

Liner Hanger Equipment

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Introduction

This specification has been developed by users/purchasers and suppliers/manufacturers of liner hanger systems and related equipment as defined herein and is intended for use in the petroleum and natural gas industry worldwide in order to give requirements and information to both parties in the selection, manufacture, testing, and use. Further, this document addresses the minimum requirements with which the supplier/manufacturer is to comply so as to claim conformity with this document.

This specification has been structured with two types of liner hanger systems (conventional and expandable) and two types of activation mechanisms for conventional liner hanger systems (mechanical-set and hydraulic-set).

This specification has been structured with grades of increased requirements in quality control and design validation. These grades allow the user/purchaser to select the level of requirements that are required for a specific application.

There are three quality grades. Quality grade QL3 is the minimum grade and aligns with supplier/manufacturer-defined quality requirements. Quality grade QL2 is an increased level of quality and generally allows the sampling of components to verify quality requirements are met. Quality grade QL1 is the highest grade provided.

There are three design validation grades for products. Design validation grade V3 is the minimum grade and aligns with supplier/manufacturer-defined product validation. Design validation grade V2 requires testing with liquid as a test medium, while validation grade V1 requires testing with nitrogen.

There are three design validation grades for systems. System design validation grade VS3 is the minimum grade and aligns with the supplier/manufacturer-defined validation methods. System design validation grade VS2 requires system testing with liquid as a test medium, while validation grade V1 requires system testing with nitrogen. Grades VS2 and VS1 can be achieved by testing an entire system, or by combining individual validated products.

Annexes A, B, C, D, and G are informative requirements, where Annexes E, F, and H are normative.

The International System of Units (SI) is used in this document; however, US Customary (USC) or other units are also shown for reference.

Users of this specification should be aware that requirements beyond those outlined in this document may be needed for individual applications. This specification is not intended to inhibit a supplier/manufacturer from offering, or the user/purchaser from accepting, alternative equipment or engineering solutions. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the supplier/manufacturer to identify any variations from this specification.

Liner Hanger Equipment

1 Scope

This specification provides requirements for conventional and expandable liner systems, including liner hangers, liner packers, liner hanger packers, tie-back/polished-bore receptacles (TBR/PBRs), seal assemblies, setting adaptors/sleeves, and running/setting tools as defined herein for use in the oil and natural gas industry. This specification provides minimum requirements for the functional specification and technical specification, including design, design verification and validation, materials, quality control, documentation and data control, repair, shipment, and storage.

Products covered by this specification apply only to applications within a conduit. Installation and field maintenance are outside the scope of this specification. Also not covered in this specification are casing crossover subs, expandable tubulars and expandable connections, end connections to the liner, cementing aids, liner wiper plugs and drill pipe darts, landing collars, float equipment, wellhead/casing hanger, sub-mudline suspension equipment, and cementing heads. Products covered by other API specifications are not in the scope of this specification.

2 Normative References

The following referenced documents are indispensable for the application of this specification. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 5C5, 4th Edition, *Procedures for Testing Casing and Tubing Connections*

API Specification 5B, *Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads*

API Specification 5CT, *Specification for Casing and Tubing*

API Specification 5L, *Specification for Line Pipe*

API Specification 7-2, *Specification for Threading and Gauging of Rotary Shouldered Thread Connections*

API Specification 11D1, *Packers and Bridge Plugs*

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

API Technical Report 5C3, *Calculating Performance Properties of Pipe Used as Casing or Tubing*

ANSI/NACE MR0175 ¹, *Petroleum and Natural Gas Industries—Materials for Use in H₂S-Containing Environments in Oil and Gas Production*

ASME Boiler and Pressure Vessel Code ² (BPVC), Section VIII: Rules for Construction of Pressure Vessel—Division 1, UW-40: Procedures for Post-weld Heat Treatment

ASME Boiler and Pressure Vessel Code (BPVC), Section IX: Welding and Brazing Qualifications

ASNT RP-SNT-TC-1A ³, *Personnel Qualification and Certification in Nondestructive Testing*

¹ NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

² American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990, www.asme.org.

³ American Society for Nondestructive Testing, PO Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518, www.asnt.org.

- ASQC H1331 ⁴, *Zero Acceptance Number Sampling Plans, Fifth Edition*
- ASTM A370 ⁵, *Standard Test Method and Definitions for Mechanical Testing of Steel Products*
- ASTM A388, *Standard Practice for Ultrasonic Examination of Steel Forgings*
- ASTM D395, *Standard Test Methods for Rubber Property—Compression Set*
- ASTM D412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension*
- ASTM D638, *Standard Test Method for Tensile Properties of Plastics*
- ASTM D785, *Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials*
- ASTM D1414, *Standard Test Methods for Rubber O-Rings*
- ASTM D1415, *Standard Test Methods for Rubber Property—International Hardness*
- ASTM D1708, *Standard Test Method for Tensile Properties of Plastics by Use of Microtensile Specimens*
- ASTM D2240, *Standard Test Methods for Rubber Property—Durometer Hardness*
- ASTM E8/E8M, *Standard Test Methods for Tension Testing of Metallic Materials*
- ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*
- ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*
- ASTM E21, *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*
- ASTM E23, *Standard Test Method for Notched Bar Impact Testing of Metallic Materials*
- ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness*
- ASTM E165/E165M, *Standard Practice for Liquid Penetrant Examination for General Industry*
- ASTM E213, *Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing*
- ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*
- ASTM E428, *Standard Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing*
- ASTM E709, *Standard Guide for Magnetic Particle Testing*
- ISO 527-1 ⁶, *Plastics Determination of tensile properties Part 1: General principles*

⁴ American Society for Quality, 600 North Plankinton Avenue, Milwaukee, WI 53203, www.asq.org.

