

Interval Control Valves (ICV)

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Introduction

This specification has been developed by users/purchasers and suppliers/manufacturers of interval control valves (ICV) and related equipment as defined herein and is intended for use in the petroleum and natural gas industry worldwide to give requirements and information to both parties in the selection, manufacture, testing and use. Further, this specification addresses the minimum requirements with which the supplier/manufacturer is to conform so as to claim conformity with this specification.

This specification covers the best practices and establishes a clear framework to define performance characteristics and validation methods. For the purposes of this document an ICV is a component of an advanced well completion that is remotely actuated multiple times to control fluid flow through the ICV in both production and injection directions. The ICV uses actuation means such as hydraulic, electric, wireless technologies or combinations thereof without use of mechanical intervention.

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 levels: 1) quality level QL3 is the minimum level of quality offered by this product specification; 2) quality level QL2 provides additional inspection and verification steps; and 3) quality level QL1 is the highest level provided. Additional quality requirements can be specified by the user/purchaser as supplemental requirements.

There are three design validation grades, which provide the user/purchaser with a choice of requirements to meet their preference or application. Design validation grade V3 is the minimum grade and V1 is the most stringent grade provided.

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

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

This specification was initiated using *Recommended Practice for Interval Control Valves 3362* provided by the Advanced Well Equipment Standards group.

Interval Control Valves (ICV)

1 Scope

This specification provides the requirements for downhole interval control valves (ICV) as they are defined herein for use in the petroleum and natural gas industries. Included are the minimum requirements for a functional specification, design verification, design validation of performance ratings, manufacturing, functional evaluations, shipping, handling, and storage. Also included are requirements for downhole control modules which are necessary for the defined operations of the ICV.

ICVs conforming to this specification are not designated as well safety devices.

This specification does not include any additional requirements for high-pressure high-temperature (HPHT) environments with a pressure rating greater than 103.4 MPa (15,000 psi) or with a temperature rating greater than 177 °C (350 °F).

This specification does not cover validation testing with gas medium.

This specification does not cover applications, installation, operation, and maintenance. Control systems components for the ICV which are designated for positions above the tubing hanger are not included.

Also not included are products covered under other API specifications and the following products: remotely operated gas lift valves, inflow control devices (ICD) and autonomous ICDs, through tubing mechanically operated sliding sleeves, valves designed to function a single time, well-condition-activated valves or well test tools. Also not included are secondary tools, control conduits including the connections, and reservoir monitoring devices not critical to the operation of the ICV. End connections of the ICV to the well conduit are not included.

2 Normative References

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

API Manual of Petroleum Measurement Standards, Chapter 10.4: *Determination of Sediment and Water in Crude Oil by the Centrifuge Method (Field Procedure)*

API Specification 14L, *Lock Mandrels and Landing Nipples*

API Specification 5CRA, *Specification for Corrosion Resistant Alloy Seamless Tubes for Use as Casing, Tubing and Coupling Stock*

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

ASME, Boiler and Pressure Vessel Code (BPVC), Section VIII: *Rules for Construction of Pressure Vessels*

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

ASNT SNT-TC-1A, *Recommended practice for personnel qualification and certification in nondestructive testing*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

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 Methods for Rockwell Hardness of Plastics and Electrical Insulating Materials*

ASTM D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*

ASTM D1414, *Standard Test Methods for Rubber O-Rings*

ASTM D1415, *Standard Test Method for Rubber Property—International Hardness*

ASTM D1708, *Standard Test Method for Tensile Properties of Plastics by Use of Microtensile Specimens*

ASTM D2240, *Standard Test Method for Rubber Property—Durometer Hardness*

ASTM D2990, *Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*

ASTM E165, *Standard Test Method for Liquid Penetrant Examination*

ASQ H1331, *5th Edition, Zero Acceptance Number Sampling Plans*

ISO 2859-1, *Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 3601-1, *Fluid power systems — O-rings — Part 1: Inside diameters, cross-sections, tolerances and designation codes*

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

ISO 6506 (all parts), *Metallic materials — Brinell hardness test*

ISO 6508 (all parts), *Metallic materials — Rockwell hardness test*

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

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

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this specification, the following terms and definitions apply.

3.1.1

absolute pressure

The highest pressure that ICV is exposed to during its use; which may include combination of hydrostatic, reservoir and applied pressures.

3.1.2

actuation parameter

A specific value of pressure, voltage, current or another parameter that is required to move the ICV from one position to another.

3.1.3**actuator**

Portion of the assembly that provides the mechanical force to move the ICV from one position to another.

3.1.4**ambient temperature**

Prevailing surface temperature at site.

3.1.5**annulus-to-tubing ICV**

ICV that controls flow from annulus of the well to tubing (commonly used examples in the industry are non-shrouded producer ICVs).

