

# 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 conform 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 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 five 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 utilizes liquid as a test medium, while validation grade V1 utilizes nitrogen. Design validation V1-L and V2-L are listed in Annex A for liner packers and liner hanger packers that were validated prior to the first edition of this document.

There are five 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 utilizes liquid as a test medium, while validation grade VS1 utilizes nitrogen. Grades VS2 and VS1 can be achieved by testing an entire system, or by combining individual validated products. System design validation grades VS1-L and VS2-L are listed in Annex A for liner systems that were validated prior to the first edition of this document and are for legacy liner systems.

Annexes B, C, D, G and J are informative requirements, where Annexes A, 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 are 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, the supplier/manufacturer will 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, and running/setting tools as defined herein for use in the oil and natural gas industry.

This specification provides minimum requirements for the functional requirements and technical specification, including design, design verification and validation, materials, quality control, documentation and data control, redress and repair, shipment, and storage.

Products covered by this specification apply only to applications installed 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, 4<sup>th</sup> 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 <sup>1</sup>, *Petroleum and Natural Gas Industries—Materials for Use in H<sub>2</sub>S-Containing Environments in Oil and Gas Production*

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

<sup>1</sup> NACE International, 15835 Park Ten Place, Houston, Texas 77084, [www.nace.org](http://www.nace.org).

<sup>2</sup> American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990, [www.asme.org](http://www.asme.org).

<sup>3</sup> American Society for Nondestructive Testing, PO Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518, [www.asnt.org](http://www.asnt.org).

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

ASNT RP-SNT-TC-1A<sup>3</sup>, Personnel Qualification and Certification in Nondestructive Testing

ASQC H1331<sup>4</sup>, Zero Acceptance Number Sampling Plans, Fifth Edition

ASTM A370<sup>5</sup>, 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 37, Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties

<sup>1</sup> American Society for Quality, 600 North Plankinton Avenue, Milwaukee, WI 53203, [www.asq.org](http://www.asq.org).

<sup>2</sup> American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, [www.astm.org](http://www.astm.org).

ISO 527-1<sup>6</sup>, *Plastics Determination of tensile properties Part 1: General principles*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

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ISO 2781, *Rubber, vulcanized or thermoplastic — Determination of density*

ISO 815-1, *Rubber, vulcanized or thermoplastic — Determination of compression set*

ISO 1183-1, *Plastics — Methods for determining the density of non-cellular plastics — Part 1: Immersion method, liquid pycnometer method and titration method*

ISO 1183-2, *Plastics — Methods for determining the density of non-cellular plastics — Part 2: Density gradient column method*

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 7619-1, *Rubber, vulcanized or thermoplastic — Determination of indentation hardness*

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*

<sup>6</sup> International Organization for Standardization, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, [www.iso.org](http://www.iso.org).

## 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**

Standard nontraceable mechanical components used for general assembly, spacing, and securing.

NOTE: Examples include 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.

#### 3.1.7

##### **conduit**

Casing, tubing, or liner.

#### 3.1.8

##### **conventional liner hanger**

A type of liner hanger that uses a slip/cone mechanism that is typically activated mechanically or hydraulically down hole to suspend the liner in the host conduit/casing.

#### 3.1.9

##### **conventional liner system**

Liner system of multiple conventional liner products, that typically uses a slip/cone mechanism that is activated mechanically or hydraulically to suspend the liner into the host conduit/casing and can 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 applies.

### **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**

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

### **3.1.18**

#### **expandable liner hanger packer**

A liner hanger packer that typically uses radial plastic deformation to suspend the liner into the host conduit/casing and has an annular sealing device and can have a TBR/PBR as an option.

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 requirements**

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 in the down-hole direction of a liner hanger system or product inside the host 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 capacity**

Maximum load capacity in the up-hole direction of a liner hanger system or product inside the host casing/conduit.

NOTE: Also referred to as the upward lifting resistance.

### **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 to cause the hanger to function and that contains a potential pressure leak path between the ID and the OD of the liner hanger.

### **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**

#### **interface seal**

Device which provides pressure integrity between the TBR/PBR and mandrel of liner packer, liner hanger packer, or setting adapter / sleeve.

### **3.1.32**

#### **internal connection**

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

### **3.1.32**

#### **intersection point**

A test point that combines axial load and pressure which establishes the performance limit for the product or system.

### **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 can 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 product used to attach or hang a liner from the internal wall of a previously set conduit string.

### **3.1.36**

#### **liner hanger packer**

A product that contains both liner hanger capabilities and packer capabilities on a single body.

NOTE: A liner hanger packer can include an interface seal and TBR/PBR.

### **3.1.37**

#### **liner packer**

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

NOTE: A liner packer can include an interface seal and TBR/PBR.

### **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/manufacture process and action used 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/manufacture.

### **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.

### **3.1.45**

#### **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 preventing communication of fluid (liquid or gas) through the annular space between conduits by sealing off the space between them.

### **3.1.47**

#### **packer element**

Device preventing communication of fluid (liquid 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 to provide pressure integrity.

#### **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.

Examples: liner hangers, liner packers, liner hanger 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,

NOTE: Established requirements include 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**

##### **redress**

The process of replacing elastomers, seals, non-metallics, shear devices, and other common hardware on a product.

#### **3.1.58**

##### **reference ID**

The inner diameter of a liner product or system used to derive piston induced forces.

NOTE: the reference ID is often the liner ID, but can change due to cross-overs and other considerations

#### **3.1.59**

##### **reference OD**

The outer diameter below the packer element of a liner product or system used to derive piston induced forces.

NOTE: the reference OD is often the liner OD, but can change due to cross-overs and other considerations

### **3.1.60**

#### **repair**

Any activity, including component replacement, beyond the scope of redress that restore the equipment to its original performance.

NOTE: Examples of repair activities include machining, welding, heat treating, or other manufacturing operations.

### **3.1.61**

#### **rework**

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

### **3.1.62**

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

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

### **3.1.63**

#### **scaled design**

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

### **3.1.64**

#### **sealing element**

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

### **3.1.65**

#### **seal assembly**

##### **seal stem**

Tubular component or assembly containing one or more seal units to be installed in a designed receptacle.

NOTE The application and validation testing described in this specification addresses static loading. For dynamic seal assembly validation testing, refer to applicable sections of API 19AC.

### **3.1.66**

#### **seal unit**

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

### **3.1.67**

#### **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.

### **3.1.68**

#### **setting sleeve**

##### **setting adaptor**

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

### **3.1.69**

#### **size**

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

### **3.1.70**

#### **special feature**

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

NOTE Special features can 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.

### **3.1.71**

#### **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.

### **3.1.72**

#### **strain factor**

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

### **3.1.73**

#### **stress factor**

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

### **3.1.74**

#### **stress relieving**

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

### **3.1.75**

#### **sub-mudline suspension equipment**

Equipment that supports the casing string below the mudline.

### **3.1.76**

#### **substantive design change**

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

### **3.1.77**

#### **supplier/manufacturer**

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

### **3.1.78**

#### **supported casing**

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

### **3.1.79**

#### **system intersection point**

an envelope intersection between two or more overlapping product performance envelopes

### **3.1.80**

#### **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 section 6.6.16.

### **3.1.81**

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

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

### 3.1.82

#### **Type 1 component**

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

### 3.1.83

#### **Type 2 component**

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

### 3.1.84

#### **validation test**

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

### 3.1.85

#### **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
CAL	connection application level
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
$ID_{nom}$	nominal internal diameter
$ID_{max}$	maximum internal diameter
$ID_{tf}$	machined bore test fixture internal diameter
$L$	the specified unsupported length of applied pressure
$OD_{nom}$	nominal outside diameter
$OD_{tf}$	machined bore test fixture outside diameter
$P_c$	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

Figures 1 through 10 illustrate typical products and liner systems.

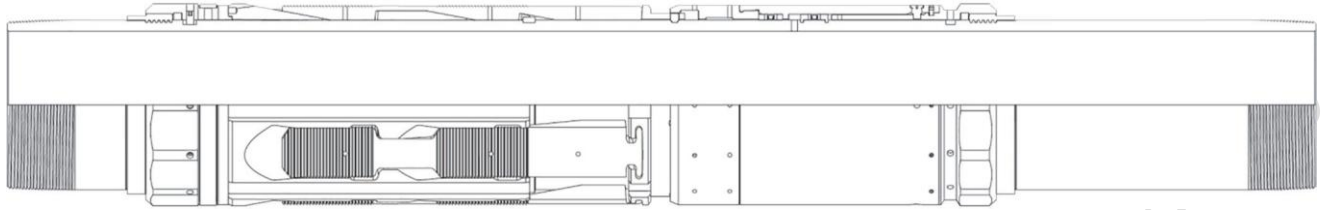


Figure 1—Hydraulic Set Hanger (Conventional)

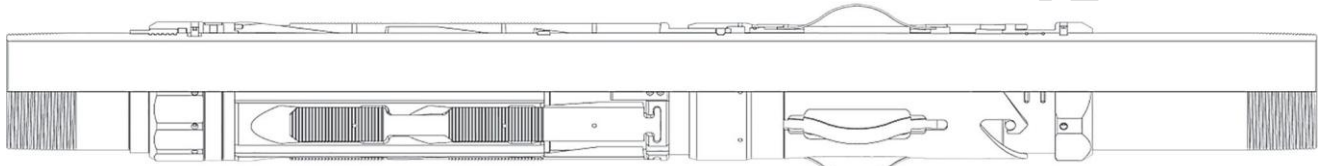


Figure 2—Mechanical Set Hanger (Conventional)

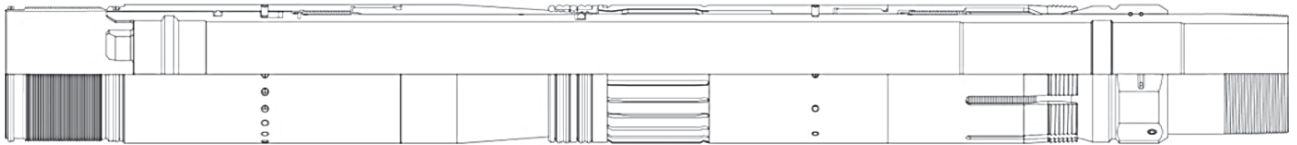


Figure 3—Liner Packer (Conventional)

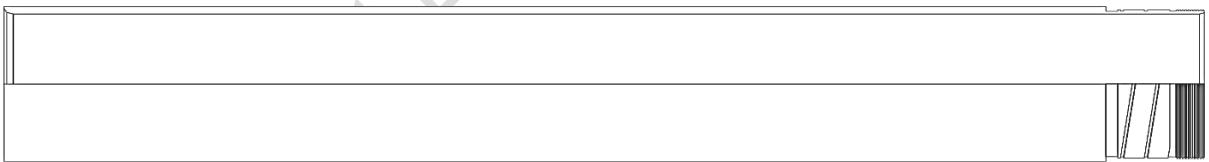


Figure 4—TBR/PBR

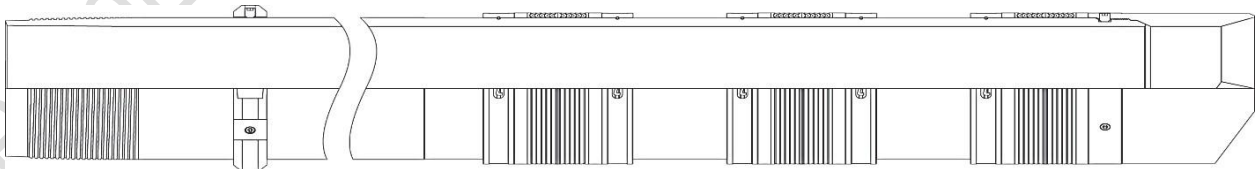
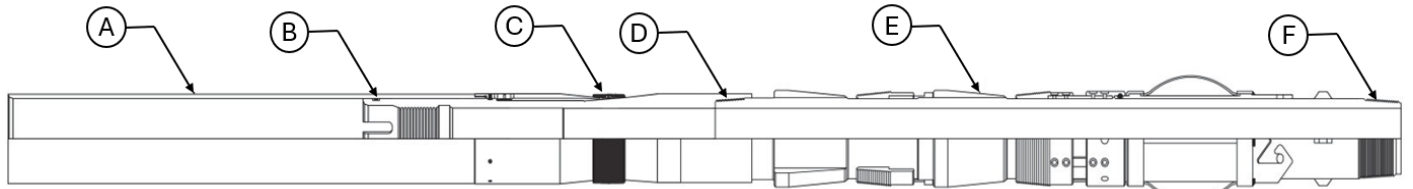


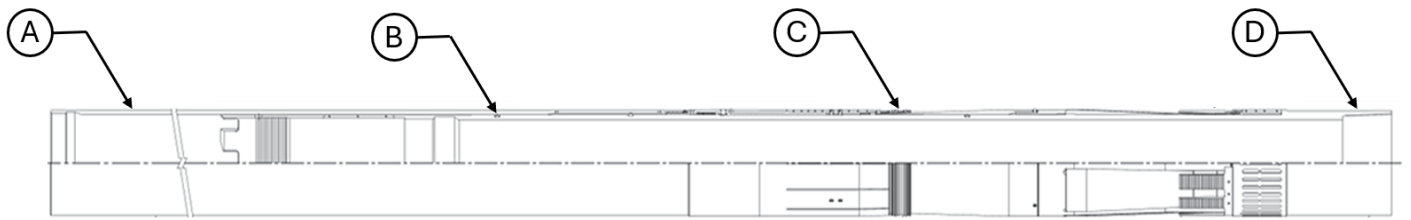
Figure 5—Seal Assembly



Key

- A TBR/PBR
- B Interface Seal
- C Liner Packer
- D Internal Connection
- E Liner Hanger
- F End Connection

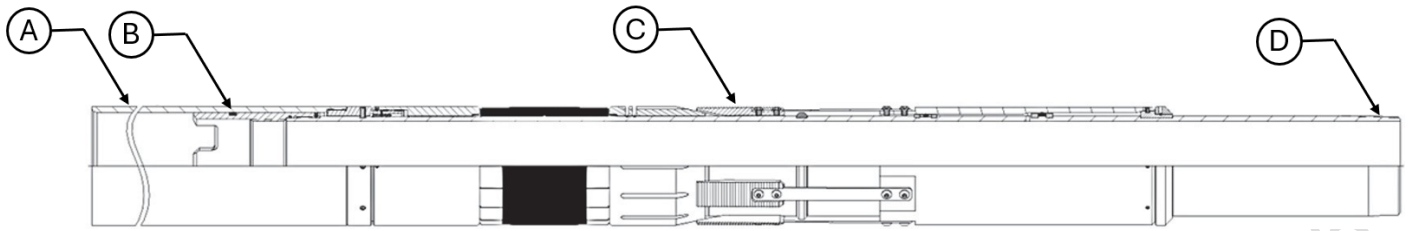
**Figure 6—Mechanical Set Liner Hanger System, Activated by Pipe Manipulation**



Key

- A TBR/ PBR
- B Interface Seal
- C Liner Hanger Packer
- D End Connection

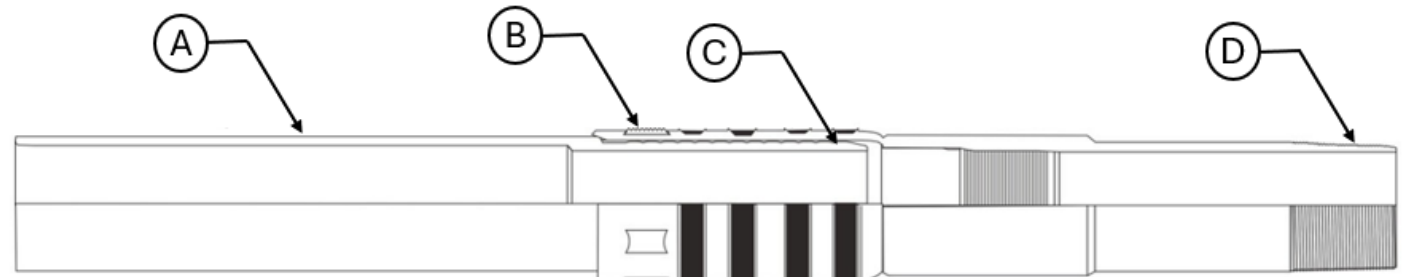
**Figure 7—Mechanical Set Liner Hanger Packer System, Activated by Hydraulic Running Tool**



Key

- A TBR/ PBR
- B Interface Seal
- C Liner Hanger Packer
- D End Connection

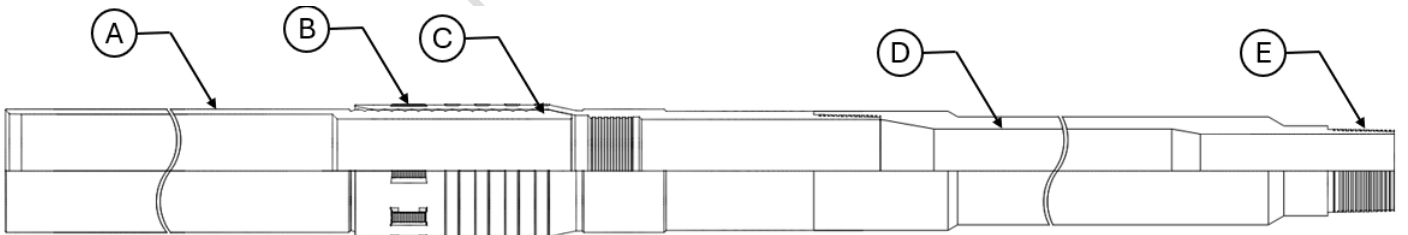
**Figure 8—Hydraulic Set Liner Hanger Packer System**



Key

- A TBR/ PBR
- B Liner Hanger Packer
- C Interface Seal
- D End Connection

**Figure 9—Expandable Liner Hanger Packer System**



Key

- A Upper TBR/ PBR
- B Liner Hanger Packer
- C Interface Seal
- D Lower PBR
- E End Connection

**Figure 10—Expandable Liner Hanger Packer System with Lower PBR**

## 5 Functional Requirements

### 5.1 General

The user/purchaser should prepare a functional requirements 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. If not provided, the supplier/manufacturer shall generate a functional specification.

NOTE The supplier/manufacturer can generate internal requirements for products as the user/purchaser.

### 5.2 Product Types and Functional Requirements

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

- a) liner hanger;
- b) liner packer;
- c) liner hanger packer;
- d) seal assembly;
- e) tie-back receptacle / polished-bore receptacle (TBR/PBR).

#### 5.2.1 Liner Hanger Functional Requirements

A liner hanger shall be capable to attach, anchor, or hang a liner from the internal wall of a previous casing or liner string. A liner hanger provides capability to resist movement from forces acting in a downward direction but may also have capability to resist movement from forces acting in the upward direction.

#### 5.2.2 Liner Packer Functional Requirements

A liner packer shall be capable of sealing the annulus between a liner or casing and the previously installed casing or liner. Hold Down capability is optional.

NOTE: While most Liner Packers will feature a TBR/PBR above the product, it is not a product requirement. A TBR/PBR can be included with the Liner Packer.

#### 5.2.3 Liner Hanger Packer Functional Requirements

A liner hanger packer shall include the functions of both a liner hanger and a liner packer on a single body.

NOTE: The liner hanger packer can have other components connected to it for additional functions, such as a TBR or setting sleeve.

#### 5.2.4 Seal Assembly Functional Requirements

A seal assembly shall be capable of being installed in a designed receptacle and provide pressure integrity under a static condition. Applications such as anchored or cemented seal assemblies are considered static and validated by this specification. For dynamic functions refer to applicable sections of API 19AC.

#### 5.2.5 TBR/PBR Functional Requirements

A TBR or PBR shall have a designated ID sealing surface for receiving a seal assembly to provide pressure integrity.

### 5.3 Functional Characteristics

The user/purchaser may specify the following functional characteristics:

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

### 5.4 Well Parameters

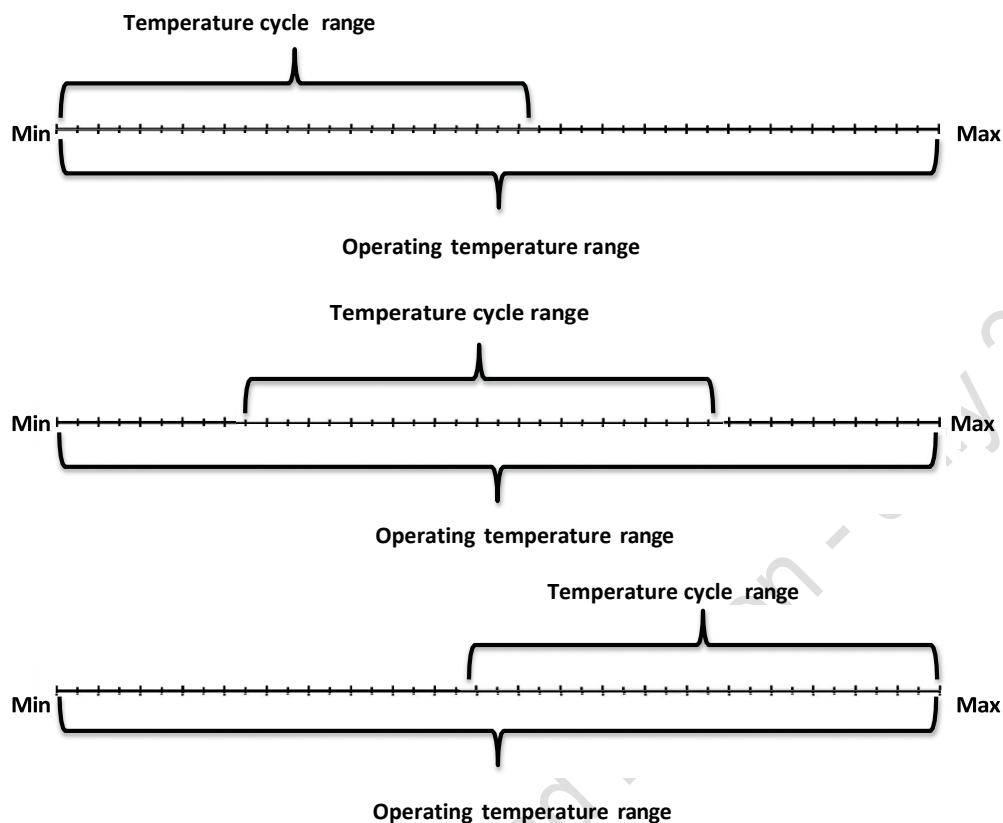
The user/purchaser may specify the following well parameters:

- 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.
- f) configurations of other products and tubulars to be used in conjunction with the liner system.

### 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 10 and Figure 12);
- d) expected operational setting temperature;
- e) 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 3.1.45) is acknowledged to be the range over which a product was validated. The temperature cycle range (see 3.1.80) is known to be the extreme temperature fluctuation that the product was validated to.

## 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 intended.

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 and installation.

## 5.7 User/Purchaser Validation Grade Selection

### 5.7.1 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 for liner systems (VS1, VS2, and VS3), three design validation grades for products (V1, V2, V3), two validation grades for legacy liner systems (VS1-L, VS2-L), and two validation grades for legacy products (V1-L, V2-L) per Annex A.

Products validated to higher grades of design validation are considered validated for the lower grade as stipulated in

Table 1 and Table 3. Liner systems validated to higher grades of design validation are considered validated for the lower grade as stipulated in Table 2 and Table 4.

**Table 1—Product Design Validation Grade Hierarchy**

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

**Table 2—Liner System Design Validation Grade Hierarchy**

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

**Table 3—Legacy Liner Packer and Liner Hanger Packer Design Validation Grade Hierarchy**

Design Validation Grade	Grades Covered
V1-L	V1-L, V2-L
V2-L	V2-L

**Table 4—Legacy Liner System Design Validation Grade Hierarchy**

Design Validation Grade	Grades Covered
VS1-L	VS1-L, VS2-L
VS2-L	VS2-L

Any system which includes a legacy validated product per Annex A, can only qualify to a legacy system grade, per the hierarchy in Tables 1-4. See section 6.6.16 for system grade definitions.

## 5.8 Quality Grades

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

## 5.9 Optional Requirements

The user/purchaser may select additional requirements from Annex C for external flow testing or Annex J for low temperature setting.

## 6 Technical Specification

### 6.1 General

The supplier/manufacturer 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 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 a packer, the 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 requirements of this specification. 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

6.3.2.1 Documentation of designs and design changes shall include methods, assumptions, formulas, calculations, and design requirements (see 7.2.2). Design requirements shall include criteria for liner and host casing size, performance ratings, materials (including coatings, welds, platings, metallics, and non-metallics), 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 person who created the original design.

6.3.2.2 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.

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

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

h) hold-down capacity;

i) torque capacity.

6.3.2.4 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.

6.3.2.5 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/manufacture's technical specifications and shall include 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. All requirements of the selected design analysis method shall be met.

The supplier/manufacture shall identify the Type 1 components of the product or system and the mode of loading. The supplier/manufacture 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:

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

When material property tests are conducted by the supplier/manufacture 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 products validated to V1, V2, V1-L, or V2-L.

For validation grade V3, a rated performance envelope shall be prepared when requested in the functional requirement.

## **6.5 Materials**

### **6.5.1 General**

Materials and coatings, including platings and surface treatments, for each component shall be stated by the supplier/manufacturer and shall be suitable for the environmental conditions specified in the functional requirements. 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 requirement. 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) A change of materials or coatings shall be evaluated per section 6.8 Design Changes. The supplier/manufacturer's selection criteria for the material or coating substitutions shall be documented, and the substituted material or coating shall conform to the design, functional, and technical requirements of this specification. Material substitutions require approval by a qualified person using the methods and practices used to accept the original material, and its supporting documentation shall be retained in accordance with 7.2.

### **6.5.2 Metals**

#### **6.5.2.1 Specifications**

The metallic 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);
  - elongation;
  - hardness; and
  - toughness.

#### **6.5.2.2 Additional Requirements**

The mechanical properties specified in 6.5.2.1 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 a 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 in 6.5.2. 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. Those characteristics critical to the performance of the material shall be defined:

- a) compound type;
- b) mechanical properties, including :
  - 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**

For welding, including overlays and brazing, the following shall apply: :

- 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.

c) Welding for sour service shall meet the requirements of ANSI/NACE MR0175.

## **6.6 Design Validation**

### **6.6.1 General**

There are three methods of design validations included in this specification: product design validation, liner system design validation, and legacy liner packer and liner hanger packer validation per Annex A. The validation testing requirements in this specification may not represent all well conditions.

Product design validation results may be used to generate product or system performance envelopes. Where the intent is to combine product validations to create a system performance envelope, the product validations shall provide the necessary information to create a system performance envelope as described in 6.7. Validation test results and dimensional inspections results shall be approved by a qualified person other than the person performing them, and validation records shall become a portion of the design documentation.

Products and systems used in validation testing shall be designed and manufactured in accordance with the applicable requirements of Sections 5, 6, and 7.

When repair or redress of the product or system occurs during validation testing, the validation test shall be repeated from the beginning.

Liner hanger running/setting tools shall be validated in accordance with Annex E.

Special features which are not validated during validation testing shall be validated in separate tests to their rated limits using documented procedures and acceptance criteria and the results approved by a qualified person.

### **6.6.2 Procedures**

The supplier/manufacturer shall develop procedures for conducting design validation. These procedures shall be documented and included in the final report of the results. The procedures shall include pre- and post-test inspection activities and identify critical areas to be inspected. The supplier/manufacturer shall document all parameters and results of the evaluations that demonstrate conformance to the defined validation grade. Validation testing shall be discontinued if the product or system fails to perform within the limits specified except when such failure(s) are determined to be the result of a failure within the test facility or test fixture and that failure and its correction do not affect the validity of the test results. Validation test procedures may include provisions to address rapid gas decompression.

For validation grade V1, V2, VS1, and VS2, pressure holds shall be a minimum of 15 minutes after stabilization of the test parameters. The time period and limits for stabilization are at the discretion of the supplier/manufacturer.

For validation grade V2 and VS2, the test medium shall be liquid. The density shall be less than 1100 kg/m<sup>3</sup> (68.67 lb/ft<sup>3</sup>). Liquid shall be visibly free from particulate matter and/or other material that has the potential of plugging small leaks.

For validation grade V1 and VS1, the test medium shall be nitrogen.

Filler material may be used to reduce the volume of nitrogen. If used the filler material shall not interfere with the validation procedure or test result.

Validation requirements for legacy liner packers, liner hanger packers, and legacy systems are specified in Annex A.

NOTE: For more information on product and system validation grades, refer to 6.6.6.

### 6.6.3 Personnel

Preparation, testing, and approval of results shall be conducted by qualified person(s).

### 6.6.4 Measuring and Monitoring Equipment

Measuring and monitoring equipment used during the validation process shall be calibrated in accordance with the requirements of 7.5.

All pressures are defined as gauge unless otherwise specified and shall be recorded on time-based equipment.

Recorded temperature measurements shall be representative of those of the product as it is installed in the test fixture.

Gas leakage shall be measured in graduated cylinders at atmospheric pressure.

### 6.6.5 Test Report

A test report shall be prepared for each design validation and approved by qualified person(s) other than those who prepared the report. Reports shall be retained as part of the design validation records for the product (as described in 7.2.2). The report shall include the following information:

- a) validation test performed;
- b) a description of the tested item, which shall include size, type, model, unique identifier;
- c) test facility name, location, and person performing the testing;
- d) date(s) of validation testing conducted;
- e) test schematic;
- f) procedures used and records demonstrating conformance to the established procedures, including acceptance criteria and discussion of those results;
- g) remarks (describing any non-specified equipment or procedures requested by manufacturer, unusual conditions observed during test, );
- h) additional information as per the applicable annex or test procedure describing the testing, as applicable;
- i) results of specific pre- and post-evaluations. This should include evidence of visual inspections of the tested product and host casing, drift testing, and test fixture surface condition;
- j) summary of results, including a discussion whether or not the test was successful;
- k) approvals and date of the report.

NOTE Records may be electronic or hardcopy.

## 6.6.6 Product and System Validation Grades

### 6.6.6.1 General

This specification defines three grades of design validation for products, three grades of design validation for liner systems, two grades for legacy liner packers and liner hanger packers, and two grades for legacy liner systems. Each product or system design shall be validated to at least the grade selected by the user/purchaser.

