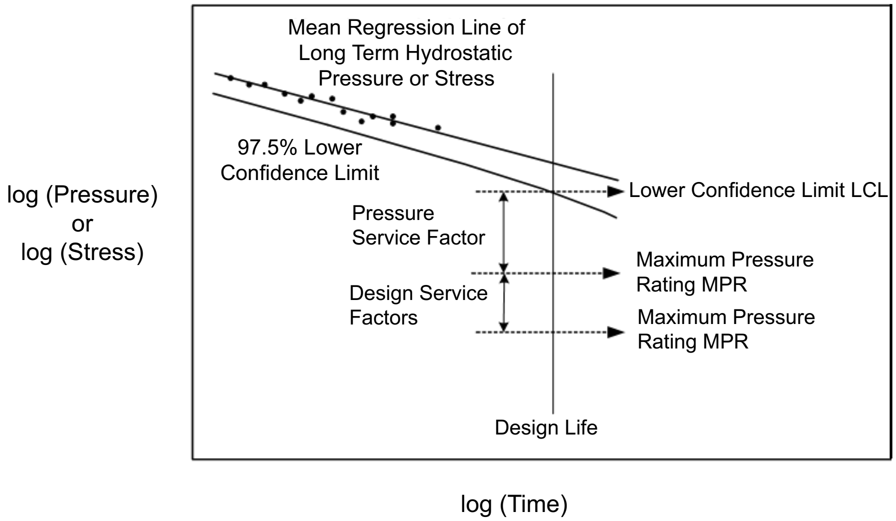

Figure 1—Procedure to Determine the LCL, MPR and MSP

Provisional product qualification based on STBP is for agreement between manufacturer and purchaser, and is considered outside the scope of this document.

5.1.3 Qualification of Product Variants

The manufacturer shall be required to test a controlled number of product variants within each product family to demonstrate that the product variants indeed belong in the family. The manufacturer should select these variants based on groups of pipe with similar design pressure or with the similar size. The specific variants tested should be either the largest diameter in a given pressure rating group or the highest pressure in a given size group.

Each selected product variant shall be subjected to a 1,000-hour constant pressure survival test. This type of survival test is designed to demonstrate that the product variant performs at least as well as the fully qualified product. This is achieved by a constant pressure test to check that the variant has an equal or better regression slope than the product family representative.

Typically, the LCL of the product variant , LCL_{PV}, should be calculated by scaling:

$$LCL_{PV} = LCL_{PFR}\left(\frac{D}{t_r}\right)_{PFR}\left(\frac{t_r}{D}\right)_{PV}$$

where

D = Mean diameter of reinforcing structure

t_r = Thickness of reinforcing structure

The 1000-hour test pressure, P_{1000}, is then calculated as follows:

$$P_{1000} = LCL_{PV} \times 10^{G(\log(DL)-3)}$$

where

DL = Design life in hours

G = Gradient of the product family representative

Two replicate samples of the selected product variant shall be pressure tested at P_{1000} or above according to test method ASTM D1598 at the qualification test temperature. Both samples shall survive for 1000 hours. If either fails, then full product family qualification is required.

Once a product variant has been qualified, the product can be scaled up or down provided that the diameter to thickness ratios for the reinforced wall (for all products) and the liner wall (for RTPs) are at least that of the product variant.

5.1.4 Pressure Service Factor

The manufacturer shall provide the value of the pressure service factor (PSF). The maximum pressure rating (MPR) is then calculated as the product of LCL and PSF:

$$MPR = LCL \times PSF$$

As a default value, PSF = 0.67 shall be employed.

5.1.5 Design Service Factors

The manufacturer should also provide design service factors, such as the cyclic service de-rating factor (f_{Cyclic}) and the fluid de-rating factor (f_{Fluid}), to determine the maximum service pressure (MSP) from the MPR for particular pipe applications:

$$MSP = MPR \times f_{Cyclic} \times f_{Fluid}$$

The cyclic service de-rating factor accounts, where appropriate, for the effect of cyclic service conditions. The fluid de-rating factor accounts for differences between the test fluid and the service fluid.

Other service factors may also apply, such as those based on area classifications. These will normally be applied through local regulations.

5.1.5.1 Cyclic Pressure Service Factor

In cases where the loading on a pipe is mainly of cyclic pressure, then additional qualification shall be required to verify the integrity of the pipe and fitting system. This shall apply when pipe in a given application will see regular, i.e. greater than once per day, pressure cycles in excess of ± 20%.