⁵ American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, www.astm.org.

ISO 3601-3, *Fluid power systems—O-rings—Part 3: Quality acceptance criteria*

ISO 6506 (All Parts), *Metallic materials—Brinell hardness test*

ISO 6507 (All Parts), *Metallic materials—Vickers hardness test*

ISO 6508 (All Parts), *Metallic materials—Rockwell hardness test*

ISO 6892-1, *Metallic materials—Tensile testing—Part 1: Method of test at room temperature*

ISO 6892-2 *Metallic materials—Tensile testing—Part 2: Method of test at elevated temperature*

ISO 9000, *Quality management systems—Fundamentals and vocabulary*

ISO 9712, *Non-destructive testing—Qualification and certification of NDT personnel*

ISO 18265, *Metallic materials—Conversion of hardness values*

ISO 10893-5, *Non-destructive testing of steel tubes—Part 5: Magnetic particle inspection of seamless and welded ferromagnetic steel tubes for the detection of surface imperfections*

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO 9000 and the following apply.

3.1.1

assembly

Product comprising more than one component.

3.1.2

barrier

Obstacle or impediment to flow and/or pressure.

3.1.3

base design

Design of a specific size, type, and model of liner equipment that has passed the validation requirements and meets the requirements of this specification.

3.1.4

common hardware

Nontraceable purchased items such as fasteners, washers, spacers, and various types of set screws.

3.1.5

component

The individual part of a product.

3.1.6

compound

Combination of constituent elements of the formulation of a nonmetallic material from a particular supplier.

⁶ International Organization for Standardization, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

3.1.7**conduit**

Casing, tubing, or liner, either metallic or nonmetallic.

3.1.8**conventional liner hanger**

Product that typically uses a slip/cone mechanism that is typically activated mechanically or hydraulically down hole to suspend the liner in the host conduit/casing. It does not require plastic deformation of the body.

3.1.9**conventional liner system**

Liner system that typically uses a slip/cone mechanism that is activated mechanically or hydraulically to suspend the liner into the host conduit/casing and may have annular sealing device and TBR/PBR.

3.1.10**design validation**

Process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.1.11**design verification**

Process of examining the result of a given design or development activity to determine conformity with specified requirements.

3.1.12**drift diameter**

Minimum inside diameter (ID) of a tube, product, or component, expressed as the outside diameter (OD) of the drift used during assembly inspection.

3.1.13**end connection**

Thread or other mechanism that connects equipment to liner or casing.

3.1.14**environment**

Set of conditions to which the product is exposed.

3.1.15**equipment**

Products or systems to which this document is applicable.

3.1.16**expandable connection**

Threaded connection that is designed to be expanded by radial deformation as part of the expansion process for the expandable tubular.

3.1.17**expandable liner hanger**

Product that uses radial plastic deformation of the body down hole to suspend the liner in the host conduit/casing.

3.1.18**expandable liner system**

Liner system that typically uses radial plastic deformation to suspend the liner into the host conduit/casing and may have an annular sealing device and TBR/PBR.

NOTE This definition excludes solid expandable tubular.

3.1.19

expandable tubular

A length of conduit that is designed to be expanded by radial deformation.

3.1.20

extrusion gap

Radial gap between the sealing ID and the OD immediately adjacent to the sealing element.

3.1.21

functional specification

Features, characteristics, process conditions, boundaries, and exclusions defining the performance and use requirements of the products or systems.

3.1.22

functional test

Test performed to confirm proper operation of liner equipment.

3.1.23

hanging capacity

Maximum load capacity of a liner hanger supported inside the host casing/conduit.

3.1.24

heat treatment

heat treating

Controlled heating or cooling of materials for the purpose of changing mechanical properties.

3.1.25

heat-traceable

Traceable to a unique heat treatment.

3.1.26

hold down

Integral component of liner system that limits upward motion of the product or system.

3.1.27

host casing

Casing into which a liner product or system is installed.

3.1.28

hydraulic set liner hanger

Liner hanger that uses hydraulic pressure internal to the liner hanger to cause the hanger to function.

3.1.29

informative

(Information) intended to enlighten the user/purchaser or supplier/manufacture, without containing requirements.

3.1.30

integrated liner system

Liner system consisting of a single mandrel/tubular device that combines the functions of two or more products.

3.1.31**internal connection**

Threaded connection integral to or between products of liner systems that are subjected to axial loads and pressures.

3.1.32**job-lot traceable**

(Material or components) having undergone the same process or series of processes and being traceable to one batch of material.