Each product or system tested shall pass all requirements within the limits specified, to the defined acceptance criteria, and with documentation and approval of the results.

Pre-test and post-test dimensional inspection of critical operational areas, as determined by the supplier/manufacturer, shall be conducted, documented, and maintained by the supplier/manufacturer.

The supplier/manufacturer shall have on file material specifications and drawings that show all the applicable dimensions and tolerances of components contained in the validation-tested product or system.

Product validation requirements are detailed in 6.6.8 through 6.6.16 and summarized in informative Table 5. System validation requirements are detailed in 6.6.17.

A mechanical set liner hanger with seals or internal connections shall be validated according to 6.6.9.5.2 with the exception that the hanger shall be set mechanically, per Step 2 of 6.6.9.4.1

**Table 5 – Summary of Validation Requirements**

<b>Product Type</b>	<b>Summary of Validation Requirements</b>
Liner Hanger	6.6.8 Liner Hanger Hanging Capacity 6.6.9 Liner Hanger Combined Load and Pressure 6.6.15 Internal Thread Connections, if present in the product 6.6.16 Minimum Operating Temperature Rating Validation, as applicable Annex F Liner Hanger Bearing, if present in the product Annex E.3, if running tool interface is integrated in the product
Liner Packer	6.6.8, Liner Packer Hold-Down Capacity, if applicable 6.6.10 Liner Packer 6.6.12 Interface Seal between the TBR/PBR and Packer, if present in the product 6.6.13 TBR/PBR, if present in the product 6.6.15 Internal Thread Connection, if present in the product 6.6.16 Minimum Operating Temperature Rating Validation, as applicable Annex E.3, if running tool interface is integrated in the product
Liner Hanger Packer	6.6.11 Liner Hanger Packer 6.6.12 Interface Seal between the TBR/PBR and Packer, if present in the product 6.6.13 TBR/PBR, if present in the product 6.6.15 Internal Thread Connection, if present in the product 6.6.16 Minimum Operating Temperature Rating Validation, as applicable Annex E.3, if running tool interface is integrated in the product Annex F Liner Hanger Bearing, if present in the product
Running / Setting Tools	Annex E.3
Seal Assembly	6.6.14 Seal Unit 6.6.15 Internal Thread Connection, if present in the product 6.6.16 Minimum Operating Temperature Rating Validation, as applicable
TBR / PBR	6.6.12 Interface Seal between the TBR/PBR and Packer, if present in the product 6.6.13 TBR/PBR 6.6.15 Internal Thread Connection, if present in the product 6.6.16 Minimum Operating Temperature Rating Validation, as applicable Annex E.3, if running tool interface is integrated in the product

NOTE: A TBR / PBR may include a Setting Sleeve or Adapter.

### 6.6.6.2 Product Validation Grades

The product validation grades are the following:

- V3: supplier/manufacturer-defined;
- V2: liquid test plus axial loads and temperature cycle range;
- V1: nitrogen test plus axial loads and temperature cycle range;
- V1-L: nitrogen test plus axial loads and temperature cycle range tested to Annex A procedures;
- V2-L: liquid test plus axial loads and temperature cycle range tested to Annex A procedures.

NOTE 1 Temperature cycle range does not apply to mechanical hanger load testing defined in 6.6.8.4 and mechanical set liner hanger combined load and pressure testing defined in 6.6.9.4.1.

NOTE 2 Seal assembly validation grades are included in 6.6.14.

Products validated to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 1 and Table 3.

### 6.6.6.3 System Validation Grades

The system validation grades are the following:

- VS3: supplier/manufacturer-defined;
- VS2: liquid test plus axial loads plus pressure plus temperature cycling
- VS1: nitrogen test plus axial loads plus pressure plus temperature cycling
- VS1-L: nitrogen test plus axial loads plus pressure plus temperature cycling for legacy systems
- VS2-L: liquid test plus axial loads plus pressure plus temperature cycling with for legacy systems
- 

Liner systems qualified to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 2 and Table 4.

## 6.6.7 Design Validation Scaling and Alternate Host Casing Calculations

### 6.6.7.1 General Scaling

Scaling may be used to validate a variation of a validated product of the same size, type, and model in the same product family. Products or systems that have been previously validated by testing to the requirements of grades V1, V2, V1-L, V2-L, VS1, VS2, VS1-L, and VS2-L can be scaled. The scaled design shall carry the same validation grade as the tested product (base design) that the scaled design was based upon. A product validated by scaling (scaled design) shall not be used for subsequent scaling.

Additional limitations of product design scaling are defined in each of the individual product validation sections. Sealing elements shall be scaled in accordance with the requirements and limitations of 6.6.7.5.

The supplier/manufacturer shall not use scaling to validate products with higher pressure ratings, higher axial load ratings, a higher maximum operating temperature, a lower minimum operating temperature, a larger temperature cycle range, or larger rating envelope than the validated product.

For products designed to operate in a range of casing weights and sizes, a performance envelope shall be provided for each casing size/weight/material adjusted for casing stress. The stress level for each casing

size/weight/material shall not exceed the stress level of the test fixture casing per section 6.6.7.2.

Each scaled product requires evaluation and justification. Design scaling shall be approved by a qualified person and records of the results shall become a portion of the design documentation indicating a scaled design.

Product designs containing substantive changes shall conform with 6.8.2.

#### **6.6.7.2 Scaling of Non-plastically Deformed Components**

The supplier/manufacturer shall establish the maximum stress within the previously validated design Type 1 components and in the same components of the scaled design. The mode of loadings and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. For the Type 1 component with the highest design stress factor, the scaled design's stress factors shall not exceed the stress factor of the same component of the validated design.

#### **6.6.7.3 Scaling of Plastically Deformed Components**

For Type 1 components which are designed to permanently deform in service, the supplier/manufacturer shall establish the maximum strain factor within the previously validated design components and in the same components of the scaled design. The mode of loadings and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. The scaled design's strain factor shall not exceed the strain factor of the same component of the validated design.

#### **6.6.7.4 Sealing Element Scaling Requirements**

Scaling of sealing element validation results shall conform with 6.6.7.1 and shall be documented and approved by a qualified person. Metallic sealing elements shall not be validated by scaling.

NOTE: Packer element scaling is not covered by this section, as it is specifically addressed in 6.6.10.5 and 6.6.11.5.

Limitations on scaling of nonmetallic seal components shall be:

- a) Allowable variation in size shall be within  $\pm 5\%$  of the nominal seal bore diameter and/or cross section thickness of the validated design.
- b) Supplier/manufacturer's material specifications of scaled sealing element shall meet the material specification which was used for the validated sealing element.
- c) Loading mode (including any support mechanisms) shall be identical for the scaled and the validated sealing element.
- d) Stress factors of metallic components surrounding the scaled nonmetallic sealing element shall not exceed those of the validated metallic components at the rated working pressure.
- e) Sealing element nominal extrusion gap and tolerances on seal gland and bore shall not be greater than that allowed by the validated design.
- f) Stress calculation method(s) shall be identical for the scaled sealing element and the validated sealing element.

#### **6.6.7.5 Axial and Combined Load Rating Calculation for Alternate Host Casings**

6.6.7.5.1 For a product designed for a range of casing sizes, weights and/or grades, the performance envelope points shall be adjusted for each casing size, weight, and material grade based on the casing stress and strain present in validation testing. The axial load tests in unsupported casing (or machined casing equivalent), as specified in 6.6.8, validate the anchoring performance with respect to a single host casing size, weight, and grade. The host casing size and weight selection is guided by the test fixture requirements (see 6.6.8.2). The test casing grade is selected by either the supplier/manufacturer or may be requested by the user/purchaser.

6.6.7.5.2 Liner hanger and liner packer products may span multiple casing sizes and weights and grades. As such, a validation performed to 6.6.8 with a specific casing size, weight, and grade can be used as the basis to establish axial load and combined load ratings within other alternate casings.

6.6.7.5.3 If the host casing specifications change from the casing used in validation testing per 6.6.8 the validation grade is retained with adjustment to the envelope points as follows:

- a) The calculated axial load rating shall not exceed the validation test value for that load point.
- b) The alternate host casing's max ID shall fall within the validated product specification.
- c) The supplier/manufacturer shall establish either the maximum stress or strain within the host casing used to validate the load capacity and in the alternate host casing. The mode of stress or strain and same method of calculation(s)/verification(s) shall be applied to the host casing of the validation test and the alternate host casing rating. Furthermore, any calculated ratings for the alternate host casing shall similarly use the same method of calculations(s)/verification(s). The stress factor or strain factor, as applicable, of the alternate host casing rating shall not exceed the stress or strain factor of the validated host casing.
- d) The supplier/manufacturer shall establish the maximum host casing ID deformation due to applied axial loads in validation testing. In addition, the casing ID deformation of the alternate host casing shall be analyzed to evaluate the casing ID deformation due to applied axial loads. The same method of calculation(s)/verification(s) shall be applied to the host casing of the validation test and the alternate host casing rating. The rating for the alternate host casing cannot impart greater deformation due to applied loads into the host casing than was calculated/verified within the validation test.

NOTE: For example, if an alternate host casing has a thinner wall thickness but higher yield stress than the validated casing, stress analysis alone can allow for an equivalent rating to be achieved. However, the requirement for casing ID deformation due to applied axial load equivalence means that the rating is selected such that an equal amount of deformation as seen during the validation test will occur within the newly proposed host casing.

6.6.7.5.4 When an alternate host casing is analyzed for a validated product, the performance envelope points for the alternate host casing shall be labeled as calculated points if the ratings change, per Annex G.3.

NOTE: This analysis does not create a scaled product, as the rating is calculated based on the validated host casing.

6.6.7.5.5 If axial load ratings reduce due to alternate host casings, then the axial load and/or pressure for any combined load intersection point shall also satisfy stress/strain factor and deformation requirements. If a combined load point was validated in machined bore thick-wall (max ID) casing, the stress and/or strain factor basis shall be established by calculation in the casing size, weight, and grade used to validate the hanging capacity and/or hold down capacity of the same product.

## **6.6.8 Product Hanging Capacity and/or Hold Down Capacity Design Validation**

### **6.6.8.1 General**

The design validation of liner hangers, liner packers and liner hanger packers with anchoring capability shall meet the requirements of 6.6.8 as applicable per the specified validation grade. Section 6.6.8 validates the hanging capacity and / or hold down capacity of the product within unsupported casing or an unsupported casing equivalent.

### **6.6.8.2 Test Fixtures**

The test fixture shall be either:

- unsupported casing conforming to API 5CT or API 5L; or
- unsupported machined-bore (casing equivalent) test fixture with mechanical properties conforming to API 5CT. A machined-bore test fixture may be machined on the OD and/or ID.

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design

requirements. Test fixture options are summarized in Table 6.

For tests conducted in an unsupported API casing test fixture:

- For a product designed to operate in a range of casing weights of the same nominal size, the product shall be tested in the lightest weight casing specified.

**Table 6—Test Fixture Options**

Test Fixture Description	6.6.8 Product Hanging Capacity and/or Hold Down Capacity Design Validation	6.6.9 Liner Hanger Combined Load and Pressure Design Validation	6.6.10 Liner Packer Design Validation	6.6.11 Liner Hanger Packer Design Validation
Unsupported API casing	Yes	Yes	Yes	Yes
Supported API casing	No	Yes <sup>a</sup>	Yes	Yes <sup>a</sup>
Unsupported machined-bore (casing equivalent) test fixture	Yes	Yes	Yes <sup>b</sup>	Yes <sup>b</sup>
Supported machined-bore (casing equivalent) test fixture	No	Yes <sup>a</sup>	Yes <sup>b</sup>	Yes <sup>ba</sup>
Machined-bore thick wall (max casing ID) test fixture	No	Yes <sup>a</sup>	Yes	Yes <sup>a</sup>
<sup>a</sup> This is only applicable to combined load and pressure testing where the capacity load is also established per 6.6.8. <sup>b</sup> Testing of packer element in machined-bore fixture is limited to maximum API ID. NOTE Testing in API casing is preferred when feasible.				

- For a product designed to operate in a range of casing weights and sizes, the product shall be tested in the size/weight combination that results in the largest nominal ID
- Casing ID shall be greater than nominal ID for casing conforming to API 5CT or API 5L, as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the liner hanger.

For tests conducted in unsupported machined-bore (casing equivalent) test fixture:

- The product shall be tested in the size/weight combination that results in the largest maximum ID.
- The machined-bore (casing equivalent) fixture ID shall be a minimum of 0.5 % greater than nominal ID, as confirmed by measurements in at least two points at 90-degree separation.
- The fixture OD shall conform to API 5CT for the given size per equation (1)

$$OD_{tf} = \sqrt{(1.065 \times (OD_{nom}^2 - ID_{nom}^2)) + ID_{tf}^2}$$

- $OD_{tf}$  is Maximum allowable test fixture OD
- $OD_{nom}$  is Nominal OD of casing;
- $ID_{nom}$  is Nominal ID of casing;
- $ID_{tf}$  is Machined bore test fixture ID

NOTE 1 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacturer. See Section 8.2 in API 5CT, 10th edition [1].

### 6.6.8.3 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capabilities.

### 6.6.8.4 Validation Grades V2 and V1 Test Procedure

The supplier/manufacturer shall conduct validation in accordance with the following steps:

- 1) Install product in fixture.
- 2) Activate product to engage anchoring in accordance with supplier/manufacturer's procedures.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test at or above the maximum rated temperature.
- 4) Apply increasing axial load in the direction of anchoring, until supplier/manufacturer-defined rated load is achieved. Applied load hold period is 5 minutes minimum, with no movement allowed after stabilization.
- 5) If the product anchors in both directions, either:
  - Step 4 shall be repeated in the opposite direction to validate the opposite direction anchoring load, or
  - An additional test shall be performed to validate anchoring load in the opposite direction.

### 6.6.8.5 Acceptance Criteria for V2 and V1

The acceptance criteria for anchoring load design validation are as follows:

- a) No movement allowed after stabilization.
- b) Casing shall not be split, breached, or perforated through the wall.
- c) The product shall drift at its specified drift diameter during the test or post-test condition. The drift bar shall conform to API 5CT.
- d) Conduct post-test inspection according to supplier/manufacturer procedure.
- e) Prepare test report according to 6.6.5.

## 6.6.9 Liner Hanger Combined Load and Pressure Design Validation

### 6.6.9.1 General

The design validation of liner hangers shall meet the requirements of 6.6.8 and 6.6.9, and shall meet the requirements of 6.6.15, 6.6.16, and E.3 as applicable per the specified validation grade. Test medium requirements are specified in 6.6.2.

Where the liner hanger includes rotational capability after setting, testing and validation shall be performed in accordance with Annex F.

If a mechanical set liner hanger were to have a leak path between the ID and the OD of the liner hanger, then it shall be validated to the hydraulic set liner hanger procedures, with the hanger being set per supplier/manufacturer procedure.

Any internal connection within a liner hanger shall be validated per section 6.6.15.

### 6.6.9.2 Test Fixtures

The test fixture shall be one of the following:

- unsupported API casing as described in 6.6.8.2;
- supported API casing conforming to API 5CT or API 5L;
- unsupported machined-bore (casing equivalent) test fixture as described in 6.6.8.2;
- supported machined-bore (casing equivalent) test fixture with mechanical properties conforming to API 5CT or API 5L, as appropriate. A machined-bore test fixture may be machined on the OD and/or ID; or
- machined-bore thick wall (max casing ID) test fixture with an ID conforming to equation (2).

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

Pressure-induced loads into the liner hanger from the test fixture configurations shall be off-set in the product testing. Any compensated load shall be documented.

The following apply for tests conducted in supported or unsupported API casing:

- For a liner hanger designed to operate in a range of casing weights of the same nominal size, the liner hanger shall be tested in the lightest weight casing specified.
- The liner hanger shall be tested in the size/weight combination that results in the largest nominal ID (for liner hangers designed to operate in a range of casing weights and sizes).
- Casing ID shall be greater than nominal ID for casing conforming to API 5CT or API 5L, as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the liner hanger.
- The validation procedures in 6.6.8 and 6.6.9 can be combined into a single procedure. Where validation testing includes both load testing and combined load with pressure testing into a single testing program, the test fixture shall conform to both the requirements of 6.6.8 and 6.6.9.

NOTE 1 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacturer. See 8.2 in API 5CT, 10th edition [1].

For tests conducted in unsupported or supported machined-bore (casing equivalent) test fixture:

For tests conducted in unsupported machined-bore (casing equivalent) test fixture:

- The product shall be tested in the size/weight combination that results in the largest maximum ID .
- The machined-bore (casing equivalent) fixture ID shall be a minimum of 0.5 % greater than nominal ID, as confirmed by measurements in at least two points at 90-degree separation.
- The fixture OD and wall thickness shall conform to API 5CT for the given size. The fixture OD shall be determined to equation (1).
- The validation procedures in 6.6.8 and 6.6.9 can be combined into a single procedure. Where validation testing includes both load testing and combined load with pressure testing into a single testing program, the test fixture shall conform to both the requirements of 6.6.8 and 6.6.9.

NOTE 2 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacture. See Section 8.2 in API 5CT, 10th edition [1].

The following apply for tests performed in a machined-bore thick wall (max casing ID) test fixture:

- The machined-bore test fixture shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range, as determined by equation (2). The tolerance on the ID shall be  $\pm 0.76$  mm. (0.030 in.) Fixture ID shall be confirmed by measurements in at least two points at 90-degree separation.

$$ID_{max} = \sqrt{OD_{max}^2 - 0.965(OD_{nom}^2 - ID_{nom}^2)} \quad (2)$$

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where

$OD_{nom}$  is Nominal OD of casing;

$ID_{nom}$  is Nominal ID of casing;

$OD_{max} = OD_{nom} \times 1.01$ .

- For liner hanger designed to operate in a range of casing weights and sizes, the liner hanger shall be tested in the size/weight combination that results in the largest maximum casing ID as determined by equation (2).
- The test fixture OD is defined by supplier/manufacturer.

NOTE 3  $ID_{max}$  as calculated by Equation (2) may differ from actual maximum ID of casing which is not made to API 5CT. Equation (2) is to calculate the test fixture's ID.

### 6.6.9.3 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capabilities.

### 6.6.9.4 Validation Grade V2

#### 6.6.9.4.1 Mechanical Set Liner Hangers Validation Procedure and Acceptance Criteria

The supplier/manufacturer shall adhere to the following test procedure and criteria for conformance to this validation grade:

- 1) Install hanger in fixture.
- 2) Activate hanger to engage slips, as in accordance with supplier/manufacturer's procedures.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test at or above the maximum rated temperature.
- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.
- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant as applicable. The Hanger-to-casing net force shall not exceed maximum hanging capacity established in 6.6.8, unless testing in unsupported API casing or unsupported machined-bore (casing equivalent).

Note: An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.

Sections 6.6.8.4 and 6.6.9.4 can be combined when the unsupported API casing or unsupported machined-bore (casing equivalent) is used for the test fixture. To perform this combined testing, Steps 4 and 5 in 6.6.8.4 shall be inserted between Step 3 and Step 4 in the procedure above. If the test fixture is supported, it shall be supported throughout all validation steps, including when setting, of the test except when testing the anchoring loads per 6.6.8.4. If the casing is supported with applied pressure, the applied casing support pressure shall not exceed 50% of the highest test pressure on the liner hanger.

The minimum operating temperature for a mechanical set liner hanger shall be determined through supplier defined methods.

The acceptance criteria for mechanical set liner hangers shall be as follows:

- a) Applied load hold period shall be 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- b) Combined load and pressure test hold periods are 5 minutes minimum, with no movement after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- d) Conduct post-test inspection and evaluate according to supplier/manufacture procedure.
- e) Prepare test report according to 6.6.5.

#### **6.6.9.4.2 Hydraulic Set Liner Hangers Validation Procedure and Acceptance Criteria**

The supplier/manufacture shall adhere to the following test parameters and criteria for conformance to this validation grade:

- 1) Install hanger in fixture. Increase temperature to the maximum operating temperature minus one half of the temperature cycle range ( $\pm 20\%$  of the temperature cycle range).
- 2) Apply pressure to activate hanger in accordance with supplier/manufacture's procedures. Setting pressure shall be within the specified range. Record internal and external mediums used when activating the liner hanger.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test, except temperature cycling, at or above the maximum rated temperature.
- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.
- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant as applicable. The Hanger-to-casing net force shall not exceed maximum hanging capacity established in 6.6.8, unless testing in unsupported API casing or unsupported machined-bore (casing equivalent).

**Note:** An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.

- 9) Reduce temperature by the minimum of the temperature cycle range value.
- 10) Repeat Step 6 and one envelope point from Quadrant IV (see 6.7).

Sections 6.6.8.4 and 6.6.9.4 can be combined when the unsupported API casing or unsupported machined-bore (casing equivalent) is used for the test fixture. To perform this combined testing, Step 4 and 5 in 6.6.8.4 shall be inserted between Step 3 and Step 4 in the procedure above. If the test fixture is supported, it shall be supported

throughout all validation steps, including when setting, of the test except when testing the anchoring loads per 6.6.8.4. If the casing is supported with applied pressure, the applied casing support pressure shall not exceed 50% of the highest test pressure on the liner hanger packer.

The acceptance criteria for hydraulic set liner hangers shall be as follows:

- a) Pressure test hold period is 15 minutes minimum, with no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization.
- b) Applied load hold period is 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) Combined load and pressure test hold period is 15 minutes minimum, with no movement and no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- d) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- e) Conduct post-test inspection and evaluate according to supplier/manufacturer procedure.
- f) Prepare test report according to 6.6.5.

#### **6.6.9.5 Validation Grade V1**

##### **6.6.9.5.1 Mechanical Set Liner Hangers**

A V2 validated mechanical set liner hanger without seals or internal connections is considered equivalent to a V1 validated mechanical hanger. The supplier/manufacturer shall adhere to the test parameters and criteria in 6.6.9.4.1 for conformance to this validation grade.

##### **6.6.9.5.2 Hydraulic Set Liner Hangers Validation Procedure and Acceptance Criteria**

To qualify the hydraulic set liner hangers to V1, all the following steps shall be performed within the acceptance criteria defined.

- 1) Install hanger in fixture. Increase temperature to the maximum operating temperature minus one half of the temperature cycle range ( $\pm 20$  % of the temperature cycle range).
- 2) Apply pressure to activate hanger in accordance with the supplier/manufacturer's procedures. Setting pressure shall be within the specified range. Record internal and external mediums used when activating the liner hanger.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test, except temperature cycling, at or above the maximum rated temperature.
- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.

- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant as applicable. The Hanger-to-casing net force shall not exceed maximum hanging capacity established in 6.6.8, unless testing in unsupported API casing or unsupported machined-bore (casing equivalent).

Note: An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.

- 9) Reduce temperature by the minimum of the temperature cycle range value.
- 10) Repeat Step 6 and one envelope point from Quadrant IV (see 6.7).

Sections 6.6.8.4 and 6.6.9.5.2 can be combined when the unsupported API casing is used for the test fixture. To perform this combined testing, Steps 4 and 5 in 6.6.8.4, as applicable, shall be included in the procedure. If the test fixture is supported, it shall be supported throughout all validation steps, including when setting, of the test except when testing the anchoring loads per 6.6.8.4. If the casing is supported with applied pressure, the applied casing support pressure shall not exceed 50% of the highest test pressure on the liner packer.

The acceptance criteria shall be as follows:

- a) Pressure hold period shall be 15 minutes minimum, with zero bubbles of nitrogen accumulated in a graduated cylinder over the hold period, after sufficient time has been allowed for stabilization.
- b) Applied load hold period shall be 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) Combined load and pressure test hold period is 15 minutes minimum, with no movement and with zero bubbles of nitrogen accumulated in a graduated cylinder over the hold period, after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- d) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- e) Conduct post-test inspection according to supplier/matrix procedure.
- f) Prepare test report according to 6.6.5.

### **6.6.10 Liner Packer Design Validation**

#### **6.6.10.1 General**

Validation of liner packers shall meet the requirements of 6.6.8 and 6.6.10, as applicable per the specified validation grade.

NOTE 1 See Annex A for liner packer and liner hanger packer products validated prior to the initial release of this specification.

Products with no anchoring devices or anchoring devices that hold in one direction may be restrained by the test fixture to prevent movement in the unanchored direction(s).

Test the products with shear-release features at the maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.

Special features of the liner packer not validated during this test shall be validated in separate tests to their rated limits using documented procedures and acceptance criteria. Interface seal with PBR/TBR included in liner packer products shall be validated to 6.6.12 if not validated with the liner packer.

Liner Packer validation testing may be performed in either tied-back, non-tied-back configuration, or both. If tested in non-tied back configuration, the tied-back performance can be verified per 6.4.2 in order to establish the performance envelope points. If testing in tied-back configuration, the supplier/manufacturer should perform intersection points in both tied-back and non-tied-back configuration.

### 6.6.10.2 Test Fixtures

6.6.10.1 The test fixture shall be one of the following:

- a) supported casing as described in 6.6.8.2;
- b) unsupported casing as described in 6.6.8.2;
- c) supported machined-bore (casing equivalent) test fixture as described in 6.6.8.2;
- d) unsupported machined-bore (casing equivalent) test fixture as described in 6.6.8.2;
- e) machined-bore thick wall (max casing ID) test fixture.

6.6.10.2 An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

6.6.10.3 The following apply for tests conducted in supported or unsupported API casing:

- a) For packers designed to operate in a range of casing weights of the same nominal size, the packer shall be tested in the lightest weight casing specified.
- b) For packers designed to operate in a range of casing weights and sizes, the packer shall be tested in the size/ weight combination that results in the largest nominal ID.
- c) Casing ID shall be greater than nominal ID for casing conforming to API 5CT or API 5L, as determined by measurements in at least two points at 90- degree separation. Casing shall not be machined on the ID, except as needed for fixturing in the area not used by the packer.

NOTE API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacturer. See 8.2 in API 5CT, 10th edition [1].

6.6.10.4 For tests conducted in supported or unsupported machined-bore (casing equivalent) test fixture:

- a) The packer shall be tested in the size/weight combination that results in the largest maximum ID.
- b) The machined-bore (casing equivalent) test fixture shall have an ID equivalent to the maximum ID of the host casing, as determined by equation (2). The tolerance on the ID shall be  $\pm 0.76$  mm. (0.030 in.) Fixture ID shall be confirmed by measurements in at least two points at 90-degree separation.
- c) The fixture OD shall conform to API 5CT for the given size. Fixture maximum OD shall be in accordance with API 5CT.

6.6.10.5 The following apply for tests performed in machined-bore thick wall (max casing ID) test fixture.

- The packer shall be tested in the size/weight combination that results in the largest maximum ID.
- Test fixtures machined from mechanical tube shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range, as determined by Equation (2) in 6.6.9.2. The tolerance on the ID shall be  $\pm 0.76$  mm (0.030 in.).

6.6.10.6 Pressure-induced loads into the packer from the test fixture configurations shall be off-set in the product testing. Compensated load shall be documented.

### 6.6.10.3 Validation Grade V3

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support stated product ratings and capabilities.

### 6.6.10.4 Test Procedures for V2 and V1

The supplier/manufacturer shall conform to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 7. Repair or redress of the packer requires validation testing to restart at the beginning.

**Table 7—Liner Packer Validation Test Procedure V1 and V2**

Step	Procedure and Acceptance Criteria	Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Part number Serial number Test fixture description and support, if present
2	Conduct pre-test inspection according to supplier/manufacturer's procedures.	Dimensional inspection results
3	The packer shall be set using procedures, methods and tools identified in referenced supplier/manufacturer procedures. Set the packer at the max operating temperature minus one half of the temperature cycle range with a setting temperature tolerance of $\pm 20\%$ of the temperature cycle range. Set the packer with the minimum rated setting force or pressure ( $\pm 10\%$ ). Record the test medium surrounding the packer while setting.	Procedure identification Temperature at set Force/pressure applied to set Test medium
4	Adjust the temperature to the maximum operating temperature or higher. Maintain temperature during Step 5 through Step 8.	Temperature during test
5	Apply pressure. Pressure testing to begin with the maximum rated differential pressure applied to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.  Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.  Relieve applied pressure, then continue to next step.  <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.  <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2
6	Apply the maximum rated differential pressure to the opposite end of the packer element. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.  Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.  Relieve applied pressure, then continue to next step.  <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.  <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Applied load during test (if applicable) Measured pressure loss for V2

7	<p>Apply the maximum rated pressure to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure then continue to the next step.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p><b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.</p>	<p>Pressuring during test</p> <p>Measured pressure loss for V2</p>
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Table 7—Liner Packer Validation Test Procedure V1 and V2 (Continued)

Step	Procedure and Acceptance Criteria	Data to be Recorded
8	<p>Test to all the envelope intersection points of the rated performance envelope, one point minimum per quadrant as applicable. The Hold Down Capacity (upward lifting resistance), without applied pressure, shall be tested as an envelope point, as applicable...</p> <p>Note: An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.</p> <p>Hold applied pressure or combinations of load and pressure for 15 minutes minimum. Stabilize load, pressure, and temperature in accordance with supplier/manufacturer requirements. If no pressure loss is observed, it shall be documented in the test report.</p> <p>May relieve applied load and pressure, before continuing to the next step.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.</p> <p><b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.</p>	<p>Applied load during test (if applicable)</p> <p>Measured pressure loss for V2</p>
9	<p>Reduce temperature by a minimum of the temperature cycle range value. Perform a pressure test at or above the maximum rated pressure from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p><b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.</p>	<p>Temperature during test</p> <p>Pressure during test</p> <p>Measured pressure loss for V2</p>
10	<p>Conduct post-test inspection according to supplier/manufacturer's procedures, and prepare test report according to 6.6.5. The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.</p>	<p>Dimensional inspection results</p> <p>Evidence of malfunction(s) or anomalies</p> <p>Test report</p>

Sections 6.6.8.4 and 6.6.10.4 can be combined when API casing or machined bore (casing equivalent) is used for the test fixture. Validation testing shall include testing to the limits and order as defined in the applicable product testing; however, test steps can be combined to effectively achieve the defined testing criteria while minimizing testing repetition. Each of the rated performance envelope intersection points shall be tested.