In such cyclic service, the purchaser may require regression analysis to be carried out at the qualification temperature according to ASTM D2992—Procedure A. Alternatively on a project by project basis, the frequency, amplitude and total number of pressure cycles shall be selected based on the requirements of a given application. Those pressure cycles shall be used to pre-condition test specimens for a 1000 hour survival test in accordance with section 5.1.3. The manufacturer shall document cyclic pressure limitations of both pipe and end fitting where known.

In all other “static” applications, it is permissible for the MSP to be exceeded for short periods during transient conditions. Excursions up to 1.5 times the MSP are permissible provided they occur no more than 5,000 times during the lifetime, and do not go above the MPR. In this case, $f_{Cyclic} = 1$.

5.1.5.2 Fluid Service Factor

In the absence of any other data, default values of f_{Fluid} can be used: 0.67 for all hydrocarbon liquid, gas, and multiphase service; and 1.00 for water-based fluids. These default values are based on a review of existing relating standards, and are generally considered consistent with those standards.

Where test data is available less conservative fluid service factors can be employed, subject to agreement between the manufacturer and purchaser. Methods for determining derating factors through qualification tests are a matter of continuing research within the industry. Growing field experience could also potentially lead to industry agreement to adjust these default values.

Chemical resistance of the liner shall be proven by the manufacturer. In general, the long term chemical performance of the common liner materials is well documented, as discussed in 4.3.2, and reflected in the default f_{Fluid} factors above. The manufacturer should be able to present data representative of the most commonly transported fluids, e.g. crude oil, gas condensate, and acidic water. Resistance to specific fluids may need to be proven by specific exposure testing, examining retained properties after simulated field exposure. Some guidance on test methods and fluids is available in API RP 17B Section 6.5 and NACE TM0298 Section 3.

In addition, the chemical resistance of the structural layer shall be considered where required. For example, stress corrosion cracking of glass fibers is known to occur under some limited conditions at higher strains and more extreme pH than will normally be encountered in oilfield flowline applications. Where a glass reinforced structural layer may be exposed to highly acidic (pH<3) or alkaline fluids (pH>9), either internally or externally, manufacturers using glass reinforcement shall demonstrate the absence of stress corrosion cracking in their products. This might typically be done through materials selection combined with a limit on the maximum operating strain. Relevant long term test data shall be provided to substantiate fiber performance.

5.2 END FITTINGS AND COUPLERS

An elevated temperature test shall be made on a product variant from each pressure rating or size group within a product family. The variant selected should be either the largest diameter in a given pressure rating group or the highest pressure in a given size group. End fittings and couplers used in qualification shall be made up in accordance with the manufacturer's written instructions.

If installation is to involve pulling on pipe which already has end fittings or couplers attached, the manufacturer shall demonstrate that the pipe body plus end fitting or coupler is capable of sustaining the applied load, as per 5.3.3.

The manufacturer shall prove to the satisfaction of the purchaser that any change to the field end fittings or couplers does not invalidate the results of qualification tests. The elevated temperature test may also be required to verify dimensional scaling of fittings unless the manufacturer can provide sufficient data or a sound engineer basis to support that scaling.

The manufacturer shall state, and be able to justify, the minimum and maximum temperature at which an end fitting or coupler may be installed on a pipe.

5.2.1 Elevated Temperature Test

An elevated temperature test procedure shall be employed to ensure that non-permissible failure modes relating to polymeric components of the pipe do not occur at times between the end of the regression test period and the end of the design life, e.g. stress relaxation resulting in loss of grip within the fitting, or liner strain rupture. The technical background to this test is summarized in Appendix C.

The manufacturer shall subject test samples, with end fittings or couplers, to a constant pressure survival test, at a temperature ΔT, in excess of the qualification test temperature, for a test period, t_{Test}, corresponding to the required lifetime. For PE lined products, the test shall be carried out with a 35°F (20°C) temperature shift for 1000 hours, or a 45°F (25°C) temperature shift for 250 hours. The test pressure shall be the LCL. These tests may be carried out in a temperature-controlled oven or water bath.

For each fitting or coupler type to be qualified, at least 2 end fittings or couplers shall be tested, and the length of spool piece between the two shall be at least 6 times the nominal diameter. All specimens shall survive without leakage for the full test period.

Following the elevated temperature test, each test-piece shall be de-pressurized and stored at ambient for at least 24 hours in air. The test-pieces shall then be pressurized to 150 psi (1.0 MPa) at SLT and examined for leakage. There shall be no visible leakage over a 24-hour period.

5.2.2 End Fitting and Coupler Components

It shall be demonstrated that no failure will occur in any parts of the end fittings or couplers during the lifetime of the pipe. This shall be accomplished using stress analysis, accepted corrosion prediction models or other means, using recognized standards. End fitting and connector metallurgy shall be specified by the purchaser.