3.1.33**landing collars**

Accessory to the liner string that is used to receive the liner wiper plug.

NOTE Landing collars may also contain a ball seat shearing device.

3.1.34**liner**

Casing string that does not extend to the top of the well or to the wellhead.

3.1.35**liner hanger**

A device used to attach or hang a liner from the internal wall of a previously set casing/conduit string.

3.1.36**liner hanger packer**

Product that contains both liner hanger capabilities and packer capabilities in which both capabilities are activated simultaneously.

3.1.37**liner packer**

Product with a packer element and optional load supporting capability used to seal the annulus between a liner or casing and the previously installed casing.

3.1.38**liner system**

Two or more liner products that are combined to perform a designated function(s).

3.1.39**machined-bore test fixture**

Tubular test fixture machined to a specific ID dimension and which may or may not be machined on the OD.

3.1.40**manufacturing**

Equipment supplier/manufacturer process and action necessary to provide finished component(s), assembly(ies), and related documentation that fulfill the requests of the user/purchaser and meet the standards of the supplier/manufacturer.

3.1.41**mechanical set liner hanger**

Liner hanger that uses either mechanical manipulation of the work string or a hydraulic activated running tool to cause the hanger to function, and that contains no potential pressure leak path between the ID and the OD of the liner hanger.

3.1.42**model**

Equipment with unique components and operating characteristics that differentiate it from other equipment of the same type.

3.1.43**mode of loading**

Means or methods of applying mechanical loads to a system or component that creates a stress or strain.

3.1.44**normative**

(Information or procedures) mandatory for the user/purchaser or supplier/manufacture to conform with this specification.

3.1.45**operating temperature range**

Specified minimum and maximum temperatures over which the product is designed to operate.

3.1.46**packer**

Device with a packer element used for blocking fluid (liquid or gas) communication through the annular space between conduits by sealing off the space between them.

3.1.47**packer element**

Device preventing passage (i.e. communication) of liquid and/or gas between the annulus of the liner system and the host casing.

3.1.48**packoff**

Device which creates a seal between the running tool and the ID of the liner in order to provide hydraulic integrity between the liner running tool and the liner system.

3.1.49**performance envelope**

Graphical illustration of combined effect of pressure and axial load at maximum rated temperature.

3.1.50**polished-bore receptacle, tie-back receptacle**

Device with a designed internal diameter (ID) sealing surface for receiving a seal assembly.

3.1.51**pressure reversal**

Change in the direction of the pressure differential.

3.1.52**product**

One or more components within a liner system that when assembled provides defined functions.

NOTE Examples include: liner hangers, liner packers, seal assemblies, and TBR/PBRs.

3.1.53**product family**

Group of products whose configurations, sizes, materials, and applications are sufficiently similar enough that identical design methodologies can be used to establish the design parameters for each product within the family.

3.1.54**quadrant**

Each of four parts of a performance envelope divided by two lines at right angles to each other.

3.1.55**qualified person**

Individual or individuals with characteristics or abilities gained through training or experience, or both, as measured against established requirements, such as standards or tests that enable the individual to perform a required function.

3.1.56**rated pressure**

Pressure limit as defined by the supplier/manufacturer for external, internal, and barrier differentials.

3.1.57**rework**

The process of returning a product to its fully operational state through the replacement of qualified components and/or manufactured activities.

3.1.58**running/setting tool(s)**

Specialized device(s) used to install liner systems in a well.

3.1.59**scaled design**

Variation of a base design that has been validated by scaling in accordance with the limitations and requirements of this specification.

3.1.60**sealing element**

Component that prevents passage of liquid and/or gas across the interface in which it is placed.

3.1.61**seal assembly****seal stem**

Mandrel containing one or more seal units to be installed in a designed receptacle.

3.1.62**seal unit**

Device which provides pressure integrity between the TBR/PBR and mandrel of the seal assembly.

3.1.63**second-trip packer**

Liner packer that is run in combination with a seal assembly that seals in the previously run liner to seal the annulus between the liner and the previously installed casing.

3.1.64**setting sleeve****setting adaptor**

Integral component of the liner system that provides an attachment interface to the running tool.

3.1.65**size**

Relevant dimensional characteristics (nominal casing/liner) of the product as defined by the supplier/manufacturer.

3.1.66**special feature**

Specific component or subassembly that provides a functional capability that is not validated during the validation test.

NOTE Special features may include items such as ambient chambers, fluid-charged chambers, equalization flow, lock open, exercise, communication devices, mechanisms that ensure fail safe activation, control fluid redirection features, or electronic sensing and control. This list of special features is not fully inclusive.

3.1.67**stabilization**

The act of achieving a defined acceptance range for applied test parameters that conforms to the supplier/manufacturer's documented requirements and occurs prior to testing hold periods.

3.1.68**strain factor**

Ratio of the calculated strain divided by the maximum allowable strain in a given component.

3.1.69**stress factor**

Ratio of the calculated maximum stress divided by the minimum yield strength in a given component.

3.1.70**stress relieving**

Controlled heating of material to a predetermined temperature for the purpose of reducing any residual stresses.

3.1.71**sub-mudline suspension equipment**

Equipment that supports the casing string below the mudline.

