

Inflow Control Devices

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This specification was initiated using Recommended Practice - Inflow Control Devices (ICDs) provided by the Advanced Well Equipment Standards group.

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Inflow Control Devices

1 Scope

This specification provides requirements and guidelines for inflow control devices (ICDs) for both production and injection, as defined herein, for use in the petroleum and natural gas industry. This specification provides requirements for the functional specification and technical specification, including design, design verification and validation, materials, documentation and data control, and quality requirements.

Products covered by any other API specification, such as sand screens and sliding sleeves are not included. Also not included are externally controlled downhole devices including interval control valves (ICVs). This specification does not cover the connections to the well conduit, the effects of corrosion, or ICDs designated for use in thermal recovery applications. Installation, application, and operation of these products are outside the scope of this specification.

This specification includes the following annexes:

- Annex A—Reserved for Future Use
- Annex B—ICD Joint Components and Screen Attributes
- Annex C—Test Article, Test Fixture and Instrumentation Requirements
- Annex D—Cavitation Testing
- Annex E—Validation Test Requirements—ICD Flow Performance Test
- Annex F—Validation Test Requirements—Device Erosion Test
- Annex G—Validation Test Requirements—Mud Flow Initiation Test and Sediment Plugging Test
- Annex H—Validation Test Requirements—Flow Integrity Test
- Annex I—Validation Test Requirements—Static Pressure Test

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

ANSI/ASQC Z1.4, *Sampling Procedures and Tables for Inspection by Attributes*

ANSI/NCSL Z540-3, *Requirements for the Calibration of Measuring and Test Equipment*

API 19SS, *Sand Screens*

API 5CT, *Specification for Casing and Tubing*

API 13B-1, *Recommended Practice for Field Testing Water-based Drilling Fluids*

API 13B-2, *Recommended Practice for Field Testing Oil-based Drilling Fluids*

API 19C, *Measurement of and Specification for Proppants Used in Hydraulic Fracturing and Gravel-packing Operations*, Second Edition

ASME, *Boiler and Pressure Vessel Code (BPVC) Section II-Materials—Part D—Properties—(Customary)*

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

ASME, *Boiler and Pressure Vessel Code (BPVC) Section V-Nondestructive Examination*

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

ASQ H1331, *Zero Acceptance Number Sampling Plans*

ASTM E165, *Standard Practice for Liquid Penetrant Testing for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

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 3452-1, *Non-destructive testing — Penetrant testing- Part 1: General Principles*

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

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

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

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

3.1.1

annulus

The space between two concentric objects, such as the clearance between the test fixture ID and the test article OD.

3.1.2

autonomous inflow control device

AICD

ICD that preferentially restricts the flow of unwanted fluids over wanted fluids based upon the fluid properties and downhole flowing conditions.

3.1.3

back pressure ratio

Ratio of outlet pressure to the differential pressure across the test article.

3.1.4

basepipe

Tubulars that may have perforations or slots to allow fluid flow through the screen jacket.

3.1.5**cavitation**

Condition where cavities or voids form in liquids that result from rapid drops in local pressure, such as occurring across an ICD, and thereby affect flow performance.

3.1.6**common hardware**

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

3.1.7**density**

The ratio of mass divided by volume.

3.1.8**design family**

ICDs where the configuration, materials, and functionality are the same, and the design stress levels in relation to material mechanical properties are based on the same criteria, but nominal sizes vary, such as basepipe diameter.

3.1.9**design validation**

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

3.1.10**design verification**

Process of examining the result of design and development output to determine conformity with specified requirements.

3.1.11**differential pressure****pressure drop**

The difference between the outlet and inlet pressure of the test article, which is used along with volumetric flow rate (and fluid properties) to characterize flow performance.

3.1.12**erodent**

The solid particulates that make up the slurry used during the erosion test.

3.1.13**erosion**

The process of abrading or wearing away a solid surface by solid particles due to contact or impact.

3.1.14**erosion test**

A test to characterize the change in flow performance of a test article caused by material loss due to erosion.

3.1.15**flow initiation pressure**

The pressure required to cause a substance to flow.

3.1.16**flow integrity rating**

The maximum flowing pressure which an ICD can operate and still perform within its flow performance.

3.1.17**flow integrity test**

A test to determine the maximum flowing pressure which an ICD can operate and still perform within its flow performance.

3.1.18**flow meter**

An instrument used to measure the volumetric or mass flow rate of a fluid.