To eliminate the possibility of end fitting failure during qualification testing, metallic fitting components shall be designed so as to not fail at the short term burst pressure. Following pipe qualification, it is permissible to redesign these metallic components, provided the manufacturer can demonstrate that operational stresses within end fitting components are equal to or lower than those experienced in the qualification tests. Such changes must not affect the geometry of the interface between the pipe and end fitting, or the way in which the end fitting and pipe interact in any way.

The design of the metallic parts of end fittings should allow for surge pressures and transients up to 1.5 times the maximum service pressure. Greater transients may sometimes be permitted, as stated by the manufacturer.

5.3 OTHER QUALIFICATION REQUIREMENTS

5.3.1 Gas or Multiphase Service

In gas or multiphase service, gases will diffuse through the liner and may accumulate at interfaces within the pipe structure. This local pressurization may result in liner collapse or cover blistering. Through a combination of analysis, testing and documented field experience, the manufacturer shall demonstrate that the design of pipe and end fittings or couplers is such that either: (i) diffused volatiles can be adequately vented or dispersed to prevent pressure build-up in the reinforcing layer to a level that could result in blistering, liner collapse or other damage; or (ii) pressure build-up in the reinforcing layers will not lead to blistering, liner collapse or other damage. A typical laboratory test method is outlined in Appendix D.

The manufacturer shall also provide information relating to the diffusion of liquids and the permeation of gases through the pipe wall at the system design pressure and temperature. This data may be used to provide estimates of operational issues related to potential diffusion of hydrocarbon liquids and permeation of H_2S through the pipe structure, or to estimate the venting frequency of any secondary containment.

In addition, the gas tightness of each end fitting and coupler type shall be demonstrated. For each end fitting or coupler type, two pipe joints shall be pressurized with air or nitrogen gas to $^1/_{10}$ of the working pressure and checked for leaks at the beginning and end of a period of at least 6 hours. The pressure shall then be increased to the working pressure and the procedure repeated for a further period of at least 6 hours, finally depressurizing. This cycle shall be repeated three times. These tests shall be carried out at both the maximum and minimum service temperatures. There shall be no leakage at any time. Leakage testing may be carried out using a soap/water solution, by observing pressure loss or by other suitable means.

5.3.2 Minimum Bend Radius

The minimum bend radius (MBR) in service shall be specified by the manufacturer and confirmed by means of a 1,000 hour survival test, as described in 5.1.3, on the product family representative at the qualification test temperature. Two samples shall be tested by being held in a suitable fixture and maintained at the MBR during the test.

The manufacturer shall also quote the recommended storage minimum bend radius of the pipe, and demonstrate that the pipe performance is not affected at this radius, as described in 5.1.2.1.

5.3.3 Axial load capability

The manufacturer shall quote the maximum allowable load on the pipe body during installation, and demonstrate the derivation of this to the satisfaction of the purchaser. Calculated values shall be acceptable, if the manufacturer can show this to be conservative.

If installation is to involve pulling on pipe which already has end fittings or couplers attached, the manufacturer shall also demonstrate this for the body plus end fitting or coupler.

5.3.4 External Pressure

The manufacturer shall specify the maximum external pressure to which a pipe should be exposed. External load performance may be characterized, for example, using a parallel plate, crush test such as ASTM D2412. This is currently primarily intended to demonstrate performance in wet ground applications, rather than subsea.

5.4 RE-QUALIFICATION

Re-qualification will be required when the manufacturer makes changes to the materials or manufacturing process used in any product family.

Where specific industry standards exist and are adhered to, use of materials from different suppliers will not constitute a change and will not require any additional testing of products by the manufacturer. The most obvious example of this is the ‘pipeline’ grades of PE described in 4.2.1.

Where no industry accepted standard exists, to circumvent arguments about whether a particular change is “major” or “minor”, changes described in Table 1 shall be accompanied by a technical justification of the effect of the change, together with partial re-qualification according to Section 12 of ASTM D2992. The technical justification shall consist of a detailed specification, documented procedures governing qualification to this specification, and documented evidence of adherence to these procedures. Failure to pass the test defined in Section 12 of ASTM D2992 shall require full qualification according to 5.1.2. Changes not described in Table 1 shall be subject to full qualification according to 5.1.2.

Table 1—Changes Acceptable with Technical Justification and Partial Re-qualification

Reinforcement	Manufacturer(s) (Both RTP and SCP) Manufacturers grade and specification (Both RTP and SCP) Filament diameter (Both RTP and SCP) Tow size / configuration (Both RTP and SCP)
Resin & adhesive	Resin/adhesive manufacturer (SCP only) Resin/adhesive grade (SCP only) Curing system manufacturer (SCP only) Curing system grade (SCP only)
Manufacturing	Tg (SCP only) Transfer of manufacture from one plant to another

5.5 OTHER DATA REQUIRED

Certain product properties, described in this section, do not have specified requirements but are nevertheless important in pipe system design and shall be provided by the manufacturer.