3.1.72**substantive design change**

Change to the design, identified by the supplier/manufacturer as affecting the performance of the product in the intended service condition.

3.1.73**supplier/manufacturer**

Principal agent in the design, fabrication, and furnishing of equipment, who chooses to conform with this specification.

3.1.74**supported casing**

API 5CT-compliant casing that is externally supported, either mechanically or hydraulically, to limit stress levels during validation.

3.1.75**temperature cycle range**

Specified change in temperature over which the product is validated.

NOTE The temperature cycle range is applicable anywhere within the product's operating temperature range. See Figure 11.

3.1.76**tie-back receptacle, polished-bore receptacle**

Device with a designed internal diameter (ID) sealing surface for receiving a seal assembly.

3.1.77**Type 1 component**

Component that isolates pressure and/or may be loaded in tension as the result of axial loads on the product.

3.1.78**Type 2 component**

Component that does not meet the criteria of a Type 1 component.

3.1.79**validation test**

Test performed to qualify a particular size, type, and model of equipment or system for a specific validation grade.

3.1.80**wellhead/casing hanger**

Equipment that supports the casing string in the wellhead.

3.2 Abbreviations

AOQL	average outgoing quality limit
AQL	acceptance quality limit
COC	certificate of compliance
FEA	finite element analysis
ID	inside diameter
MTR	material test report
MYS	minimum yield strength
NDE	non-destructive examination
OD	outside diameter
PBR	polished-bore receptacle
PMI	positive material identification
QC	quality control
QMS	quality management system
TBR	tie-back receptacle
TOL	top of liner
D	pipe outside diameter
ID_{max}	maximum internal diameter
L	the specified unsupported length of applied pressure
P_c	pressure for yield strength collapse
P_i	internal pressure at yield for a thin tube
S_E	equivalent stress
S_Y	minimum yield strength
t	pipe wall thickness (also defined as minimum pipe thickness 6.6.13.2)

4 General Information

4.1 Product and System Illustrations

Figures 1 through 10 illustrate typical products and liner systems.

/

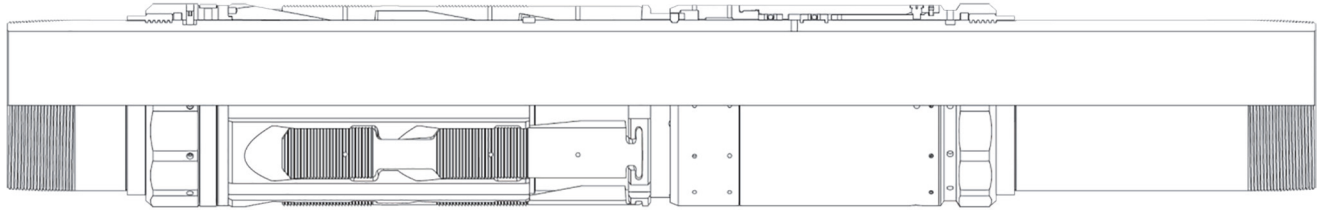


Figure 1—Hydraulic Set Hanger (Conventional)

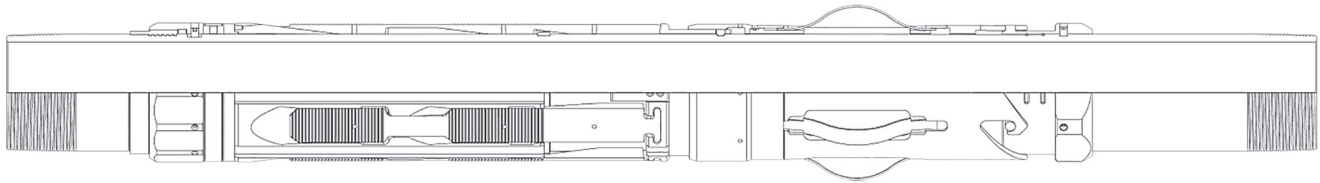


Figure 2—Mechanical Set Hanger (Conventional)

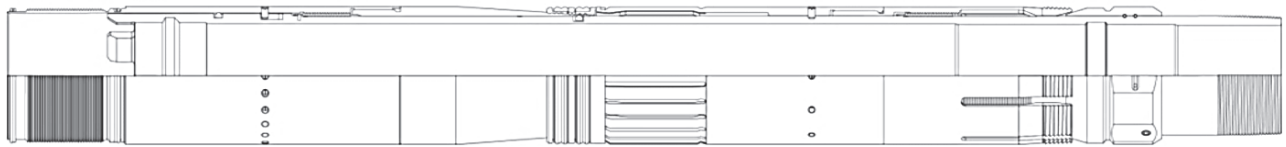


Figure 3—Liner Packer (Conventional)