Note: An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.

If the test fixture is supported, it shall be supported throughout all validation steps, including when setting, of the test except when testing the anchoring loads per 6.6.8.4. If the casing is supported with applied pressure, the applied casing support pressure shall not exceed 50% of the highest test pressure on the liner packer.

Gas pressure-relieving (bleed-down) operations should be performed at a rate of 0.69 MPa (100 psi) per minute or less when the pressures are less than 10.34 MPa (1500 psi).

### 6.6.10.5 Limitations of Scaling for Liner Packer Design

Scaling may be used to validate variations in a product family, in accordance with the requirements and limitations of 6.6.7. This applies to products validated to grade V2 or V1, in accordance with 6.6.10.1, and V2-L and V1-L validated in accordance with Annex A.2.

Testing a product design in the largest nominal ID of the ID range of the product design and in the **smallest** nominal ID of the ID range of the product design validates the product design for all IDs between the two tested sizes.

Packer elements and anti-extrusion components of the scaled product design shall be of the same geometry and materials specification as the validated product design prior to testing.

The supplier/manufacturer's specified OD of the component under the packer element(s) of the scaled product design shall be the same as the validated product design prior to testing.

## 6.6.11 Liner Hanger Packer Design Validation

### 6.6.11.1 General

Validation of liner hanger packers shall meet the requirements of 6.6.11, as applicable per the specified validation grade. Interface seal with PBR/TBR included in liner hanger packer products shall be validated to 6.6.12 if not validated with the liner hanger packer.

NOTE See Annex A for validation of liner packer and liner hanger packer products prior to the initial release of this specification.

Test those products having shear-release features at their maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.

Liner Packer validation testing may be performed in either tied-back, non-tied-back configuration, or both. If tested in non-tied back configuration, the tied-back performance can be verified per 6.4.2 in order to establish the performance envelope points. If testing in tied-back configuration, intersection points in both tied-back and non-tied-back configuration should be performed.

### 6.6.11.2 Test Fixture

6.6.11.2.1 The test fixture shall be one of the following:

- supported casing, as described in 6.6.8.2;
- unsupported casing as described in 6.6.8.2;
- unsupported machined-bore (casing equivalent) test fixture as described in 6.6.8.2; or

- supported machined-bore (casing equivalent) test fixture as described in 6.6.8.2; or
- machined-bore thick wall (max casing ID) test fixture.

6.6.11.2.2 If a thick wall machined-bore test fixture is used to validate combined loading, an additional test shall be performed to validate the hanging capacity, per section 6.6.11.4.

6.6.11.2.3 An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

6.6.11.2.4 The following apply for tests conducted in supported or unsupported casing:

- For hanger packers designed to operate in a range of casing weights of the same nominal size, the hanger packer shall be tested in the lightest weight casing specified.
- For hanger packers designed to operate in a range of casing weights and sizes, the hanger packer shall be tested in the size/ weight combination that results in the largest nominal ID.
- Casing ID shall be greater than nominal ID for casing conforming to API 5CT or API 5L as determined by measurements in at least two points at 90- degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the liner hanger packer.

NOTE API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacturer. See 8.2 in API 5CT, 10th edition [1].

6.6.11.2.5 For tests conducted in supported or unsupported machined-bore (casing equivalent) test fixture:

- The packer shall be tested in the size/weight combination that results in the largest maximum ID.
- The machined-bore (casing equivalent) test fixture shall have an ID equivalent to the maximum ID of the host casing, as determined by equation (2). The tolerance on the ID shall be  $\pm 0.76$  mm. (0.030 in.) Fixture ID shall be confirmed by measurements in at least two points at 90-degree separation.
- The fixture OD shall conform to API 5CT for the given size. Fixture maximum OD shall be in accordance with API 5CT.

6.6.11.2.6 The following apply for tests performed in machined-bore thick wall (max casing ID) test fixture.

- The packer shall be tested in the size/weight combination that results in the largest maximum ID.
- Test fixtures machined from mechanical tube shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range, as determined by Equation (2) in 6.6.9.2. The tolerance on the ID shall be  $\pm 0.76$  mm (0.030 in.).

6.6.11.2.7 Pressure-induced loads into the packer from the test fixture configurations shall be off-set in the product testing. Any compensated load shall be documented.

### 6.6.11.3 Validation Grade V3

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support stated product ratings and capabilities.

### 6.6.11.4 Validation Grades V2 and V1

Liner Hanger Packer shall be validated to 6.6.10.4, and anchoring capacity shall be validated to 6.6.8.4. Validation testing shall include testing to the limits and order as defined in the applicable product testing; however, test steps can be combined to effectively achieve the defined testing criteria while minimizing testing repetition. Each of the rated performance envelope intersection points shall be tested.

Note: An intersection with the x or y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.

If the test fixture is supported, it shall be supported throughout all validation steps, including when setting, of the test except when testing the anchoring loads per 6.6.8.4. If the casing is supported with applied pressure, the applied casing support pressure shall not exceed 50% of the highest test pressure on the liner hanger packer.

### 6.6.11.5 Limitation of Scaling of Liner Hanger Packer Designs

Scaling may be used to validate variations in a product family, in accordance with the requirements and limitations of 6.6.7. This applies to products validated to grade V2 or V1, in accordance with 6.6.11.4, and V2-L and V1-L validated in accordance with Annex A.2.

The product design for all IDs between the two tested sizes is validated by the successful validation testing of a product design in the largest nominal ID of the ID range of the product design, and in the smallest nominal ID of the ID range of the product design.

Packer elements and anti-extrusion components of the scaled product design shall be of the same geometry and materials specification as the validated product design prior to testing.

The supplier/manufacturer's specified OD of the component under the packer element(s) of the scaled product design shall be the same as the validated product design prior to testing.

## 6.6.12 Interface Seal between the TBR/PBR and Packer Body or Setting Adaptor/Sleeve Design Validation

### 6.6.12.1 General

The performance of these test procedures validates the interface seal between TBR/PBR and packer, hanger packer, or setting adaptor/sleeve, if present in the product. For applications using a seal assembly with the TBR/PBR, the interface seal shall be validated. In designs where an internal connection performs the function of an interface seal, it shall be validated in accordance with 6.6.15.

### 6.6.12.2 Test Fixtures

The supplier/manufacturer shall document the test fixture configuration and dimension for each validation test performed. An MTR, which verifies the yield strength, shall be available for the test fixture.

Validation testing shall be conducted in a test fixture that is designed and manufactured to the same sealing surface tolerances and dimensions as the production product.

### 6.6.12.3 Validation Grade V3

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capabilities.

#### 6.6.12.4 Validation Grades V2 and V1

The supplier/manufacturer shall adhere to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 8.

The supplier/manufacturer, gas pressure-relieving (bleed-down) operations should be performed at a rate of 0.69 MPa bar (100 psi) per minute or less when the pressures are less than 10.34 MPa (1500 psi).

**Table 8—Interface Seal between TBR/PBR and Packer Body or Setting Adaptor/Sleeve  
Validation Test Procedure V1 and V2**

Step	Procedure and Acceptance criteria	Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Unique identifier
2	Conduct pre-test inspection according to supplier/manufacturer's procedures. Dimensional inspection results shall conform with supplier/manufacturer's requirement.	Dimensional inspection results
3	Adjust temperature of the test fixture to the maximum temperature or higher. Maintain temperature during Step 4 and Step 5.	Temperature during test
4	Apply the maximum rated differential pressure to one side of the seal. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements. Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report. Relieve applied pressure then continue to the next step. <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period. <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2
5	Perform a minimum of two pressure reversals at or above the maximum operating pressures. Hold applied pressures for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report. Relieve applied pressure then continue to the next step. <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period. <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Applied load during test (if applicable) Measured pressure loss for V2
6	Reduce temperature by a minimum of the temperature cycle range value. Perform a pressure test at or above the maximum rated pressure.	Temperature during test Pressure during test
7	Hold applied pressures for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report. <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period. <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Measured pressure loss for V2
8	Conduct post-test inspection according to supplier/manufacturer's procedures. Prepare test report according to 6.6.5.	Visual inspection results Evidence of malfunction(s) or anomalies Test report

### 6.6.12.5 Limitations of Scaling for Interface Seal

Limitations on scaling for interface seal between the TBR/PBR and packer body or setting adaptor/sleeve are contained in 6.6.7.

### 6.6.13 TBR/PBR Design Validation

#### 6.6.13.1 General

Each TBR/PBR design shall be validated by analysis or by testing. TBR/PBR products made up of multiple segments containing an internal thread connection shall be validated with testing in accordance with 6.6.13.3 unless axial loads are present. When axial loading is present in the TBR/PBR internal thread(s), the TBR/PBR shall be validated in accordance with 6.6.17.

#### 6.6.13.2 Design Validation by Analysis (Grades V3, V2, and V1)

The manufacturer shall use a temperature derated yield strength at the maximum rated temperature.

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support stated product ratings and capabilities.

For calculation of validation grades V1 and V2, the supplier/manufacturer shall:

- calculate long (partially engaged) PBR collapse pressure with partial engagement of the seal assembly according to API 5C3. Long collapse may also be validated according to the supplier/manufacturer defined procedure and analysis. The procedure shall be validated by documented test results. The resulting output shall include details of engagement, methodology, and assumptions.
- calculate short (fully engaged) collapse pressure according to the Equation (3).

$$P_C = 2 \times S_Y \left[ \frac{\left(\frac{D}{t}\right) - 1}{\left(\frac{D}{t}\right)^2} \right] \quad (3)$$

where

$P_C$  is the pressure for yield strength collapse;

$D$  is the specified minimum pipe outside diameter;

$S_Y$  is the specified minimum yield strength;

$t$  is the specified minimum pipe wall thickness.

For a seal assembly to be fully engaged and in short collapse, it shall meet one of the following criteria:

- a) a PBR having  $D/t \leq 20$  and the distance from the bottom of the unsupported PBR to the lower seal unit on the seal assembly shall not exceed  $L/D$  of 2.
- b) a PBR having  $D/t > 20$  and  $< 44$ , and the distance from the bottom of the unsupported PBR to the lower seal unit on the seal assembly shall not exceed  $L/D$  of 1.

$L$  is the specified unsupported length of applied pressure.

- calculate internal yield pressure according to Equation (4).

$$P_i = 2 \times S_y \left( \frac{t}{D} \right) \quad (4)$$

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where

$P_i$  is the internal pressure at yield for a thin tube;

$D$  is the specified pipe outside diameter;

$S_Y$  is the specified minimum yield strength;

$t$  is the minimum pipe wall thickness. Calculations shall indicate conformance to the supplier/manufacturer's documented criteria for that design and material.

### 6.6.13.3 Design Validation by Testing

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support stated product ratings and capabilities.

For validation grades V1 and V2, the supplier/manufacture shall document the TBR/PBR's critical dimensions for each validation test performed. An MTR, which verifies the yield strength, shall be available for the tested TBR/PBR.

A V2 validated TBR/PBR without internal seal or internal connections is considered to meet the requirements of a V1 validated TBR/PBR.

A V2 or V1 validated TBR/PBR with seals or internal connections shall be validated according to the following requirements:

- Test the TBR/PBR in burst and collapse at the maximum rated temperature and pressure. Acceptance criteria for V2 is less than 1 % measured pressure drop during the pressure hold period of 15 minutes. Acceptance criteria for V1 is zero bubbles of nitrogen observed over the hold period of 15 minutes.
- For the burst test, test the entire TBR/PBR with a sealing element at each end of the TBR/PBR's sealing bore at maximum operating temperature.
- For the collapse testing, the following tests shall be performed;
  - Test with a sealing element to provide a minimum of 3.98 m (10 ft) of unsupported length of the TBR/PBR. The maximum unsupported length of TBR/PBR shall be documented at maximum operating temperature.
  - Test with the maximum engagement of the seal assembly at maximum operating temperature. The minimum unsupported length of TBR/PBR shall be documented.

Post-test acceptance criteria for both V1 and V2 is to pass drifting through the full length with a drift OD equal to or greater than the maximum outer diameter of the seal unit, less the sealing element with a minimum drift length at that diameter of 30.5 cm (12 in.).

Conduct post-test inspection according to supplier/manufacturer procedure.

Prepare test report according to 6.6.5.

#### 6.6.13.4 Limitations of Scaling for TBR/PBR Designs

Scaling may be used to validate variations in a product family, in accordance with the requirements and limitations of 6.6.7.

A validation test conducted on a TBR/PBR design with a minimum length of 3.98 m (10 ft) validates all TBR/PBR designs of the same product family that are longer.

A validation test conducted on a TBR/PBR design may be applied to a TBR/PBR design of the same product family that is shorter than the validated design.

#### 6.6.14 Seal Unit Design Validation Testing

##### 6.6.14.1 General

Seal assemblies are used in conjunction with the TBR/PBR. This test only validates one seal unit as defined by the supplier/manufacturer.

**NOTE** The validation testing described in this section addresses static loading. For dynamic seal assembly validation testing, refer to applicable sections of API 19AC.

This specification includes three grades of design validation for seal assemblies:

- V3: Supplier/manufacturer-defined validation method.
- V2: Multiple stab-in at temperature with static liquid pressure test plus temperature cycling.
- V1: Multiple stab-in at temperature with static nitrogen pressure test plus temperature cycling.

##### 6.6.14.2 Test Fixtures

Validation testing shall be conducted in a test fixture that is designed and manufactured to the ID tolerances and surface finishes of the production TBR/PBR.

The seal assembly mandrel shall be designed and manufactured to the OD tolerances, gland dimensions, and/or surface finishes of the production product.

The sealing unit shall be designed and manufactured to the nominal size, ID and OD tolerances, and material specification of the production product.

##### 6.6.14.3 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capabilities.

##### 6.6.14.4 Design Validation Grades V1 and V2

The supplier/manufacturer shall adhere to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 9.

**Table 9—Seal Unit Validation Procedure Grade V1 and V2**

Step	Procedure and Acceptance Criteria	Data to be Documented
1	Conduct pre-test inspection according to supplier/manufacturer's procedures, which shall include dimension measurements.	Record inspection results
2	Heat fixture and seal unit to the max operating temperature minus one-half of the temperature cycle range with a tolerance of $\pm 20\%$ of the temperature cycle range.	Record temperature during test
3	Engage, disengage, engage, disengage, and engage (stab-in, stab-out, stab-in, stab-out, stab-in) the entire seal unit to the sealing bore (TBR/PBR).	Record linear movement
4	Increase the temperature to maximum rated temperature.	Record temperature during test
5	Perform pressure holds at or above the maximum rated differential pressures and a minimum of two pressure reversals. May relieve applied pressure then continue to next step. <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period. <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2 Record acceptance or rejection
6	Reduce temperature by a minimum of the temperature cycle range value.	Record temperature during test
7	Perform a pressure hold and then a pressure reversal at or above the maximum rated differential pressures. Relieve applied pressure then continue to next step. <b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period. <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2 Record acceptance or rejection
8	Disengage entire seal unit from the sealing bore (stab-out).	—
9	Conduct post-test inspection according to supplier/manufacturer's procedures. Prepare test report according to 6.6.5.	Dimensional inspection results Evidence of malfunction(s) or anomalies Test report

#### 6.6.14.5 Limitations of Scaling of the Seal Assembly Design

Seal assemblies may be validated by scaling in accordance with 6.6.7.4.

#### 6.6.15 Internal Thread Connections Design Validation

##### 6.6.15.1 General

There are three grades of internal connection design validation: V1, V2, and V3. Each type, nominal size/ weight, and minimum material yield strength of the internal connection design shall be validated to the grade selected by the user/ purchaser. Internal connections shall be supplied to at least the design validation grade specified.

Internal connection validation test in accordance with this specification shall expose the connection to temperature, pressure (internal and/or external) and axial force (tension and/or compression), as defined in the functional requirements.

**NOTE** The connection testing prescribed by this specification is a single combined loads test of the connection and does not include all of the connection testing variables as described in API 5C5.

### 6.6.15.2 Test Fixtures and Test Samples

Each test sample component shall:

- a) have an MTR that verifies the yield strength of the test sample is within the material specification;
- b) have measured and documented dimensions conforming to the design requirements;
- c) have a certificate of conformance or thread form dimensional verification stating that the thread form/type meets thread manufacturer requirements; and
- d) be made up in accordance with supplier/manufacturer specifications (including application of thread compounds).

Validation testing shall be performed within a test fixture that houses the internal connection and provides functionality of applying temperature, internal pressure, external pressure, tension, and compression and any combination of these.

For the test fixture, a filler bar(s) is acceptable for the ID of the test sample and annulus space in the test fixture. Multiple connections may be tested in series.

### 6.6.15.3 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capabilities.

### 6.6.15.4 Validation Grade V2

This design validation shall be one of the following:

- a) V2 validation testing per Table 10 with the connection validated only to the conditions that were present during the testing.
- b) Conformance to API 5C5, CAL III or CAL IV;
- c) Product or system testing (see 6.6.17.3) with the connection validated only to the conditions that were present during the testing.

### 6.6.15.5 Validation Grade V1

This design validation shall be one of the following:

- a) V1 validation testing per Table 10 with the connection validated only to the conditions that were present during the testing.
- b) Conformance to API 5C5 CAL III or CAL IV;
- c) Product or system testing (6.6.17.3) with the connection validated only to the conditions that were present during the testing.

NOTE Typically the thread supplier/manufacturer's validation testing does not include external nitrogen testing.

**Table 10—Internal Connection Validation Test Procedure Grades V2 and V1**

Step	Procedure and Acceptance Criteria	Minimum Data to be Recorded
1	Record test data as specified. The steps shall be performed in the numbered order shown. The required test points within a given step may be performed in any order. Repair or redress of a connection during the testing phase requires the testing to restart at the beginning.	Validation test number and grade Date Part number Serial number
2	Conduct test sample pre-test inspection according to supplier/manufacturer's procedures.	Dimensional inspection results MTR data
3	The connection shall be made up and installed in the test fixture using procedures and methods identified in referenced supplier/manufacturer procedures.	Make up torque Thread compounds
4	Increase and maintain the temperature to maximum rated temperature or higher through Step 7.	Temperature during test
5	<p>Hold applied pressures or combinations of load and pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Hold pure tension loads and pure compression loads for 5 minutes minimum.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p><b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.</p>	<p>Applied pressure and load during test (if applicable)</p> <p>Measured pressure loss for V2</p>

**Table 10—Internal Connection Validation Test Procedure Grades V2 and V1 (Continued)**

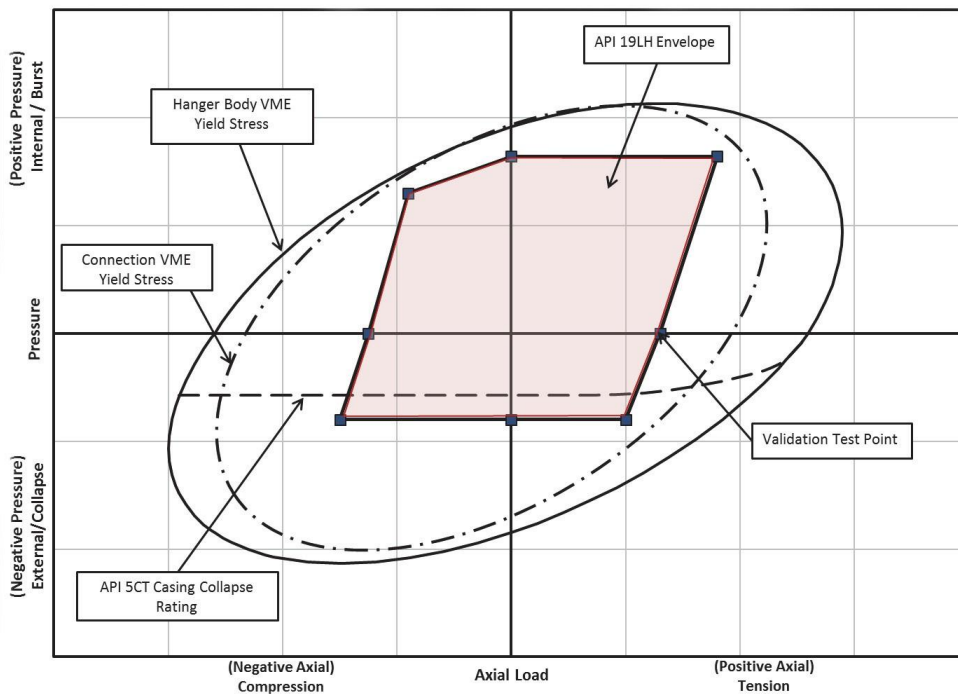
Step	Procedure and Acceptance Criteria	Minimum Data to be Recorded
6	<p>Apply pressure. Stabilize load, pressure, and temperature in accordance with supplier/manufacturer requirements.</p> <p>Test to a minimum of the pressure and load rating at the following points of the rated performance envelope:</p> <ul style="list-style-type: none"> <li>• Maximum external pressure.</li> <li>• Intersection point(s) in Quadrant III (external pressure with compression) of the rated performance envelope, one point minimum as applicable.</li> <li>• Intersection point(s) in Quadrant IV (external pressure with tension) of the rated performance envelope, one point minimum as applicable.</li> </ul> <p>Remove all pressure and load before proceeding on to the next step.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.  <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.</p>	<p>Applied pressure and load during test (if applicable)</p> <p>Measured pressure loss for V2</p>
7	<p>Test to a minimum of the pressure and load rating at the following points of the rated performance envelope:</p> <ul style="list-style-type: none"> <li>• Maximum internal pressure.</li> <li>• Maximum tension.</li> <li>• Maximum compression.</li> <li>• Intersection point(s) in Quadrant I (internal pressure with tension) of the rated performance envelope, one point minimum as applicable.</li> <li>• Intersection point(s) in Quadrant II (internal pressure with compression) of the rated performance envelope, one point minimum as applicable.</li> <li>• Maximum external pressure.</li> </ul> <p>Remove all pressure and load before proceeding on to the next step.</p> <p><b>Acceptance criteria for V2:</b> No more than 1 % reduction in the maximum rated differential pressure over the hold period.  <b>Acceptance criteria for V1:</b> Zero bubbles of nitrogen observed over the hold period.</p>	<p>Applied pressure and load during test (if applicable)</p> <p>Measured pressure loss for V2</p>

8	Reduce and maintain the temperature by a minimum of the temperature cycle range value through Step 9.	Temperature during test
9	Repeat Steps 6 and 7.	Repeat Step 6 and 7
10	Drift the connection at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT. Conduct post-test inspection according to supplier/ manufacturer's procedures.	Dimensional inspection results Evidence of malfunction(s) or anomalies

**6.6.15.6 Internal Connection Rated Performance Envelope**

The supplier/manufacturer shall state the performance ratings for the following: pressure, temperature, and axial loads, as applicable for the internal connection. The stated performance rating shall be included as applicable in product and system performance envelopes, as explained in G.3.

An example envelope is illustrated in Figure 11.



**Figure 11—Internal Thread Rated Performance Envelope**

**6.6.15.7 Limitations of Scaling of Internal Thread Connection**

For validation grade V1, scaling is not permitted.

For validation grades other than V1:

- a) Scaling is not permitted for internal connections supplied by a third-party supplier except for material changes in which the specified minimum yield strength does not change.
- b) Successfully testing the lightest and heaviest weights of an internal connection design validates the connection design for all weights between the two tested. The tests shall be performed in accordance with documented

procedures and acceptance criteria. The tested connections shall be of the same thread geometry and specified material yield strength.

### 6.6.16 Minimum Operating Temperature Rating Validation

For validation grades V1 and V2 where the minimum operating temperature was not validated during the temperature cycle range test, the minimum operating temperature of the product shall be validated.

The minimum operating temperature shall be validated by product or system testing. The minimum operating temperature rating is the lowest temperature achieved during the temperature cycle range test. To achieve a lower operating temperature rating, additional validation tests shall be conducted. When performing additional tests for minimum operating temperature validation, the maximum temperature of the test can be at least the minimum operating temperature plus the temperature cycle range.

When performing additional tests for minimum operating temperature validation, the setting temperature is the minimum operating temperature, plus one half of the temperature cycle range, with a setting temperature tolerance of  $\pm 20\%$  of the temperature cycle range.

When multiple validation tests are required to establish the operating temperature range, the tests may be performed with different temperature cycle ranges. The smallest temperature cycle range becomes the temperature cycle range across the entire operating temperature range.

EXAMPLE: Figure 12 shows how the operating temperature range is established with two tests. A product was tested multiple times under the requirements of V1 validation testing with the following temperature-cycle ranges achieved: 50 °F to 180 °F and 200 °F to 350 °F. The published operating temperature range of the product is 50 °F to 350 °F, and the temperature cycle range is 130 °F.

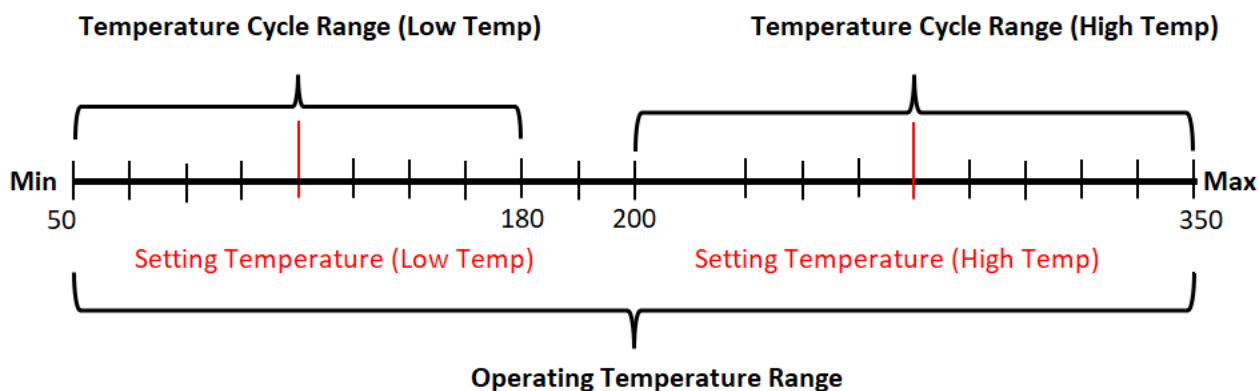


Figure 12 – Example of achieving an operating temperature range with two temperature cycle ranges

### 6.6.17 Liner System Design Validation

#### 6.6.17.1 General

As stated in 6.6.6, five grades of liner system design validation are specified. The equipment shall be supplied to at least one of the validation grades:

- 
- VS3: supplier/manufacturer-defined validation methods;
  - VS2: liquid test plus axial loads plus pressure plus temperature cycling, tested as a liner system or all V2 grade or better products combined, see Table 1;
  - VS1: nitrogen test plus axial loads plus pressure plus temperature cycling, tested as a liner system or all V1 grade products combined, see Table 1;
  - VS2-L: liquid test plus axial loads plus pressure plus temperature cycling, tested as a liner system or at least one V2-L product and other V2 grade or better products combined, see Table 1 and 3;
  - VS1-L: nitrogen test plus axial loads plus pressure plus temperature cycling, tested as a liner system or at least one V1-L product and other V1 products combined, see Table 1 and 3.

Liner systems qualified to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 2 and Table 4.

The method used to validate a liner hanger system shall be identified by the supplier/manufacturer:

- combined individual product validation and/or
- system validation.

An integrated liner system consisting of a single mandrel/tubular device that combines the functions of two or more products can be validated as a system, or the products can be validated individually. Those validation tests shall simulate the pressure and loading conditions that would be present if the entire integrated liner system were tested. Section 6.7 and Annex G specify the process for establishing product and system envelopes from multiple tests.

#### 6.6.17.2 Liner System Validation by Assembly of Individually Validated Products

Individually validated products may be assembled to form a validated system, where the system grade and rating is determined by the lowest grade and rating limits of the individual products. Products validated individually may have different ratings. Individual products tested during prior system validation shall be considered individually validated to that system's grade and rating.

For a system validation grade, products within the system shall be validated to the corresponding product grade, including tie-back and non-tie-back applications, if the products are in the system.

Supplier/manufacturer shall document any differences in the mechanisms, actuation, and load paths of the validated products used in the system and determine whether these differences constitute a substantive design change. When a substantive design change is identified, the liner system shall be validated by testing in accordance with 6.6.17.3.

NOTE Ratings of validated products used during liner system validation may be limited by the performance properties of the test casing (size, weight, and grade).

#### 6.6.17.3 Liner System Validation

The liner system validation shall test to a performance envelope and demonstrate individual product validation requirements of 6.6.8 through 6.6.15, as applicable.

Liner system validation testing shall include testing to the limits and order as defined in the applicable product testing. Test steps can be combined to effectively achieve the defined testing criteria while minimizing testing repetition. Each of the rated performance envelope intersection points shall be tested. The blended liner system testing procedures, testing practices, and the documented testing results shall be performed by a qualified person, and the report of the results shall be approved by a second qualified person.

The supplier/manufacturer shall document the validation procedure and results, and shall have on file material specifications and drawings that show applicable dimensions and tolerances of components contained in the validated products and liner systems. Supplier/manufacturer shall perform pre- and post-test dimensional inspections and have material certificates for Type 1 components. The products within the system shall drift at the specified system drift diameter during the test or post-test condition. The drift shall conform to API 5CT.

If a validated product within the liner system undergoes a substantive design change as described in 6.8.2, or any product is substituted by another product, liner system validation in accordance with this section is required.