3.1.6**applications**

Details of how the ICV is being used.

3.1.7**assembly**

A product comprised of more than one component.

3.1.8**casing**

Pipe extending from the surface and intended to line the walls of a drilled well.

3.1.9**chamber**

An enclosed volume area within the tool. This may be a hydraulic chamber connected to surface, an electrical chamber sealed at atmospheric pressure, a compensation system, or another functional chamber.

3.1.10**choke**

A component or set of components designed to restrict the flow of fluids.

3.1.11**choke position**

The position of the ICV choke. An ICV with choking capability will have multiple choke positions ranging from closed to fully open position. The ICV choke can be commanded to different choke positions from surface.

3.1.12**choke seal**

Unloading seal when ICV cycles from closed to open position and prevents annulus-to-tubing, tubing-to-annulus or tubing-to-tubing fluid passage.

3.1.13**choke setting**

The flow area through the ICV choke at each choke position expressed as a percentage of the cross-sectional flow area of the ICV.

3.1.14**city water**

Water that is provided by the local water utility system, without visible solids, and is unprocessed thereafter.

3.1.15**common hardware**

Non-traceable nuts, bolts, washers, screws, and spacers.

3.1.16**control conduit**

Components connecting downhole ICV to surface control mechanism that enables communication and/or power transfer.

NOTE This could be electrical, hydraulic, or other, and is commonly embodied as a metallic tube.

3.1.17**control system**

Assembly of devices necessary to provide the designated operations of a downhole ICV device.

3.1.18**deflector**

A deflector is a feature that may be part of the ICV that protects the casing adjacent to the ICV from injection erosion damage.

3.1.19**design margin**

Ratio of the material yield stress divided by the design stress in a given component at the rated conditions.

NOTE Design margins account for a level of reduced performance capability to compensate for uncertainties in the potential loading (applied stress) and the intrinsic variations in the mechanical properties such as yield strength, ultimate strength, endurance strength, and modulus of elasticity that have distribution about their mean value.

3.1.20**design validation**

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

3.1.21**design verification**

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

3.1.22**downhole control module**

A permanently installed downhole device that controls the actuation of the ICV and can be added or removed from the ICV without losing basic functionality of the ICV as defined in 3.1.39.

3.1.23**drift diameter**

ID of an ICV, expressed as the OD of the passed drift bar.

3.1.24**dynamic seal**

A seal or seal system in which there is motion between a hardware component and the sealing element. The motion can be, but is not limited to linear, rotary, intermittent contact, or a combination of more than one type of motion.

3.1.25**environment**

Set of conditions to which a product is exposed during its use.

3.1.26**flow geometry**

Geometric features of the ICV that impact its flow performance or characteristics exclusive of choke flow area and ICV size.

3.1.27**flow-wetted component**

Component that comes in direct contact with the movement of well fluids in the flow stream.

3.1.28**function**

Designed operation of a product during service.

3.1.29**functional specification**

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

3.1.30**functional test**

Test processes performed to confirm proper operation of ICV products.

3.1.31**Job Lot**

Batch of material or components that have undergone the same process or series of processes a single, discrete grouping.

3.1.32**heat**

Material originating from a final melt, or for re-melt alloys, the raw material originating from a single re-melt ingot.

3.1.33**heat treat lot**

A group (lot) of pieces of material that have undergone the same process or series of processes in a single heat treatment furnace load or continuous furnace run and are uniquely identified.

3.1.34**heat treatment**

Alternate steps of controlled heating and cooling of materials for the purpose of changing mechanical properties or microstructural condition.

3.1.35**ICV system**

Devices necessary to operate an ICV.

3.1.36**inflow control device****ICD**

A downhole device designed to control the volumetric flow rate of fluids from or to the reservoir based upon an induced pressure drop, without intervention from surface.

3.1.37**installation**

Activities required to position the ICV into its operational location.

3.1.38**internally wetted component**

Flow-wetted component and any component out of the flow stream but contacted by well fluids through a port or other passage to the flow-wetted area.

3.1.39**interval control valve****ICV**

Remotely controlled downhole valve which is permanently installed in a wellbore and is adjustable without physical intervention to regulate fluid flow from and to the formation.

NOTE The term regulate may include choking of the flow or on-off functions. Downhole control modules are not included in ICV.

3.1.40**life cycle**

Expected period of time or specified number of actuations that the product shall function according to the manufacturer's specifications.

3.1.41**manufacturing**

Processes and actions performed by an equipment supplier/manufacturer that are necessary to provide finished component(s), assembly(ies) and related documentation, that fulfill the requests of the user/purchaser and meet the standards of the supplier/manufacturer.