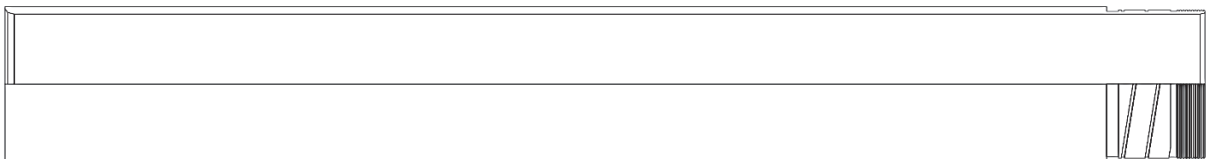


Figure 4—TBR/PBR

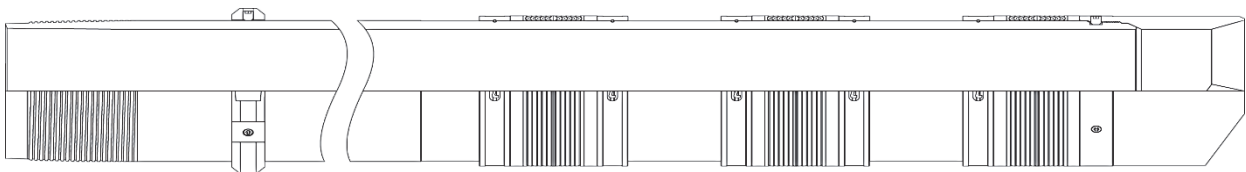
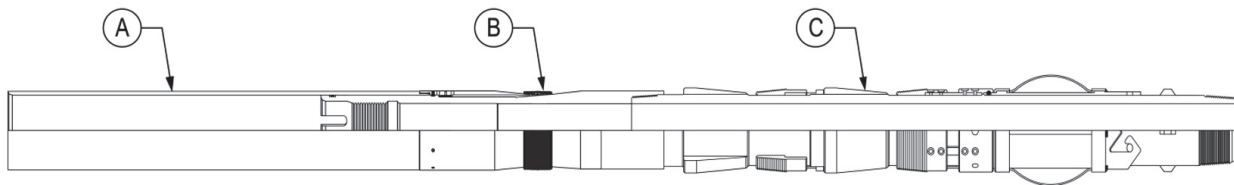


Figure 5—Seal Assembly



Figure 6—Setting/Adaptor Sleeve



Key

- A PBR/TBR
- B Liner packer
- C Liner hanger

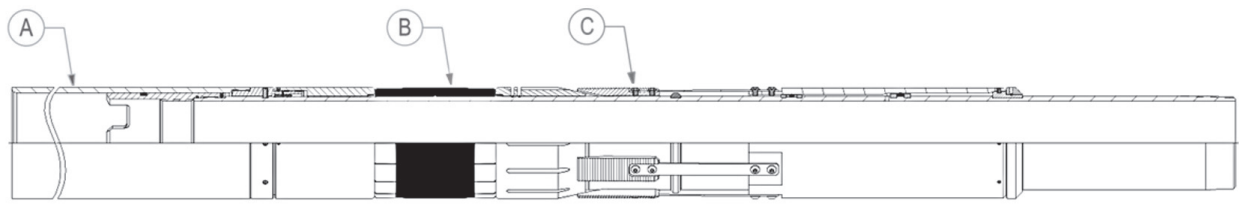
Figure 7—Mechanical Set Liner Hanger System, Activated by Pipe Manipulation



Key

- A PBR/TBR
- B Liner packer
- C Liner hanger

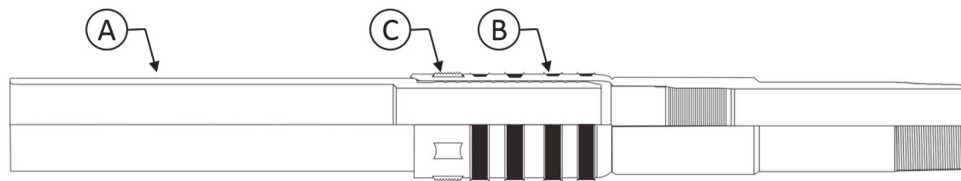
Figure 8—Mechanical Set Liner Hanger System, Activated by Hydraulic Running Tool



Key

- A PBR/TBR
- B Liner Packer
- C Liner Hanger

Figure 9—Hydraulic Set Liner Hanger System



Key

- A PBR/TBR
- B Liner packer
- C Liner hanger

Figure 10—Expandable Liner Hanger System

5 Functional Requirements

5.1 General

The user/purchaser shall prepare a functional specification for ordering products or systems that conform to this specification and specify the following requirements and operating conditions, as applicable, and/or identify the supplier/manufacturer's specific product or system. These requirements and operating conditions may be conveyed by means of text, dimensional drawing, data sheet, or other suitable documentation. An example of a functional specification checklist is provided in Annex B.

The user/purchaser may select a system type of conventional or expandable. For a conventional system type, the user/purchaser may select a setting method of hydraulic or mechanical.

5.2 Product Types

The user/purchaser may specify the following products of a liner system:

- a) liner hanger;
- b) liner packer;

- c) liner hanger packer;
- d) running/setting tools;
- e) seal assembly;
- f) setting sleeve/adaptor;
- g) tie-back receptacle / polished-bore receptacle (TBR/PBR).

5.3 Functional Characteristics

The user/purchaser may specify the following functional characteristics:

- a) type of hanger and packer actuation method (hydraulic, mechanical, or expandable);
- b) rotating capability while running liner in the hole;
- c) rotating or pipe movement capability while cementing;
- d) circulating capability.