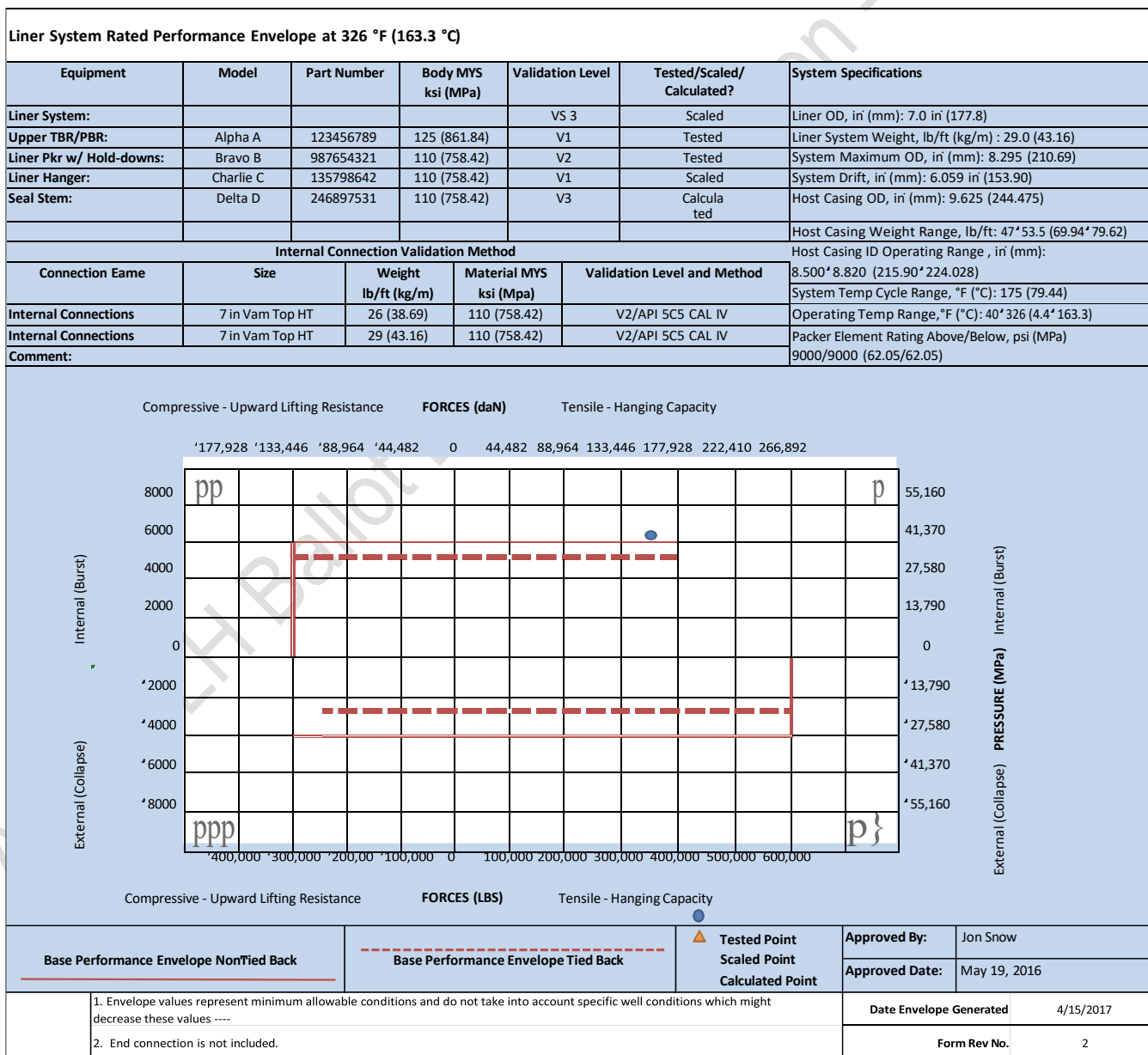
### 6.7 Performance Envelope Requirements

#### 6.7.1 General

Liner packer, liner hanger, and liner hanger packer products supplied to grades V2, V1, or when requested by the user/purchaser for V3, product performance envelopes shall be supplied. These envelopes shall include graphic illustrations of the combined effects of pressure and axial loads on the product at maximum rated temperature.

Liner system performance envelopes shall be supplied if requested by the user/purchaser. These envelopes shall include graphic illustrations of the combined effects of pressure and axial loads on a liner system at maximum rated temperature.

An example envelope is illustrated in Figure 13. The area within the boundaries defines the rated performance envelope. The lines forming the boundary of the envelope are defined as the maximum operational limits for the product or system, inclusive of internal threads. Refer to Annex G for an explanation of performance envelope theory and interpretation, as well as additional performance envelope examples.



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**Figure 13—Performance Envelope Example**

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### 6.7.2 Performance Envelope Data

The supplier/manufacturer defines the performance envelope. The envelopes shall include the criteria specified as follows, as applicable:

- a) The boundary lines of the envelope shall represent the supplier/manufacturer's maximum ratings of compression (upward lifting resistance), tension (hanging capacity), internal pressure (burst), and external pressure (collapse) for the product or system design. Each of the illustrated ratings shall have defined increments. Material mechanical properties over the temperature range shall be considered when determining performance ratings.
- b) The product or system's load bearing and pressure-containing internal connections shall be stated with material minimum yield strength (MYS) and design validation method.
- c) The minimum and maximum host casing size, weight range, and ID operating range shall be specified with the envelope. The envelope shall be applicable over the specified ID range. The host casing minimum yield stress (MYS) shall be identified.
- d) Packer differential pressure rating above and below the element shall be stated.
- e) If TBR/PBR long and/or short collapse ratings limit the system, they shall be included with a line and label.
- f) Axis and rating increments shall be identified. The axial load shall be on the x-axis. The internal and external pressure shall be on the y-axis.
- g) A legend shall be provided to identify calculated, scaled, tested, and system intersection points.
- h) The performance envelope shall be prepared and approved by separate qualified persons.
- i) Design validation grade of each product and the system.
- j) System or product maximum OD and minimum ID.
- k) Operating temperature range and temperature cycle range.
- l) Each product within the system shall be listed with the model, part number, body MYS, design validation grade, and whether the product design validation was scaled.
- m) System and/or product specifications shall be listed, including the liner OD and liner system weight that the liner system is suited for.
- n) The end connection shall be reported. It shall be communicated whether end connection ratings are included in the performance envelope rating or not.
- o) All envelope point values shall be recorded; either on the graph or provided in a tabular format.
- p) Reference OD.
- q) PBR/TBR location (lower and/or upper).

### 6.7.3 VS2 and VS1 Envelopes

Envelopes shall be based upon full-scale testing and/or calculated data. The envelopes shall include the criteria specified in 6.7.2 and indicate whether the envelope was obtained by testing a complete system or was obtained by evaluating and combining various product tests.

Users/purchasers shall consider applied loading of the system's applications when designing the wellbore configuration to ensure that operation of the product is within its rated capability.

NOTE Envelope values represent the maximum allowable conditions and do not consider well conditions, which can increase or decrease these values.

## 6.8 Design Changes

### 6.8.1 General

6.8.1.1 Design changes to existing validated product designs shall be documented and reviewed against the design verification and design validation to determine if the change is a substantive design change (see 3.1.76).

6.8.1.2 This evaluation shall include the following :

- a) stress factors of the replaced or changed components or subassemblies relative to the base design;
- b) for components designed to plastically deform, strain factors of the replaced or changed components, or subassemblies relative to the base design;
- c) interchangeability of the changed components or subassemblies relative to the base design;
- d) functional or operational changes, including interaction with secondary and contingency tools;
- e) the addition, removal or change of materials, welds, coatings, platings, and surface treatments and their compatibility with the service environment.

6.8.1.3 Design changes shall conform to the design criteria and verification (see 6.3 and 6.4) that were applied to the base component or assembly and shall conform to requirements of 6.3.2 and 6.4.

6.8.1.4 Evaluation results and justifications as a non-substantive design change shall be approved by a qualified person (3.1.55) other than the person performing them, and records of the results shall become a portion of the design documentation (see 7.2).

### 6.8.2 Substantive Design Change

6.8.2.1 A product design that undergoes a substantive design change becomes a new product design requiring design verification (see 6.4) and design validation (see 6.6). Scaling may be performed in accordance with 6.6.7 and the product-specific limitations on scaling.

6.8.2.2 Design validation for changes to components or subassemblies may be done by validation testing only the component or subassembly. Component tests shall simulate the test conditions that would be present if the entire assembly were tested. The supplier/manufacturer shall document the test results and analysis that demonstrate that the component or subassembly test simulates the required loading conditions.

## 7 Supplier/Manufacturer Requirements

### 7.1 General

Section 7 contains the detailed requirements necessary to verify that each product manufactured meets the requirements of the functional and technical specifications. These include requirements for:

- a) documentation and data control;
- b) product identification, materials;
- c) quality control;
- d) traceability;

- e) assembly verification;
- f) operational/functional testing; and
- g) shipping and storage.

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

## **7.2 Documentation and Data Control**

### **7.2.1 General**

The supplier/manufacturer shall establish and maintain documented procedures to control all documents and data that relate to the requirements of this specification. These documents and data shall be maintained to demonstrate conformance to specified requirements. All documents and data shall be legible and shall be stored and retained such that they are readily retrievable in facilities that provide environment to prevent damage or deterioration and to prevent loss. Documents and data may be in any form or type of media, such as hard copy or electronic media. All documents and data shall be available to the user/purchaser.

All documentation and data associated with design verification, design validation, and design change justification shall be maintained for ten years after the date of last manufacture of the design.

Quality-control documentation includes all documents and data necessary to demonstrate conformance to 7.2.2 through 7.4.10. Quality-control documentation shall be retained by the supplier/manufacturer for a minimum of ten years from date of manufacture.

### **7.2.2 Design Documentation**

Design documentation shall include:

- a) functional and technical specifications;
- b) design verification documents;
- c) design changes;
- d) one complete set of drawings, written specifications and standards;
- e) material type, yield strength, and connection identification for the actual end connection(s) provided with the product or system;
- f) operating manual;
- g) validation test files containing documentation to demonstrate conformance with 6.6.

### **7.2.3 Operating Manual**

An operating manual shall be available prior to use for products or systems. Operating manuals shall contain the following information:

- a) manual reference number;
- b) storage recommendations;
- c) pre-installation inspection procedures;

- d) operational procedures and required running/setting tools;
- e) a representative drawing showing major dimensions (ODs, IDs, lengths);
- f) repair/redress requirements and limitations, if applicable as determined by supplier/manufacturer.

#### **7.2.4 Data Sheets**

##### **7.2.4.1 General**

Performance ratings included in data sheets should be calculated at ambient conditions, unless stated otherwise on datasheet, and without the application of combined loading conditions.

##### **7.2.4.2 Product Data Sheets**

Product data sheets shall be available prior to transport, and shall contain the following information, as applicable:

- a) general information;
- b) name of supplier/manufacturer;
- c) manufacturer product number and description;
- d) operating manual reference number;
- e) product type;
- f) metallic and non-metallic materials, by industry-accepted nomenclature;
- g) minimum ID of the product;
- h) drift diameter;
- i) gauge OD;
- j) overall length;
- k) liner and casing size, weight, and range;
- l) top, bottom, and internal connections, as applicable;
- m) design validation grade and method (tested or scaled);
- n) performance characteristics, as applicable;
- o) operating temperature range;
- p) calculated performance ratings, including:
  - burst and collapse pressure ratings;
  - hanging capacity in unsupported casing;
  - hold down capacity in unsupported casing;
  - tensile and compressive load ratings;

- 
- torque rating and
  - tied back burst and collapse pressure ratings, including TBR/PBR short and long collapse;
  - q) setting method, including minimum (maximum, as applicable) setting force/pressure;
  - r) temperature cycle range for products validated for V1 and V2;
  - s) maximum seal differential pressure rating(s);
  - t) minimum run-in bypass area using nominal casing ID;
  - u) minimum cementing bypass area using nominal casing ID
  - v) manufacturer-defined operational limitation;
  - w) a report of the external flow test rating (if Annex C has been performed);
  - x) a report of the bearing rating (if Annex F has been performed);
  - y) a report of the low temperature setting validation (if Annex J has been performed).

#### 7.2.4.3 System Data Sheets

If requested by the user/purchaser, system data sheets shall be supplied and include the following information, as applicable:

- a) general information;
- b) name of supplier/manufacturer;
- c) manufacturer system description;
- d) operating manual reference number;
- e) system type;
- f) metallic and non-metallic materials, by industry-accepted nomenclature;
- g) minimum ID of the system;
- h) drift diameter;
- i) gauge OD;
- j) overall length;
- k) liner and casing size, weight, and range;
- l) top, bottom, and internal connections, as applicable;
- m) design validation grade and method of validation;
- n) performance characteristics, as applicable;
- o) operating temperature range;
- p) calculated performance ratings, including:

- burst and collapse pressure ratings;
  - hanging capacity in unsupported casing;
  - hold down capacity in unsupported casing;
  - tensile and compressive load ratings;
  - torque rating;
  - tied back burst and collapse pressure ratings, including TBR/PBR short and long collapse;
- q) temperature cycle range for systems validated for VS1 and VS2;
- r) setting method, including minimum (maximum, as applicable) setting force/pressure;
- s) minimum run-in bypass area using nominal casing ID;
- t) minimum cementing bypass area using nominal casing ID
- u) supplier/maker-defined operational limitation;
- v) rated performance envelope in accordance with 6.7;
- v) a report of the external flow test rating (if Annex C has been performed);
- w) a report of the bearing rating (if Annex F has been performed).
- x) TBR/PBR location (lower and/or upper)

### 7.3 Product Identification

Each product furnished to this specification shall be permanently physically marked according to the supplier/maker's specifications. The supplier/maker's specifications shall define the type, method of application, and location of the identifications. The following information shall be included:

- a) supplier/maker name or logo;
- b) supplier/maker's product description, such as size, weight, connection type, product name;
- c) supplier/maker's product and/or part number;
- d) product(s) date of manufacture (month/year);
- e) API 19LH, product type, and design validation grade;
- f) product(s) quality grade and applicable traceability information in accordance with 7.4.6, including:
  - for quality grade QL1, a unique serial number is required;
  - for quality grade QL2, job-lot traceability (see 3.1.31) is required;
  - for quality grade QL3, supplier/maker marking is required.
- g) . Repaired products shall be permanently marked for traceability of the repair.

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## 7.4 Quality Control

### 7.4.1 General

This specification provides three quality grades—QL1, QL2, and QL3, which are selected by the user/purchaser. Products and systems shall be supplied to at least the quality grade selected. Quality requirements shall be implemented to the documented requirements of supplier/manufacturer-defined practices and acceptance criteria. Quality requirements are detailed in 7.4.3 through 7.4.9 and are summarized in informative Table 11.

### 7.4.2 Personnel Qualifications

Personnel performing visual examinations shall have an annual eye examination, as applicable to the discipline to be performed, in accordance with ISO 9712 or ASNT SNT-TC-1A.

Personnel performing NDE evaluations and interpretations shall be qualified in accordance with ISO 9712 or ASNT SNT-TC-1A, to a minimum of Level II.

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**Table 11—Summary of Quality Requirements**

	QL3	QL2	QL1
Metallic material (see 7.4.3.1 and 7.4.3.2)	certificate of compliance (COC) or MTR	COC or MTR	Verify independent MTR for metallic Type 1 components COC or MTR for Type 2 components
Nonmetallic material (see 7.4.3.1 and 7.4.3.3)	COC or MTR	COC or MTR	COC or MTR
Heat treatment (see 7.4.4)	Heat-treat traceability	Heat-treat traceability	Heat-treat traceability
Product traceability (see 7.4.6.2)	Supplier/multiplier-defined	Job-lot traceable	Serialized traceability
Metallic component traceability (see 7.4.7.3)	Supplier/multiplier-specified traceability	Job-lot traceable for Type 1 components Supplier/multiplier-specified for Type 2 components	Serialized and heat-traceable to an MTR for Type 1 components Job-lot traceable for Type 2 components
Nonmetallic component traceability (see 7.4.7.3)	Supplier/multiplier-specified traceability	Job-lot traceable	Job-lot traceable
General non-destructive examination (NDE) (see 7.4.7.1)	Supplier/multiplier-defined	Visual inspection for Type 1 and 2 components	Visual inspection for Type 1 and 2 components
Metallic NDE (see 7.4.7.2)	Supplier/multiplier-defined	Sampling plan in accordance with Annex H for Type 1 components	100 % magnetic-particle or liquid-penetrant and ultrasonic inspection for Type 1 components
Nonmetallic NDE (see 7.4.7.3)	Supplier/multiplier-defined	Sampling plan in accordance with Annex H	100 % of components
Component dimensions (see 7.4.7.4)	Supplier/multiplier-defined	Sampling plan in accordance with Annex H	100 % for Type 1 components Sampling plan in accordance with Annex H for Type 2 components
Hardness (see 7.4.7.6)	Supplier/multiplier-defined	Type 1 components are inspected in accordance with Annex H	Type 2 components are inspected in accordance with Annex H
Castings and forgings (see 7.4.7.7)	COC	COC	100 % magnetic-particle or liquid-penetrant and radiographic or ultrasonic inspection for Type 1 components
Coatings, plating, surface treatment (see 7.4.7.8)	Supplier/multiplier-defined	Supplier/multiplier-defined	Supplier/multiplier-defined
Welding and brazing (see 7.4.7.9)	Visual inspection	Magnetic-particles or liquid-penetrant inspection sampling plan in accordance with Annex H	100 % magnetic-particles or liquid-penetrant inspection
Shear devices (see 7.4.8)	Shear verification	Shear verification	Shear verification
Assembly verification (see 7.4.9)	Supplier/multiplier-defined	Low pressure test, functional test, ID drift	Low/high pressure test, functional test, ID drift, OD dimensional, torque documentation
QC documentation (see 7.2.1)	Supplier/multiplier-retained	Supplier/multiplier-retained	Supplier/multiplier-retained

<sup>a</sup> "Supplier/multiplier-defined" indicates that there are no requirements listed in 7.4.3 through 7.4.9.

Personnel performing inspections for acceptance that are not defined by ISO 9712 or ANST SNT-TC-1A shall be qualified in accordance with the supplier/manufacturer's documented requirements.

NDE instructions shall be approved by a qualified NDE Level III examiner in accordance with ISO 9712 or ASNT SNT-TC-1A. Visual examination requirements do not require Level III approval.

### 7.4.3 Materials

#### 7.4.3.1 General

Material, metallic or nonmetallic, used in the manufacture of components, shall meet one of the following requirements:

- a) COC to the supplier/manufacturer stating that the material meets the supplier/manufacturer's documented specifications; or
- b) MTR to the supplier/manufacturer so that the supplier/manufacturer can verify that the material meets the supplier/manufacturer's documented specifications.

For quality grade QL1 metallic Type 1 components, the chemical/mechanical properties shall be verified independently of the original MTR testing facility. This verification may use chemical analysis determinations which are performed with positive material identification (PMI) equipment following the guidelines of API 578 or by chemical testing performed in accordance with the applicable ASTM test method. Mechanical properties may be determined by hardness tests or tensile tests conducted in accordance with 7.4.3.2. Each material's test results shall be approved by a qualified person as meeting the supplier/manufacturer's specifications for the material.

#### 7.4.3.2 Metals

7.4.3.2.1 To validate that the materials meet the supplier/manufacturer's material specifications, the following methods shall be used where required by the material specification:

- Tensile testing shall be in accordance with ISO 6892-1 or ASTM E8 or ASTM A370 for the metallic materials used for traceable components.
- Elevated temperature tensile testing, where required by the supplier/manufacturer material specification, shall be in accordance with ISO 6892-2 or ASTM E21.
- Charpy testing shall be in accordance with ASTM E23 or ASTM A370.

7.4.3.2.2 Hardness testing shall be in accordance with the following:

- a) ISO 6506-1, ASTM E10, ISO 6508-1, or ASTM E18;
- b) ISO 6507-1 or ASTM E384 may be used if neither ISO 6506-1 nor ASTM E10 nor ISO 6508-1 nor ASTM E18 can be applied due to size, accessibility, or other limitations.

7.4.3.2.3 Hardness conversion to other measurement units shall be in accordance with either of the following:

- a) ASTM E140 or ISO 18265, with the exceptions noted in ANSI/NACE MR0175,
- b) or where the supplier/manufacturer has documented conversions approved by a qualified person for individual materials, they may be used in place of ASTM E140 or ISO 18265.

#### 7.4.3.3 Nonmetals

This section does not cover electronic or electrical components. Electrical and electronic components shall be covered by documented requirements of the supplier/manufacturer, which include performance requirements and acceptance criteria.

The supplier/manufacturer shall purchase nonmetallic goods and services only from their approved suppliers. A documented procedure shall be implemented to ensure that each nonmetallic supplier's products conform to the supplier/manufacturer's material specification on a repeatable basis.

NOTE ISO 23936-1 and ISO 23936-2 contain provisions on quality controls of nonmetallic sealing material.

Each nonmetallic seal supplier shall be evaluated to ensure that the applicable controls of all materials, compounds, and component processes effectively ensure consistent conformance to the material and technical specifications. These evaluations shall be performed by qualified persons in the applicable technology.

Note: API STANDARD 20L contains information to assist with evaluation of nonmetallic seal manufacturers.

Supplier evaluation records shall identify the materials/components that are approved to be provided by each specific supplier. Supplier documented evaluation records shall include the necessary corrective measures and verification of their implementation.

The supplier/manufacturer's documented specifications for nonmetallic compounds shall include handling, storage, and labeling requirements and define the quality control limits of characteristics necessary for the performance of the material. Mechanical properties required by the material specification shall be validated by test conducted on a material sample produced from the same batch of material.

Table 11 and 12 contain the minimum mechanical properties required for the supplier/manufacturer's documented specifications for nonmetallic compounds.

**Table 11 – Parameters for Elastomeric Materials**

<b>Mechanical Property</b>	<b>Test Method</b>
Tensile Properties to Include: Ultimate Tensile Strength Elongation at Break Tensile Modulus	ASTM D412 or ISO 37
Hardness	ASTM D2240, ASTM D1415, or ISO 7619-1
Specific Gravity or Density	ASTM D297 or ISO 2781
Compression Set	ASTM D395 or ISO 815-1

NOTE: ASTM D1414 provides guidance for material property testing in the O-ring geometry.

**Table 12 – Parameters for Thermoplastic Materials**

<b>Mechanical Property</b>	<b>Test Method</b>
Tensile Properties to Include: Tensile Strength Elongation at Break	ASTM D638 or ASTM D4745 (PTFE-compounds only) or ISO 527-1/-2

#### 7.4.3.4 Castings and Forgings

The production of castings and forgings shall conform to the same practices and controls as were applied to the successfully validation-tested component and the first article produced.

NOTE API 20A, API 20B, and API 20C contain information on castings, open die forgings, and closed die forgings, respectively.

#### 7.4.4 Heat Treatment

The supplier/manufacturer shall have documented procedures for each material, material condition, and process that includes acceptance criteria for the heat treatment of components. Heat treatment of components or raw materials shall meet the following requirements:

- a) Heat treatment shall be performed with controlled and monitored heat-treating equipment that has been calibrated and surveyed in conformance with a referenced national or international standard such as AMS 2750, API 6A, or API 20H. Calibration intervals shall not exceed twelve calendar months.
- b) Heat treatment shall conform with the supplier/manufacturer's documented specifications and acceptance criteria. This shall be documented and approved by a qualified person.
- c) Heat treated material shall be traceable to the documented heat treatment process(es) applied to that component.

#### 7.4.5 Stress Relief

Stress relief is heat treatment used to release integral material stresses caused by manufacturing. Stress relief may be performed without a furnace (e.g. a localized stress relief of a weld), to a documented procedure, and with the temperature measurement and recording instruments calibrated to 7.5. A hardness test shall be performed on each stress relieved area, and the results shall be evaluated by a qualified person as within the documented acceptance criteria.

Each welded component shall be stress relieved as specified in the supplier/manufacturer's written specifications or in accordance with ASME BPVC, Section VIII, Division 1, UW-40. In addition, carbon and low-alloy steel weldments on sour service equipment shall be stress relieved in accordance with ANSI/NACE MR0175.

#### 7.4.6 Traceability

##### 7.4.6.1 General

Traceability shall be in accordance with the manufacturer's documented procedures. The supplier/manufacturer shall determine what components will be classified as Type 1, in accordance with documented procedures.

##### 7.4.6.2 Product Traceability

QL1 products shall be uniquely serialized.

QL2 products shall have job-lot traceability.

QL3 products shall have supplier/manufacturer-defined traceability.

##### 7.4.6.3 Component Traceability

Component traceability shall meet the following requirements:

- a) For quality grade QL3, components shall have supplier/manufacturer-specified traceability.
- b) For quality grade QL2, metallic Type 1 components shall be job-lot traceable, and metallic Type 2 components shall have supplier/manufacturer-specified traceability.
- c) For quality grade QL1, metallic Type 1 components shall be serialized and be heat-traceable to an MTR. For quality grade QL1, Type 2 components and all castings shall have job-lot traceability.
- d) Nonmetallic components shall be job-lot traceable for quality grades QL1 and QL2.

- e) Common hardware (see 3.4) does not require traceability.
- f) For all quality grades, shear devices shall be job-lot traceable with one heat per job-lot.

#### 7.4.7 NDE Inspections

##### 7.4.7.1 General

NDE of components shall meet the following requirements:

- a) NDE shall be performed in accordance with the supplier/manufacturer's documented requirements and acceptance criteria.
- b) Type 1 and 2 components for quality grade QL1 and QL2 shall be visually inspected in accordance with the supplier/ manufacturer's documented specifications.

##### 7.4.7.2 Metallic

NDE of metallic components shall meet the following requirements, as applicable.

- a) NDE for metallic components shall be magnetic-particle inspection or liquid-penetrant inspection:
  - magnetic-particle inspection, see 7.4.7.11;
  - liquid-penetrant inspection, see 7.4.7.12.
- b) Type 1 components for quality grade QL2 shall be NDE-inspected using liquid-penetrant or magnetic particles, as defined in 7.4.7.11 or 7.4.7.12 in a sampling plan, in accordance with Annex H.
- c) Type 1 components for quality grade QL1 shall be 100 % NDE-inspected using liquid-penetrant or magnetic particles, as defined in 7.4.7.11 or 7.4.7.12.
- d) Raw material for Type 1 components for quality grade QL1 shall be 100 % inspected using ultrasonic inspection, as defined in 7.4.7.10.

##### 7.4.7.3 Nonmetallic

NDE of nonmetallic components shall meet the following requirements:

- a) NDE for nonmetallic components shall be visual inspection in accordance with supplier/manufacturer's documented specifications. Visual inspection of O-rings shall be in accordance with ISO 3601-3 or equivalent.
- b) Components for quality grade QL2 shall use a sampling plan in accordance with Annex H.
- c) Components for quality grade QL1 shall be 100 % NDE-inspected.

##### 7.4.7.4 Component Dimensional Inspections

Components, except common hardware, shall be dimensionally inspected according to the supplier/manufacturer's procedures by a qualified person(s) to ensure proper function and conformance with the design criteria and specifications. Inspection shall be performed during or after the manufacture of the components, but prior to assembly, unless assembly is required for proper measurement.

- a) Type 1 and Type 2 components for quality grade QL2 shall be inspected in accordance with the sampling plan in Annex H.

- b) Type 1 components for quality grade QL1 shall be 100 % dimensionally inspected and documented.
- c) Type 2 components for quality grade QL1 shall be inspected in accordance with the sampling plan in Annex H.

Dimensional tolerances of O-rings shall be in accordance with supplier/manufacturer's specifications.

Sealing elements and nonmetallic components other than O-rings shall meet dimensional tolerances of the supplier/manufacturer's documented specifications and acceptance criteria.

#### **7.4.7.5 Thread Inspection**

API tapered-thread tolerances, inspection requirements, gauging, gauging practice, gauge calibration, and gauge certification shall be in accordance with API 5B or API 7-2, as applicable.

All other thread tolerances, inspection requirements, gauging, gauging practice, gauge calibration, and gauge certification shall conform to the specified thread design owner's written specifications.

#### **7.4.7.6 Hardness Inspection of Components**

Hardness inspection of metallic components shall be performed in accordance with ISO 6506, Parts 1 through 4 (Brinell) or ISO 6508, Parts 1 through 3 (Rockwell). ISO 6507, Parts 1 through 4 (Vickers) may be used when ISO 6506-1 or 6508-1 cannot be applied due to size, accessibility, or other limitation.

NOTE For the purposes of this standard, ASTM E10 is equivalent to ISO 6506, ASTM E18 is equivalent to ISO 6508, and ASTM E92 is equivalent to ISO 6507.

- a) Slips shall be hardness tested in accordance with supplier/manufacturer approved procedures and acceptance criteria.
- b) Type 1 components for quality grade QL1 shall be 100 % hardness inspected.
- c) Type 2 components for quality grade QL1 shall be hardness inspected in accordance with a sampling plan (see Annex H).
- d) Type 1 components for quality grade QL2 shall be hardness inspected in accordance with a sampling plan (see Annex H).

The durometer hardness of O-rings or other elastomeric seals shall be determined in accordance with a national or international standard, such as the test methods in Table 11. A minimum of one seal manufactured from each batch shall be hardness tested.

#### **7.4.7.7 Castings, Forgings, and Wrought Products**

The casting subcontractor or supplier shall provide a COC to the supplier/manufacturer stating that the casting meets the supplier/manufacturer's documented specifications.

Type 1 castings, forgings, and wrought components for quality grade QL1 shall be magnetic particle or liquid-penetrant inspected (see 7.4.7.11 and 7.4.7.12) for surface defects and shall be volumetrically inspected by ultrasonic techniques (see 7.4.7.10) to verify conformance with the supplier/manufacturer's specifications.

#### **7.4.7.8 Coatings, Platings, and Surface Treatments**

Coatings, platings, and surface treatments shall be performed in accordance with supplier/manufacturer specifications and acceptance criteria, including thickness, and approved by a qualified person.

Specifications shall include requirements for the following:

- a) surface cleanliness;
- b) surface preparation;
- c) application process;
- d) wet and dry film thickness;
- e) inspection requirements;
- f) personnel qualification;
- g) environmental conditions.

#### **7.4.7.9 Welding and Brazing**

NDE of welds shall meet the following requirements:

- a) Welds shall be visually inspected in accordance with the requirements of a specification or national standard, such as the ASME Boiler and Pressure Vessel Code, Section V, Article 9, with acceptance criteria in accordance with ASME BPVC Section IX articles QW-194 and QW-195, 2.2.
- b) Welds for quality grade QL2 shall be NDE-inspected using liquid-penetrant or magnetic particle in accordance with a sampling plan (see Annex H).
- c) Welds for quality grade QL1 shall be 100 % NDE-inspected using liquid-penetrant or magnetic particle (see 7.4.7.11 and 7.4.7.12).
- d) When required by the supplier/manufacture's documented specification, each welded component shall be stress-relieved. All final inspections shall be performed after all thermal operations are completed.