NOTE Manufacturing begins when the supplier/manufacturer receives the order and is completed at the moment the component(s), assembly(ies) and related documentation are surrendered to a transportation provider.

3.1.42**maximum rated temperature**

The maximum temperature the ICV is validated with operational cycling and unloading.

3.1.43**mechanically operated sliding sleeve**

A downhole tubing mounted device that is moved by physical intervention to open or close a flow controlling sleeve.

3.1.44**minimum rated temperature**

The minimum temperature the ICV is validated with operational cycling and unloading.

3.1.45**model**

ICV products with unique components and operating characteristics that differentiate it from other product designs of the similar type.

3.1.46**non-sandy service**

Downhole flowing conditions in production wells where sand is not expected to be produced.

3.1.47**operational compressive load**

Compressive load with conditions defined by the supplier/manufacturer.

3.1.48**operational tensile load**

Tensile load with conditions defined by the supplier/manufacturer.

3.1.49**operating cycle**

One operating cycle is defined as actuating the ICV from starting position, including intermediate positions, if any, and returning to the starting position.

3.1.50**operating dog-leg rating**

Maximum change in trajectory over a defined length that the ICV will operate within, expressed in degrees per 100ft for the minimum rated casing or open hole ID (e.g. Three degrees/100ft in 8.525in. drift ID).

3.1.51**operating manual
operator's manual**

Publication issued by the manufacturer, which contains detailed data and instructions related to the design, installation, operation, and maintenance of the ICV.

3.1.52**post-production**

Indicating the point in time when production/injection has begun.

3.1.53**pre-production/injection**

Indicating the point in time prior to injection or production.

3.1.54**product family**

A group of products of similar geometry, materials, and functionality.

3.1.55**profile**

Feature that is designed for the reception of a locking or shifting mechanism.

3.1.56**qualified person**

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

3.1.57**rated pressure**

Maximum ICV pressure limit as defined by the supplier/manufacturer for external, internal and actuator pressure limits.

3.1.58**redress**

Activities involving the replacement of non-metallic qualified components, and common hardware.

3.1.59**repair**

Activities beyond the scope of redress that may include disassembly, reassembly, and testing with or without the replacement of qualified components and may include machining, welding, heat treating, or other manufacturing operations that restore the equipment to its original performance.

3.1.60**reservoir monitoring device**

Downhole equipment that is designed to monitor reservoir parameters.

3.1.61**run in hole dog-leg rating
RIH dog-leg rating**

Maximum change in trajectory over a defined length that the ICV will drift through, expressed in degrees per 100ft for the minimum rated casing or open hole ID (e.g. Three degrees/100ft in 8.525in. drift ID).

3.1.62**sandy service**

Downhole flowing conditions in production wells where sand is expected to be produced.

3.1.63**sealing element**

Device preventing passage (i.e. communication) of liquid and/or gas across the interface in which it is placed and provide pressure barrier.

3.1.64**secondary function**

Secondary functions may include mechanical override, isolation, plugging, or backup means to operate the ICV. This may allow full redundant functionality, or a minimal set of operational functions.

3.1.65**secondary tool**

Tools and other equipment used with ICVs to perform a secondary function(s) including contingency operations or provide another intended design function.

3.1.66**size**

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

3.1.67**special feature**

Specific additional functional capability including but not limited to position sensing, integrated reservoir monitoring.

3.1.68**stabilization**

The process and time by which the test parameters come to a steady state prior to performing a test period.

3.1.69**storage**

Pre-installation ICV retention requirements.

3.1.70**stress relieving**

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

3.1.71**subassembly**

An assembly of components designated as a unit to become incorporated within a validated product.

3.1.72**substantive change**

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

3.1.73**temperature range**

Specified minimum and maximum rated temperatures (as defined in 3.1.42 and 3.1.44) at which the ICV is validated.

3.1.74**thermal cycle range**

Specified amount of temperature change within the product's temperature range over which the product is designed to operate.

NOTE The thermal cycle range is applicable anywhere within the product's temperature range (see [Annex F](#)).

3.1.75**tubing-to-annulus ICV**

ICV design that controls flow from tubing to the annulus of the well (commonly used examples in the industry are non-shrouded injector ICVs).

3.1.76**tubing-to-tubing ICV**

A valve design that controls and chokes flow from one tubing area to another (commonly used examples in the industry are shrouded ICV, inline ICV, ball valves used as ICV).

3.1.77**type**

ICV product with unique characteristics that differentiate it from other ICV equipment.

3.1.78**Type 1 component****Type 1 weld**

Metallic component or weld that isolates pressure and/or may be loaded in tension as the result of axial loads.

3.1.79**Type 2 component****Type 2 weld**

Metallic component or weld that does not meet the criteria of Type 1 or weld.

3.1.80**unloading differential pressure**

The pressure acting across the closed flow port of the ICV at the time of opening.