5.4 Well Parameters

The user/purchaser may specify the following well parameters:

- a) well location (land, platform, subsea);
- b) size, mass (weight), grade, material, and connections of the casing, liner, and drill pipe;
- c) casing architecture, trajectory, deviations, maximum dogleg severity;
- d) restrictions through which the liner equipment and accessories shall pass;
- e) wellbore fluids type and composition.

5.5 Operational Parameters

The user/purchaser may specify the following operational parameters:

- a) maximum rated pressure, for both external, internal and barrier differential pressures;
- b) operating temperature range, for both maximum and minimum operational conditions;
- c) temperature cycle range (see Figure 11);
- d) loading conditions, including combined loading (pressures, tension/compression, torque) and the corresponding temperature limits expected.

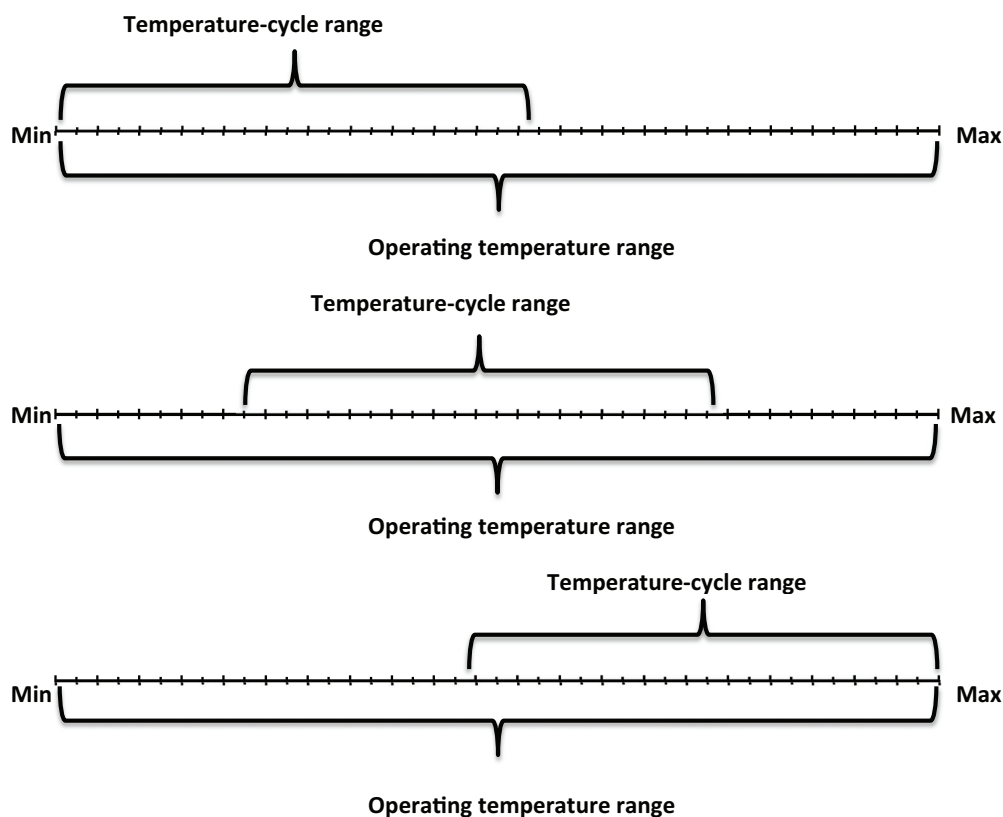


Figure 11—Temperature Cycle Range Illustration

NOTE The operating temperature range (see 3.1.44) is acknowledged to be the range over which an elastomer compound was determined to be effective; both in its ability to compress and set at low temperatures as well as its ability to block an extrusion gap and be resistant to extrusion failure at higher temperatures. The temperature cycle range (see 3.1.75) is similarly known to be the extreme temperature fluctuation that the elastomer can tolerate while still maintaining an adequate amount of sealing force at lower temperatures.

5.6 Environmental Compatibility

In cases where the user/purchaser has access to corrosion property data and/or research that is applicable to the functional specification, the user/purchaser shall state which material(s) have the ability to perform as required.

In cases where the user/purchaser elects to use materials specified by the supplier, the user/purchaser shall provide the necessary environmental conditions to enable the proper selection of materials for the environment.

The user/purchaser shall specify any requirements for environmental conditions during transportation, storage, and at surface prior to and during deployment.

5.7 Compatibility with Related Equipment

To ensure that the liner system is compatible with the application and related well equipment, the user/purchaser shall specify, where applicable, the following:

- a) liner size, weight, grade, drift, connection;

- b) casing size, weight, grade, drift, connection in which liner equipment is installed;
- c) configurations of other products and tubulars to be used in conjunction with the liner system.

5.8 User/Purchaser Validation Grade Selection

5.8.1 General

The user/purchaser shall select one design validation grade for each liner system or product design to be provided.

This specification provides three design validation grades (VS1, VS2, and VS3) for liner systems and three design validation grades (V1, V2, V3) for products as stipulated in 6.6.6.