#### **7.4.7.10 Ultrasonic Inspection of Components**

Ultrasonic inspection of components shall be in accordance with ASTM E428 and ASTM A388, or ASTM E213, as applicable.

Any of the following product defects shall be basis for rejection:

- a) Back reflection technique—indications greater than 50 % of the referenced back reflection accompanied by a complete loss of back reflection;
- b) Flat bottom hole technique—indications equal to or larger than the indications observed from the calibration flat bottom hole;
- c) Angle beam technique—amplitude of the discontinuities exceeding those of the reference notch.

#### **7.4.7.11 Magnetic Particle Inspection of Components**

Wet magnetic particle examination shall be in accordance with ISO 10893-5 or ASTM E709.

Indications shall be described as one of the following:

- a) Relevant indication—only those indications with major dimensions greater than 1.6 mm (1/16 in.) shall be considered relevant, whereas inherent indications not associated with a surface rupture (i.e. magnetic permeability variations, nonmetallic stringers, etc.) shall be considered nonrelevant;
- b) Linear indication—any indication in which the length is equal to or greater than three times its width;
- c) Rounded indication—any indication which is circular or elliptical in which the length is less than three times its width;
- d) Acceptance criteria:
  - i) any relevant indication greater than or equal to 4.8 mm (3/16 in.) shall be unacceptable;
  - ii) no relevant linear indications shall be allowed for weldments;
  - iii) no more than 10 relevant indications shall be present in any 39 cm<sup>2</sup> (6 in.<sup>2</sup>) area;
  - iv) four or more rounded relevant indications in a line separated by less than 1.6 mm (1/16 in.) shall be unacceptable.

#### **7.4.7.12 Liquid-penetrant Inspection of Components**

Liquid-penetrant inspection shall be in accordance with ASTM E165 and meet the following acceptance criteria:

- a) no relevant linear indications;
- b) no relevant rounded indications greater than 5 mm (3/16 in.);
- c) no more than four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less (edge-to-edge).

#### **7.4.8 Shear Device Verification**

At least one shear device per heat-lot shall be sheared in accordance with the supplier/matrix manufacturer's documented procedure to verify that the shear value meets the documented specification.

#### **7.4.9 Assembly Verification**

Assembly verification shall meet the following:

- a) For quality grade QL3, assembly verification shall be conducted in accordance with supplier/matrix manufacturer-defined specification.
- b) For quality grades QL1 and QL2, an internal test shall be performed on each product that contains a potential leak path between the ID and the OD of the product by applying internal pressure to a minimum of 0.35 MPa (50 psi), using either liquid with corrosion inhibitors or nitrogen as the test medium. Test duration shall be a minimum of 5 minutes after stabilization. Acceptance criteria shall be defined by the supplier/matrix manufacturer's documented procedures. Test data shall be recorded, dated, and signed by the qualified person performing the tests. Connections that are not made up as a part of product assembly are excluded from this requirement.

For quality grade QL1, an additional internal test shall be conducted to a minimum of 60 % of rated internal pressure or 34.50 MPa (5000 psi), whichever is less. Test duration shall be a minimum of 15 minutes after stabilization.

- c) For quality grades QL1 and QL2, a suppliers/manufacturee-defined functional test shall be completed, as applicable.
- d) For quality grades QL1 and QL2, ID drift each product in accordance with the supplier/manufacturee's documented specifications. Drift diameter shall match the rated drift diameter of the product. Drift dimensions shall meet the requirements specified in API 5CT, where applicable.
- e) For quality grade QL1, the OD shall be inspected according to the supplier/manufacturee's documented specifications. OD dimensional inspection shall verify that the entire OD of the assembly is less than or equal to the maximum specified OD.
- f) For quality grade QL1, actual torque values for all connections that require torque value shall be recorded and verified to be within the supplier/manufacturee's documented specifications. End connections are specifically excluded from this requirement.

#### 7.4.10 Manufacturing Nonconformance

The supplier/manufacturee shall establish and maintain documented procedures to ensure that an assembly or component that does not conform to specified requirements is prevented from unintended use or installation. This control shall provide for identification, documentation, evaluation, segregation (when applicable), and disposition of nonconforming assemblies or components.

The responsibility for review and authority for the disposition of nonconforming assemblies or components shall be defined by the supplier/manufacturee. Nonconforming assemblies or components may be one of the following:

- a) accepted with or without repair with technical justification;
- b) reworked to meet the specified requirements; or
- c) rejected or scrapped.

Reworked assemblies or components shall be inspected in accordance with the requirements of the appropriate quality grade and the documented specifications of the supplier/manufacturee.

### 7.5 Calibration

7.5.1 Inspection, measuring, and testing equipment used for acceptance shall be used within its calibrated range and shall be identified, controlled, calibrated, and adjusted at specific intervals in accordance with the manufacturer's procedures that are based on an internationally recognized standard, such as ISO/IEC 17025 or ANSI/NCSL Z540-3. Technologies for inspections with verifiable accuracies equal to or better than those listed in this international standard may be applied with appropriate documentation and when approved by a qualified person(s). Calibration intervals for measuring and testing equipment shall be established based on repeatability and degree of usage.

7.5.2 Calibration intervals shall be a maximum of three months until a recorded calibration history can be established. Intervals may then be lengthened or shortened based on documented repeatability, amount of usage, and calibration history. The calibration interval cannot be increased by more than twice the previous interval, which is not to exceed one year. Calibration standards used to calibrate measuring equipment shall be checked and approved at least once every three years by an independent agency with traceability to the applicable recognized national or international standards agency. When a device is found to be out of calibration, an assessment shall be performed per API Q1 or ISO 29001.

## **8 Redress or Repair**

Redress activities for products after original manufacture shall be defined by the supplier/manufacture's procedures.

Repair activities for products returned to the supplier/manufacture after delivery shall conform to the requirements of Section 7 and the supplier/manufacture documented requirements returning the product to a condition meeting all requirements stated in this edition or the edition in effect at the time of original manufacture. Repaired products shall be permanently marked for traceability of the repair.

Documentation of the redress, repair, or any combination thereof, and all subsequent testing results shall be included in records traceable to the product assembly.

## **9 Shipping, Handling, and Storage**

Products shall be handled and stored according to the documented specifications of the supplier/ manufacturer in order to prevent deterioration.

Products shall be packaged for transport according to the documented specifications of the supplier/ manufacturer in order to prevent damage to the equipment from normal handling and contamination. All material provided as protection for transport shall be clearly identified for removal prior to equipment use.

Recommendations for storage shall be identified in the product operating manual.

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## **Annex A** (normative)

### **Requirements for Legacy Liner Packers and Legacy Liner Hanger Packers, and Liner Systems**

#### **A.1 General**

This annex applies to equipment that was validated prior to the release of the first edition of this document dated June 2019. Requirements for design validation are provided entirely within this annex. The requirements for design verification, design changes, and scaling are governed within section 6.

This annex shall be used when a user/purchaser specifies equipment validation grade of V1-L or V2-L for a Liner Packer or Liner Hanger Packer product or VS1-L or VS2-L for a liner system. The requirements stated in this annex shall replace the corresponding requirements in the main body of this edition, while all other sections of this edition shall be subject to conformance.

See section 6.6.16 for requirements for legacy system validation grades.

#### **A.2 Design Validation**

##### **A.2.1 General**

This section replaces the requirements of 6.6.10 (Liner Packer Design Validation) and 6.6.11 (Liner Hanger Packer Design Validation).

The supplier/manufacturer shall document the validation test procedure and results, and shall have on file material specifications and drawings that show all the applicable dimensions and tolerances of parts contained in the validation-tested product. Pre-test and post-test dimensional inspection of critical operational areas, as determined by the supplier/manufacturer, shall be conducted, documented, and maintained by the supplier/manufacturer. Validation test results and dimensional inspection results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation.

The validation grades for legacy products per Annex A are the following:

- V2-L: liquid test plus axial loads and temperature cycle range;
- V1-L: nitrogen test plus axial loads and temperature cycle range with zero bubble criterion.

NOTE Grade V2-L is based upon Grade API 11D1 third edition (ISO 14310:2008) Grade V3 and Grade V1-L is based upon API 11D1 third edition (ISO 14310:2008) Grade V0.

Products qualified to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 3.

Products with V1-L and V2-L validation grades shall not be rated for use in casing sizes and masses (weights) that can have a maximum ID larger than the ID used in the validation test.

The design validation grade hierarchy for legacy products is found in Table 3.

##### **A.2.2 Validation Test Requirements**

###### **A.2.2.1 General**

The supplier/manufacturer shall document all parameters and results of the evaluations that demonstrate conformance to the validation grade. Test data shall identify the leak rate for the duration of the subject test. If no leakage occurred, this shall be clearly stated.

## Annex A

### A.2.2.2 Grade V2-L: liquid test plus axial loads and temperature cycle range

The supplier/manufacturer shall adhere to the following test parameters and criteria for conformance to this validation grade:

- Set in maximum rated casing ID  $\pm 0.76$  mm ( $\pm 0.030$  in.) or as-rolled API 5CT or 5L compliant casing.
- Set with the minimum rated setting force or pressure ( $\pm 10$  %).
- Products with no anchoring devices or anchoring devices that hold in one direction may be restrained by the test fixture to prevent movement in the un-anchored direction(s).
- Set and run the entire test, except temperature cycling, at or above the maximum rated temperature.
- Test at or above the maximum rated differential pressure.
- Perform a minimum of two pressure reversals at or above the maximum rated pressure from above to below or vice versa.
- Test to all intersection points of the rated performance envelope.
- Test those packers having shear-release features at their maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.
- Test a minimum of one temperature cycle. Start the temperature cycle at or above the maximum rated temperature and cool down by at least the maximum rated temperature-cycle range. A pressure hold is required at the low end of the temperature-cycle range and after heating back up to the maximum rated temperature.
- Use a liquid test medium of water, with or without additives, or hydraulic oil. The density shall be less than 1100 kg/m<sup>3</sup> (68.67 lb/ft<sup>3</sup>). Liquid shall be visibly free from particulate matter or other material that can plug a small leak.
- Maintain a minimum hold period of 15 min for pressure tests.
- Acceptance criterion: no more than 1 % reduction in the maximum rated differential pressure over the hold period after sufficient time has been allowed for stabilization. The time period for stabilization is at the discretion of the supplier/manufacturer.

### A.2.2.3 Grade V1-L: nitrogen test plus axial loads and temperature cycle range plus zero bubble acceptance criterion

The supplier/manufacturer shall adhere to the following test parameters and criteria for conformance to this validation grade:

- Set in maximum rated casing ID  $\pm 0.76$  mm ( $\pm 0.030$  in.) or as-rolled API 5CT or 5L compliant casing..
- Set with the minimum rated setting force or pressure ( $\pm 10$  %).
- Products with no anchoring devices or anchoring devices that hold in one direction may be restrained by the test fixture to prevent movement in the un-anchored direction(s).
- Set and run the entire test, except temperature cycling, at or above the maximum rated temperature.
- Test at or above the maximum rated differential pressure.
- Perform a minimum of two pressure reversals at or above the maximum rated pressure from above to below or vice versa.
- Test to all intersection points of the rated performance envelope.
- Test those packers having shear-release features at their maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.
- Test a minimum of one temperature cycle. Start the temperature cycle at or above the maximum rated temperature and cool down by at least the maximum rated temperature-cycle range. A pressure hold is required at the low end of the temperature-cycle range and after heating back up to the maximum rated temperature.
- Use a gas test medium of air, nitrogen, or other gas or mixture of gases.
- Maintain a minimum hold period of 15 min for pressure tests.

## **Annex A**

- Acceptance criterion: zero bubbles of gas accumulated in a graduated cylinder over the hold period after sufficient time has been allowed for stabilization. The time period for stabilization is at the discretion of the supplier/manufacturer. Graduated cylinders for accumulated gas shall be at atmospheric pressure.

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## Annex B (informative)

### Functional Requirements Example Check List

#### B.1 Well Parameters

The following is a list of well parameters:

- a. Company name;
- b. Field name;
- c. Lease/block;
- d. Well name/number;
- e. City/county;
- f. State/province/country;
- g. Company contact (office/rig);
- h. Rig (contractor/name/type);
- i. Well type (producer/injector/oil/gas/steam/disposal/etc.);
- j. Liner type (drilling/production);
- k. Wellbore schematic (depths/hole sizes/casing details/etc.);
- l. Restrictions (wellhead/previous liners/etc.);
- m. Liner (specifications/connections/shoe depth/top depth/etc.);
- n. Casing (specifications/connections/shoe depth/top depth/etc.);
- o. Well fluid (type/density/etc.);
- p. Directional (type profile/dogleg severity/maximum inclination);
- q. Combined loading constraints (tension/compression/burst/collapse/torque);
- r. Differential pressure (maximum/minimum at top of liner [TOL]);
- s. Temperature (bottom hole/TOL/etc.)
- t. Any other relevant well parameters.

## B.2 Operational Parameters

The following is a list of operational parameters:

- a) Liner hanger type (conventional/expandable/hydraulic/mechanical/etc.);
- b) Equipment requirements (primary/back-up, second-trip packer, etc.);
- c) Dimensional (maximum OD/minimum ID/bypass area/maximum flow rate/etc.);
- d) Metallurgy (carbon steel/corrosion-resistant alloys/etc.);
- e) Sealing material environmental compatibility;
- f) Running tool (dimensions/specifications/operating pressures/etc.);
- g) Rotational capability (drill-in/reaming/while cementing/etc.);
- h) Running string (specifications/connections/lengths/etc.);
- i) Cement company;
- j) Cementing objective (shoe/zonal isolation/etc.);
- k) Cement head (type/company);
- l) Plugs and darts (single/dual/etc.);
- m) Shoe track (shoe/float collar/landing collar/auto-fill/etc.);
- n) Surge reduction (diverter/flow-back tools/providers/etc.);
- o) Integral liner packer;
- p) Polished-bore receptacle (length/configuration/dressing mills/etc.);
- q) Tie-back (objective/casing/cement/seal assembly/space-out/etc.);
- r) Centralization (type/supplier/etc.);
- s) Running constraints (maximum set-down/torque limits/emergency release/etc.);
- t) Setting constraints (setting loads/maximum pressure/contingency set/etc.);
- u) Post-installation constraints (burst/collapse/hanging capacity/differential/etc.);
- v) Any other relevant operational parameters.

## **Annex C** **(informative)**

### **External Flow Testing**

#### **C.1 Scope**

This annex defines the requirements for external flow testing of liner hanger equipment.

#### **C.2 General**

##### **C.2.1 Testing Requirements**

Testing shall be performed within the limits specified with liquid, to defined acceptance criteria, with suitable documentation, and approval of the results. The supplier/manufacturer stated external flow rating(s) shall be within the measurements recorded during this testing. The test results and ratings shall be included in the product design documentation.

##### **C.2.2 Personnel**

Preparation, testing, and approval of results shall be conducted by qualified personnel.

##### **C.2.3 Measuring and Monitoring Equipment**

Measuring and monitoring equipment used during the testing shall be calibrated to 7.5. All pressures and flow rates are defined as gauge unless otherwise specified and shall be recorded on time-based equipment.

##### **C.2.4 Procedures**

The supplier/manufacturer shall develop procedures for conducting the external flow tests, which shall be documented and included in the final report of the results. The procedures shall include acceptance criteria.

##### **C.2.5 Test Fixture**

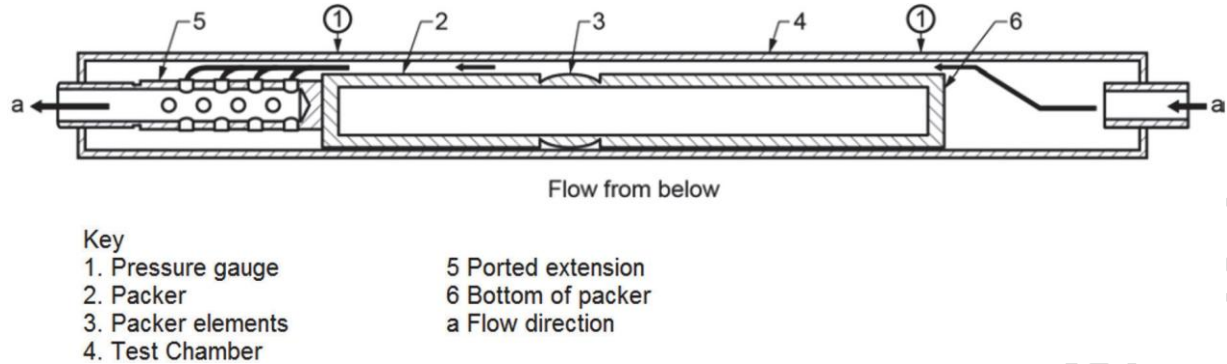
The liner hanger equipment shall be installed in a section of casing/fixture within the weight range of the product's specification. The actual ID of the test casing shall be recorded in the test report. The end of the liner hanger equipment shall be closed in order to direct all flow entering the fixture to flow around the outside of the product.

See Figure C.1 for an illustration of an example test fixture.

#### **C.3 Test Processes**

Conduct the external flow testing according to the following steps:

- 1) Place the liner hanger equipment under test into the test fixture;
- 2) Secure the test fixture, and attach the flow lines to each end of the fixture;
- 3) Direct the water through the fixture starting at 79 l/m (0.5 bpm) or 50 % of the defined maximum flow rate, whichever is greater, while monitoring pressure drop across the defined location for a minimum of 5 minutes;



**Figure C.1—Illustration of an Example Test Fixture for Flow Testing**

- 4) Increase the flow rate by 79 l/m (0.5 bpm) every 5 minutes until the external flow rate meets or exceeds to the supplier/major manufacturer-defined maximum external flow rate.
- 5) Pump the water through the test fixture for a minimum of two hours at the defined maximum external flow rate.
- 6) The test is concluded when the pressure or flow rate meets the supplier's/major manufacturer's stated acceptance criteria or when the maximum flow rate is achieved.

#### **C.4 Report**

A test report shall be prepared in conformance with 6.6.5.

#### **C.5 Scaling of External Flow Testing**

The supplier/major manufacturer shall not scale to flow rates which result in higher velocity than the validated product. The validated fluid velocity must be retained on the scaled product and/or casing size and weight.

Packer elements and anti-extrusion components of the scaled product design shall be of the same material specification as that of the validated product.

For elastomers that are not bonded to a metallic component, the thickness and length of the packer element of the scaled design shall be within 5 % of that of the validated design.

## Annex D (informative)

### FEA Method for Analyzing a Pressure-containing Liner Hanger Component

#### D.1 Scope

This annex illustrates a method for analyzing a pressure-containing liner hanger component, such as a liner hanger body or mandrel.

#### D.2 Summary

Table D.1 is a summary of the presented FEA method.

**Table D.1—FEA Method Data**

Pressure Type	Geometrical Feature	Wall Thickness	Material Model	Failure Mode	Related Capacity
Internal pressure	Simple cylinder	Thick ( $D/t < 20$ )	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
		Thin ( $D/t \geq 20$ )	Elastic	Membrane Stress	0.90 x Yield
	Complex cylinder	N/A	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
External pressure	Simple/complex cylinder	N/A	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
				Instability	0.80 x ultimate collapse
				Drift requirement	Deflect to drift diameter

#### D.3 Internal Pressure

##### D.3.1 FEA Models

A 3-D model of the component shall be created which contains all slots, grooves, and other geometrical features. Once the correct geometrical model is created, two FEAs shall be run using the following:

- purely elastic material data; and
- true stress-true strain material data.

##### D.3.2 Post-processing

Both FEAs are examined, and the points of earliest failure are located (with failure being determined by the presence of yielding). The points of interest are then more closely analyzed in accordance with the following steps to determine the rated capacity.

Determine whether the points of interest are simple thick-walled, simple thin-walled, or complex cylinder:

- Simple thick-walled = (cylinder  $w/D/t < 20$ )
- Simple thin-walled = (cylinder  $w/D/t \geq 20$ )
- Complex cylinder = (cylinder w/ axial slots)

NOTE 1 Any region of concern containing significant bending stresses produced by slots or other geometrical features is considered to be thick for the purposes of determining component capacity.

Thin wall regions are rated using the purely elastic FEA model.

Membrane stress (average stress through the wall) is examined as pressure is increased.

The pressure that creates a membrane stress equivalent to 90 % of minimum specified yield strength of the material is considered the rated pressure for the thin wall section.

NOTE 2 Ninety percent of the membrane stress is used as the rating criterion because of the catastrophic nature of failure associated with thin-walled members.

Thick wall regions or complex cylinders are rated using the elastic-plastic FEA model.

The von Mises stress is examined at various pressures.

The thick region is rated to the pressure that causes surface yielding due to primary stresses.

NOTE 3 Secondary stresses, which often occur at sharp geometric transitions, are ignored for the purpose of determining static capacity. Although secondary stresses may cause localized yielding, they do not propagate through the component and thus do not contribute to failure. If a localized secondary stress begins to propagate, it is reclassified as a primary stress and considered a possible failure point.

## D.4 External Pressure

### D.4.1 FEA Model

A 3-D model of the component shall be created that contains all slots, grooves, and other geometrical features. In order to accurately determine external pressure capacity, the FEA model should include the following:

- complete elastic-plastic material behavior (true stress-true strain material data);

NOTE 1 Bilinear material models are not recommended for this method.

- nonlinear geometry analysis;
- ID ovality to initiate geometric instability.

NOTE 2 Ignoring instability can result in overestimated external pressure capacities.

### D.4.2 Post-processing

External rated pressure capacities are determined by considering the following failure modes:

Geometric instability—instability is characterized by rapid changes in deflection over small changes in pressure, which can be analyzed by creating a graph of deflection vs pressure at the node of highest deflection. As the pressure

is increased incrementally, the deflection goes near asymptotic at the point of complete collapse. Because collapse due to instability is catastrophic and may occur suddenly, it is recommended that the external pressure capacity is rated at 80 % of the ultimate collapse pressure.

The magnitude of stresses—regions in which yielding occur are rated to the pressure that causes surface yielding due to primary stresses. Secondary stresses, which often occur at sharp geometric transitions, are cautiously ignored for the purpose of determining capacity. Although secondary stresses may cause localized yielding, they do not propagate through the component and thus do not contribute to failure. If a localized secondary stress begins to propagate, it is reclassified as a primary stress and considered a possible failure point.

System drift requirements—if the component is required to remain above certain drift requirements under all loading scenarios, the external pressure capacity is rated at the pressure that causes a component to violate drift requirements.

The rated external pressure capacity is the lowest pressure to cause any of the preceding failure modes, as per Figure D.1.

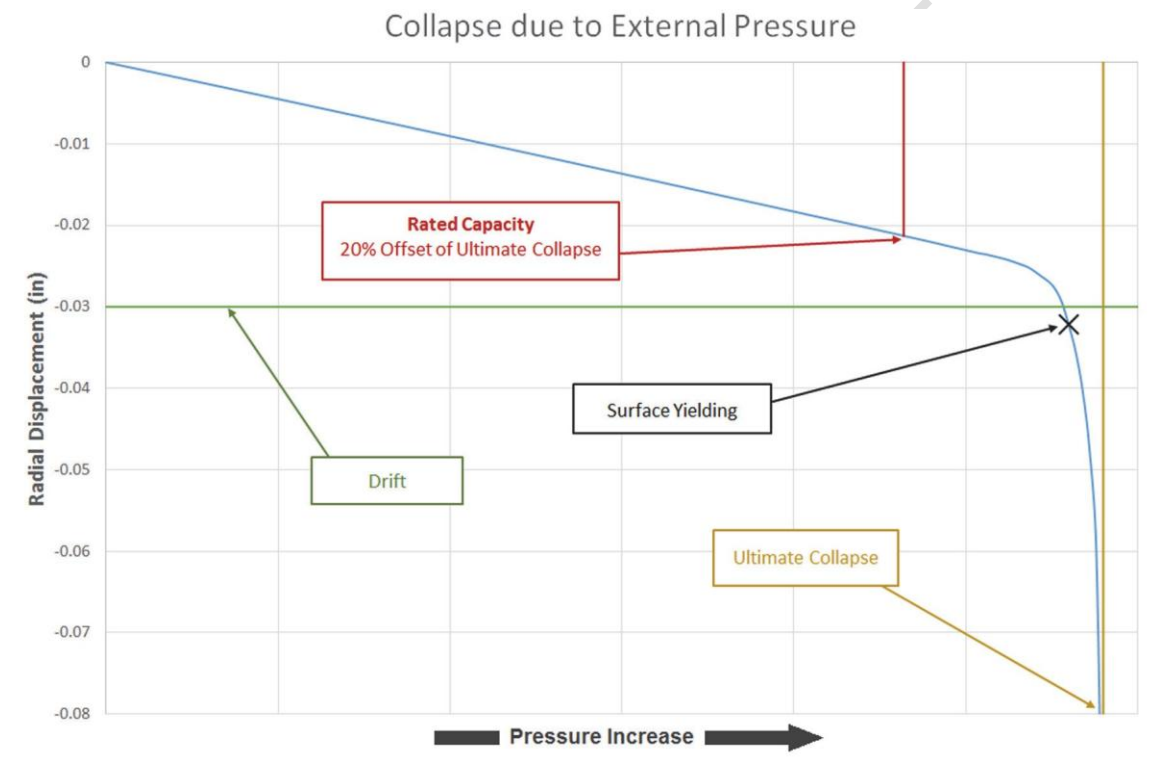


Figure D.1—Example of an External Pressure Plot

## **Annex E** (normative)

### **Liner Hanger Running/Setting Tool Requirements**

#### **E.1 General**

This annex includes the requirements for design verification (including interface capabilities), manufacturing, design validation, design scaling, and reporting requirements for running/setting tools. These tools shall be identified in the operating manuals (7.2.3) and are required for the liner systems to perform as designed.

Contingency tools, milling tools, cementing packoffs, and destructive removal systems are not included in the requirements of this annex. Post manufacturing running/setting tool redress, repair, and servicing is not covered by this annex.

The activities required by this annex shall be performed by qualified person(s). All results shall conform to the acceptance criteria and be supported by documentation.

#### **E.2 Design Verification**

Running/setting tool design and its operational/interface capability shall be supported by design verification records/reports to the ratings of the tool. Reports shall be approved by the supplier/manufacture's qualified person. The qualified person shall be someone other than the person who prepared the report. Each tool's operational capabilities shall enable the installation of the associated products or systems. Design verification shall include activities such as design reviews, design calculations, and comparison with similar designs and historical records of defined operating conditions. Verification results shall be approved, and records of the results shall be included in the tool's design documentation.

#### **E.3 Design Validation Requirements**

##### **E.3.1 General**

The design validation shall conform to API Q1 or ISO 29001 and support the stated product ratings and capacities.

When tools from the product supplier/manufacture are specified, the interface and performance of the tool design may be validated by a review of reports of the tools' testing and performance ratings. The review shall be documented and approved by the supplier/manufacture's qualified person.

The supplier/manufacture shall have on file material specifications and drawings that show all the applicable dimensions and tolerances of the components contained in the validated product.

Where testing is performed, pre-test and post-test dimensional and visual inspection of critical operational areas, as determined by the supplier/manufacture, shall be conducted, documented, and maintained by the supplier/manufacture. The assembly results and dimensional inspection results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation.

The running/setting tool design shall conform to the supplier/manufacture-specified acceptance criteria and the requirements of this annex. Failure to do so requires a new set of evaluations, verifications, or validation tests after corrections conforming to the original design requirements are completed.

Testing and evaluations shall be performed to documented procedures and acceptance criteria with approvals. Testing shall conform to the requirements of 7.2 and 7.5, as applicable to requirements for running/setting tools.

### **E.3.2 Testing During Previous Liner System or Product Validations**

A running/setting tool that has had all of its functional capabilities successfully validated to its ratings in the performance of the liner system validation testing shall be considered as meeting the requirements of this annex after the resulting documentation is approved by a qualified person.

Any operational capabilities that have not been validated during the system or product validation testing shall be validated separately to the requirements of this annex.

### **E.3.3 Testing Requirements**

Testing equipment, fixtures (where applicable), and procedures shall conform to the requirements of Section 7.

The design and performance of the test fixture shall replicate the interface of the running/setting tool within its designated system or products and shall not influence the testing results. Design validation by testing shall be done with the applicable system or products, or with a fixture with the equivalent fits, clearances, and minimum required loads as the affected portion of the products or system.

Validation testing shall be discontinued if the running/setting tool or its interface fails to perform within the limits specified, except when such failures are determined to be a result of a failure within the test facility alone, and that failure and its correction do not affect the validity of the testing results.

During validation testing of hydraulically operated tools, fluid metering may be used to provide readable control signals during the testing if necessary, to simulate downhole conditions.

### **E.3.4 Final Design Validation Report**

A final report of the design validations shall be prepared and conform to 6.6.5.

### **E.3.5 Design Changes**

Design changes to a validated running/setting tool shall conform to 6.8.

### **E.3.6 Design Scaling**

Scaling may be used to validate variations of a validated running/setting tool of the same design family. A product family is a group of assemblies where the same design configuration principles apply to materials, geometry, and functionality.

The supplier/manufacturer shall establish the maximum stress within the previously validated design of the Type 1 components and in the same components of the scaled design. The mode of stress and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. For the Type 1 component with the highest design stress factor, the scaled design's stress factors shall not exceed the stress factor of the same component of the validated design.

Design scaling shall be approved by a qualified person. The qualified person shall be someone other than the person who conducted the design scaling, and records of the results shall become a portion of the design documentation.

## **E.4 Manufacturing Requirement**

### **E.4.1 General**

Running/setting tools shall be manufactured to the requirements of 7.4 (as applicable) with a minimum of quality grade QL3.

### **E.4.2 Assembly Requirements**

Any required assembly of the running/setting tool shall follow the supplier/manufacturer's documented procedures using components that conform to documented specifications. A bill of materials shall be prepared for each assembly.

### **E.4.3 Documentation, Data Control, and Operations Manual**

The documentation and data control for the assembled tool shall meet the requirements of 7.2, excluding 7.2.4.