In addition, the manufacturer shall, when required, provide the purchaser with guidelines regarding fire performance, static electricity build-up, and wear and erosion. Typically, guidance will be based on existing experience with composite and polymeric pipe products.

5.5.1 UV Resistance

The manufacturer shall quote the UV resistance of the pipe, and if required by the purchaser shall demonstrate this through an appropriate standard test or sufficiently detailed and well-documented field experience. Low solar heating shall also be demonstrated or otherwise proven, where required.

5.5.2 Impact Resistance

The manufacturer shall quote the impact resistance of the pipe and if required by the purchaser shall demonstrate this. Where it is necessary to verify impact resistance, a performance-based test should be devised. This should preferably involve an existing impact testing procedure, such as ISO 3127, combined with a 1000 hour survival test to demonstrate performance.

5.5.3 Rapid Crack Propagation

For pipe used at low temperatures, testing for resistance to RCP may be required as part of the risk assessment procedure for the product. However, RCP is not envisaged as a major problem for spoolable reinforced plastic line pipe. For polyethylene based RTPs, absence of RCP has been demonstrated down to –40ºF (–40ºC). For SCPs, the combination of limited liner strain and the crack arresting properties of fiber reinforced structural composites make RCP unlikely.

It is envisaged that, as performance data become available, more detailed guidance regarding the need for RCP testing will be provided.

5.5.4 Thermal expansion co-efficient

The manufacturer shall measure and quote the axial thermal expansion co-efficient of the pipe, over the whole temperature range. Thermal expansion effects are not felt to be a concern with these products.

5.5.5 Growth and shrinkage on application of pressure

The manufacturer shall measure and quote changes in pipe length which take place as the pipe is pressurized.

6 Process and Quality Assurance Requirements

The manufacturer shall produce a quality plan relating to all aspects of the manufacturing process. This written manufacturing quality plan shall be available to the purchaser on request.

6.1 MATERIALS

All materials shall be purchased in accordance with either a written specification or an industry standard. The specification shall include measurable physical and mechanical properties. Test results shall be recorded on materials test certificates.

The manufacturer shall ensure that the suppliers of raw materials operate an effective quality plan in the manufacturing process. The manufacturer shall have an internal quality control inspection plan to ensure that the incoming materials meet required specifications.

All materials shall be traceable and suitably marked for identification. The quality plan shall describe all procedures for handling and storage of raw materials.

6.2 MANUFACTURING

The manufacturer shall carry out the manufacturing operation according to the manufacturer's documented procedures. The manufacturer shall document all critical production parameters and their tolerances during production. The data shall form a production record for each production batch. Non-conformances shall be reported to the purchaser.

Production records shall be kept for a minimum of 5 years unless the purchaser specifies a longer period, and it shall be possible for each batch to be traced uniquely to a product record.

6.3 QUALITY ASSURANCE TESTS

The manufacturer, by agreement with the purchaser, shall carry out either batch pressure tests or a factory acceptance test (FAT) or both, on completed product. While it is unusual in the oilpatch to not enforce FAT on a mandatory basis, the plastic pipe industry has always relied on batch testing and process control. The wording in this RP is therefore designed to make both approaches acceptable, subject to agreement between manufacturer and purchaser.

In addition, for SCP pipe samples, Tg of the resin in the structural layer shall be measured on a batch basis.

6.3.1 Batch Pressure Tests

For pipe which is produced continuously, a batch shall be a single production run.

Two samples of pipe body per batch (one cut-off from each end) shall be tested.

Two options are available for batch pressure testing: the short-term burst test, or the constant pressure survival test. Re-usable end fittings, different in design to those used in the field, may be employed for these tests.

6.3.1.1 Short-Term Burst Test

The short-term burst test shall follow the ASTM D1599—Procedure A and the test results shall compare with the baseline value. The baseline value shall be established from the product family representative, as described in 5.1.2.3.

If a sample fails to pass this batch test, i.e. the stress at failure is lower than the baseline value, then the re-test procedure, stipulated in 6.3.1.3 shall be adopted.

6.3.1.2 Constant Pressure Survival Test

Alternatively, a constant pressure survival test may be employed, with the test period chosen as either 1 hour or 10 hours, performed at the qualification test temperature. The pressure level shall be chosen as the LCL pressure corresponding to 1 hour or 10 hours from the regression curve.