Products validated to higher grades of design validation are considered validated for the lower grade as stipulated in Table 1. Liner systems validated to higher grades of design validation are considered validated for the lower grade as stipulated in Table 2.

Table 1—Product Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
V1	V1, V2, V3
V2	V2, V3
V3	V3

Table 2—Liner System Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
VS1	VS1, VS2, VS3
VS2	VS2, VS3
VS3	VS3

5.8.2 Liner Packers and Liner Hanger Packers

See 6.6.6.1 for validation of products previously validated under API 11D1.

5.9 Quality Grades

The user/purchaser shall select one quality grade for each liner system or product design to be provided. This specification provides three grades of quality (QL1, QL2, and QL3) as stipulated in detail in 7.4.

5.10 Optional Requirements

The user/purchaser may select additional requirements from Annex C for external flow testing.

6 Technical Specification

6.1 General

The supplier/manufacture shall provide the user/purchaser with a technical specification that conforms to the requirements defined in the functional specification of Section 5 or identifies in detail where the variance(s) are offered.

Products and systems produced according to this specification shall be designed and manufactured under a quality management system (QMS) that conforms to a recognized quality management standard such as API Q1 or ISO/TS 29001.

6.2 Technical Characteristics

The following criteria shall be met:

- a) The liner system shall be capable of setting at the specified location and remain so until intentional intervention defines otherwise. If equipped with packer, liner system shall be capable of sealing and remain so until intentional intervention defines otherwise.
- b) While being run, installed, and in service, the liner system shall be capable of performing in accordance with the functional specification.
- c) Where applicable, the liner system shall not compromise well intervention operations.

NOTE Well condition or casing failure may prevent proper operation of liner systems.

6.3 Design Criteria

6.3.1 General

Products shall be designed to meet the design validation and functional specification requirements. Final approval of the design shall be performed and documented by a qualified person(s) of the supplier/manufacturer other than the person who created the original design.

6.3.2 Design Requirements

Documentation of designs and design changes shall include methods, assumptions, formulas, calculations, and design requirements (see 7.2.2). Design requirements shall include, but not be limited to, criteria for size, performance ratings, materials, environment, temperature cycle range and/or operating temperature range, validation grade, and other pertinent requirements upon which the design is based. Final design documentation shall be reviewed and verified by a qualified person other than the individual who created the original design.

Equipment conforming to this specification shall be manufactured to drawings and specifications that do not have substantive design changes from those of the size, type, and model equipment that have passed the applicable validation tests.

The supplier/manufacturer shall establish the following verified performance ratings, as applicable:

- a) internal yield pressure;
- b) collapse pressure;
- c) differential pressure across packer element;
- d) tensile load strength;
- e) compressive strength;
- f) operating temperature range;
- g) hanging capacity;

- h) hold-down capacity;
- i) torque capacity.

The design shall take into account the effects of pressure containment and pressure-induced loads, including forces and loads induced during the running and setting of the system.

Internal connections shall meet or limit the performance rating of the product or system in which the internal connection is used.

6.4 Design Verification

6.4.1 General

Design verification shall be performed using documented procedures to ensure that each product/system design meets the supplier/manufacturer's technical specifications and shall include activities such as design reviews, design calculations, physical tests, comparison with similar designs and historical records of defined operating conditions.

Verification results shall be reviewed and approved by a qualified person and records of the review shall become a portion of the design documentation (see 7.2).

6.4.2 Design Analysis

6.4.2.1 General

The equipment shall be analyzed to determine the performance limits. The performance limits of the assembly shall be determined by the component of the design with the highest stress factor (or strain factor for plastically deformed components). One of the design analysis methods in 6.4.2.2 shall be used to determine the maximum state of stress of a component. Once the method is selected, it becomes the requirement.

The supplier/manufacturer shall identify the Type 1 components of the product or system and the mode of loading. The supplier/manufacturer shall calculate the stress level (and strain level for plastically deformed components) in the identified component(s) based upon the worst-case loads in the design requirements.

The minimum acceptable material condition and minimum acceptable material yield shall be used in the calculations to determine equipment ratings. The minimum acceptable material yield shall include the effects of temperature. Where other material properties, such as Young's modulus, are used in calculations, the material properties used shall include the effects of temperature. The effects of temperature on material properties shall be in accordance with one or more of the following:

- industry recognized published data reviewed and verified by a qualified person;
- data
- provided by the material supplier;
- data
- used by the supplier/manufacturer.

When material property tests are conducted by the supplier/manufacturer to determine the effects of temperature, the tests shall be conducted in accordance with ASTM E21 for yield strength.

6.4.2.2 Design Analysis Methods

6.4.2.2.1 Distortion Energy Theory

The distortion energy theory, also known as the von Mises yield criterion, may be used for design calculations for pressure-containing components.

NOTE The distortion energy theory predicts a combined stress that will exceed the material's minimum yield strength; this is also commonly known as von Mises stress. This theory determines a combined stress at a point from the given principal stresses. The von Mises stress predicts failure when the total amount of distortion in a differential cube of material is equivalent to the distortion experienced by the same cube when loaded by a uniaxial force to the yield point.