### **E.4.4 Product Identification**

Running/setting tools' components shall be permanently identified according to the supplier/manufacturer's specifications. The supplier/manufacturer's specifications shall define the type, method of application, and location of the identifications.

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## **Annex F** **(normative)**

### **Liner Hanger Bearing Validation Testing Requirements**

For design validation grade V2 and V1 liner hangers with rotational capability after setting, the following actions shall be performed:

- 1) Load the bearing to rated dynamic axial capacity.
- 2) Begin bearing rotation. Record the parameters required to determine the initial rotational torque.
- 3) Rotate bearing at a minimum of 20 rpm. Continuously measure the parameters required to determine the rotational torque.
- 4) Apply cooling fluid as specified by supplier/manufacturer.
- 5) Continue rotation while continuously measuring the parameters required to determine the rotational torque.
- 6) Stop test when rotational torque reaches the supplier/manufacturer's defined limits. Report elapsed time to test stop and cooling fluid application parameters.

Conduct post-test inspection according to supplier/manufacturer procedure.

Prepare test report according to 6.6.5.

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## **Annex G** (informative)

### **Performance Envelopes Using Validated Products**

#### **G.1 Introduction**

This annex is intended to provide guidance on how to create and interpret Performance Envelopes for products and systems covered by this specification. Section 6.7 describes the performance envelope as graphic illustrations of the combined effects of pressure and axial loads on the product at maximum rated temperature. The lines forming the boundary of the envelope are defined as the maximum operational limits for the product or system. These boundaries are tested, per V1 and V2 procedures, and represented in the envelope. This annex intends to guide both supplier/manufacturers and user/purchasers so that the operational limits tested in validation are understood for the intended field application.

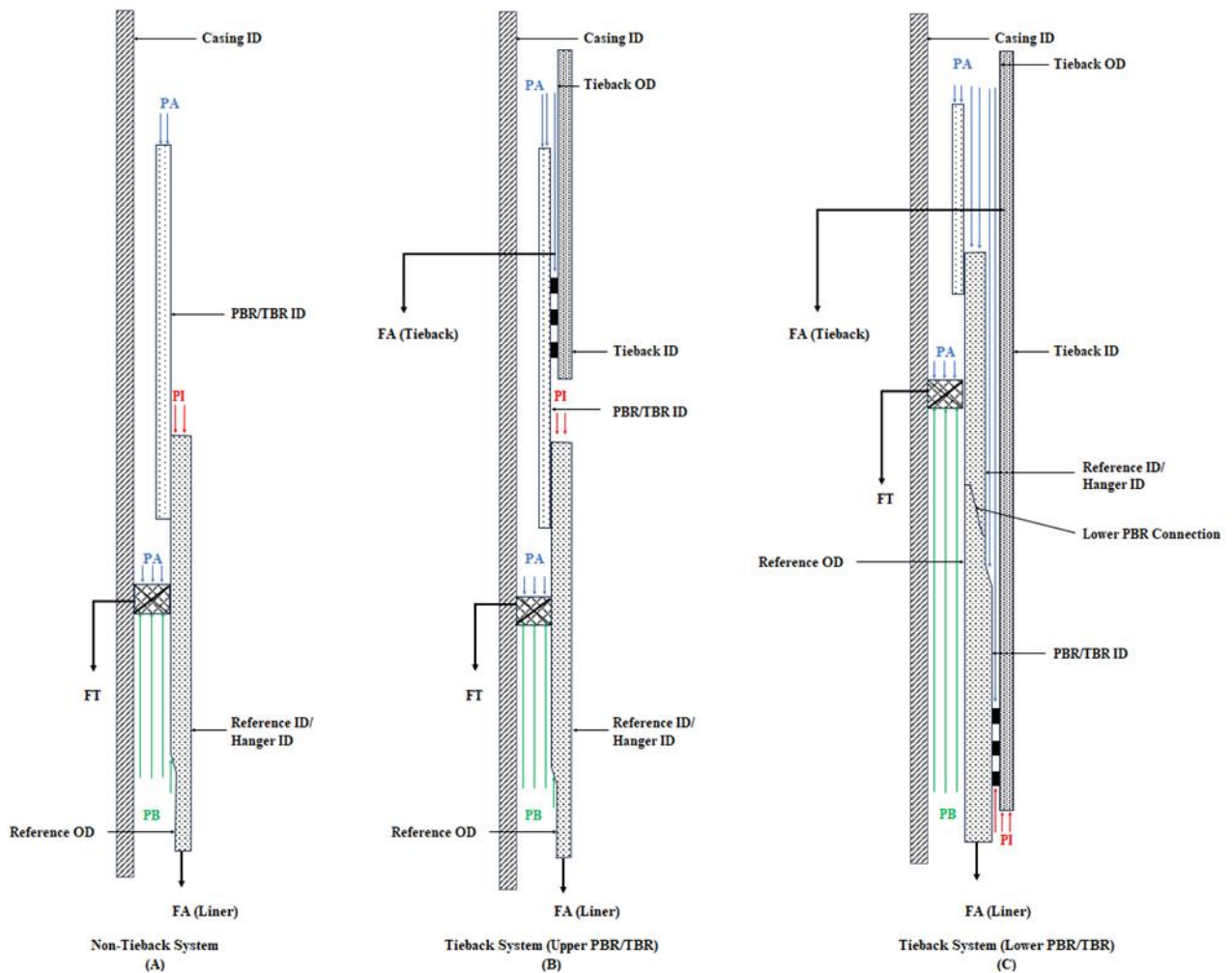
Historically, various methods of data representation have been utilized within the industry to communicate similar information. The lack of consistency between performance envelopes provided by suppliers/manufacturers can lead to misinterpretation of the information by users/purchasers. The goal of this section is to remove any ambiguity in understanding a performance envelope by creating uniform requirements for what data is provided and what it means.

#### **G.2 Performance Envelope Schematic, Definitions, and Equations**

Performance envelopes are presented in terms of net force transmitted from the liner product or system to the host casing. The net force is a summation of all forces, which can be created due to various causes as explained in Section G.4. This net force is shown in Figure G.1 and is labeled as FT.

The net force (FT) performance envelope is a graphical illustration of the forces and pressures, that may be applied to the product that represents safe loading conditions at maximum rated temperature. The forces plotted on the net force performance envelope are the total forces on a product(s) that is transferred through the product(s) to the host casing (liner-to-casing force), inclusive of the applied load plus additional pressure-induced piston effects. See FT in Figure G.1.

The boundary lines of the envelope shall represent the supplier/manufacturer's maximum ratings of Hold Down Capacity (compression), Hanging Capacity (tension), Internal Pressure (burst), and External Pressure (collapse), and combined loads for the product(s) at maximum rated temperature. Each of the illustrated ratings shall have defined increments with the axial load on the X axis and the pressure on the Y axis. The performance envelopes shall be prepared and approved by a qualified person(s).



**Figure G.1—Schematic of Liner System Forces and Effective Seal Diameters**

In addition, Figure G.1 illustrates pressure areas above, below, and internal to liner systems. Internal pressure-induced loads will result from pressures acting on packer components between the casing ID and the seal diameter.

Pressure-induced loading effects acting on the liner, identified by the area up to the seal diameter, should be included when calculating the liner-to-hanger forces, indicated as FA in Figure G.1. In other words, these piston areas and pressures affect the net force acting upon a liner system. Sections G.6, G.7, and G.8 provide further details around the relation between net force (FT) and applied force (FA) and how to interpret well loads against a performance envelope.

Typically, pressure-induced forces acting on liner system are from the following pressure acting on respective effective area for each.

- Pressure Above (PA): The pressure acting above the packer element from the casing ID to the TBR/PBR ID.
- Pressure Below (PB): The pressure acting below the packer element from the casing ID to the liner system reference OD.
- Pressure Internal (PI): The pressure acting on the internal ID of the TBR/PBR to the reference ID of the liner system mandrel.

NOTE: The pressure above and pressure internal are same for a non-tied back system.

The results of a validation test by a supplier/manufacture are represented on the performance envelope with the applied differential pressures and net force (FT). This creates an intersection point on the envelope. Multiple test

points are performed per the validation procedures, and these intersection points create the bounds of the performance envelope. The pressure-induced loads within the test may differ from the user/purchaser's application due to various factors, including tie-back seal assemblies, cross-overs, tapered liners, and test fixture seal diameters. These factors, however, do not affect the net force (FT), as long as they are correctly calculated by the supplier/manufacturer when performing the validation test as well as the user/purchaser when performing application casing load analysis.

### G.3 Generating the Performance Envelope

The performance envelope may be based on test data and/or calculated data. The envelopes shall at a minimum include the requirements defined per section 6.7 of this specification.

The performance envelope for the product is established using straight lines between the tested and/or calculated points within each quadrant. **Figure G.2** and **Figure G.3** illustrate the applicable pressure/load combination in the four quadrants of the performance envelope for a Non-Tieback application and Tieback application respectively.

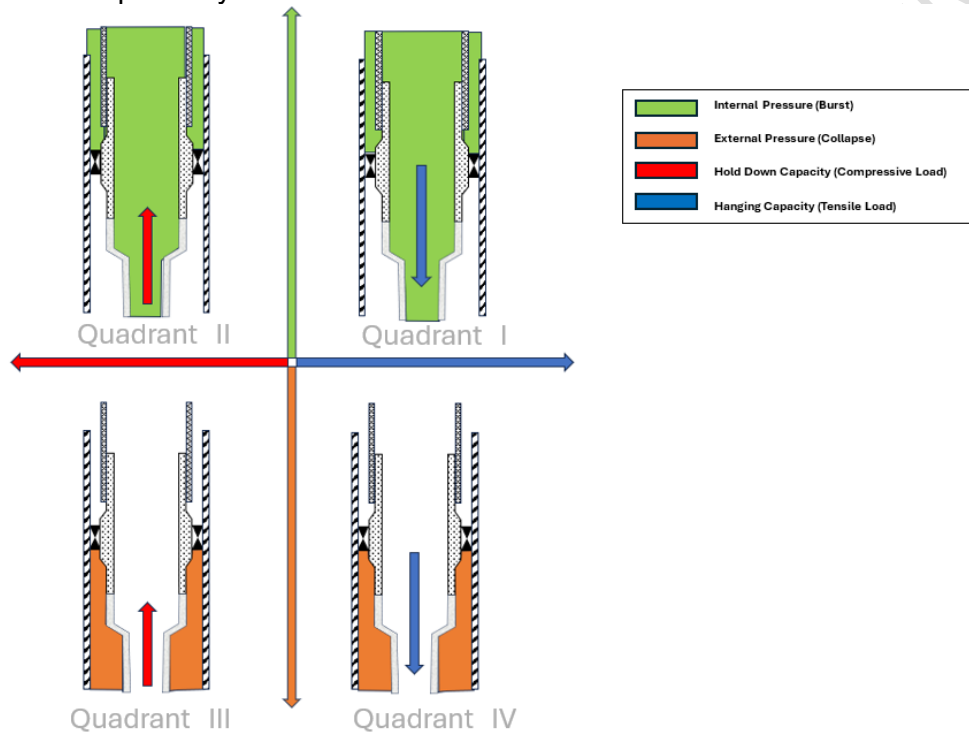
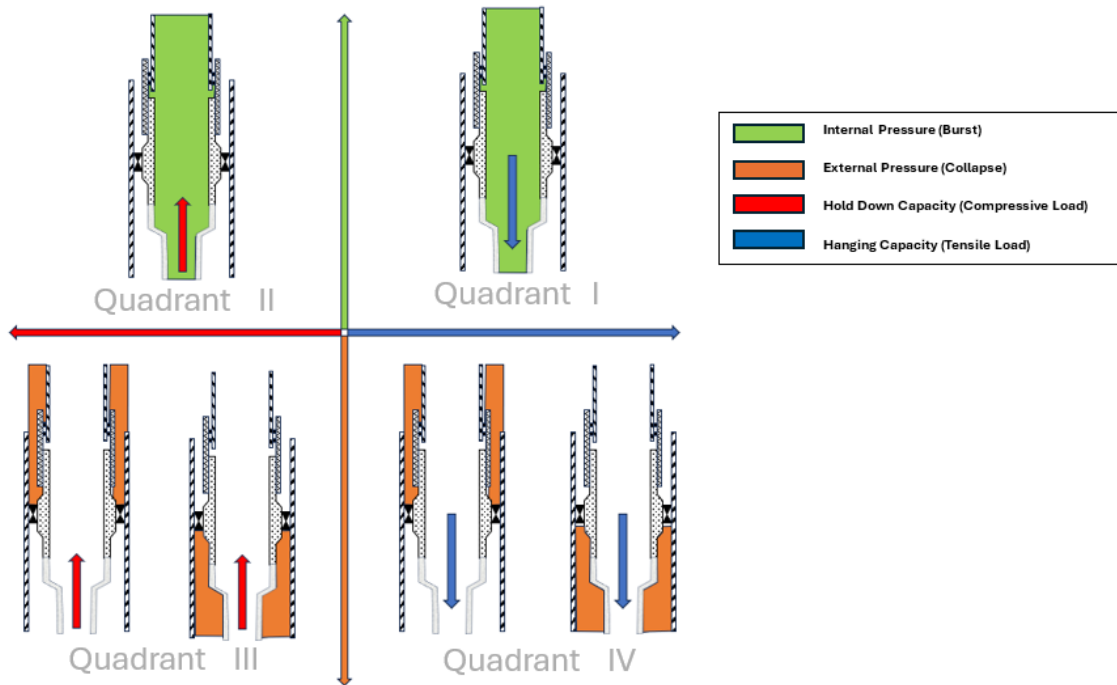


Figure G.2: Applicable pressure and load combinations (Non-Tieback)



**Figure G.3: Applicable pressure and load combinations (Tieback)**

Calculated and scaled ratings shall be differentiated from tested points of envelope data and clearly identified.

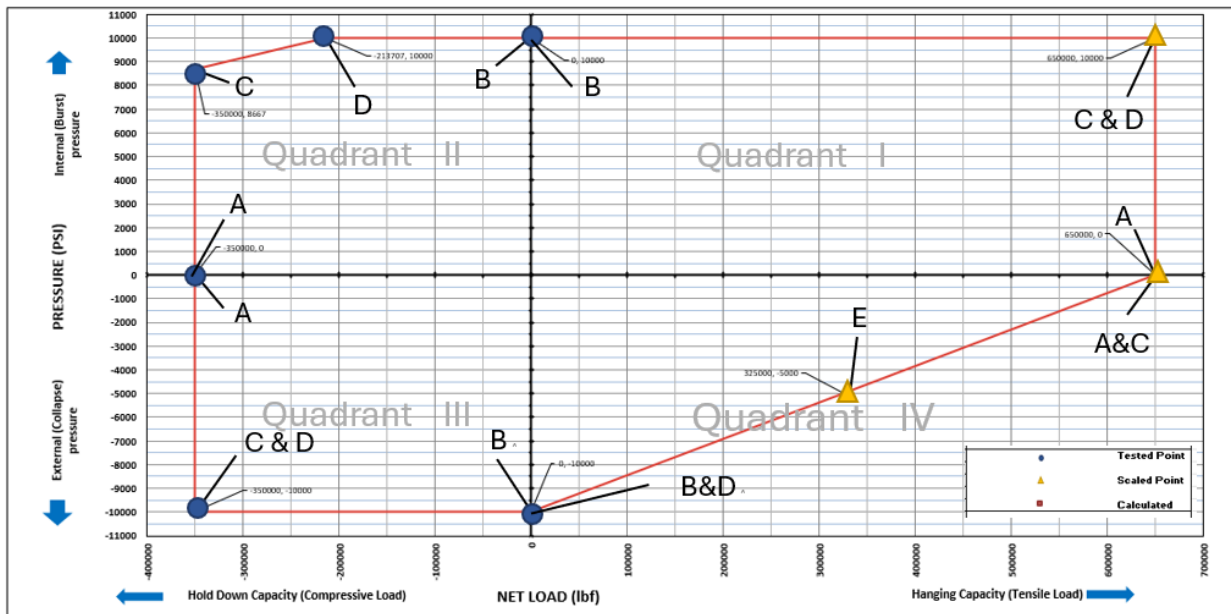
For some products, such as Tieback Seal assemblies, the rated performance envelope may be a straight line. For products with axial load capability in one direction only, the rated performance envelope may not include all four quadrants.

### G.3.1 Performance Envelope Data Points

G.3.1.1 Following are the recommended points to be considered for each quadrant.

- Maximum axial load – maximum allowable axial load (Hanging Capacity or Hold Down Capacity) without any applied pressure as applicable for each quadrant.
- Maximum pressure – maximum allowable pressure (internal, or external) without any applied axial load as applicable for each quadrant.
- Allowable pressure at maximum axial load – allowable pressure in combination with maximum axial load if different from point A as applicable for each quadrant.
- Allowable axial load at maximum pressure – allowable axial load in combination with maximum pressure if different from point B and C as applicable for each quadrant.
- Axial load and pressure combination – minimum of one intersection point with both axial load and pressure greater than zero if not covered by point C and D as applicable for each quadrant.

G.3.1.2 An example performance envelope is illustrated in Figure G.4 below showing examples of points A, B, C, D, and E within each quadrant as applicable. Maximum load and pressure points C and D can be achieved with a single point as illustrated in quadrant I and quadrant III or achieved with different points as shown in quadrant II. For cases where point C and D are the same as point A and B respectively, a point E shall be included to validate the performance boundary of the product between point A and B. This case is illustrated in quadrant IV in Figure G.4.

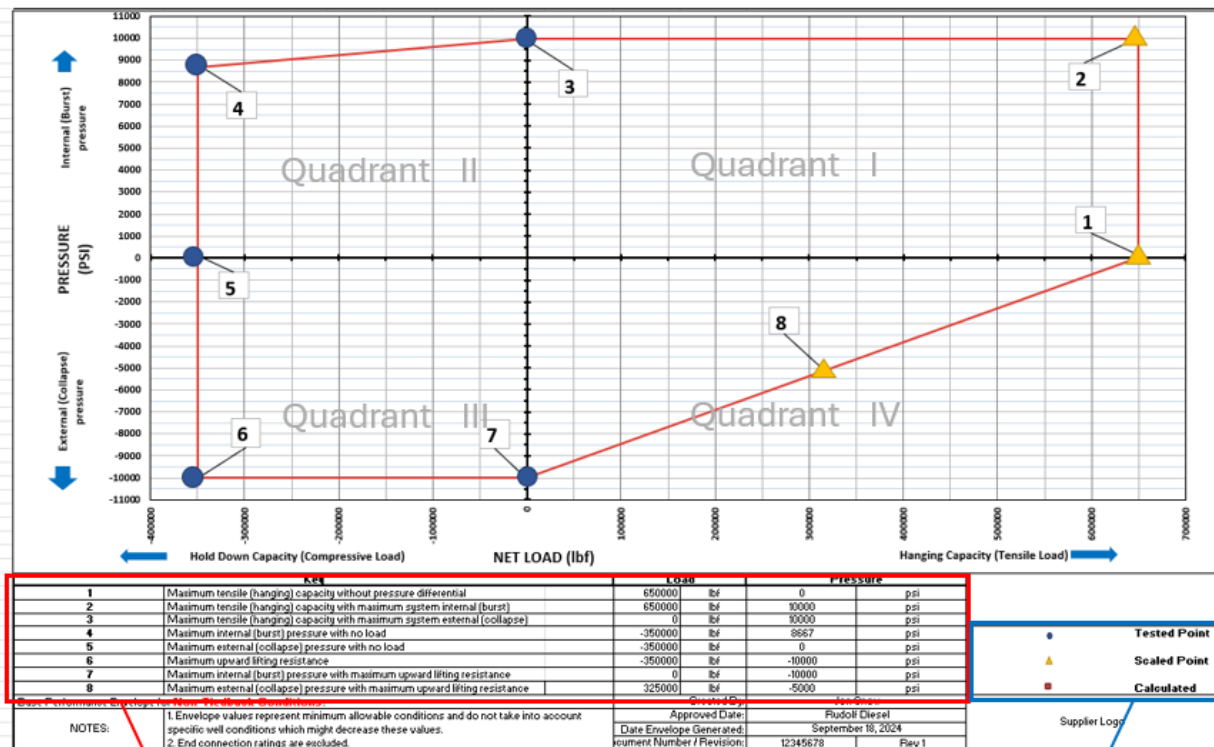


**Figure G.4 - Performance envelope data points**

G.3.1.3 Envelope values represent the maximum allowable conditions and do not consider well conditions. Envelope values shall be established using one of the following methods.

- Tested point – the performance envelope tested points are ratings validated by testing. The tested points are loading conditions that have been validated successfully per requirement of this specification for the applicable product(s).
- Calculated point – when a tested performance envelope point is not available or when using a calculated value is allowed by this specification, the performance envelope point may be calculated to define the operational boundary of the product. Calculated values shall be based on the worst-case material condition using the material properties at the maximum rated temperature.
- Scaled point – the performance envelope scaled points are ratings that are generated from actual test points in accordance with the scaling limitation and requirement of this specification for the applicable product(s).
- System intersection point – the point at which two or more product envelopes overlap when creating a system envelope.

G.3.1.4 The axial load and pressure for performance envelope data points, and the method used to establish the values, shall be provided. The information can be included in the performance envelope using legends and data labels as illustrated in Figure G.4 or in a table format as illustrated in Figure G.5.



Data points values

Legends for method used to establish values

Figure G.5 – Data values and legend for performance envelope points

G.3.2 Performance Envelope Data

A title block shall be included in the performance envelope to provide required information per section 6.7.2 of this specification. An example of title block is illustrated in Figure G.6 with following sections included.

Equipment list – Each product included in the performance envelope shall be listed with the model, part number, body MYS, design validation grade, and validation method for each product.

Connection information – Internal connections and end connections shall be identified on the performance envelope. The internal connection details shall include the validation level and validation method.

System Specifications – System specifications shall be listed and include the product(s) specifications, casing specifications, reference dimensions, operating temperature range, temperature cycle range, and packer differential pressure rating as applicable.

Equipment list

System Specifications

Net Force Liner System Rated Performance Envelope at 350°F							
Equipment	Model	Part Number	Rev.	Body MYS	Validation Level	Tested/ Scaled?	
Liner System:	API 19LH V51 - Liner Hanger Packer Sys	24681012	A1	125 (862.0)	V51	API 19LH Validated	
Upper TBR/PBR:	ALPHA A 7.500 Tie-Back Receptacle	24679821	B2	125 (862.0)	V1	API 19LH Validated by Calculation	
Seal Stem:	BRAVO B Seal Assembly	25123581	A3	125 (862.0)	V1	API 19LH Validated	
Liner Pkr w/ Hold Down:	CHARLIE C Packer w/ Hold Down Slips	21495081	A4	125 (862.0)	V1	API 19LH Validated	
Liner Hanger:	DELTA D Hanger	29481235	C4	125 (862.0)	V1	API 19LH by Scaling	

System Specifications							
Liner OD	7.000 in.	(177.8) mm					
Liner System Weight	32.0 lbf/ft	(47.6) kg/m					
System Maximum OD	8.350 in.	(212.1) mm					
System Minimum ID	6.060 in.	(153.9) mm					
System Drift	6.000 in.	(152.4) mm					
Host Casing OD	9.625 in.	(244.5) mm					
Host Casing Weight Range	47.0 lbf/ft - 53.5 lbf/ft	(69.9) kg/m - (79.6) kg/m					
Host Casing Nom. ID (optional)	8.680 in. - 8.535 in.	(220.5) mm - (216.8) mm					
Host Casing Max. ID	8.822 in. - 8.686 in.	(224.1) mm - (220.5) mm					
Host Casing ID Operating Range	8.500 - 8.822 in.	(215.9 - 224.1) mm					
Tested Casing Material Yield Strength (ksi)	125 ksi	861.8 Mpa					
PBR/TBR ID	7.375 in.	(187.3) mm					
Reference OD (Packer/Mandrel OD)	7.000 in.	(177.8) mm					
Reference ID (Hanger ID)	6.060 in.	(153.9) mm					
System Temperature Cycle Range	200°F	(111°C)					
Operating Temperature Range	150°F - 350°F	(66°C) - (177°C)					
Packer Element Rating Above/Below	10,000 psi/10,000 psi	(69) Mpa/(69) Mpa					

Internal Connection Validation Method							
Location of Thread	Size (in)	Thread Name	Weight	Material MYS	Validation Level	Validation Method	
Packer / Hanger Connection	7 in.	VAM Top HT	32.0 lbf/ft / 47.6 kg/m	125	API 5C5??	??	

Reference Information for End Connection							
Location of Thread	Size (in)	Thread Name	Weight	Material MYS	Validation Level	Validation Method	

Connection details including validation level/method

Figure G.6 - Performance envelope title block

For liner packer, liner hanger, and liner hanger packer products supplied to grades V2, V1, or when requested by the user/purchaser for V3, a performance envelope shall be supplied. The performance envelope shall meet the requirement of section 6.7.2 and include the information as outlined in previous section.

### G.3.3. System Performance Envelopes

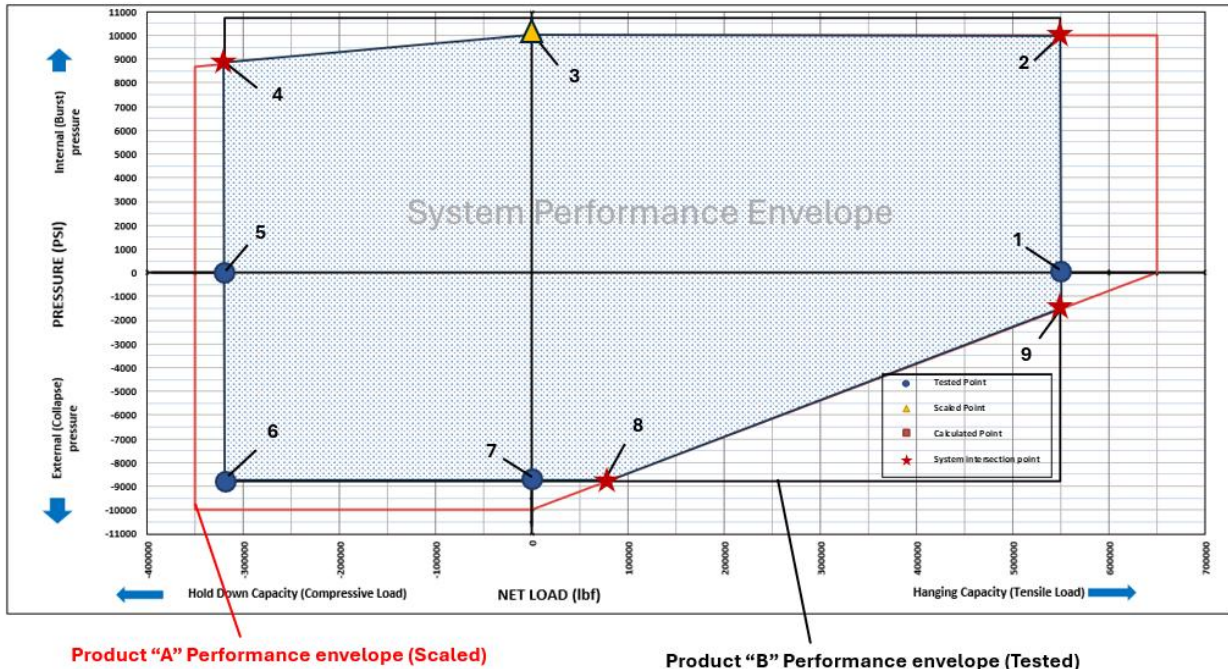
For liner systems, a rated performance envelope shall be supplied for VS2 and VS1 if requested by the user/purchaser. These envelopes shall include graphic illustrations of the combined operational limits from each product included in the liner system and indicate whether the envelope was obtained by testing a complete system or by evaluating and combining various product tests.

For liner system performance envelopes obtained by evaluating and combining various product tests, the boundary lines of the system envelope shall be within the ratings of individual products included in the system. System data points established from the intersection of multiple product envelopes are considered system intersection points. Data points established directly from one of the performance envelopes are considered tested or scaled points as applicable. An example of a liner system performance envelope is illustrated in **Figure G.7** that is generated by combining performance envelopes for scaled product "A" and tested product "B". In this example, data points 2, 4, 8, and 9 are system intersection points established from the intersection of performance envelopes for product "A" and product "B". Data point 3 is a scaled point directly from product "A", and points 1, 5, 6, and 7 are tested points from product "B".

When the liner system performance envelope is based on multiple products tested individually, the Operating Temperature Range for the system shall be within the ratings of each individual product. The system Temperature Cycle Range will be the minimum of all individual products.

#### EXAMPLE:

Product "A" has an operating temperature range from 40°F - 350°F and was tested with the temperature-cycle ranges of 200° F. Product "B" has an operating temperature range of 70°F - 400°F and was tested with the temperature-cycle ranges of 330°F. The liner system that is a combination of product "A" and "B" will have an operating temperature range of 70°F - 350° F and temperature-cycle ranges of 200°F.



**Figure G.7 – Liner System Performance Envelope**

#### G.3.3.1 Performance Envelope for Tied-Back Applications

For products or liner systems designed with a receptacle used for accepting a seal assembly, a performance envelope for tied-back applications shall be provided when requested by the user/purchaser.