The length of time of the test shall be chosen to coincide with a region of the regression curve where sufficient experimental points are available to ensure accuracy.

If a sample fails to pass this batch test, i.e. the time to failure is lower than the corresponding LCL value, then the re-test procedure, stipulated in 6.3.1.3 shall be adopted.

6.3.1.3 Re-Test Procedure

If any specimen fails to conform to any of the above specified requirements, it shall be rejected, but the manufacturer may elect to make re-tests on 2 additional replicate samples from the same batch. If all the retest samples conform to the requirements then the batch shall be accepted. If any retest specimen fails to conform then the batch shall be rejected.

6.3.2 Factory Acceptance Test (FAT)

The FAT pressure shall be 1.5 times the MPR, and shall be applied to the entire pipe length. Unless otherwise specified, e.g. for cold weather testing, potable water should be used for the test fluid. Water quality should be assessed versus any limitations provided by end fitting metallurgy. A suitable dye may be added to assist in leakage detection. The test may be carried out, if desired, with the pipe coiled on a drum. Trapped air shall be removed from the pipe in accordance with the manufacturer's procedures. Safety procedures shall take account of the very high strain energy stored in this type of product.

The details of the FAT procedure shall be agreed between the purchaser and the manufacturer. Typically, the pressure should be gradually increased, at a rate not greater than specified in the manufacturer's test procedure, to no greater than 110% of the nominal test pressure, and held for a period of at least 2 hours to allow for initial stabilization. Pressure should then be increased to between the nominal test pressure and 110% of the nominal test pressure, and maintained for a period of hours, during which time there shall be no leakage or other signs of deterioration. The shut-in pressure of the pipe shall be monitored and recorded during the test, and compared to master curves provided by the manufacturer to account for both pipe expansion under pressure and any thermal effects.

Depressurization shall be performed at a rate in accordance with the manufacturer's test procedure. After depressurization, the end fitting areas shall be visually examined for any sign of damage or leakage from both the pipe and the end fittings or couplers. Procedures should remove as much water as possible from the pipe after completion of the test.

The test should be used to complement other QA procedures described in this section.

7 Dimensions, Tolerances and Marking

7.1 DIMENSIONS

The manufacturer shall state both the internal and external diameter of the pipe.

The manufacturer shall document the tolerances to be used for each layer of the pipe. These tolerances shall be verified in the design process to be acceptable, such that the performance of the individual layers and pipe are unaffected by variations within the specified tolerances. As a minimum, tolerances shall be specified for the outside diameter and thickness of the liner, and the thickness of the structural layer. The tolerance for the length of the pipe shall be stated.

When dimensional criteria are based on manufacturing considerations rather than design considerations, the manufacturer shall document that the criteria used meet the design requirements.

7.2 MARKING

The following information shall be given on the pipe body:

- Manufacturer name or trademark.
- Nominal pipe size in millimeters (mm) or inches (in.).
- Product identifiers indicating product capability and traceability.

The purchaser may request additional specific markings if necessary.

Markings shall be durable and non-damaging. The required information shall be permanently marked, in a color that contrasts that of the pipe, the height of the characters being at least $^1/_4$ in. (5 mm). The required markings shall be repeated at intervals of no more than 10 ft (3 m), or as agreed with the purchaser.

8 Documentation

8.1 DOCUMENTATION PROVIDED BY THE PURCHASER

The purchaser shall provide the design conditions for the pipe system, including:

- System design pressure (and pressure range in the case of cyclic service),
- Maximum and minimum design temperature,
- Internal fluids, and
- Design lifetime.

The full information that shall accompany a purchase order for spoolable reinforced plastic line pipe is outlined in Appendix B.

8.2 DOCUMENTATION PROVIDED BY THE MANUFACTURER

The manufacturer shall provide the purchaser with a full data sheet for each pipe structure, ensuring that it is clear which values are measured, which are calculated and which are assumed.

The data sheet will, as a minimum, include:

a. Dimensions, including: inside diameter; outside diameter; minimum reinforced wall thickness; pipe weight per unit length (empty and water filled); maximum end fitting outside diameter;
b. Description of materials used in each layer of the product;
c. Minimum and maximum operating temperatures;
d. Internal pressure rating, including: Manufacturers nominal pressure rating, MPR, and MSP for different fluids;
e. External collapse pressure;
f. Minimum bend radius for storage and operation;
g. Thermal expansion co-efficient;
h. Axial growth / shrinkage with application of internal pressure (up to 1.5 x MPR).

The full qualification test report shall be made available to the purchaser on request.

9 Handling, Storage and Transportation

The manufacturer shall provide the purchaser with written recommendations on the handling, storage and transportation requirements for the pipe system.