3.1.19**flow performance**

The pressure drop vs volumetric flow rate response when flowing fluid through the test article.

3.1.20**flow performance test**

A test to characterize flow performance of a device, which can be performed for several ICD element settings or sizes in production or injection direction.

3.1.21**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.

3.1.22**ICD element**

The specific component of the ICD joint that controls flow by generating a pressure drop response to fluid flow.

3.1.23**ICD joint**

A complete joint, including connections, that contains one or more ICD elements and any accessories, such as a sand control screen.

3.1.24**ICD settings**

Unique combinations that achieve different flow characteristics per ICD joint.

3.1.25**inlet pressure**

The pressure directly upstream of the ICD element as defined by the flow direction.

3.1.26**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 reservoir.

NOTE The term regulate may include choking of the flow or on-off functions.

3.1.27**manufacturer**

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

3.1.28**mass flow rate**

The amount of mass flowing per unit of time.

3.1.29**mud**

High density fluid that contains solids and exhibits a Bingham plastic behavior.

3.1.30**Newtonian fluid**

A fluid the viscosity of which is independent of shear rate (shear stress divided by shear rate is a constant).

3.1.31**non-Newtonian fluid**

A fluid that exhibits a yield point and/or its viscosity is shear rate dependent. Examples are Bingham, pseudoplastic, and viscoelastic fluids.

3.1.32**outlet pressure**

The pressure directly downstream of the ICD element as defined by the flow direction.

3.1.33**outlet temperature**

Temperature of fluid directly downstream of the test fixture as defined by the flow direction.

3.1.34**particle concentration**

In a given volume of slurry, the mass of the particles divided by the total mass of the slurry (i.e. mass fraction or ppmw).

3.1.35**particle size distribution**

A distribution of particle diameters representative of a bulk supply of particles and is typically measured via sieve or a laser particle scanning technique which outputs cumulative and incremental fractions by weight versus particle diameter.

3.1.36**plugging test**

A process of evaluating a drilling mud's potential to plug or influence the performance of the test article.

3.1.37**pressure sensor**

A sensor used to measure the (gauge) pressure of the fluid within a specific section of the test fixture.

3.1.38**qualified person**

An individual 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.

3.1.39**rheology**

The quantitative/mathematical relationship between shear stress and shear rate for a fluid.

3.1.40**static pressure rating**

The differential pressure rating of the ICD when flow through the ICD element is in the injection direction and intentionally blocked off at the ICD element.

3.1.41**static pressure test**

A test to determine the differential pressure rating of the ICD when flow through the ICD element is in the injection direction and intentionally blocked off at the ICD element.

3.1.42**substantive design change**

A change to the design, identified by the supplier/manufacturer, that may affect the performance of the product in the intended service condition.

3.1.43**test article**

A representative assembly used for ICD testing purposes.

3.1.44**test fixture**

An assembly which houses a test article. (See Annex C.)

3.1.45**thermal recovery applications**

An application that intentionally introduces heat to recover hydrocarbons from a reservoir.

3.1.46**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.

3.1.47**type 2 component****type 2 weld**

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

3.1.48**unwanted fluid**

The downhole fluid type that the ICD preferentially restricts to flow through the device.

3.1.49**viscosity**

The measure of a fluid's resistance to shear deformation, usually given in units of centipoise (cP).

3.1.50**volumetric flow rate**

The volume of fluid flowing per unit of time.

3.1.51**wanted fluid**

The downhole fluid type that the ICD preferentially allows to flow through the device.

3.2 Abbreviations

AICD	autonomous inflow control device
AQL	acceptance quality limit
CFD	computational fluid dynamics
COC	certificate of conformance
dP	differential pressure

FEA	finite element analysis
ICD	inflow control device
ID	inside diameter (in.)
LB	box handling length (reference Figure B.2)
LH	ICD housing length (reference Figure B.2)
LS	length of screen or debris barrier (reference Figure B.2)
LP	pin handling length (reference Figure B.2)
MD	measured depth
MTR	material test report
NDE	non-destructive evaluation
OD	outside diameter (in.)
ppm	parts per million (by weight or by volume)
ppmw	parts per million by weight
Q	volumetric flow rate
SiO ₂	silicon dioxide
TVD	true vertical depth

4 Functional Specification

4.1 General

The user/purchaser should provide a functional specification to order products which conform to this specification. The specification shall include the following requirements and operating conditions as the user deems appropriate, and/or may identify the supplier/manufacturer's specific product. These requirements and operating conditions may be conveyed by means of a dimensional drawing, data sheet, or other suitable documentation and other technical documentation as applicable to the validation grade.