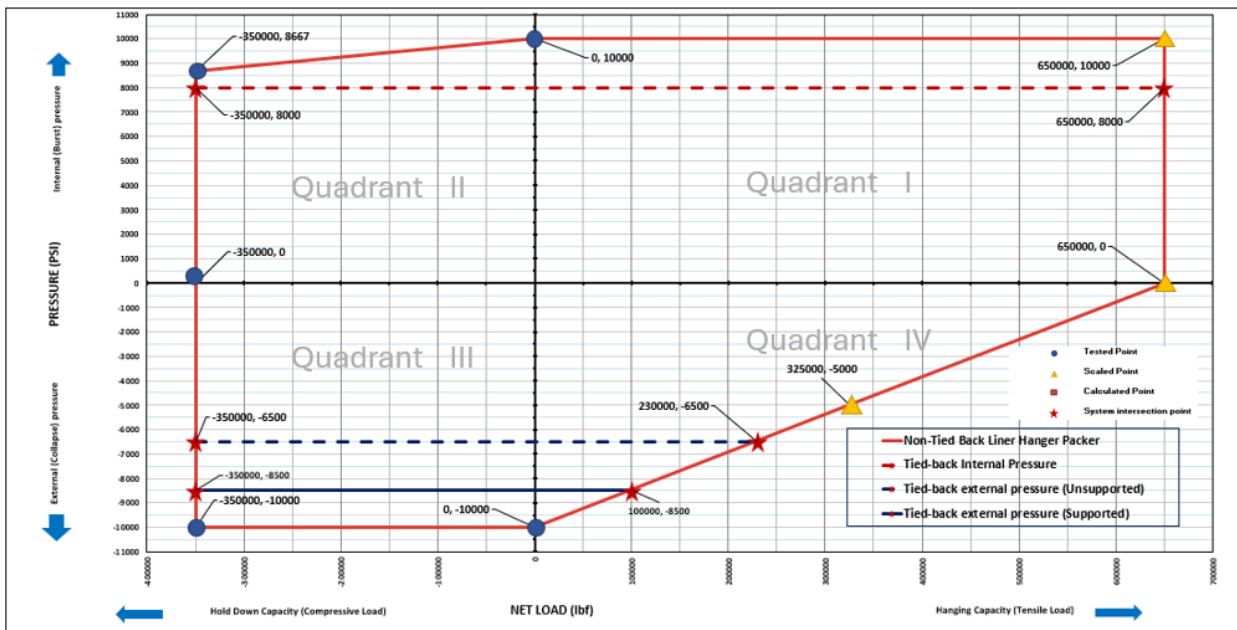
The tieback receptacle may be placed above or below the liner hanger. For a tied back application, the external pressure for the liner system shall be evaluated for two different scenarios as presented in Figure G.3. The hydraulic effect of each application will have different resultant loading on the liner system. The hydraulic forces

shall be considered when evaluating the applied forces (FA) accordingly.

For performance envelope representing the net force (FT), the pressure rating limitations resulting from tieback condition shall be included in the envelope. The pressure limitations shall, as a minimum, consider the following ratings as applicable.

- 1) Internal and external pressure limitation of the tieback receptacle. External pressure limitation for the tieback receptacle shall include both short and long collapse ratings as defined per section 6.6.13.2.
- 2) Pressure rating of the interface seal.
- 3) Pressure and load ratings of the connection between the tieback receptacle and liner system component as applicable. Connections that are pressure containing are considered internal connection per section 3.1.31 and require validation per section 6.6.15.
- 4) Internal and external pressure limitation of the tieback seal assembly.
- 5) Differential pressure rating of the seal unit.

The pressure limitation(s) considered in the performance envelope, and the validation method(s), shall be included in the equipment list. An example of a performance envelope for tied-back application with TBR above the liner top packer is illustrated in **Figure G.8**. In this example, the internal pressure, and the external pressure above the liner top packer, are reduced by the tieback system. The external pressure limitation below the packer element would not be affected by the tieback condition in this example. For the external pressure limitation above packer element, the unsupported length of the TBR shall be considered.



**Figure G.8 – Liner System Performance Envelope with tied-back condition (Upper TBR/PBR)**

### G.3.3.2 Special consideration for Tied-Back Applications

When considering the external pressure limitation for tied-back applications, special attention should be given to differential pressure across the packer elements.

In order to illustrate the tied-back application it can be useful to compare tied-back and non-tied-back applications. In the performance envelope for non-tied-back applications the internal pressure and above pressure are the same. The differential pressure across the liner system is the same as the differential pressure across the element in this application.

For the tied-back applications with upper TBR/PBR, the pressure from above, pressure from below, and the internal pressure are isolated. Under this condition the differential pressure across the packer element may not be the same as the external collapse pressure. The element rating shall be evaluated based on the pressure from above and pressure from below. The burst and collapse ratings for the equipment shall be based on the internal pressure and the applicable external pressure.

Both the differential pressure across the element and pressure rating limitation of the products shall be met.

The following example illustrates a condition where the system differential pressures meet **Figure G.8** envelope but

exceeds the pressure rating of the element assuming that the non-tieback performance envelope is limited by the element ratings:

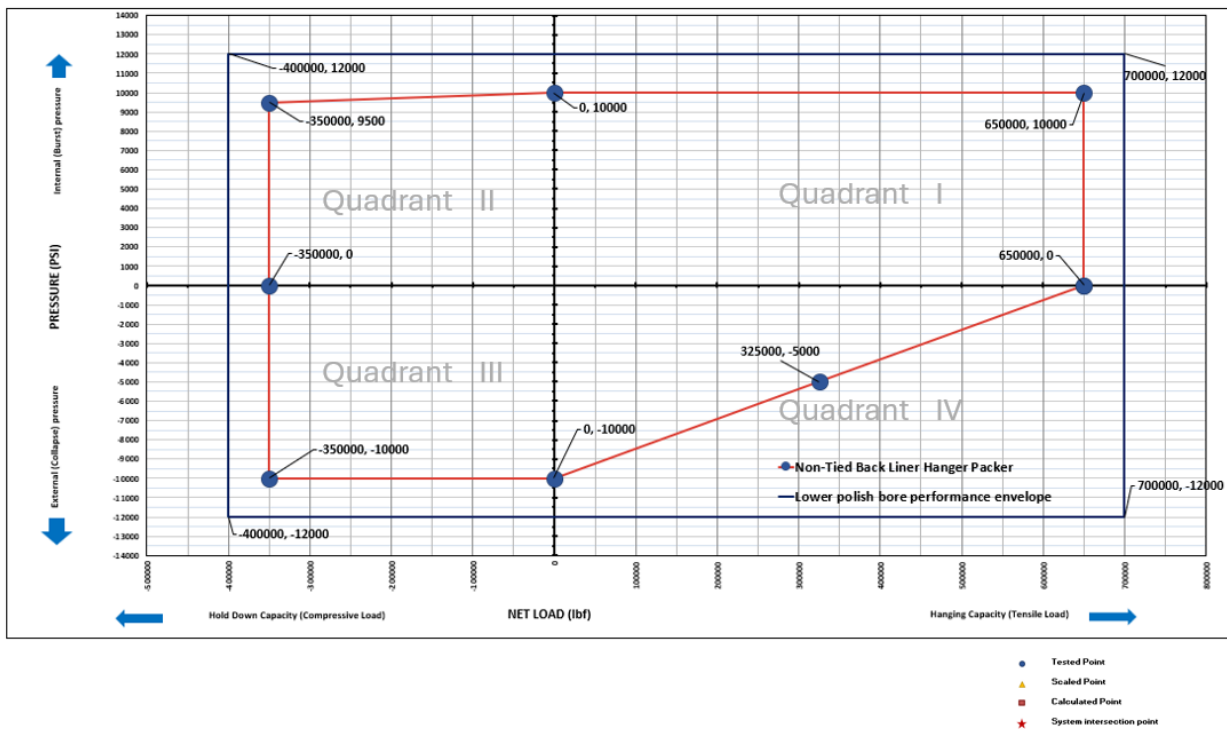
- Pressure from above (PA)                    3000 psi
- Pressure from below (PB)                    14000 psi
- Internal pressure (PI)                        10000 psi

In this example the differential pressure across the element in the tieback application is 11000 psi from below which is higher than the element rating of 10000 psi. While the differential pressure for the liner and tieback products is 4000 psi collapse, and 7000 psi burst respectively and fall within the performance envelope ratings.

For the same system, the following example illustrates a condition where the system differential pressures meet **Figure G.8** envelope if the seal assembly is fully engaged (short collapse) but would fail if the unsupported length of the TBR does not meet the requirement of section 6.6.13.2 for fully engaged seal assembly (long collapse):

- Pressure from above (PA)                    12000 psi
- Pressure from below (PB)                    4000 psi
- Internal pressure (PI)                        5000 psi

In this example the differential pressure for the liner and packer element is 1000 psi burst, and 8000 psi from above element respectively and fall within the performance envelope ratings. The differential pressure for the TBR is 7000 psi collapse which is less than the 8500 psi rating for supported TBR but exceeds the 6500 psi external pressure rating for unsupported TBR. The system will therefore meet the requirement if the seal assembly is fully engaged (short collapse) as defined per section 6.6.13.2 but fails if the unsupported TBR length does not meet this requirement.



**Figure G.9 – Liner System Performance Envelope with tied-back condition (Lower PBR)**

For the tied-back applications with lower polished bore receptacle (PBR), the pressure from above and the internal pressure remain the same for the liner hanger packer. Under this condition, the liner hanger packer will be subject to the same burst and collapse as non-tied-backed condition based on the pressure from above and pressure below the element. The packer element would see the same differential pressure as the liner hanger packer system.

The tieback seal assembly is subject to pressure from above and the internal pressure. The external pressure for the lower polish bore receptacle (PBR) is the same as pressure from below the element but the internal pressure would be different above and below the tieback seal unit. Both conditions need to be evaluated based on pressure ratings. When using a lower polish bore receptacle, the tensile load and compressive load ratings of the polish bore receptacle shall be included in the performance envelope.

The following example illustrates a condition where the system differential pressures meet **Figure G.9** envelope but

exceeds the pressure rating of the seal unit for the tieback seal assembly assuming that the tieback seal assembly pressure ratings are the limitations:

- Pressure from above (PA) 2500 psi
- Pressure from below (PB) 10000 psi
- Internal pressure (PI) 15000 psi

In this example the differential pressure across the element in the tieback application is 7500 psi from below which is lower than the element rating of 10000 psi. While the differential pressure across the tieback seal assembly is 12500 psi which is higher than the 12000 psi rating. The liner hanger packer would be subject to 7500 psi collapse. The polish bore receptacle (PBR) will be subject to 7500 psi collapse and 5000 psi burst on the sections above and below the tieback seal respectively.

#### **G.4 Common Liner Hanger System Loading Effects**

As explained in G.2, the net force (FT) represents the total force transmitted by the liner system to the host casing. This section intends to further explain liner hanger applications and how various down-hole scenarios can create forces on the liner system.

When temperatures and/or pressures change in a wellbore, conditions are created that will cause the liner string to change its length. The liner will either shorten or elongate. If the liner string is constrained (e.g. anchored at both ends), forces are generated on both the hanger and the liner shoe because the end of the liner is prevented from moving freely. While this specification does not intend to cover down-hole load modeling, this section is presented to improve understanding of liner hanger system loads.

There are various effects that create these length changes. These effects are combined to achieve the total effect for the hanger loading. Effects creating these length changes may include:

- a) initial installation state (hanging weight of liner, loads from tie-back strings, )
- b) piston effect (including buoyancy);
- c) buckling effect,
- d) ballooning effect,
- e) temperature effect.

These effects combine to load the liner system, and this total force is called the liner-to-hanger force. The liner-to-hanger force is also referred to as the applied force, which is defined as the axial forces transferred to a liner system from the liner below and/or tieback string. The applied force is represented as FA in **Figure G.1**.

The components of the liner-to-hanger forces can be calculated either by hand or by using tubing movement simulation software or programs. In either case, it is important to ensure that how and where the liner and/or tieback string interacts with the hanger is correctly identified.

#### **G.5 Typical Liner-to-hanger Interaction Types**

The calculation of the liner-to-hanger load will depend on the type of liner-to-hanger interaction (load path) being considered.

The connection type defines if, and how, liner movement may be restricted. If liner movement is restricted, tubing movement programs convert the movement into loads at each end of the liner system as applicable. As illustrated in **Figure G.10**, for the purpose of tubing movement analysis, liner-to-hanger connections can be categorized as follows:

- a) Non-Tieback cemented liner system which permits no liner lengthening or shortening. The liner system is threaded directly to the liner. Liner movement is fully constrained and all resulting forces from tubing movement are transferred to the liner system. Cemented liner system with floating Tieback, which permits no liner length change but allows limited tieback lengthening or shortening. The tieback is terminated using a seal assembly that mates with seal surface within the liner system. Limited tieback movement is accommodated between an upper and lower constraint.
- b) Cemented liner system with tieback anchored to liner system, which permit no liner or tieback lengthening or shortening. The tieback is terminated using a seal assembly that mates with seal surface within the liner

system and anchored to the liner system. Liner and Tieback movement is fully constrained and all resulting forces from tubing movement are transferred to the liner system.

- c) Cemented liner system with tieback anchored to host casing, which permit no liner or tieback lengthening or shortening. The tieback is terminated using a seal assembly that mates with seal surface within the liner system and anchored to the casing. Liner and Tieback movement is fully constrained and only the resulting forces from liner are transferred to the liner system. The resulting forces from tieback are transferred to the tieback to casing anchoring system and is not included in the liner system evaluation.

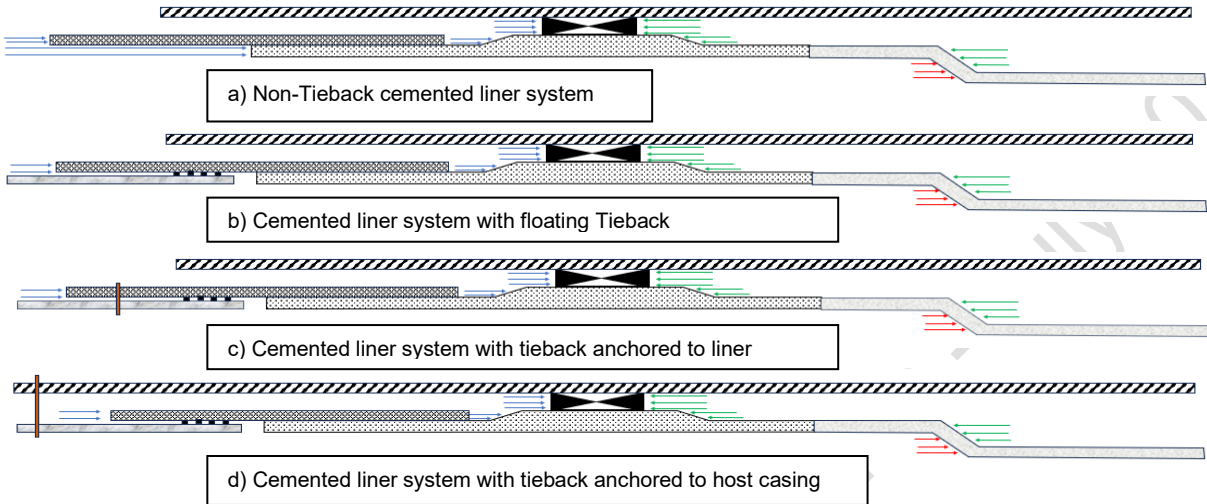


Figure G.10—Typical Liner-to-hanger Interaction Types

## G.6 Performance Envelope Types

Liner system performance envelopes have historically been created in two primary methods; with or without the internal hydraulic forces included. This section summarizes the two approaches. Supplier/manufactures shall specify the type of performance envelope provided. Following are the two types of performance envelope used for liner hanger systems:

- a) **Net Force (FT) Performance Envelope** – A graphical illustration of the forces and pressures, that may be applied to the liner system that represents safe loading conditions at maximum rated temperature. The forces plotted on the net force system performance envelope are the total forces on a liner hanger system that is transferred through the liner hanger system to the host casing (liner system-to-casing force), inclusive of the applied load plus additional pressure-induced piston effects. The envelope shall consider the effects of hydraulics that are applied to the liner system, and the resulting stress/strain effects on the type I components. See Ft in **Figure G.1**.
- b) **Applied Force (FA) Performance Envelope** – A graphical illustration of the forces and pressures, that may be applied to the liner system that represents safe loading conditions at maximum rated temperature. The forces plotted on the applied force envelope are the axial forces transferred to a liner system (liner -to- liner system forces) from the liner below and/or tieback string above. The rated performance envelope for the hanger system will account for all internal forces acting on the hanger system, whereas the tubing movement calculations should account for all forces acting on the liner. See FA in **Figure G.1**.

The standard format for this specification is Net Force performance envelope.

## G.7 Conversion from Net Force Envelope to Applied Force Envelope

Performance envelopes for liner systems may alternatively be presented in terms of applied force. The applied force (FA) performance envelope is a graphical illustration of the forces and pressures, that may be applied to the liner system that represents safe loading conditions at maximum rated temperature. The applied force (FA) performance envelope for the hanger system will account for all internal forces (including pressure induced forces) acting on the hanger system. The forces plotted on the applied force envelope are the axial forces transferred to a liner system (liner -to- liner system forces) from the liner below and/or tieback string above. See FA in **Figure G.1**.

Induced hydraulic forces acting on the liner hanger system result from changes in pressure applied to liner system. Each pressure effect will have a magnitude and direction. Once each pressure is known, the hydraulic forces are calculated using the effective area for each pressure defined in section G.2.

- Effective Area for Pressure Above ( $PA_{EA}$ ): The area prescribed from the nominal host casing ID to the TBR/PBR sealing diameter.

$$PA_{EA} = \frac{\pi}{4} * (Casing ID^2 - TBR ID^2) \quad (G.1)$$

- Effective Area for Internal Pressure ( $PI_{EA}$ ): The area prescribed from the TBR/PBR sealing diameter to the Reference ID of the liner hanger system.

$$PI_{EA} = \frac{\pi}{4} * (TBR ID^2 - Hanger ID^2) \quad (G.2)$$

- Effective Area for Pressure Below ( $PB_{EA}$ ): The area prescribed from the nominal host casing ID to the Reference OD.

$$PB_{EA} = \frac{\pi}{4} * (Casing ID^2 - Reference OD^2) \quad (G.3)$$

The net force ( $FT$ ) performance envelope of a product or system may be converted into an applied force ( $FA$ ) performance envelope by adding or subtracting the induced hydraulic forces at each intersection point of the performance envelope as applicable.

$$FA = FT - (PA_{EA} * PA) - (PI_{EA} * PI) + (PB_{EA} * PB) \quad (G.4)$$

Note: The pressures in the equation above are absolute values as shown in **Figure G.1**. The pressure above and pressure internal are same for a non-tied back system.

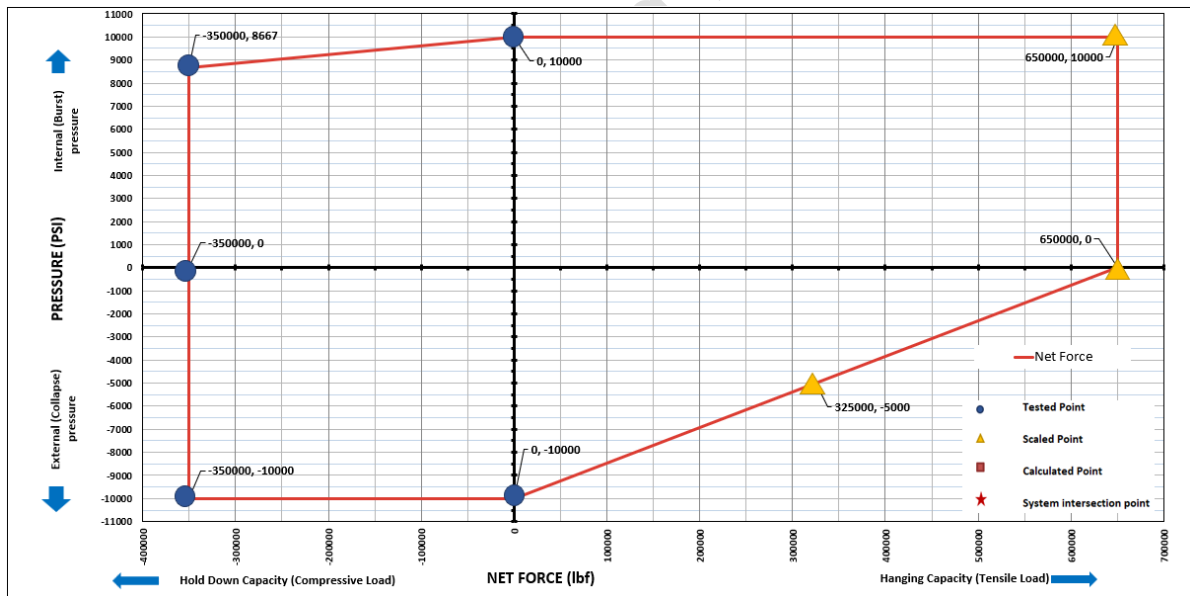
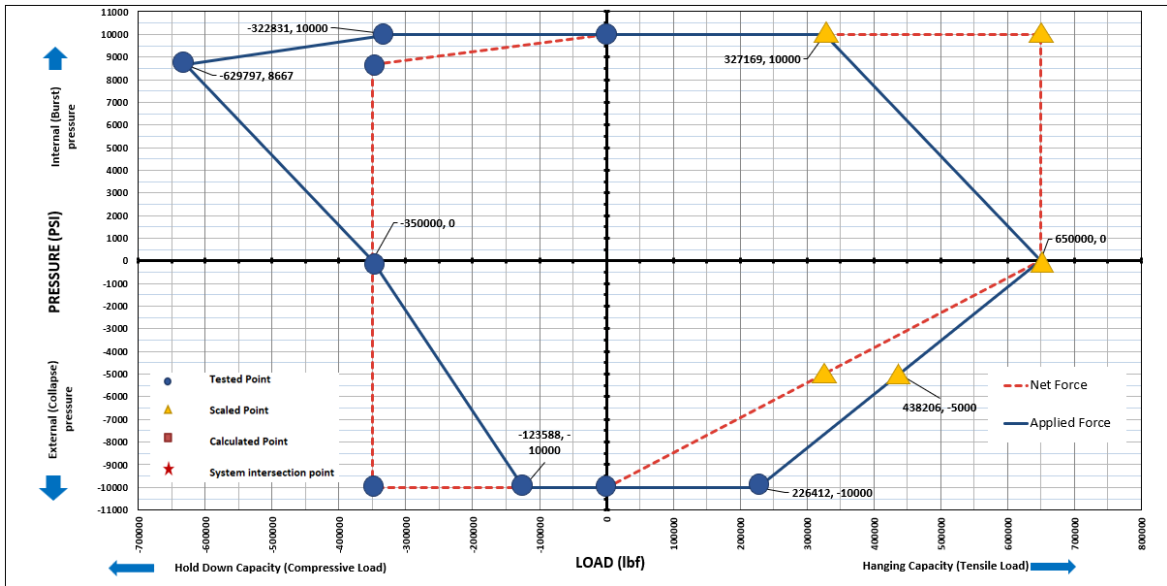
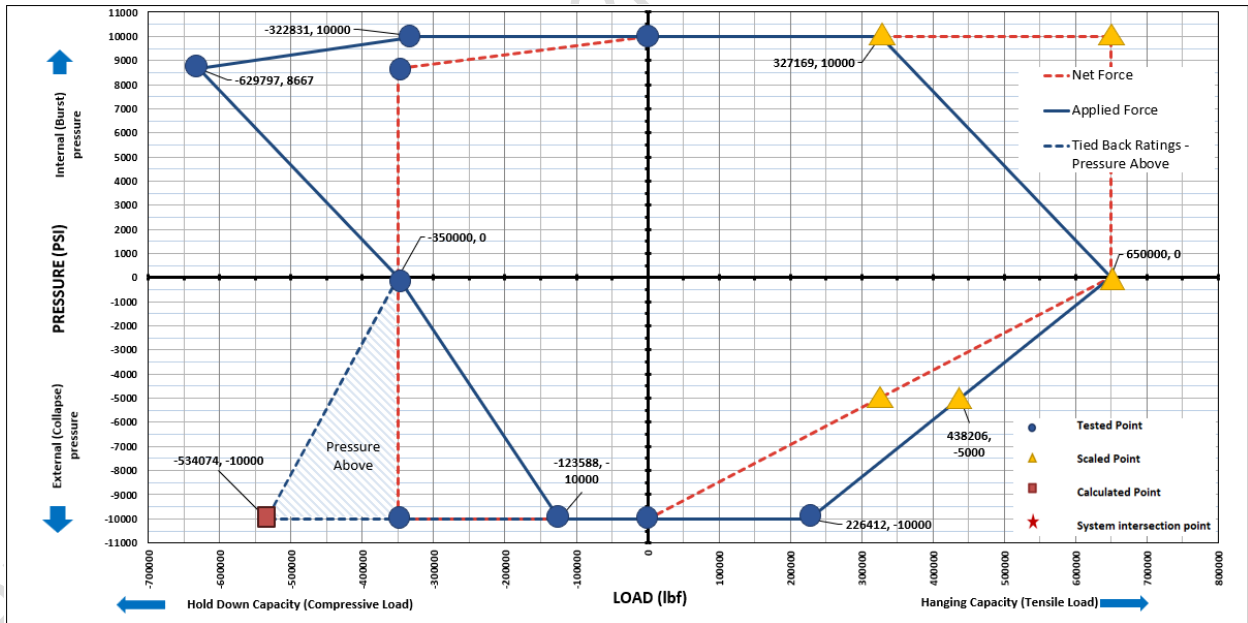


Figure G.11 – Liner System Net Force (FT) Performance Envelope



**Figure G.12 – Liner System Applied Force (FA) Hybrid Performance Envelope**

When using Applied Force (FA) performance envelopes, note that in the Tied Back conditions, the envelope is different if external pressure is applied above or below the packer element. The example in **Figure I G.13** assumes that external pressure is applied below the packer element only and internal pressure and pressure above are equal. The extended section in Quadrant III, shows the shape of the applied force performance envelope in case external pressure is applied above the packer element. For simplicity, in the example in **Figure G.13**, the TBR internal and external pressure ratings exceed those of the liner hanger and packer.



**Figure G.13 – Liner System Applied Force (FA) Tied Back Performance Envelope**

## G.8 Performance Envelope Application Guide

This section illustrates how predicted forces from a given liner hanger application can be evaluated against the performance limits from an envelope.

Assume a liner hanger system, that is subject to the following applied forces and pressures:

**Table 20 – Sample Load Cases for Non-Tied Back application**

Load Case	Applied Force (FA)	Internal Pressure (PI)	Pressure Below (PB)
	lbf	psi	psi
A	-80,000	11,000	11,000
B	-200,000	6,000	12,500
C	-250,000	2,000	11,000

Using the formulae provided below and the areas described in Section G.7, the Net Force and the Differential Pressures on the liner hanger system are calculated:

- Net Force acting on the Liner Hanger System (FT),

$$FT = FA + (PA_{EA} * PA) + (PI_{EA} * PI) - (PB_{EA} * PB) \quad (G.5)$$

Since PA = PI for Non-Tied Back applications,

$$FT = FA + (PA_{EA} + PI_{EA}) * PI - (PB_{EA} * PB) \quad (G.6)$$

- Differential Pressure Below the Element (DPB): The differential pressure acting on the liner hanger system below the packer Element.

$$DPB = PI - PB \quad (G.7)$$

- Differential Pressure Above the Element (DPA): The differential pressure acting on the liner hanger system above the packer Element. In case of Non-Tied Back applications, this pressure differential is zero, as PA = PI.

$$DPA = PI - PA \quad (G.8)$$

- Differential Pressure across the Element (DPE): The differential pressure acting across the Liner Packer Element.

$$DPE = PA - PB \quad (G.9)$$

Since PA=PI, the DPE is also equal to DPB for Non-Tied Back applications.

Note: The pressures in the equation above are absolute values as shown in Figure G.1. The pressure above and pressure internal are same for a non-tied back system.

A positive DPB or DPA implies burst pressure, while a negative value implies a collapse pressure, in line with the envelope annotations. A positive DPE implies differential pressure above the element, while a negative value implies differential pressure below the packer element.

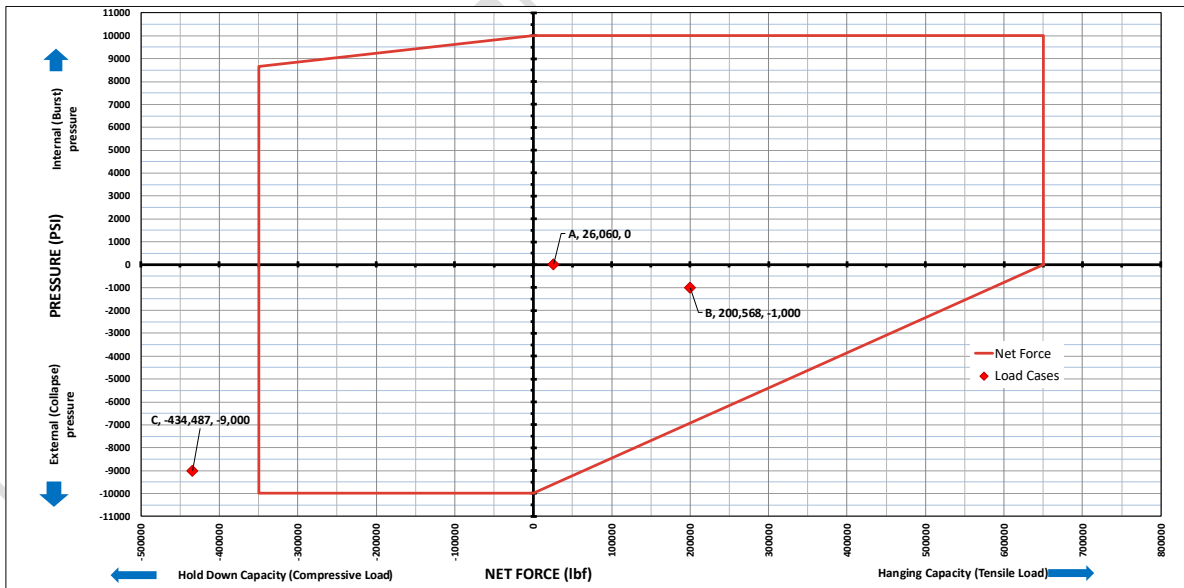
The table below shows the Net Force and the differential pressure calculated for the sample load cases:

**Table 21 – Calculated Net Force (FT) and Differential Pressure for Non-Tied Back application**

Load Case	Net Force (FT) lbf	Diff. Pressure DPB / DPE psi
A	26,060	0
B	200,568	-1,000
C	-434,487	-9,000

The differential pressures are checked against the Packer Element Rating (Above / Below) in the title block of the Performance Envelope, to ensure that the rated element differential pressure is not exceeded. The Load Cases are then plotted on the envelope, as shown in Figure G.14, to ensure that they do not exceed the combined loading limits of the liner hanger system. In this example, Load Case C is outside the performance limit of the liner hanger system.

<b>Packer Element Rating Above/Below</b>	10,000 psi/10,000 psi
--	-----------------------



**Figure G.14 – Sample load cases plotted on a Non-Tied Back Net Force Performance Envelope**

Assume a liner hanger system, as discussed in the example in a Tied Back scenario, that is subject to the following applied forces and pressures:

**Table 22 – Sample Load Cases for Tied Back application**

Load Case	Applied Force (FA)	Internal Pressure (PI)	Pressure Above (PA)	Pressure Below (PB)
	lbf	psi	psi	psi
A	-240,000	6,000	14,000	13,000
B	150,000	6,000	6,000	7,000
C	-130,000	2,000	12,000	7,000
D	150,000	12,000	3,000	6,000

In order to plot on a 19LH envelope, the applied force must be converted to net force. In addition, the pressures are converted from absolute pressures to differential pressures. Using the formulae provided discussed in the previous example, the Net Force and the differential pressures are calculated, as shown in the table below:

**Table 23 – Calculated Net Force (FT) and Differential Pressure for Non-Tied Back application**

Load Case	Net Force (FT)	Diff. Pressure Above DPA	Diff. Pressure Below DPB	Diff. Pressure Element DPE
	lbf	psi	psi	psi
A	-193,378	-8,000	-7,000	1,000
B	185,210	0	-1,000	-1,000
C	-39,848	-10,000	-5,000	5,000
D	235,883	9,000	6,000	-3,000

The differential pressures across the packer element are checked against the Packer Element Rating (Above / Below) in the title block of the Performance Envelope, to ensure that the rated element differential pressure is not exceeded. In all the above load cases, the differential pressure DPE across the packer element is not exceeded.

<b>Packer Element Rating Above/Below</b>	10,000 psi/10,000 psi
--	-----------------------

The Load Cases are then plotted on the envelope, as shown in **Figure G.15**, to ensure that they do not exceed the combined loading limits of the liner hanger system. Note that each load case results in two different points to be plotted, one corresponding to the net force (FT) and the differential pressure above (DPA) and the second corresponding to the same net force (FT) and the differential pressure below (DPB). The load cases with the differential pressure below are compared against the non-tied back performance limits and those with the differential

pressure above are compared against the tied back performance limits. In this example, although, at first glance all the load cases are within the Non-Tied Back envelope of the liner hanger system, Load Cases C and D for Pressure Above are outside of the Tied-Back External and Internal pressure limits respectively.

**Table XX...**

<b>Load Cases – Pressure Above</b>	<b>Net Force (FT)</b> lbf	<b>Diff. Pressure Above DPA</b> psi
A	-193,378	-8,000
B	185,210	0
C	-39,848	-10,000
D	235,883	9,000

<b>Load Case – Pressure Below</b>	<b>Net Force (FT)</b> lbf	<b>Diff. Pressure Below DPB</b> psi
A	-193,378	-7,000
B	185,210	-1,000
C	-39,848	-5,000
D	235,883	6,000

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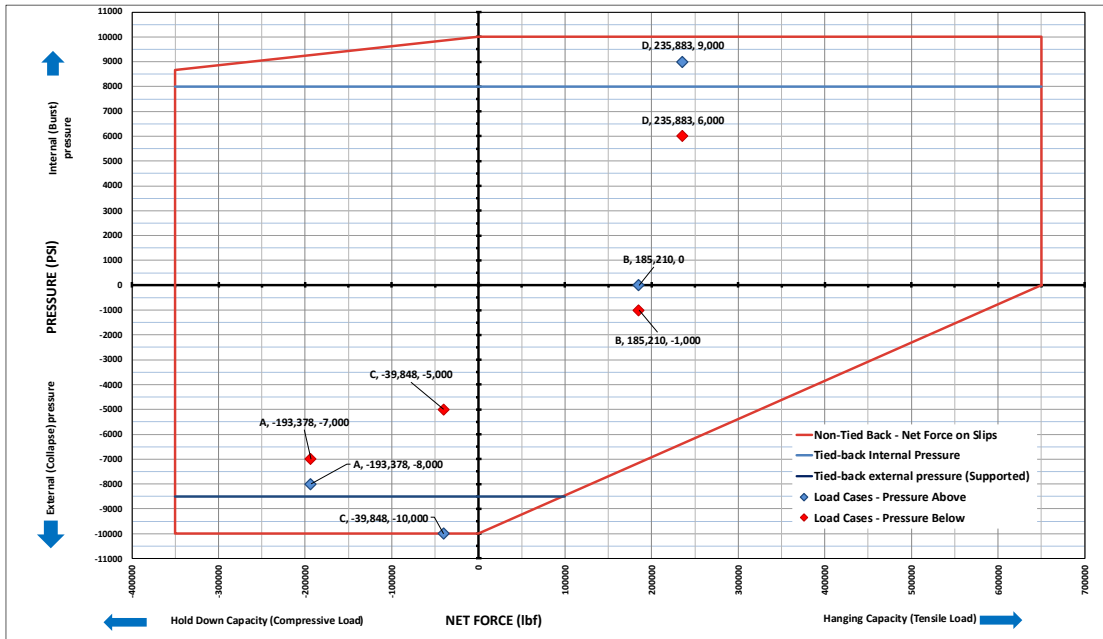


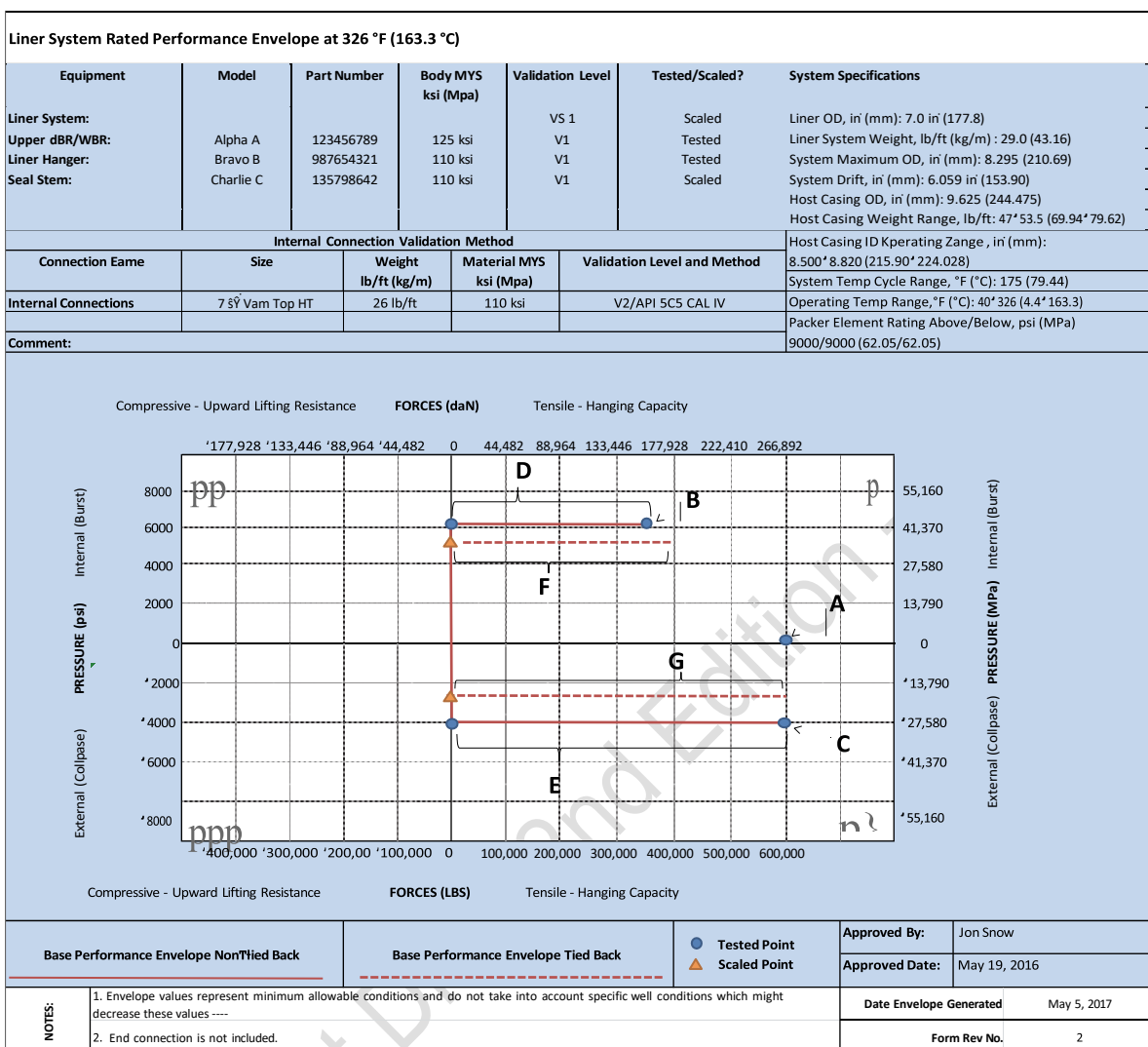
Figure G.15 – Sample load cases plotted on a Net Force Performance Envelope with Tied Back Limits

### G.9 Example of Performance Envelope for Seal Assembly—TBR/PBR—Liner Hanger for Non-tied Back and Tied Back Conditions

The example, shown in Figure G.16, depicts the following pressure and loading conditions as shown on the performance envelope.

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**Key**

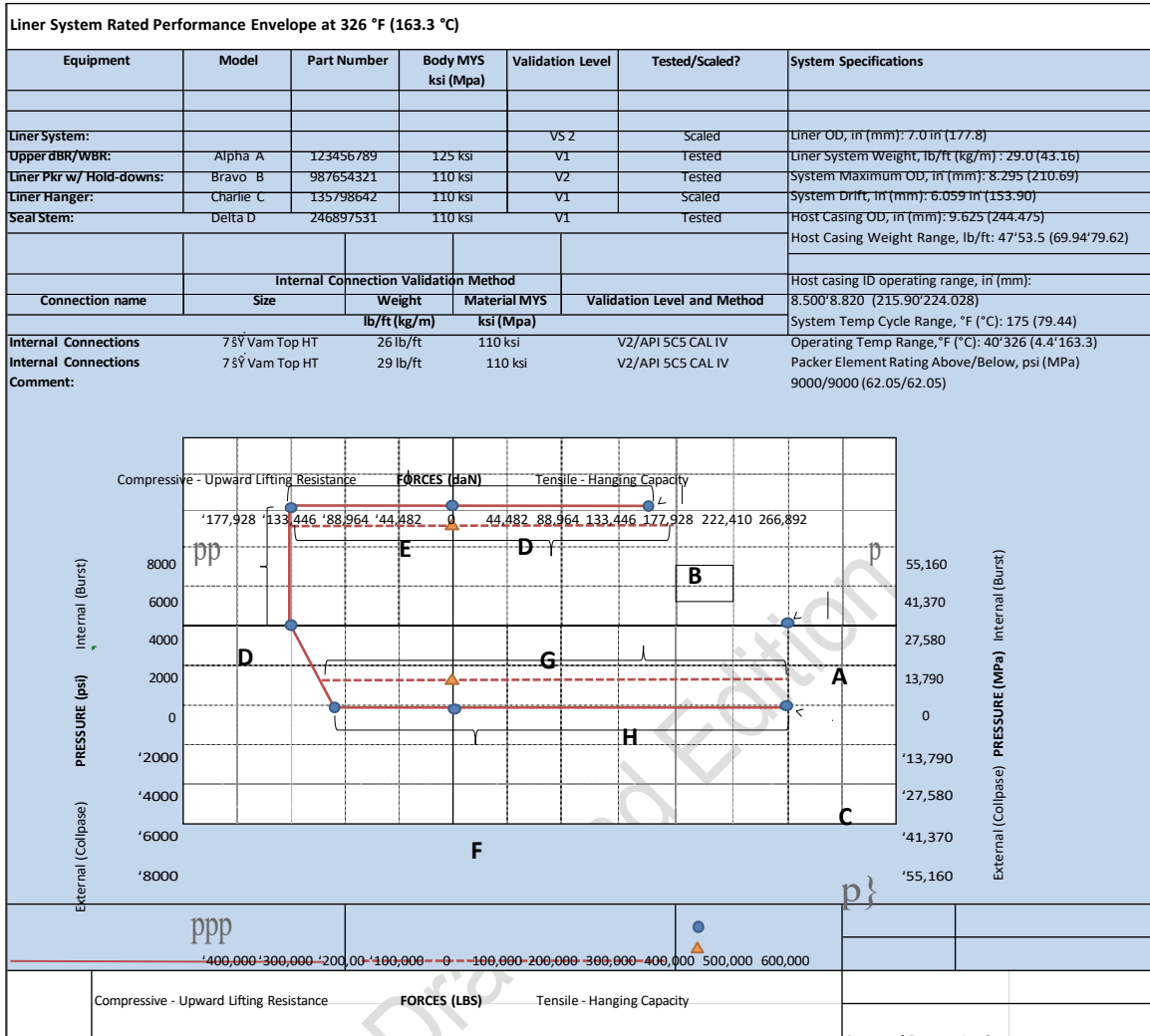
- A Maximum tensile (hanging) capacity without pressure differential
- B Maximum tensile (hanging) capacity with maximum system internal (burst) pressure
- C Maximum tensile (hanging) capacity with maximum system external (collapse) pressure
- D Maximum internal (burst) pressure with no load
- E Maximum external (collapse) pressure with no load
- F Maximum internal pressure with no load in tie back condition G
- G Maximum external pressure with no load in tie back condition I
- Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

**Figure G.16—System Performance Envelope Example—Illustrating Tied Back and Non-tied Back Conditions**

**G.10 TBR/PBR—Liner Packer with Hold-downs—Liner Hanger, Non-tied Back, and Tied Back conditions**

The example in Figure G.17 depicts the following pressure and loading conditions as shown on the performance envelope.

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Base Performance Envelope NonTied Back

Base Performance Envelope Tied Back

Tested Point

Approved By: Jon Snow

Scaled Point

Approved Date: May 19, 2016

NOTES:

- Envelope values represent minimum allowable conditions and do not take into account specific well conditions which might decrease these values ----
- End connection is not included.

Date Envelope Generated 4/15/2017

Form Rev No. 2

### Key

- A Maximum tensile (hanging) capacity without pressure differential
- B Maximum tensile (hanging) capacity with maximum system internal (burst) pressure
- C Maximum tensile (hanging) capacity with maximum system external (collapse) pressure
- D Maximum upward lifting resistance of the system
- E Maximum internal pressure rating in non-tied back condition
- F Maximum external pressure rating in non-tied back condition
- G Maximum internal pressure rating in tied back condition
- H Maximum external pressure rating in tied back condition
- I Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

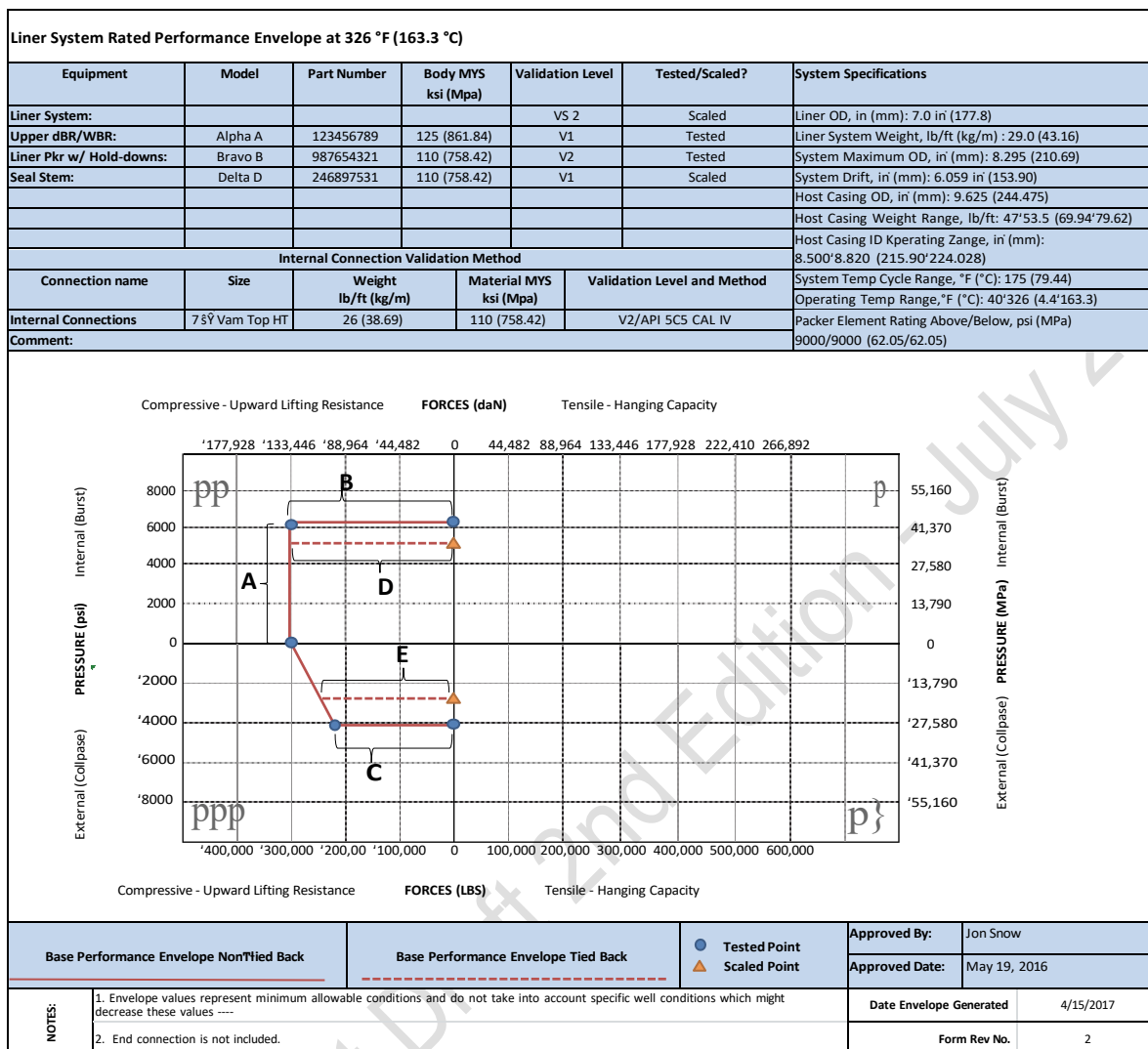
**Figure G.17—System Performance Envelope Example—Illustrating Liner Packer with Hold-downs in Tied Back and Non-tied Back Conditions**

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### **G.11 TBR/PBR—Packer—Seal Assembly**

The example in Figure G.18 depicts the following pressure and loading conditions as shown on the performance envelope.

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**Key**

- A Maximum upward lifting resistance of the system
- B Maximum internal pressure rating in non-tied back condition
- C Maximum external pressure rating in non-tied back condition
- D Maximum internal pressure rating in tied back condition
- E Maximum external pressure rating in tied back condition
- I Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

**Figure G.18—System Performance Envelope Example—Illustrating Packer—Seal Assembly in Tied Back and Non-tied Back Conditions**

## Annex H (normative)

### Sampling Plans

#### H.1 General

When sampling is permitted, the requirements of this section shall apply, including the alternatives.

#### H.2 Sampling Requirement

Table H.1 shall be used in selecting the samples to be inspected. When sampling is permitted in the quality grade table the requirements of this section apply except where alternatives are defined.

If the lot size is smaller than the sample size, then all the items in the inspection lot shall be inspected.

Each sample that is inspected shall meet the supplier/matrix-defined inspection criteria.

Table H.1—Inspection Sample Sizes

Inspection Lot Size	Required Sample Size
1—5	2
6—10	3
11—25	4
26—50	7
51—150	11
151—280	13
281—500	16
501—1200	19

NOTE Larger lots shall conform to ASQC H1331 (Fifth Edition) with an index of 2.5.

#### H.3 Randomness

Each sample shall be selected at random from the inspection lot. Randomness is achieved when each unit within the lot has an equal chance of being selected as the sample(s) to be inspected.

#### H.4 Inspection Limits

An inspection lot is defined as those units that consist of a single type, grade, class, size, and composition, manufactured under essentially the same conditions at the same time and presented for inspection at the same time.

NOTE Failure to select the sample pieces randomly may introduce incorrect sampling results.

The identification of a single nonconforming unit rejects the entire lot. The units within a rejected lot shall be dispositioned according to the applicable QMS. In every case, all units from a rejected lot shall be re-evaluated before use.

## H.5 Alternative Methods

Alternately, other national or international sampling standards may be used, provided that the acceptance number (c) is zero and the average outgoing quality limit (AOQL) is the same or better than the values in ASQC H1331 for an index value of 2.5. The requirements of H.1 through H.5 also apply.

NOTE When using other sampling plans such as ANSI/ASQ Z1.4 or ISO 2859-1, particular attention is to be paid to the notes associated with the tables, as these can change the sample size for a given lot.

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## **Annex J**

### **(informative)**

#### **Low Temperature Setting and Pressure Seal Validation**

##### **J.1 General**

The minimum setting temperature of liner packers and liner hanger packers may be higher than the minimum operation temperature of the product established through validation in 6.6. This annex was developed to validate setting force and performance of liner top packers and hanger packer products when setting at low temperature. This annex is recommended as a supplement to standard validation per section 6.6 and may be specified by the user/purchaser. Testing as specified by this annex does not establish a standalone validation grade or change any temperature ratings of the product.

The requirements specified in this annex are in addition to sections 1 through 9 of this specification.

Activities required by this annex shall be performed by a qualified person. All results shall conform to the acceptance criteria and be supported by approved documentation.

Claiming a minimum operating temperature below the temperature validated in accordance with this Annex or section 6.6 is not permitted.

##### **J.2 Functional Requirements**

The user/purchaser may specify the addition of low temperature setting validation per this annex in the functional requirements.

##### **J.3 Technical Specification**

###### **J.3.1 Design Requirements**

###### **J.3.1.1 Materials**

Material requirements shall follow section 6.5. Additional evaluation and selection requirements for use in low temperature environments shall be in accordance with the supplier / manufacturer's documented procedures and additional requirements if specified by the user/purchaser.

###### **J.3.2 Design Verification Requirements**

Design verification shall be performed in accordance with section 6.4 and shall include evaluation and analysis of setting equipment at low temperature per the supplier/manufacturer's documented requirements and procedures and per additional requirements if specified by the user/purchaser. Any component validation that is planned in place of a full product test shall have a verification to justify that the component test simulates the load and test conditions that would be present if the entire assembly were present and tested and shall be approved by a qualified person.

###### **J.3.3 Design Validation**

Design validation shall meet the requirements of 6.6.1 through 6.6.5, and 6.6.10 for liner top packers or 6.6.11 for liner hanger packers in addition to requirements of this annex. Acceptance criteria used to validate products according to this annex shall match the original validation acceptance criteria. For example, a packer or hanger packer that was validated to a V1 product validation grade would follow the V1 Annex J acceptance criteria for low temperature setting validation per this annex.

Liner top packers and liner hanger packers may be tested as a full product or by validation testing only the affected component(s) rather than the entire product. All ratings affected by a change in setting force or by temperature as determined by the supplier / manufacturer shall be tested. The supplier/manufacturer shall document the validation test procedure and results and shall have on file material specifications and drawings that show all the applicable material properties, dimensions and tolerances of parts contained in the validation test. Pre-test and post-test dimensional inspection of critical operational areas and components, as determined by the supplier/manufacturer, shall be conducted, documented, and maintained by the supplier/manufacturer. Validation test results and dimensional inspection results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation. Results requiring higher setting force, a lower differential pressure capability, or lower axial ratings shall be clearly stated in the design documentation.

###### **J.3.3.1 Design Validation Grades**

Validation per this annex does not establish a standalone validation grade. For products validated according to this

annex, the validation grade remains as established from 6.6, and an additional reference to indicate validation per this annex is an option to the supplier / manufacturer. Reference call outs should include the original validation grade, a reference to this annex, and the minimum setting temperature validated during testing. Some examples may include “V1 Annex J (70F)” or “V1J 70F” to indicate that the previously validated V1 equipment had successfully set and passed the zero-bubble gas testing acceptance criteria of this annex when set at 70F. “V2 Annex J (50F)” or “V2J 50F” would indicate that the previously validated V2 equipment had successfully met the acceptance criteria of this annex with less than a 1% drop in differential over the hold period when setting at 50F.

### J.3.3.2 Design Validation Scaling

Scaling for design validation performed according to this annex shall follow the requirements specified in 6.6.7 and are subject to requirements and limitations specified in 6.6.10.5 for liner packers or 6.6.11.5 for liner hanger packers. Scaling to a lower minimum operating or setting temperature than what is tested and validated by this annex is not permitted.

### J.3.3.3 Test Fixtures

Test fixtures may be as defined in sections 6.6.10 and 6.6.11 and use the same material specifications and dimensional tolerances and limits as the V1 or V2 product validation.

For component validation, the test shall simulate the load and test conditions that would be present if the entire assembly were present and tested. Test fixture material specifications for component validation shall be the same as those used in the original V1 or V2 testing. Dimensions shall match the test fixture dimensions and tolerancing from the original V1 or V2 validation except for dimensions required to accommodate the component test assembly provided the conditions simulate the loading and test conditions of the full product as determined and documented in the design verification and approved by a qualified person.

### J.3.3.4 Test Procedure

The supplier/manufacturer shall adhere to the following test parameters and criteria for conformance to this annex, which are listed in Table J.1.

Repair or redress of the equipment being tested requires validation testing to restart at the beginning. A different setting force, differential capability, and/or axial load result from what was validated in the existing V1 or V2 validation shall be clearly reported.

If the same setting force or less from the previous V1 or V2 validation is utilized to set the equipment, the entire test as specified in Table J.1 may be performed at the minimum setting temperature for the entire test, skipping steps 6 through 9. A different differential capability and/or axial load result from what was validated in the existing V1 or V2 validation shall be clearly reported.

**Table J.1—Liner Packer Validation Test Procedure V1J and V2J**

Step	Procedure and Acceptance Criteria	Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Part number Serial number Test fixture description, material yields, hardness and support, if present
2	Conduct pre-test inspection according to supplier/manufacturer's procedures.	Dimensional inspection results
3	The packer or liner hanger packer shall be set using procedures, methods and tools identified in referenced supplier/manufacturer procedures. Set at the planned minimum setting temperature or less. Set with the minimum rated setting force or pressure ( $\pm 10\%$ ) or as specified by the supplier/manufacturer requirements. Record the test medium surrounding the packer while setting.	Procedure identification Temperature at set Force/pressure applied to set Test medium
4	Maintain the temperature at the minimum setting temperature or lower during Step 5.	Temperature during test
	Apply pressure. Pressure testing to begin with the maximum rated differential pressure applied to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.	Temperature during test Pressure during test Measured pressure loss for V2 Annex J Observation of bubbles for

5	<p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure, then continue to next step.</p> <p>Acceptance criteria for V2 Annex J: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1 Annex J: Zero bubbles of nitrogen observed over the hold period.</p>	V1 Annex J
6	<p>Raise temperature by at least half of the product temperature cycle range established by previous V1 or V2 validation testing. Tolerance on the temperature shall be maintained at the desired target temperature or higher.</p> <p>Perform a pressure test from a direction where the setting load into the packer element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Acceptance criteria for V2 Annex J: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1 Annex J: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Temperature during test</p> <p>Pressure during test</p> <p>Measured pressure loss for V2 Annex J</p> <p>Observation of bubbles for V1 Annex J</p>
7	<p>Apply the maximum rated differential pressure to the opposite end of the packer element. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure, then continue to next step.</p> <p>Acceptance criteria for V2 Annex J: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1 Annex J: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Temperature during test</p> <p>Pressure during test</p> <p>Measured pressure loss for V2 Annex J</p> <p>Observation of bubbles for V1 Annex J</p>
8	<p>Apply the maximum rated pressure to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/ manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure then continue to the next step.</p> <p>Acceptance criteria for V2 Annex J: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1 Annex J: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Temperature during test</p> <p>Pressuring during test</p> <p>Measured pressure loss for V2 Annex J</p> <p>Observation of bubbles for V1 Annex J</p>

9	<p>Test to all the <u>envelope</u> intersection points of the rated performance envelope, one point minimum per quadrant as applicable. The Hold Down Capacity (upward lifting resistance) or hanging capacity, without applied pressure, shall be tested as envelope points, as applicable.</p> <p><u>Note: An intersection with the y axis is not an envelope intersection point unless the envelope line changes slope at the axis. Intersection points on an axis do not satisfy the requirement to include one point per quadrant.</u></p> <p>Hold applied pressure or combinations of load and pressure for 15 minutes minimum. Stabilize load, pressure, and temperature in accordance with supplier/manufacturer requirements. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Applied load and pressure may be relieved before continuing to the next test point.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.</p>	<p>Applied load during test (if applicable)</p> <p>Measured pressure loss for V2 Annex J</p> <p>Observation of bubbles for V1 Annex J</p>
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	Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.	
10	Reduce temperature to a minimum of the setting temperature or lower. Perform a pressure test at or above the maximum rated pressure from a direction where the setting load into the element is least boosted or enhanced by the test pressure while maintaining the temperature at or below the setting temperature. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements. Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report. Acceptance criteria for V2 Annex J: No more than 1 % reduction in the maximum rated differential pressure over the hold period. Acceptance criteria for V1 Annex J: Zero bubbles of nitrogen observed over the hold period.	Temperature during test Pressure during test Measured pressure loss for V2 Annex J Observation of bubbles for V1 Annex J
11	Conduct post-test inspection according to supplier/manufacturer's procedures, and prepare test report according to 6.6.5. The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.	Dimensional inspection results Drift results Evidence of malfunction(s) or anomalies Test report

#### J.4 Product Data Sheets

Validation per this annex may be included on the product data sheet and is an option left to the supplier / manufacturer unless requested by the user / purchaser.

#### J.5 Running Tool / Setting Tool Requirements

For Running tools / setting tools required to operate liner system products at low temperature, verification and validation shall follow requirements as specified in Annex E with the additional considerations required for operation in lower temperature applications.

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