In general, these guidelines should minimize the opportunity for external damage to the pipe through contact with lifting gear and installation equipment, and ensure that pipe stays within its performance capability, e.g. bend radius. Guidelines should also take account of the potential danger of the stored energy of the pipe when wound on a reel.

Appendix E summarizes recent experience with installation of spoolable reinforced plastic line pipe.

APPENDIX A—ADDITIONAL REQUIREMENTS FOR PRODUCTS USING “DRY” FIBER REINFORCEMENT

The use of fiber reinforcement which is neither completely impregnated by, nor encapsulated within, a polymer resin as it is applied over the liner is a relatively new concept. The performance based nature of this RP means that a wide range of fiber reinforced product may be qualified using the methodologies described, but at this stage of the development and use of such “dry” fiber reinforced products specific additional requirements should be applied.

While precise definition and understanding of the major failure modes in any product can only come through experience, the use of “dry” fiber reinforcement introduces the possibility of two additional failure modes which must be addressed during qualification.

The first is abrasion between fibers during handling and installation and as a result of pressure fluctuations during service. The effects of handling and installation are covered by the requirements of the third paragraph of 5.1.2.1, while the effects of pressure fluctuations are covered generally in 5.1.5.1. For products using “dry” fiber reinforcement, there shall be a requirement to qualify the cyclic pressure capability for all applications, typically on the project by project basis described in the second paragraph of 5.1.5.1.

The second is stress corrosion of glass fibers. The guidance on certain aspects of this phenomenon is provided in the last paragraph of 5.1.5.2. For products using “dry” glass fiber reinforcement, there shall be a requirement to justify the stress corrosion capability of the product for all pH values, rather than just the very low and high pH conditions mentioned in 5.1.5.2. Relevant long test data shall be provided to substantiate fiber performance.

APPENDIX B—PURCHASE ORDER INFORMATION

The purchaser should provide the following information with all purchase orders for spoolable reinforced plastic line pipe.

Basic Design data	
Bore diameter	
Pipeline length	
Design life	
Max / Min design temperature	
Normal operating temperature	
Max / Min design pressure	
Normal and maximum operating pressures	
Pressure fluctuations (Size and frequency)	
External pressure	
Soil loading	
Thermal insulation requirements	
End fitting and connector metallurgy	
Fluid service	
Gas / Water / oil / multiphase?	
Production / injection?	
Fluid Composition	
CO_2 / H_2S content	
Solids content	
Other fluids, e.g. production chemicals	
Quality assurance	
Required batch and hydrotest procedures	
Operational requirements	
Inspection requirements – Internal / external	
Pigging requirements	
Reparability requirements	
Impact resistance requirements	
External wear requirements	
Corrosion protection requirements (CP etc.)	
Installation details	
Description of installation (above / below ground)	
Ground conditions	
External environment (Temperature, sun etc.)	
External interference hazards	
Installation procedure	
Routing and spatial limitations	
Future tie-in requirements	
Delivery/shipping instructions	
End fitting interface requirements	
Min / Max ambient temperature	

APPENDIX C—TECHNICAL BACKGROUND TO ELEVATED TEMPERATURE TEST

The elevated temperature test relies on time-temperature equivalence to shift the time-scale of possible, unwanted failure modes into a time domain where they would be observed. The grade of polymer used for the liner should therefore possess well-documented creep and stress rupture characteristics over a range of temperatures exceeding the qualification temperature and over a time period long enough to allow any possible undesirable failure modes to be observed.

The procedure is based on well documented methods, described for PE for example in ISO 9080, which predict long term tensile behavior by accelerated testing at elevated temperature through the principles of Arrhenius. The application of these principles to end fitting testing is, however, relatively new, and the procedure is expected to develop as more industry experience is gained.

The procedure involves subjecting spool pieces, with end fittings or couplers, to a constant pressure survival test, at a temperature ΔT degrees in excess of the qualification test temperature, for a test period, t_{Test}, corresponding to the required lifetime. The values of t_{Test} and ΔT shall be chosen by the manufacturer, according to the following equation:

$$\Delta T = \frac{1}{\alpha} \log\left(\frac{t_{Lifetime}}{t_{Test}}\right)$$

where

α = time-temperature shift factor

$t_{Lifetime}$ = the design lifetime

The pressure at which the elevated temperature test should be carried out should relate directly to the regression curve at the qualification temperature, and so the test pressure should therefore be the LCL. These tests may be carried out in a temperature-controlled oven or water bath.

In the case of pipe-grade PEs, i.e. PE80, PE100, which do not display a transition from ductile to brittle regression behavior, a value of 0.2 decades/°C has been found for α. Test times calculated from the equation above are relatively short. In this case, the elevated temperature test defined in 5.2.2 is regarded as a conservative verification test.