3.1.81**valve coefficient**

C_v

The relation coefficient (constant) that relates the flow rate through the choke at different pressure drop and liquid specific density for each choke position. The valve coefficient has units (usgpm/psi^{0.5}).

3.1.82**water depth**

Measured depth of the water above a subsea installation of an ICV.

3.1.83**well-condition-activated valve**

Downhole valve that is not activated by intervention or intentional action(s).

EXAMPLE Chemical—or temperature-activation methods.

3.2 Abbreviations

BPD	barrels per day
COC	certificate of conformity
FEA	finite element analysis

HPU	hydraulic power unit
ICD	inflow control device
ICV	interval control valve
ID	inside diameter
MTR	material test report
NDE	non-destructive examination
OD	outside diameter
RIH	run in hole
SIT	system integration test

4 Functional Specifications

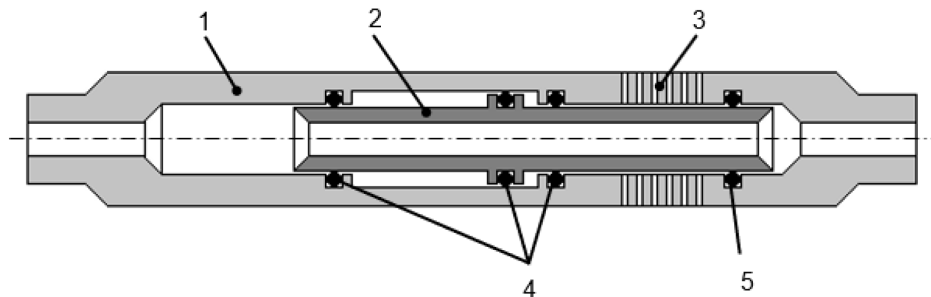
4.1 General

A functional specification for ordering products that conform to this document shall be prepared. A user/purchaser may prepare a new functional specification or identify a supplier/manufacture's specific product by unique identification after reviewing the product's technical specifications. Supplier/manufacture shall prepare the functional specification if one is not provided by the user/purchaser.

4.2 Product Type

ICV Type and intended application shall be stated in the functional specification:

- a) Application—Production service only, injection service only, or both injection and production;
- b) Flow port type—On/Off or Choking;
- c) Actuation type—Hydraulic, Electric or Electrohydraulic;
- d) Flow path type—Annulus-to-Tubing/Tubing-to-Annulus (see [Figure 1](#)) or tubing-to-tubing flow i.e. Shrouded ICV (see [Figure 2](#)).



Key

- 1 Housings (body joints not shown)
- 2 Translating flow control mechanism—piston, mandrel (other architectures also possible)
- 3 Choking section—ports, slots, on/off (other geometries also possible)
- 4 Actuator seals—typically dynamic seals
- 5 Choke seal—unloading seal when ICV cycles from closed to open position

Figure 1—Example of ICV—Choking, Annulus-to-Tubing or Tubing-to-Annulus

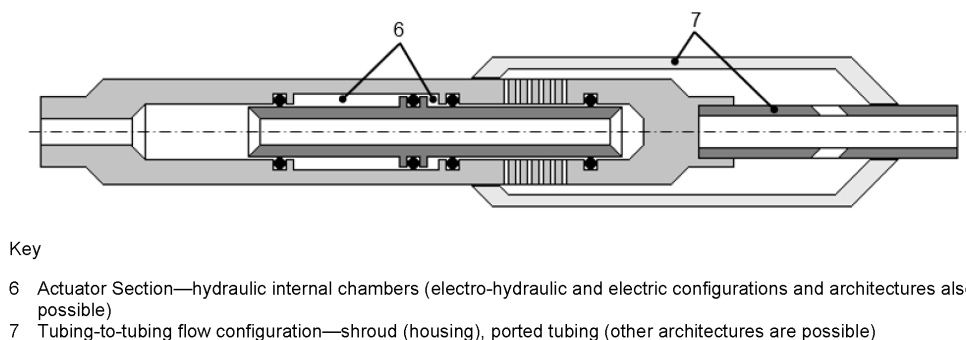


Figure 2—Example of an ICV—Choking, Tubing-to-Tubing

4.3 Functional Characteristics

The functional characteristics shall include, as applicable:

- a) type of control system and its limits;

NOTE Control system may include control fluid type/properties, supply pressure, supply lines, power consumption, and connection ratings.

- b) operating life requirements;

NOTE Operating life may include several cycles, years of service, erosion limits, corrosion limits, accumulated contaminants, thermal cycling.

- c) contingency actuation requirements.