Rules for the consideration of discontinuities and stress concentrations are beyond the scope of this method and this specification. However, the basic pressure vessel wall thickness may be sized by combining triaxial stresses based on hydrostatic test pressure and limited by the following criterion:

$$S_E \leq S_Y \quad (1)$$

where:

S_E is the maximum allowable equivalent stress at the most highly stressed distance into the pressure vessel wall, computed by the distortion energy theory method;

S_Y is the material-specified minimum yield strength.

6.4.2.2.2 Triaxial Yield and Collapse Equations

API 5C3 provides equations that may be used to derive the triaxial yield and collapse of a cylinder.

6.4.2.2.3 Finite Element Analysis

Finite element analysis (FEA) is a design verification methodology that may be used to predict equipment performance for complex geometry and/or complex loading where conventional verification methodologies are considered incomplete by the design engineer.

NOTE An example FEA method for analyzing a pressure-containing component is described in Annex D.

6.4.2.2.4 Supplier/Manufacturer Defined Analysis

Supplier/manufacturer defined analysis may be used for design calculations for pressure-containing components.

6.4.3 Rated Performance Envelope

A rated performance envelope as specified in 6.7 shall be prepared for systems validated to VS1 or VS2.

For validation grade VS3, a rated performance envelope shall be prepared when requested in the functional specification.

6.5 Materials

6.5.1 General

Materials for each component shall be stated by the supplier/manufacturer and shall be suitable for the environmental conditions specified in the functional specification. The supplier/manufacturer shall have documented specifications for all materials, and materials shall conform with these specifications.

- a) The user/purchaser may specify materials for the specific use and corrosion environment in the functional specification. If the supplier/manufacturer proposes to use another material, the user/purchaser has the option to accept or reject the proposed material alternative. This applies to metallic and nonmetallic components.
- b) Material substitutions from those materials used in the validation-tested liner system or components are allowed without further validation testing. The supplier/manufacturer's selection criteria for these substitutions shall be documented, and the substituted material shall conform to the design, functional, and technical requirements of this specification. Material substitutions require approval by a qualified person(s) using the methods and practices used to accept the original material, and its supporting documentation shall be retained in accordance with 7.2.1.
- c) Substantive changes to materials (metallic and nonmetallic) that can affect product performance shall be considered in accordance with 6.8.

6.5.2 Metals

6.5.2.1 General

Metallic materials used in the manufacture of liner system components shall meet the requirements in 6.5.2.2 to 6.5.2.3.

6.5.2.2 Specifications

The material specifications shall include:

- a) chemical composition limits;
- b) heat treatment requirements/conditions, as applicable;
- c) mechanical property limits, including as applicable:
 - tensile strength;
 - yield strength (transverse and longitudinal, as applicable);
 - elongation;
 - hardness; and
 - toughness.

6.5.2.3 Additional Requirements

The mechanical properties specified in 6.5.2.2 c) for traceable components shall be verified by tests conducted on a material sample produced from the same heat of material. The material sample shall experience the same heat treatment process as the component it qualifies. The resulting material test report (MTR) shall be approved by supplier/manufacturer's qualified person and retained in accordance with 7.2.1.

Materials selected for use in sulfide stress cracking environments shall be in accordance with the supplier/manufacturer's documented procedure or as specified by the user/purchaser. Metallic materials specified by supplier/manufacturer used in sulfide stress cracking environments shall meet requirements of ANSI/NACE MR0175.

6.5.3 Nonmetals

6.5.3.1 General

The supplier/manufacturer shall have documented procedures, including acceptance criteria, for evaluations or testing of seal materials or other nonmetals.

6.5.3.2 Sealing System Requirements

Verification or validation shall establish that the nonmetal sealing element used is suitable for the specific configuration, environmental effects, and application. The evaluations or tests shall ensure compatibility with the technical and functional requirements.

6.5.3.3 Bonding to Substrates

Nonmetallic seal components may be bonded to substrates for additional reinforcement or to perform other functions. The integrity of the bond shall be evaluated in accordance with the supplier/manufacturer's defined methods and acceptance criteria.

Substrate metals shall conform to the requirements for metallic components. Nonmetallic substrates shall conform to the requirements of 6.5.3.4.

6.5.3.4 Nonmetallic Components

The supplier/manufacturer's documented specifications for nonmetallic compounds shall include handling, storage, and labeling requirements, including the cure date, batch number, compound identification, and shelf life appropriate to each compound and shall define those characteristics critical to the performance of the material, such as:

- a) compound type;
- b) mechanical properties, including as a minimum:
 - tensile strength (at break);
 - elongation (at break); and
 - tensile modulus (at 50 % or 100 %, as applicable).
- c) compression set;
- d) durometer hardness.

6.5.4 Welding and Brazing

Welding, including overlays and brazing, shall require the following:

- a) Weld materials and practices not listed in the ASME BPVC Section IX shall be applied using weld procedures qualified in accordance with the methods of ASME BPVC Section IX or equivalent.
- b) Welding and brazing procedure and personnel qualification shall be in accordance with ASME BPVC Section IX or equivalent.