For other polymers, a value for α shall be determined, or a default value of 0.05 decades/°C assumed.

APPENDIX D—BLOWDOWN TEST PROCEDURE

D.1 Specimen preparation

D.1.1 The origin of each specimen shall be fully documented. Each specimen shall be traceable to a position (length) within a production run, which shall have passed all QA requirements.

D.1.2 Each specimen shall be uniquely identified with a laboratory specimen number, traceable to the production run.

D.1.3 The length of each specimen shall be at least six times the nominal diameter.

D.1.4 Each specimen shall be measured and weighed prior to testing.

D.2 Test

CAUTION: Fluids under high pressure can be dangerous. It is the responsibility of laboratory personnel to utilize proper safety procedures in handling and testing.

D.2.1 Attach field connectors to either end of the specimen according to standard assembly practices.

D.2.2 Install the specimen in the appropriate equipment for temperature generation and pressure containment. Attach one end to a source of high pressure gas. Fill the specimen with test media and increase the temperature and pressure to the maximum operating, or other specified temperature, and maximum operating pressure and hold.

D.2.3 With pressure and temperature stabilized, begin timing the test. The hold period shall be such as to saturate the pipe structure with gas. During the hold period, maintain the pressure and temperature.

D.2.4 Upon completion of the hold period, rapidly remove pressure from the specimen. Rate of de-pressurization shall not be less than 1,000 psi (6.9 MPa) per minute.

D.2.5 Remove the specimen from the fixtures and remove end fittings. Visually examine the inside diameter for evidence of blistering or liner collapse. Record the results of testing.

D.3 Protocol to determine the CO_2 operating envelope

D.3.1 Conduct the first test at rated operating pressure with supercritical carbon dioxide (usually 100% CO_2 gas) at room temperature.

D.3.2 If the specimen shows no signs of blistering or collapse, conduct the next test at the next higher temperature. If the specimen does exhibit signs of blistering or collapse that can not be correlated with known pre-existing anomalies, then conduct the next test with reduced internal pressure.

D.3.3 Testing should continue until either of these two conditions is met:

- Blistering or collapse at minimum pressure (first pressure value less than one-half operating pressure).
- No blistering or collapse at maximum temperature (usually max rated product temperature).

APPENDIX E—INSTALLATION METHODS

Spoolable reinforced plastic line pipe is designed to be stored, handled and deployed using reels. This demands installation techniques that differ substantially from methods used to install jointed steel or fiberglass pipe.

Visual inspection of all pipe should be undertaken by competent personnel as soon as it reaches site. Any damage should be marked for assessment and repair before installation. Similar visual inspection should be applied throughout the installation and commissioning process.

Field installation of pipe, end fittings and couplers should be according to the manufacturer's written procedures, which should state requirements for installer certification and training. Safety precautions should be in place to take account of the high degree of strain energy stored in these products during handling and pressure testing.

E.1 Unreeling

A reeling frame, suitable for supporting and controlling the reel, is required, typically with hydraulic drive and integral brake, and the capability to lift the reel off the ground and provide a secure mounting. Experience has shown that pipe can be unreeled in a number of ways:

E.1.1 Un-reeling from a Stationary Reel—If the reeling frame is fixed, pipe can be deployed by pulling the pipe off the reel. This method is useful where soil is not excessively rocky or abrasive. Experience has shown that line pipe may be pulled by a pickup truck, tractor, backhoe or similar. The maximum pulling load, as measured by a load cell inserted between the pipe and the pulling equipment, must not exceed the maximum allowable tensile of the pipe being deployed, and should be recorded and retained as part of the installation documentation. Tension should be maintained on the pipe at the reel at all times to prevent "bird nesting" of several layers of reeled pipe. Pipe should not be cut until the ends are securely restrained, due to the residual "elastic" energy in the reeled pipe.

E.1.2 Un-reeling From a Moving Reel—Pipe can also be un-reeled by anchoring the free pipe end at the starting point and pulling the reel away from that point on a trailer or truck bed along the right-of-way. This is the preferred method for areas with rocky or very abrasive soil, and for lines that are not straight. The center-of-gravity of the vehicle with the reel on board must be evaluated to ensure that the track of the vehicle is adequately smooth, wide, and level to prevent overturning along the intended route.

E.2 Buried Installations

Line pipe can be buried either by conventional "trench & backfill" methods using conventional trenching equipment, or "plowing-in" with specialized trenching plows.

For buried installations, consideration must be given to the method of attachment to surface equipment. This is particularly critical in areas subject to soil movement or heave. The transition from ditch to riser must be on a gentle slope with mechanical support.

Proper trench construction is important. Trenches must be wide and deep enough to accommodate both the line pipe (or multiple lines) and backfill material. Trenches should be as straight as possible, with any changes of direction having a radius greater than the operating MBR of the product. The bottom of the trench should be "bedded" so that it is as uniform as possible and provides a smooth, firm bearing surface to support the bottom of the pipe circumference. This may be accomplished by "healing" the bottom of the trench with the hoe bucket, or by partial back filling with river sand or other clean backfill before the pipe is laid. Particular attention should be paid to road crossings. SCP may require the use of carefully designed conduits, taking account of potential soil movement, while RTP typically does not.

Prior to hydro testing the trench should be back-filled every 30 ft (10 m) to surface. The trench should be back-filled as soon as possible after hydrostatic testing to eliminate the chance of damage to the pipe, floating if the trench floods, or shifting due to collapse of the side-walls of the trench. It is recommended that line pipe be completely surrounded with select quality backfill, e.g. river sand or $^{1}/_{8}$ in. to $^{3}/_{4}$ in. (3.2 mm to 19.1 mm) pea gravel, free from rocks, boulders, large clods of dirt, or frozen dirt.

E.3 Surface Installations

In surface installations, line pipe is laid on the surface, either directly at grade, or above grade on built-up (usually fabricated steel) stands. For pipe laid at grade, the surface should be free of rocks and other sharp objects that could damage the pipe. Spacing and construction requirements of above ground supports will vary according to the application. Line pipe should not come in direct contact with steel.

Design must evaluate pressure expansion and thermal expansion, and anticipated temperature swings (including black-body absorption of the line pipe), although expansion loops are generally not necessary.

Surface installed pipe must be restrained horizontally with thrust blocks whenever it changes direction, and periodically anchored vertically to piles, foundations, or other supports. Bends in the pipe should always be made with a radius greater than the operating MBR of the product. Pipe must always be properly restrained before hydrotest.

E.4 Relining Applications

Relining is a technique used to replace steel lines that have failed by pulling or inserting pipe into the existing line. This clearly results in a reduction of cross-sectional flow area, although this may be partially offset by the low friction of the smooth liner surface (Hazen-Williams flow coefficient typically 150).

In relining applications, there must be adequate clearance between the outside diameter of plastic line pipe and the inside diameter of the existing steel line, and there must be no obstructions in the steel pipeline, e.g. any unexpectedly sharp turns, dents or kinks in the pipe, or internal weld-splatter. Such defects can reduce the effective ID of the steel line and damage plastic line pipe.

It is recommended that the "drift" of the steel pipe be checked by pulling a straight 30 ft (10 m) length of plastic pipe through the line using a pulling line with swivel joints attached to both ends. If this "drift segment" of pipe successfully passes through the entire steel line, insertion can proceed. If it becomes stuck, the trailing pull line can be used to retrieve the drift segment. Then the steel pipe can be prepared as required for the application.

If laid wire rope is used as the pull line, a swivel must be installed between the pull line and line pipe to prevent the laid wire rope from applying torque to the pipe as it is pulled during installation.

It is recommended that both ends of the pipe be capped during pulling or insertion to prevent a build up of foreign material in the line. Conduit entry and exit points should be covered to prevent damage to the pipe.

A pulling-load indicator system which provides real-time read-out of axial pull during installation is typically required. Actual pulling force should be limited to the product's maximum allowable tensile rating, and should be recorded and retained as part of the installation documentation.

E.5 Field Testing

Hydrostatic testing of field-installed line pipe should be undertaken to verify the integrity of installed end fitting and connectors. Suitable safety precautions should be taken throughout, bearing in mind that the stored energy of plastic pipe can be large.

Complex systems should be broken into smaller runs for testing, and all lines should be adequately restrained before filling commences.

The pipe should be filled using a soft foam pig in such a way as to expel as much air as possible. Test water should enter the system at the lowest available point and air vented from the highest point or points.

Pressure should be slowly applied up to 50% of the required test pressure or 250 psi (1.7 MPa), whichever is lower, and held for 1 hour during which time the line should be checked for leaks particularly at end fitting and connectors. The pressure should then be increased to the desired test pressure. The customer and/or applicable regulations should define the test period. The final pressure should be held at the desired test pressure until the pressure stabilizes. Test pressure and hold time, and acceptance criteria should be put in place in advance, by agreement between the purchaser and manufacturer, and take account of ambient temperature variation. Maximum hydrostatic test pressure should not exceed 1.5 times the MPR of the specific product, and will normally be governed by national or local regulations.

At first indication of a leak, the test should be stopped, the pressure bled-off and repairs made.

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