4.4 Well Parameters

The following well parameters shall be specified, when applicable:

- a) well location (land, platform, subsea);
- b) well type (producer or injector, or both);
- c) size, mass, material and grade of the casing and tubing;
- d) well construction and overall completion architecture;
- e) maximum dogleg severity that the ICV will pass through, maximum dogleg severity where the valve will be installed;
- f) water depth, setting depth (maximum required for application), angle from the vertical to the installed position;
- g) restrictions or profiles, or both, through which the ICV shall pass (e.g. liner tops);
- h) requirements for by-pass of additional lines (electrical, hydraulic, fiber optic) between the valve outer diameter and the casing/liner inner diameter;
- i) type of wellhead/tubing hanger system and its number and type of penetrations;
- j) sandy vs non-sandy service flowing conditions.

4.5 Operational Parameters

The operational parameters shall include, but not be limited to, the following, as applicable:

- a) Material requirements including any required conformance to industry standards such as ANSI/NACE MR0175/ISO15156 pressure requirements.

- 1) Minimum and maximum absolute pressures in tubing and annulus.

NOTE Considering minimum estimated future abandonment pressure, maximum reservoir pressure.

- 2) Static differential pressure range (tubing-to-annulus, annulus-to-tubing).
 - 3) Sandy service flowing maximum differential pressures (annulus-to-tubing and tubing-to-annulus, if applicable).
 - 4) Non-sandy service flowing maximum differential pressures (tubing-to-annulus, annulus-to-tubing).
 - 5) Expected maximum unloading differential pressure for opening an ICV for each intended flow direction (annulus-to-tubing and tubing-to-annulus).
- b) Hydraulic fluid specification and supply pressure per wellhead infrastructure.
- c) Electrical interface requirements (power and communication).
- d) Minimum and maximum temperatures or temperature range at installation depth.
- e) Anticipated flow rates and direction being controlled by the ICV (controlled flow rate), and the anticipated flow rates through the inside of the ICV (ID flow rate).
- f) Number of choking positions desired.
- g) C_v values or pressure vs flow rate desired.
- h) Loading conditions, including combined loading (pressures, tension/compression, and temperatures), at the anticipated flow rates.
- i) Composition ratio of the production/injection fluid (gas/oil/water) and content of each component: H_2S , CO_2 , and Chlorides. pH of the fluid shall be included.
- j) Well suspension time frame and conditions.
- k) Well-servicing activities through the ICV; sizes, type and configuration of secondary tools or other devices to be run with or through the ICV.
- l) Operations and maintenance requirements.

4.6 Design Validation Grade Selection

The user/purchaser shall specify the required design validation grade. If the user/purchaser does not specify the validation grade, V3 applies. This specification provides three design validation grades (V3 to V1), as defined in [5.7](#), [Table 2](#), [Table 3](#) and [Annex A](#).

4.7 Quality Levels

The user/purchaser shall specify the required quality level. If the user/purchaser does not specify the quality level, QL3 applies. This specification provides three quality levels (QL3, QL2, and QL1) of quality control (QC), as defined in [6.4](#) and summarized in [Table 4](#).

4.8 Environmental Compatibility

The following shall be identified for the ICV and required tools to ensure environmental compatibility:

- a) Anticipated production/injection/annulus fluid chemical and physical composition, including solids (e.g. sand production, scale, hydrates, asphaltenes) to which the ICV is exposed during its life cycle. This information may include:
 - 1) completion fluid composition, pH, and existence of bromides (Zn, Ca, Na), formates (Cs, K, Na), chlorides (K, Ca, Na), acetates (Cs);
 - 2) mud composition type, mud density, and pH;
 - 3) aromatic and aliphatic solvents where present (type/amount);
 - 4) inhibitor treatments (type, concentration, and pH);
 - 5) oxygen scavenger systems;
 - 6) emulsifier systems;
 - 7) continuous or batch treatment, including solid divert agents as applicable;
 - 8) duration and temperature of exposure;
 - 9) control line fluid type, density, and chemistry.
- b) In cases where the user/purchaser has access to corrosion property data or research that is applicable to the functional specification, the user/purchaser shall state which material(s) have the ability to perform as required.
- c) 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.
- d) At valve setting depth, the minimum, maximum, and typical values of the production/injection pressures and temperatures at the anticipated flow rates.
- e) Environmental conditions during transportation, storage, and at surface prior to and during deployment.

4.9 Compatibility with Related Well Equipment

The following information, as applicable, shall be specified to ensure the compatibility of the ICV and associated secondary tools:

- a) ICV size, type, material, and configuration of the interface connections (those connections not included in the evaluation of combined loading).
- b) Internal profile(s), sealing bore dimension(s), outside diameter (OD), inside diameter (ID), and their respective locations to the ICV.