4.2 ICD Type Description

ICDs are installed in the completion string to control the inflow or outflow of fluids from or to the reservoir. An ICD may contain moving parts or no moving parts and, once installed, is not connected to surface for adjustability, such as with a permanent electric or hydraulic line.

The user/purchaser should specify:

- ICD Service Level: Production, Injection, or Both
- ICD Type Classification per Table 1
- ICD Validation Grade per Table 2
- ICD Quality Level per Table 3

The user/purchaser should provide well parameters, operational parameters, and other relevant parameters, as applicable, according to 4.3, 4.4, 4.5, and 4.6.

For all sand screens defined with an ICD, API 19SS may be referenced and applied as required for validation grade and quality grade of the sand screen component.

ICDs are classified into three Types shown in Table 1.

Table 1—ICD Type Classification

Type 1	An ICD with no moving parts, such as a nozzle, orifice, tube or channel.
Type 2N	An AICD with no moving parts.
Type 2M	An AICD with moving parts.

4.3 Well Parameters

The user/purchaser should specify, as applicable, the following well parameters:

- True vertical depth (TVD) and measured depth (MD)
- Directional survey of the well with maximum dogleg severity
- Fluid type(s) to be controlled
- Viscosity of well fluids (oil, gas, water) at reservoir conditions
- Density of well fluids (oil, gas, water) at reservoir conditions
- Static reservoir pressure
- Static reservoir temperature
- Future reservoir abandonment pressure
- Well head pressure
- Artificial lift type
- Minimum required tensile and torque ratings for ICD product
- Maximum OD for ICD joint
- Minimum required internal ID drift for the installed ICD product
- Any other relevant well parameter(s)

4.4 Operational Parameters

The user/purchaser should specify, as applicable, the following operational parameters:

- ICD Adjustability: wellsite adjustable or non-adjustable
- Installation method: tubing or liner deployment
- Setting depth, TVD and MD
- Number of completion interval compartments
- Estimated length of each completion interval compartment

- Target fluid rate(s) by compartment with maximum production and/or injection dP across ICDs during well operation
- Stimulation requirements, including maximum injection rates and dP across ICDs during stimulation
- Minimum required burst and collapse ratings for ICD joint
- Downhole ICD shut-off capabilities: unique settings, temporary shut-off, or permanent shut-off
- ICD settings

4.5 Environmental Compatibility

4.5.1 General

Where the user/purchaser has material selection and/or corrosion property data of the operating environment based on historical data and/or research, the user/purchaser may state which material(s) should be used. Otherwise, material compatibility may be specified according to 4.5.2.

4.5.2 Well Conditions

The following should be provided by the user/purchaser to ensure compatibility, as applicable:

- Volumetric flow rate range
- Pressure range
- Temperature range
- Well life estimate and solids loading estimate
- Production/Injection fluid type(s)
- CO₂ concentration estimate (%)
- H₂S concentration estimate (ppm)
- Chloride concentration estimate (ppm)
- Composition and properties of any additional fluid treatments such as kill pills, solvents, or acids
- Exposure contact time duration for stimulation treatments

4.6 Compatibility with Related Well Equipment

The following information should be provided by the user/purchaser, as applicable:

- Sand control screen or debris barrier type and micron size (see API Specification 19SS for sand screen types)
- Basepipe size for ICD installation, including pipe OD, weight, and metallurgy
- Drift ID of the casing and open hole ID
- Minimum restrictions through which the ICD joint must pass (a completion diagram is preferred)
- IDs and ODs of tubing and casing sizes

- Lengths applicable to the ICD joint
- ICD diagnostic plans: pressure/temperature sensors or tracers
- Size, type, material, configuration, and connections between product and other well equipment
- Size, type, and configuration of other products or tools that pass through or over the product
- Size, type, and configuration of other products used in conjunction with this product

4.7 Design Validation Grades

The user/purchaser may select the design validation grade V3, V2, or V1 as per Table 2 for each product to be provided. If the user/purchaser does not specify the validation grade, V3 shall apply.

4.8 Quality Levels

The user/purchaser may select the quality level QL3, QL2, or QL1 as per Table 3 for each product that is to be provided. If the user/purchaser does not specify the quality level, QL3 shall apply.

5 Technical Specification

5.1 General

The supplier/manufacturer shall prepare a technical specification, which conforms to the requirements defined in the functional specification. If the technical specification does not fully meet the functional requirements, the supplier/manufacturer shall identify the differences to the user/purchaser. The supplier/manufacturer shall also provide to the user/purchaser the product data sheet as noted in 6.2.3.

ICDs produced according to this specification shall be designed and developed under a quality management system (QMS) that conforms to API Specification Q1.

The following technical documentation contains performance and test documentation for the ICD device as applicable to the defined validation grade.

- Operating flow performance curve dP versus Q and basis for curve, including fluid types with viscosities and densities
- Erosion test minimum/maximum volumetric flow rate and dP
- Erosion test duration and sand concentration
- Flow initiation pressure(s)
- Static pressure rating(s)
- Flow integrity test; maximum pressure, rate and duration
- Sediment plugging test; pre/post flow performance curves

5.2 Technical Characteristics

The following criteria shall be met:

- The ICD shall perform in accordance with the functional specification and provide predictable flow performance, resistance to erosion and plugging, and shall maintain integrity across the pressure range as applicable to the validation grade.

5.3 Design Requirements

5.3.1 Materials

Materials (both metallic and non-metallic) shall be stated by the supplier/manufacturer and shall be suitable for the operational parameters and the environment specified in the functional specification. The supplier/manufacturer shall have documented specifications for all materials except common hardware used in the manufacture of ICD elements and ICD joints.

The performance characteristics of the materials shall be suitable for the parameters specified for production or injection or both.

The user/purchaser may specify materials for the specific corrosion environment in the functional specification. If the supplier/manufacturer proposes to use another material, the supplier/manufacturer shall provide documented evidence to the user/purchaser for acceptance that this material has performance characteristics suitable for all requirements specified for the well, including any production/injection parameters.

Material types used in the construction of the ICD components shall be provided to the user/purchaser.

Base pipe material shall conform to the requirements of API Specification 5CT unless otherwise specified in the functional specification.

5.3.2 Material Substitution

Material substitution is a temporary change to a bill of material for a validated component which does not reduce the rating of the product. The manufacturer's selection criteria for these substitutions shall be documented and the substituted material shall conform to the design, functional, and technical requirements of this specification.

Material substitutions require approval by a qualified person from the supplier/manufacturer and the supporting documentation shall be incorporated into the manufacturing records for those units affected. In cases where the user/purchaser specifies material(s) of construction, deviations from such materials shall require user/purchaser notification.

Material substitutions from the materials used in the validation tested product are allowed without validation.

5.3.3 Metals

The supplier's/manufacturer's specifications shall define the following, as applicable:

- a) Chemical composition limits
- b) Heat treatment conditions
- c) Mechanical property limits, as applicable:
 - 1) Tensile strength
 - 2) Yield strength
 - 3) Elongation
 - 4) Hardness

5.3.4 Non-metals

The supplier/manufacturer's documented specifications for non-metallic compounds shall define those characteristics critical to the performance of the material, such as:

- Compound type
- Tensile strength (at yield and/or break for thermoplastics)
- Tensile strength (at break for elastomers)
- Elongation at break
- Tensile modulus (at 50 % or 100 % as applicable)
- Compression set (elastomers)
- Durometer (elastomer/thermoplastics hardness)
- Hardness (ceramic/carbides)
- Density (ceramic/carbides)

Specifications shall include test methods used for determining the material characteristics.

5.4 Design Verification

Design verification shall be performed to ensure that the ICD design meets the supplier/manufacturer's technical specifications. Design verification examines the design by evaluating activities such as design reviews, design calculations, validation tests, comparison with similar designs and historical records of defined operating conditions.

The supplier/manufacturer shall apply a design margin to each component and/or assembly using a documented methodology and practice. The documented design margins shall be used in the creation of component or assembly capabilities and/or ratings.

Within each design family, the supplier/manufacturer may utilize FEA, CFD, mechanical strength calculations or other proven methods to determine performance ratings for sizes and similar configurations not tested but shall be within the limitations of scaling as outlined in 5.5.4.

The material's minimum specified yield strength and minimum specified material conditions shall be used in the calculations, and the calculations shall include consideration of temperature effects.

De-rating of metal mechanical properties due to temperature shall be verified by a qualified person and in accordance with:

- a) industry recognized published data, or
- b) data established by the supplier/manufacturer, or
- c) data provided by the material supplier.

NOTE ASME BPVC, Section II, Part D contains temperature de-rated tensile strengths for many materials.