- c) Requirement(s) for continuity of flow path and/or through bore access (e.g. size, length), passage of conduits (e.g. electrical, hydraulic or fiber optic) between valve OD and casing ID, and open-hole ID restrictions.

4.10 Optional User/Purchaser Selected Requirements

The end user may require optional tests that are described in the informative annexes of this specification:

- a) System integration test (SIT) per [Annex E](#).
- b) ICV actuation in absolute pressure environments per [Annex G](#).
- c) Injection erosion test per [Annex H](#).

5 Technical Specification

5.1 General

The supplier/manufacture shall provide a technical specification for the ICV which conforms to the functional specification defined by the user/purchaser or functional requirements of the order or service to which conformance is claimed.

The supplier/manufacture shall define in the technical specification if a separate control module is required to perform in accordance with the functional specification. If a separate downhole control module is required, a technical specification for the downhole control module shall be provided to the user/purchaser when requested.

5.2 Technical Characteristics

The product shall perform in accordance with functional specification during installation and operation. The product shall regulate the flow to and or from the formation from the casing or tubing as requested. Features of the ICV which limit well intervention operations shall be included in the technical specification. The requirements for downhole control module(s) are as stated in [5.8](#).

5.3 Performance Ratings

Design verifications and validations are required to support the manufacturer/supplier rated limits. These include rated capabilities communicated in the supplier/manufacture's technical specification for the ICV and the downhole control module.

The supplier/manufacture shall state the performance ratings as applicable to the product:

- a) Pressure ratings
 - 1) absolute pressure limits (tubing, annulus, and atmospheric or hydraulic chamber);
 - 2) static differential pressure ranges (tubing-to-annulus, annulus-to-tubing, internal chambers ratings and tubing-to-tubing);
 - 3) sandy service flowing maximum differential pressures (annulus-to-tubing and tubing-to-annulus, if applicable);
 - 4) non-sandy service flowing maximum differential pressures (tubing-to-annulus, annulus-to-tubing);
 - 5) maximum unloading differential pressure for opening the ICV.
- b) Temperature range of the ICV.

- c) Thermal cycle range for V1 (see [Annex F](#)).
- d) Number of choking positions.
- e) Minimum flow area through the ICV.
- f) Maximum flow area through the flow ports.
- g) C_v values or pressure vs flow rate for each choke position as per [Figure A.1](#) and [Figure A.2](#). Displaying tested points on these graphs for the data sheet is not required.
- h) Load ratings or performance envelope per [5.4](#).

5.4 Performance Envelope

Performance envelope is graph that illustrates the combined effects of differential pressure and axial loads on a product at the maximum rated temperature.

The supplier/manufacturer shall state the performance ratings for the following: pressure, temperature, axial loads, as applicable for each product. For ICVs validated to grade V1, a rated performance envelope is required.

An example envelope is illustrated in [Figure 3](#). 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 products.

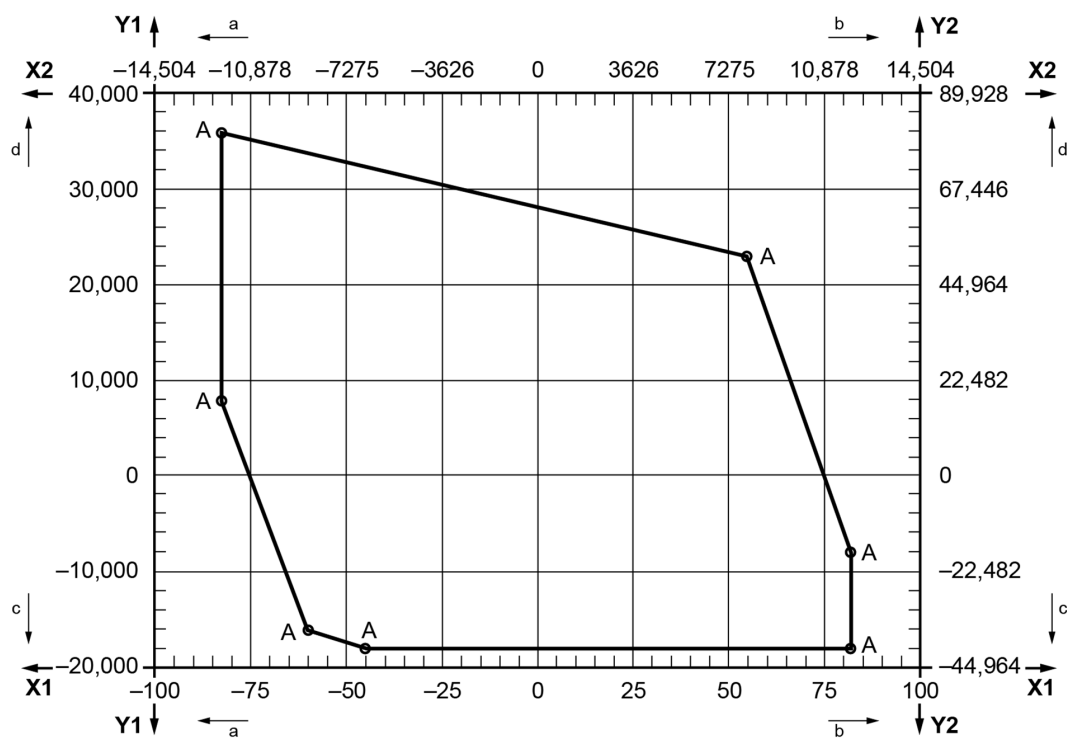
Rated performance envelopes shall meet the following criteria:

- a) The rated performance envelope shall represent the supplier/manufacturer's validated ratings including internal chambers or performance envelope shall use design margins as per [5.5.2](#) for scaled calculated envelopes.
- b) Products with IDs shall be represented with the ID not plugged unless specified with the envelope.
- c) The ratings of the end connections shall not be included.
- d) Axis and sign convention shall be oriented as shown in [Figure 3](#).
- e) More than one graph may be displayed with the envelope if a legend is included for explanation. For example, tubing-to-tubing and annular-to-tubing flow valves can be displayed on the same graph.

Some products may be represented by a curved or elliptical envelope as shown below in [Figure 4](#). Points on the curved envelope within any quadrant where the maximum magnitude of either the load or pressure value exceeds the magnitude of the load or pressure value at the axes are considered maximum operational limit points of the tool.

The product(s) covered by the envelope shall be specified with the envelope. If the envelope covers two or more products that are used together downhole, then this shall be stated on the envelope.

The performance envelope of the ICVs shall state and graphically illustrate the pressure, temperature, and axial load rating for the rated limits of the body of the product, exclusive of end connections. The performance envelope may be based on test data or calculated data, or both.

**Key**

X1	pressure, expressed in megapascals	a	external
X2	pressure, expressed in pounds per square inch	b	internal
Y1	force, expressed in decanewtons	c	compression
Y2	force, expressed in pounds	d	tensile

NOTE Points labelled "A" are intersection points of two or more operational limits.

Figure 3—Example of a Rated Performance Envelope

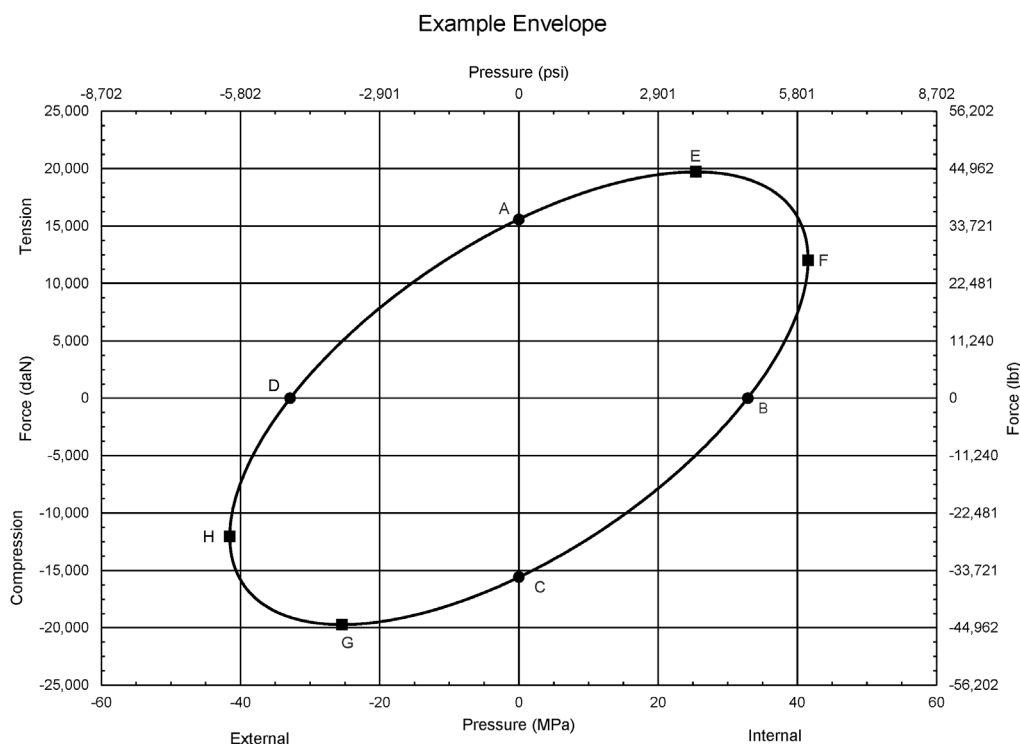


Figure 4—Example of an Elliptical Performance Envelope

5.5 Design Requirements and Verification

5.5.1 General

The supplier/manufacturer shall establish internal pressure, external pressure, internal chamber(s) pressure and tensile/compressive strength ratings (excluding end connections), and the operational capabilities necessary to meet the technical specification. Additionally, ID, OD, length, and other dimensions needed to meet operational requirements shall be provided. A qualified person shall establish the ratings based on design analysis, calculations or full-scale testing using supplier/manufacturer's approved methods.

The supplier/manufacturer shall identify all related tools or downhole control modules necessary for the ICV to meet the functional specifications.

Temperature, environment, material properties and combined loading effects on all materials used in ICVs shall be considered when establishing the products rated pressures and load capabilities. The design shall consider the effects of pressure containment and pressure-induced loads. Where applicable, specialized, or temporary conditions, such as pressure testing with temporary test plugs, shall also be considered in the design ratings.

As applicable, the ICV design shall include features to protect any control lines (ICV's control lines or bypass lines) from the effects of flow through the choke such as flow induced vibration and erosive damage to the lines.

Design verification shall be performed to ensure that each ICV design meets the supplier/manufacturer's technical specifications. Design verification includes activities such as design reviews, design calculations, physical tests, and comparison with similar designs. For V3, historical records of defined operating conditions may be used for design verification. Verification results shall be approved by a qualified person other than the person that created the original design.

The design of ICV shall permit prediction and repeatability of conditions required for the defined operating scenarios.

ICVs, downhole control modules and components conforming to the technical specification shall contain no substantive changes from those of the products that passed the applicable validation tests.

5.5.2 Design Margins

Design margin(s) and mode(s) of stress shall be identified for each Type 1 component, as determined by the supplier/manufacture, using a documented methodology. The performance of the component or product shall be established using the component or products minimum material condition, minimum allowable yield strength at the maximum rated temperature (including thermal cycles) and the maximum operational stresses.

Component or assembly capabilities or ratings shall be established using the documented design margins. The rating of a product shall be determined by the lowest capability or performance potential of any component of the design after the application of the design margin. Design scaling, replacement components and design revisions shall conform to the design margin, design assumptions, and design analysis methods that were applied to the base component or product.

5.5.3 Design Analysis

5.5.3.1 General

The product design shall be analyzed to determine the performance limits and the method shall be documented and the final design shall be approved by a qualified person.

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 lowest design margin. The design shall consider all operational loading conditions defined in the functional specification. One or more of the design analysis methods shown below shall be used to determine the maximum state of stress of a component:

- a) The distortion energy theory for ductile materials (also known as the von Mises yield criterion): The equivalent stress shall be calculated using equations provided in ASME *BPVC*, Section VIII, Division 3, KD-131(b) and be limited by the supplier/manufacture's documented margin methodology and practice.

NOTE This standard does not provide any guidance for brittle material analysis such as tungsten carbides. The analysis for them falls under [5.5.3.1](#), Item d).

- b) Finite Element Analysis (FEA)—This may be used for complex geometry or complex loading where conventional verification methodologies are considered incomplete (see [5.5.3.2](#)).
- c) Computational Fluid Dynamics—This may be used to predict equipment performance under flowing conditions, such as erosion, flow characteristics through the choke or flow assurance considerations (see [5.5.3.3](#)).
- d) Manufacturer Defined Analysis—Any supplier/manufacture defined calculation methods and processes for components that have been proven to provide valid component designs.

5.5.3.2 Finite Element Analysis

FEA is a design verification methodology that may be used to predict equipment performance for complex geometry or complex loading where conventional verification methodologies are considered incomplete by the design engineer. FEA shall include the following information (as applicable) to enable verification of the results:

- a) description of the numerical method used, including name and version of computer software;
- b) geometry details:
 - computer-aided design (CAD) format,

- simplified model for symmetry or full 3D model,
- element type,
- part dimensions that result in the highest state of stress;
- c) loading conditions:
 - type (pressure, force, moment),
 - magnitude and system of units,
 - region of application (point, surface);
- d) boundary conditions:
 - symmetry planes,
 - spatial or displacement constraints,
 - contacts (rigid, frictionless);
- e) material properties at temperature:
 - modulus of elasticity;
 - Poisson's ratio;
 - yield strength;
 - tensile strength;
 - material nonlinearity model (true stress, true strain curve; cyclic true stress, true strain curve);
- f) numerical analysis procedure:
 - static,
 - dynamic,
 - buckling,
 - harmonic,
 - fatigue,
 - fracture,
 - geometrically linear or nonlinear;
- g) graphical display of results:
 - stress contour plot,
 - deformation plot;
- h) verification of numerical model: