
**Petroleum and natural gas
industries — Drilling and production
equipment — Electric submersible
pump systems for artificial lift**

*Industries du pétrole et du gaz naturel — Équipement de forage et
de production — Systèmes de pompes submersibles électriques pour
relevage artificiel*

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023



STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023



COPYRIGHT PROTECTED DOCUMENT

© ISO 2023

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

	Page
Foreword.....	vi
1 Scope.....	1
2 Normative references.....	1
3 Terms and definitions.....	2
4 Symbols and abbreviated terms.....	16
5 Functional specification.....	18
5.1 General.....	18
5.2 Component type.....	19
5.3 Functional requirements.....	19
5.3.1 General.....	19
5.3.2 Application parameters.....	19
5.3.3 Environmental compatibility.....	21
5.3.4 Compatibility with related well equipment and services.....	22
5.4 User/purchaser selections.....	23
5.4.1 General.....	23
5.4.2 Design validation.....	23
5.4.3 Component functional evaluation.....	23
5.4.4 Quality grades.....	24
5.4.5 Shipping, handling and storage.....	24
5.4.6 Operator's manual.....	24
5.4.7 Subcomponent condition classifications in manufacture of components.....	24
5.4.8 Additional documentation.....	24
6 Technical specification.....	24
6.1 General.....	24
6.2 Design criteria.....	25
6.2.1 General.....	25
6.2.2 Design documentation.....	25
6.2.3 Materials.....	25
6.2.4 Dimensional information.....	29
6.2.5 Component and assembled system design verification.....	29
6.2.6 Component design validation.....	29
6.2.7 Component functional evaluation requirements.....	29
6.2.8 Assembled system functional evaluation.....	29
6.2.9 Design changes.....	30
6.3 Technical specification — All components.....	30
6.3.1 Technical characteristics.....	30
6.3.2 Performance rating.....	30
6.4 Technical specification — Bolt-on discharge.....	30
6.4.1 General.....	30
6.4.2 Technical characteristics for the discharge.....	30
6.4.3 Performance ratings.....	31
6.4.4 Scaling of design validation.....	31
6.5 Technical specification — Pump and gas handler.....	31
6.5.1 General.....	31
6.5.2 Technical characteristics for the pump and gas handler.....	31
6.5.3 Performance ratings.....	31
6.5.4 Scaling of design validation.....	31
6.6 Technical specification — Bolt-on intake.....	31
6.6.1 General.....	31
6.6.2 Technical characteristics for the bolt-on intake.....	32
6.6.3 Performance ratings.....	32
6.6.4 Scaling of design validation.....	32

6.7	Technical specification — Mechanical gas separators	32
6.7.1	General	32
6.7.2	Technical characteristics	32
6.7.3	Performance ratings	32
6.7.4	Scaling of design validation	32
6.8	Technical specification — Seal chamber sections	32
6.8.1	General	32
6.8.2	Technical characteristics	32
6.8.3	Performance ratings	33
6.8.4	Scaling of design validation	33
6.9	Technical specification — Motors	33
6.9.1	General	33
6.9.2	Technical characteristics	33
6.9.3	Performance ratings	33
6.9.4	Scaling of design validation	34
6.10	Technical specifications — Power and motor lead extension cable	34
6.10.1	General	34
6.10.2	Technical characteristics	34
6.10.3	Performance ratings	34
6.10.4	Scaling of design validation	34
6.11	Technical specifications — Pothead	34
6.11.1	General	34
6.11.2	Technical characteristics	34
6.11.3	Performance ratings	35
6.11.4	Scaling of design validation	35
6.12	Assembled ESP system – Additional requirements	35
6.12.1	General	35
6.12.2	Technical characteristics	35
6.12.3	System capabilities	35
6.13	Technical specification response guideline – ESP components	36
7	Supplier's/manufacture's requirements	37
7.1	General	37
7.2	Documented information	37
7.2.1	General	37
7.2.2	Delivery documentation	37
7.2.3	Operator's manual	38
7.2.4	Certificate of conformance	38
7.2.5	Component data sheet	38
7.3	Component identification	42
7.3.1	Permanent identification	42
7.3.2	Semi-permanent identification	42
7.4	Quality	42
7.4.1	General	42
7.4.2	Quality grade requirements	42
7.5	Raw materials	44
7.6	Additional processes applied to components	44
7.6.1	Documentation	44
7.6.2	Coatings and surface treatments	44
7.6.3	Welding	44
7.7	Traceability	45
7.8	Calibration systems	45
7.9	Examination and inspection	45
7.9.1	General	45
7.9.2	Weld	46
7.9.3	Component and subcomponent dimensional inspection	46
7.9.4	Construction features	48
7.10	Manufacturing non-conformance	48
7.11	Component functional testing	48

8	Shipping, handling and storage	48
8.1	General	48
8.2	Storage	49
9	Subcomponent condition classifications in manufacture of components	49
Annex A (normative)	Design validation performance rating requirements by component	50
Annex B (normative)	Requirements for determining performance capabilities as an assembled system	80
Annex C (normative)	Functional evaluation: single component	83
Annex D (normative)	Cable reference information	91
Annex E (informative)	Functional evaluation guideline — Assembled ESP system	98
Annex F (informative)	Establishing recommended operating range of ESP system	103
Annex G (informative)	Example of user's/purchaser's ESP functional specification form	105
Annex H (informative)	Considerations for use of three-phase low and medium voltage adjustable speed drives for ESP applications	109
Annex I (informative)	Analysis after ESP use	115
Annex J (informative)	Downhole monitoring of ESP assembly	127
Annex K (informative)	Information on permanent magnet motors for ESP applications	129
Annex L (informative)	User guide	131
Bibliography		135

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 4, *Drilling, production and injection equipment*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Oil and gas industries including lower carbon energy*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition cancels and replaces ISO 15551-1:2015, which has been technically revised.

The main changes are as follows:

- the relationship between the design verification/validation activities and the functional specification/technical specification has been revised. In this document, the design verification/validation activities have been tied to a “basis of design” rather than to the functional specification/technical specification;
- [Annex E](#) has been augmented to incorporate additional details, guidelines and options for completing functional evaluation of assembled systems;
- [Annex L](#) is a “user’s guide”, which has been added to this document to provide a simplified view of the practical workflow of the document.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Petroleum and natural gas industries — Drilling and production equipment — Electric submersible pump systems for artificial lift

1 Scope

This document specifies requirements for the design, design verification and validation, manufacturing and data control, performance ratings, functional evaluations, handling and storage of tubing-deployed electrical submersible pump (ESP) systems. Additionally, this document provides requirements for assembled ESP system.

This document is applicable to those ESP related components meeting the definition of centrifugal pumps, including gas handling devices, discharge heads, seal chamber sections, intake systems, mechanical gas separators, asynchronous 3 phase - 2 pole induction motors (herein motor), shaft couplings, downhole power cables (herein power cables), motor lead extension, and pothead. Components supplied under the requirements of this document exclude previously used subcomponents, except where the use of such subcomponents is as defined in this document ([Clause 9](#)).

This document addresses design validation performance rating requirements by component (see [Annex A](#)), requirements for determining ratings as an assembled system (see [Annex B](#)), functional evaluation: single component (see [Annex C](#)) and cable reference information (see [Annex D](#)).

This document addresses functional evaluation guidelines for assembled ESP systems, establishing recommended operating range (ROR) of the ESP system (see [Annex F](#)), example user/purchaser ESP functional specification form (see [Annex G](#)), considerations for the use of 3-phase low and medium voltage adjustable speed drives for ESP applications (see [Annex H](#)), analysis after ESP use (see [Annex I](#)), downhole monitoring of ESP assembly operation (see [Annex J](#)), information on permanent magnet motors for ESP applications (see [Annex K](#)) and users guide (see [Annex L](#)).

This document also includes a user guide that offers a high-level process workflow when applying this document.

This document does not apply to: wireline and coiled tubing-deployed ESP systems, motor shrouds and pump shrouds, electric penetrators and feed-through systems, cable clamps and banding, centralizers, intake screens, passive gas separators, by-pass tools, check and bleeder valves, component adaptors, capillary lines, electric surface control equipment, downhole permanent magnet motors and non-conventionally configured ESP systems such as inverted systems. This document does not apply to Repair and redress equipment requirements.

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 amendments) applies.

IEC 60228, *Conductors of insulated cables*

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

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

API RP 11S2, *Electric Submersible Pump Testing*

API RP 11S6, *Recommended Practice for Testing of Electrical Submersible Pump Cable Systems*

API RP 11S7, *Recommended Practice of Application and Testing of Electric Submersible Pump Seal Chamber Section*

API RP 11S8, *Practice on Electric Submersible Pump System Vibrations*

ASTM B3, *Standard Specification for Soft or Annealed Copper Wire*

ASTM B8, *Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft*

ASTM B33, *Standard Specification for Tin Coated Soft or Annealed Copper Wire for Electrical Purposes*

ASTM B189, *Standard Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes*

ASTM B193, *Standard Test Method for Resistivity of Electrical Conductor Materials*

ASTM B258, *Standard Specification for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors*

ASTM B496, *Standard Specification for Compact-Round Concentric-Lay-Stranded Copper Conductors*

ASTM D471, *Standard Test Method for Rubber Property — Effect of Liquids*

ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials*

ANSI/NEMA WC 53, *Standard Test Methods for Extruded Dielectric Power, Control, Instrumentation, and Portable Cables for Test*

ASTM D877, ASTM D877M, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*

ASTM D1816, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes*

IEEE Std 1018, *Recommended Practice for Specifying Electric Submersible Pump Cable - Ethylene-Propylene Rubber Insulation*

IEEE Std 1019, *Recommended Practice for Specifying Electric Submersible Pump Cable-Polypropylene Insulation*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

adapter

device used to connect components that are not directly compatible

3.2

adjustable speed drive

device that controls an electric motor's speed by manipulating both the output voltage and the power frequency being supplied to the motor

3.3**ampacity**

maximum current that can pass through a power cable without exceeding its temperature limit for a specific operating environment

3.4**ampacity coefficient**

temperature rise of the power cable divided by the square of the amperage for a specific operating environment

3.5**armor**

outer covering to the power cable that can provide protection from mechanical damage and provides mechanical constraint against swelling or expansion of underlying materials on exposure to well fluids

3.6**assembled electrical submersible pump system****assembled ESP system**

assembly of electric submersible pump downhole equipment which includes some or all components such as centrifugal pumps, gas handling devices, discharge head, seal chamber sections, intake system, mechanical gas separators, motors, shaft couplings, power cable, motor lead extension, and pothead

3.7**auxiliary equipment**

equipment or components that are typically selected and/or installed by the user/purchaser

EXAMPLE Cable protectors, motor shrouds, by-pass tools and electrical penetrators.

3.8**axial flow stage**

type of stage with inlet and exit flow path essentially parallel to the shaft axis

3.9**positive seal element**

flexible subcomponent of a seal chamber section that functions as a positive barrier that isolates the wellbore production fluid from the motor fluid, commonly referred to as bag, bladder or bellows.

3.10**positive seal element chamber**

chamber that houses the positive seal element

3.11**barrier**

subcomponent of an electrical submersible pump power cable that can be applied over the insulated conductors and provides fluid protection, hoop strength or both

3.12**best efficiency point****BEP**

pump performance values at the flow rate where the pump efficiency is highest

3.13**bleeder valve**

valve placed above a check valve for the purpose of reducing pressure or draining the fluid from within the production tubing

3.14**braid**

supplementary layer of material used to provide mechanical performance characteristics to the power cable system such as hoop strength for gas decompression

3.15

bubble point

pressure at which gas begins to break out of under-saturated oil/fluid and form a free gas phase

3.16

by-pass tool

device that is installed into the wellbore along with the electrical submersible pump (ESP) assembly that divides the tubing system to permit the installation of additional tubing string parallel to the ESP

3.17

cable band

metal band that is used to secure electrical submersible pump power cable to production tubing

3.18

cable clamp

device, usually of rigid material, for strengthening or supporting power cable to production tubing

3.19

capillary line

independent tubing string commonly used for hydraulic control of safety valves and sliding sleeves or for chemical injection

3.20

casing

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

3.21

centralizer

device used to keep the electrical submersible pump assembly or other downhole equipment in the centre of the tubing, casing or wellbore

3.22

centrifugal pump

component of an electrical submersible pump system that uses rotating impeller(s) to impart kinetic energy (velocity) by centrifugal force to a fluid and stationary diffusers to convert the kinetic energy to potential energy (pressure)

3.23

chamber

subcomponent of the seal chamber section

3.24

check valve

device that allows one-directional flow of fluid when a differential pressure exists

3.25

coefficient of determination

statistic used to determine the strength of a fit between a mathematical model and a set of observed data values

3.26

coiled tubing

pipe typically supplied and installed in one continuous length and wound onto a reel or spool

3.27

common hardware

hardware that does not require traceability and is included as part of an electrical submersible pump component

EXAMPLE Bolts, washers, screws, and snap rings.

3.28**compact stranded**

electrical conductor configuration in which a multiple-strand conductor has been compacted to reduce its circumference while maintaining conductor area

3.29**component**

individual part of an assembly

EXAMPLE Pumps (including gas handling devices), discharge heads, seal chamber sections, intake systems, mechanical gas separators, induction motors, shaft couplings, downhole cables, motor lead extensions, and potheads.

3.30**compression pump**

configuration where the impeller is fixed to the shaft to prevent axial movement

3.31**conductor**

subcomponent of the power cable that functions to conduct electrical power

3.32**conductor shield**

layer adjacent to the conductor to distribute voltage stress evenly over the surface of the conductor

3.33**configuration**

component designation that identifies the end connection designs for attaching additional components in series

EXAMPLE Upper tandem, lower tandem, middle/centre tandem, and single tandem.

3.34**contraction capacity**

volume that a chamber or set of parallel chambers can draw in due to temperature and pressure cycles without allowing wellbore fluid ingress through the chamber or causing damage

3.35**coupling**

device that connects the shafts of electrical submersible pump components

3.36**conductor resistance test**

method for determining the cable conductor resistance value

3.37**deployment method**

method used to deploy the electrical submersible pump downhole equipment to its setting location

3.38**design basis**

documented set of conditions, needs, and requirements taken into account by the supplier/manufacturer in designing and establishing performance ratings of a facility or product

3.39**design validation**

process of proving a design by testing to demonstrate conformity of the product to design requirements and performance ratings

3.40

design verification

process of examining the premise of a given design by calculation, comparison or investigation, to substantiate conformity with specified requirements

3.41

deviation survey

measurement of a borehole's trajectory over the wellbore length for the purposes of electrical submersible pump design and application

3.42

diffuser

stationary stage segment of a centrifugal pump which converts the pumped fluid velocity (kinetic energy) to a pressure (potential energy)

3.43

discharge head

component on the output end of the pump for connecting to the production tubing

3.44

dogleg severity

total angular inclination and azimuth in the wellbore, casing or liner, calculated over a standard length

3.45

effective diameter

theoretical minimum diameter through which the assembled electrical submersible pump system passes, including installation of all required electrical submersible pump ancillary equipment

3.46

efficiency

output work divided by input work

3.47

elastomer

polymer with the property of viscoelasticity (elasticity), generally having a low Young's modulus and a high yield strain

3.48

electric penetrator

electrical connector that functions to transition power cable and/or instrument wires through a sealing barrier

EXAMPLE

Wellhead, wellbore packer, electrical submersible pump pod or canister.

3.49

electric surface control equipment

electrical equipment used to control the operation of the electrical submersible pump assembly

Note 1 to entry: This electrical equipment is commonly referred to as an adjustable speed drive or switchboard.

3.50

electromagnetic region

region of an induction motor relative to the cylindrical boundary defined by the outside diameter of the stator laminations, and the axial length which encompasses all the coiled wire of the stator

3.51

electric submersible pump assembly

ESP assembly

assembly of ESP downhole equipment that includes some or all components such as centrifugal pumps, gas handling devices, discharge head, seal chamber sections, intake system, mechanical gas separators, motors, shaft couplings, power cable, motor lead extension, and pothead

3.52**enhanced oil recovery**

reservoir process involving the injection of materials not normally present in the reservoir to enhance the overall oil recovery from such reservoir

[SOURCE: ISO/TS 3250:2021, 3.1.10]

3.53**failed item**

item that can no longer perform its required function

3.54**failure mechanism**

process that leads to failure

Note 1 to entry: The process can be physical, chemical, logical, or a combination thereof.

[SOURCE: ISO 14224:2016, 3.29, modified — Note 2 to entry has been deleted.]

3.55**failure cause****root cause**

circumstances during design, manufacture or use, which have led to a failure. set of circumstances that leads to failure

Note 1 to entry: A failure cause can originate during specification, design, manufacture, installation, operation or maintenance of an item.

3.56**fault**

inability to perform as required, due to an internal state

Note 1 to entry: A fault of an item results from a failure, either of the item itself, or from a deficiency in an earlier stage of the life cycle, such as specification, design, manufacture or maintenance.

[SOURCE: ISO 14224:2016, 3.33, modified — Notes 2 and 3 to entry have been deleted.]

3.57**feed-through system**

fixture which allows the passage of electricity from one side of a barrier to another while maintaining a seal of gas or liquid through the barrier

3.58**floater type pump construction**

configuration where the impeller is not fixed to the shaft to permit limited axial movement

3.59**flowing pressure**

pressure in the wellbore at a specific vertical depth at a specific flow rate

3.60**fretting**

special wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force

3.61**functional evaluation**

test(s) performed to confirm electrical submersible pump (ESP) component operation or assembled ESP system operation as per design

Note 1 to entry: Occasionally referred to as factory acceptance test in case of ESP component and as string test in case of assembled ESP system.

3.62

functional specification

document that describes the features, characteristics, process conditions, boundaries and exclusions defining the performance and use requirements of the product, process or service

Note 1 to entry: See ISO 13879 and ISO 13880.

3.63

gas handler

component of an electrical submersible pump system that conditions multiphase flow, without gas separation, to decrease the degradation of pump performance

3.64

gas oil ratio

GOR

produced gas-oil ratio

volumetric ratio of gas to oil at standard conditions

3.65

gas separator

component of an electrical submersible pump system that mechanically separates a portion of the free gas from the wellbore fluids prior to the fluids entering the pump or gas handler

3.66

head curve

amount of head generated by the pump as a function of flow rate for a specific speed

3.67

high potential test

test comprising of applying a DC voltage higher than the nominal voltage rating of the component for a specified amount of time

3.68

housing pressure rating

value of the maximum allowable difference of internal less external pressure

3.69

impeller

stage segment rotated by the shaft which adds kinetic energy (velocity) to the fluid being pumped

3.70

inclination

angle, measured in degrees, by which the wellbore or survey-instrumented axis varies from a true vertical line

3.71

**induction motor
motor**

component of an electrical submersible pump system where AC power input is transformed to mechanical torque by means of electromagnetic induction

3.72

intake

subcomponent of a pump which provides a flow path to the first impeller, constructed either integral to the pump or bolted-on to the pump

3.73

intake screen

attachment to the pump intake used to filter solid particles from the produced fluid to protect the internal components of the pump

3.74**insulation**

provision to isolate the electrical potential between conductors and other conducting materials and to minimize leakage current from the conductors

3.75**insulation AC discharge test**

test where a high AC voltage is applied until the insulation breaks down or fails

3.76**insulation resistance test**

DC voltage-based test to evaluate the general condition of an insulation system

Note 1 to entry: This test is performed by measuring total leakage current flowing through the insulation system by applying a DC test voltage lower than the nominal voltage rating of the component.

Note 2 to entry: For the purposes of this test, the DC voltage applied shall be approximately $(0,5 \times \text{nameplate voltage})$ but not less than 500 V.

3.77**inversion point**

water cut percentage at which the emulsion viscosity is at its maximum

3.78**inverted system**

electrical submersible pump system configured with the pump on the bottom and motor on the top

3.79**item**

subject being considered

Note 1 to entry: The item can be an individual part, component, subunit, equipment, system, plant or installation.

Note 2 to entry: The item may consist of hardware, software, people or any combination thereof.

[SOURCE: ISO 14224:2016, 3.43].

3.80**jacket**

subcomponent of an electrical submersible pump power cable that covers the insulated conductors and provides mechanical protection from the downhole environment

3.81**labyrinth chamber**

chamber which utilizes a vertical U-tube, maze-like or tortuous flow path to delay wellbore fluid ingress through the chamber

3.82**lamination**

thin electrical grade metallic subcomponents that form the magnetic core of the stator and the rotor(s)

3.83**liner**

pipe extending from the surface or another point lower in the wellbore to a depth within or below the existing casing

3.84**manufacturing**

process and action performed by an equipment supplier/manufacture that are necessary to provide finished component(s), assembly(ies) and related documentation, that fulfil the requests of the user/purchaser and meet the standards of the supplier/manufacture

3.85

mechanical seal

subcomponent used to prevent flow between a rotating shaft and a stationary body

3.86

megger

instrument that generates a high voltage to test the resistance of insulation

3.87

minimum allowable bending radius insulation discharge

high-voltage test which is applied to a cable at its minimum allowable bending radius until the insulation breaks down/fails

3.88

mixed flow stage

type of stage with inlet flow path essentially parallel to shaft axis and exit between perpendicular and parallel to the shaft axis

3.89

model

equipment with unique components and operating characteristics which differentiate it from other equipment of the same type

3.90

motor fluid

fluid internal to the motor and seal chamber section that provides lubrication to the bearing systems, heat transfer to the unit skin, and dielectric insulation for the motor

3.91

motor lead extension

MLE

cable connected to the pothead for splicing to the power cable

3.92

motor operating temperature

temperature at or near the coils of the stator when it is energized

3.93

motor shroud

tube which covers the motor length of the electrical submersible pump to promote fluid flow past the motor

3.94

net positive suction head

NPSH

head corresponding to the difference between the pump inlet pressure and the vapour pressure and the density of fluid and the gravitational acceleration

3.96

new subcomponent

subcomponent which meets all supplier/manufacturer specifications and that has not been previously utilized in a component that has been either operated or installed in a field environment

3.97

operator

user of the equipment

3.98

operator's manual

publication issued by the supplier/manufacturer which contains detailed data and instructions related to the design, installation, operation and maintenance of the equipment

3.99**operating environment**

set of downhole conditions to which the component is exposed during its full life cycle

3.100**parallel chambers**

configuration of at least two seal chambers that function together to increase contraction capacity

3.101**passive gas separator**

device intended to reduce the amount of free gas entering into the pump intake through a selective fluid intake point or directing fluid flow path

3.102**performance rating**

technical limit(s) of a product when functioned at defined operating condition(s) and exposed to defined environmental condition(s)

3.103**permanent identification**

marking that remains legible over the intended service life of the component and/or subcomponent

3.104**permanent magnet motor**

type of motor that uses permanent magnet rotor(s) instead of induction rotor(s) as a way to create torque

3.105**pothead**

power connector on the end of the motor lead extension or power cable which mates to the motor

3.106**power cable**

component of the electrical submersible pump (ESP) system that connects the motor lead extension (MLE) or ESP motor surface electrical equipment or electrical penetrator connector to the MLE or motor

3.107**primary failed item**

failed component within the electrical submersible pump (ESP) system responsible for initiating the failure of the ESP system

3.108**primary failure mechanism**

failure mechanism associated with the primary failed item

3.109**pump construction**

configuration of which the pump stages are assembled with respect to axial movement relative to the shaft such as compression, floater, modular

3.110**pump differential pressure**

difference between discharge and intake pressures

3.111**pump housing**

tube containing pump subcomponents pertaining to the impellers and diffusers and functioning as a pressure barrier

3.112

pump shroud

tube which covers the pump length of the electrical submersible pump intended to limit free gas migration into the pump intake

Note 1 to entry: This item is sometimes referred to as an inverted shroud.

3.113

qualified person

individual with 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

3.114

radial flow stage

type of stage with inlet flow path essentially parallel to shaft and exit essentially perpendicular to the shaft axis

3.115

redress

activities performed to a component restricted to the replacement of parts that restores the equipment to its acceptable performance

3.116

recertified subcomponent

subcomponent that has been previously utilized in a component that has been operated or installed in a field environment and where the subcomponent has then been tested and/or inspected by the supplier/manufacturer using the same specifications and test equipment used in the evaluation of new subcomponents

3.117

reference fluid

water corrected to specific gravity of 1,0 at standard conditions

3.118

reference speed

shaft rotational speed at 60 Hz operation (3 500 r/min) and/or 50 Hz operation (2 918 r/min)

3.119

reference temperature

temperature set at 20 °C

3.120

repair

activity beyond the scope of redress that includes disassembly, re-assembly, and testing with or without the replacement of parts and can include machining, welding, heat treating or other manufacturing operations that restores the equipment to its original performance

3.121

reason for pull

motive for the electrical submersible pump assembly being pulled from the well

3.122

required function

function or a combination of functions of an item, which is considered necessary to provide a given service

3.123

rotor

subcomponent of a motor, mechanically attached to the shaft, whose magnetic field is induced by the magnetic field of the stator, resulting in torque applied to the shaft

3.124**safety factor**

defined measure of a reduced value from a known capacity

3.125**sand cut**

amount of sand or solid material in the wellbore fluid, typically expressed as a volumetric or mass percentage

3.126**seal chamber section**

component of an electrical submersible pump system that protects the interior of the motor from well fluids and other contaminants, carries the pump thrust, maintains pressure equalization with wellbore fluid pressure and/or transmits the motor torque to the component above it

3.127**semi-permanent identification**

marking that remains legible until the component and/or subcomponent is installed, such as, a metal stamped nameplate or tag

3.128**series**

component designation that identifies the outer diameter of its housing

3.129**shaft end play**

axial movement the component shaft has, generally measured from a reference point

3.130**shaft extension**

measurement of the component shaft end in relation to a reference point

3.131**shaft side play**

radial movement of a component shaft, resulting from clearances between rotating and stationary radial support components

3.132**shipping hardware**

auxiliary equipment that is shipped as part of an electrical submersible pump component to help protect the component during the shipping and handling process

3.133**slip**

difference between the AC motor synchronous speed and the actual operating speed divided by the synchronous speed, expressed in percentage

3.134**slugging**

well production characterized by cyclic flow of fluid mixtures of different densities, such as gas and liquid or two differing liquid viscosities

3.135**solution gas-oil-ratio**

amount of gas dissolved in the oil and increases with pressure until the bubble point pressure is reached, after which it is a constant

3.136**spline type**

machined configuration of the end of component shafts to allow connection by couplings to adjoining components, such as modified SAE and involute

3.137

stage

matched set of one impeller and one diffuser

3.138

stage name

nomenclature given to each pump stage type that typically defines its flowrate (best efficiency point), its size (diameter), and any special fluid handling characteristics

3.139

standard condition

condition set at 100 kPa (14,7 psia) and 15 °C (60 °F)

3.140

stator

subcomponent of the motor which contains laminations and coiled wire and housed in a tube

3.141

stock tank flow rate

wellbore fluid rate reported at standard conditions

3.142

subcomponent

portion of a component made up of one or more pieces

3.143

substantive design change

change to the design that is identified by the supplier/manufacturer as affecting the performance rating of the product

3.144

synchronous speed

supply power frequency divided by the number of poles of the AC motor

Note 1 to entry: When expressed in revolutions per minute, the formula to calculate synchronous speed is power frequency (expressed in Hz) times 120, divided by the number of poles.

3.145

tandem

designation that indicates where in the modular system an electrical submersible pump (ESP) component, such as a motor, would be used

Note 1 to entry: There are four different tandem designations for ESP components: upper tandem, middle tandem, lower tandem and single.

3.146

technical specification

document that prescribes the technical characteristics of the product, process or service to be provided to demonstrate its appropriateness to meet the requirements of the functional specification

3.147

test open flow

maximum pump flow rate attainable on test

3.148

thrust bearing

device to support axial load of a rotating part

3.149

thrust load bearing capacity

axial load capacity of a thrust bearing as defined by the bearing design, lubrication fluid and operating environment

3.150**thrust washer**

subcomponent mounted on an impeller which carries the axial thrust

3.151**torsional yield ratio**

ratio of the material yield point in torsion to the material yield point in tension

3.152**total demand distortion****TDD**

measure of the distortion of a current profile relative to its full load value

Note 1 to entry: It is calculated as the ratio of the root-mean-square total of the harmonic content to the full load value, expressed as a percentage. Using this measure, rather than total harmonic distortion (THD), allows for higher current THD when load is low.

3.153**total harmonic distortion****THD**

measurement of the harmonic distortion present in a voltage or current waveform

Note 1 to entry: It is calculated as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

Note 2 to entry: See H.2.

3.154**tubing-deployed electrical submersible pump****tubing-deployed ESP**

ESP system which is deployed into the wellbore using jointed tubing rather than by other deployment means such as wireline or coiled tubing

3.155**unique identifier**

unique combination of alphanumeric characters to identify a specific component

3.156**water cut**

ratio of produced water to produced liquids

Note 1 to entry: It is expressed as a percentage.

3.157**wireline deployed electrical submersible pump****wireline deployed ESP**

ESP system which is deployed into the wellbore using wireline rather than by other deployment means such as jointed tubing or coiled tubing

3.158**specified requirement**

design basis that the supplier/manufacturer uses for designing and establishing the performance ratings of the product

4 Symbols and abbreviated terms

AC	alternating current
ASD	adjustable speed drive
AWG	American wire gauge
BEP	best efficiency point
c	ampacity coefficient
C_{load}	de-rating factor
cP	centipoise
DC	direct current
dV/dt	change in voltage divided by change in time
E	efficiency
ESD	emergency shut down
ESP	electric submersible pump
F_a	adjusted thrust
F_n	thrust at test revolutions per minute
g	unit for g-force
G	gas volume fraction
GVF	gas volume fraction
H	head
H_a	adjusted head
H_n	head at test revolutions per minute
HP	horsepower
I	amperage
IEC	International Electrotechnical Commission
ID	internal diameter
K	extrapolated temperature for zero resistance
kVA	kilovolt-amperes
kW	kilowatt
L_t	thrust test load
L_0	nominal thrust load rating of bearing at 3 500 r/min and 5 cP lubricating fluid viscosity
MD	measured depth

MLE	motor lead extension cable
NEMA	National Electrical Manufacturers Association
NDE	non-destructive examination
OD	outside diameter
P_a	adjusted power
pH	potential of hydrogen
p_i	pump intake pressure
P_f	fluid power
PMM	permanent magnet motor
P_m	shaft mechanical power
P_n	power at test revolutions per minute
p_o	pump discharge pressure
PSD	pump setting depth
P_s	shaft power rating
P_{sc}	shaft coupling power rating expressed in kilowatt or horsepower
PVT	pressure, volume, temperature
PWM	pulse width modulated
Q	flow rate
Q_a	adjusted flow rate
Q_n	flow rate at test revolutions per minute
Q_{GGE}	gas flow rate out of gas exit
Q_{Gi}	intake gas flow rate
Q_{Li}	intake liquid flow rate
R^2	coefficient of determination
R_f	resistance of winding at the time of motor de-energization
R_b	resistance of winding before test at a known temperature
RMS	root mean square
ROR	recommended operating range
SCR	silicon controlled rectifier
T	temperature
T_{aw}	Average winding temperature rise

T_b	temperature at the time R_b is taken
T_f	temperature of the test fluid at the time of motor de-energization
THD	total harmonic distortion
TVD	true vertical depth
TVSS	transient voltage surge suppressors
UL	Underwriter's Laboratories
u_t	actual lubricating fluid test viscosity (absolute) in cP
v	rotational speed in revolutions per minute (r/min)
VDC	volts direct current
VFD	variable frequency drive
v_n	actual shaft rotational speed during test in revolutions per minute
v_r	reference revolutions per minute
VSD	variable speed drive
WAG	water alternating gas
Y_i	predicted value of the dependent variable as determined by the mathematical model
y_i	observed value of the dependent variable
$\bar{y}$	mean of the observed data y_i
β	Input power in kilowatts (kW)
ρ_f	fluid density
τ	torque

5 Functional specification

5.1 General

The user/purchaser shall prepare a functional specification when ordering components which conform to this document and shall specify the requirements and operating conditions as appropriate. This information is used by the supplier/manufacturer to recommend the components for the application. The user/purchaser shall specify the units of measurement for the data provided.

ESPs are designed for specific applications. When used in other applications, re-evaluation is required. The process used for this re-evaluation shall be no less stringent or documented than that required for the initial application, and shall be subject to approval.

The user/purchaser shall specify in the functional specification, whether the supplier/manufacturer technical specification response is based on supply of component(s) only or on component(s) and assembled system(s).

5.2 Component type

The user/purchaser shall request an ESP system on the basis of the following conditions:

- production profile for production period (i.e. the expected operating time period of the system);
- fluid characteristics;
- deployment method of the ESP, such as jointed tubing, wireline, coiled tubing.

5.3 Functional requirements

5.3.1 General

The user/purchaser shall specify the known and anticipated application parameters and requirements to the best of their knowledge. Operational issues that can have an effect on the systems operation and durability, such as frequency of shutdowns, power interruptions, production fluid changes, power quality and other issues, shall also be specified.

5.3.2 Application parameters

5.3.2.1 General

While installed, the ESP system shall perform in accordance with its functional requirements, which are typically determined based on application parameters.

5.3.2.2 Well information

5.3.2.2.1 Requirements

The following well information, whether planned or existing, shall be specified:

- a) geographical location;
- b) operating environment, such as heavy and conventional oil production, coal bed methane applications and source water production;
- c) well type, such as vertical, slant, deviated or horizontal;
- d) wellhead location, such as onshore, platform or subsea;
- e) reservoir type, such as carbonate, consolidated sandstone, unconsolidated sandstone, coal or shale;
- f) reservoir recovery mechanism or process, such as aquifer drive, solution gas drive, water flood, thermal or coal dewatering;
- g) enhanced oil recovery, such as CO₂ flood, water-alternating-gas or polymer flood;
- h) existing or planned power supply details, such as generator/utility, volts, frequency, kVA/Amp supply limitations;
- i) existing or planned surface equipment details, such as switchboard, 6-step ASD, PWM ASD, filtered PWM ASD, space restrictions.

5.3.2.2.2 Supplemental Information

The following well information shall be specified, if available:

- a) well profile, such as “S shaped”, “U shaped”, sinusoidal or multilateral;

- b) geothermal gradient/profile;
- c) pertinent production history using ESP's and other methods, such as other artificial lift methods or natural flow.

5.3.2.3 Completion information

5.3.2.3.1 Requirements

The following completion information, whether planned or existing, shall be specified:

- a) proposed pump setting depth in terms of MD and TVD of the pump intake;
- b) existing or planned total well depth, such as plug back depth in terms of MD and TVD;
- c) depth(s) of producing interval(s), top and bottom, in terms of MD and TVD;
- d) casing/liner size including outside diameter and weight, connection type and grade of production casing;
- e) minimum drift diameter through wellhead to bottom of the ESP assembly;
- f) production tubing size(s) including outside diameter, mass (weight), connection type, and grade;
- g) completion type, such as perforated casing or open hole;
- h) sand control measures, such as none, slotted liner, gravel pack or sand screen;
- i) ESP system configuration, such as single, dual back-up/boost or y-tool.

5.3.2.3.2 Supplemental information

The following completion information shall be specified, if available:

- a) well deviation survey; or, if not provided, as a minimum:
 - inclination and estimated dogleg severity at pump setting depth;
 - maximum dogleg severity between wellhead and pump setting depth for each casing or liner segment that the ESP has to pass through during installation;
- b) production tubing inner coating type and thickness;
- c) completion thermal characteristics, such as heat transfer coefficients for completion, insulated tubing/annulus, or flowing temperature profile;
- d) completion diagram.

5.3.2.4 Operating and production information

5.3.2.4.1 Requirements

The following operating and production information shall be provided over the life cycle of the system, such as early life, mid-life and late life:

- a) expected well production flow performance, including, as a minimum, expected flow rate such as stock tank flow rate or pump discharge rate, flowing bottom-hole pressure or fluid level at expected flow rate for a specified depth, and any maximum drawdown limitations;
- b) water cut;
- c) tubing head flowing pressure;

- d) casing head pressure;
- e) static temperature at a reference depth;
- f) total producing gas-oil-ratio;
- g) special operational conditions, such as unloading heavy completion fluids, sand face control limitations, delayed start-up, unusual anticipated duty cycles (stops and starts);
- h) minimum expected bottom-hole temperature;
- i) maximum expected bottom-hole temperature.

5.3.2.4.2 Supplemental information

The following operating and production information shall be provided over the life cycle of the system, such as early life, mid-life and late life, if available:

- a) sand cut;
- b) wellhead flowing fluid temperature;
- c) flowing temperature at a reference depth;
- d) slugging tendency, such as gas, water, solids or steam;
- e) desired operating frequency range and desired operating frequency at target rate.

5.3.3 Environmental compatibility

The user/purchaser shall specify the environmental compatibility requirements and preferred fluid property correlations by providing the following parameters:

- a) oil:
 - 1) density at standard temperature and pressure or API gravity;
 - 2) viscosity at standard conditions;
 - 3) bubble point pressure at reservoir temperature;
 - 4) solution gas-oil-ratio;
- b) water:
 - 1) pH;
 - 2) density;
 - 3) chloride concentration/salinity;
 - 4) other corrosives, if applicable;
- c) gas:
 - 1) Composition, such as:
 - i) CO₂ concentration (mole percentage);

- ii) H₂S concentration (mole percentage);
- 2) specific gravity;
- d) solids:
 - 1) history of solids related problems (e.g. erosion, plugging, wear);
 - 2) erosional velocity limit, if known;
 - 3) morphology, such as size, structure, angularity, composition;
 - 4) if sand control system is present, expected particle size distribution that will be present in production fluid;
 - 5) scale deposition tendency;
 - 6) asphaltene deposition tendency;
 - 7) paraffin deposition tendency.
- e) other:
 - 1) emulsion properties, such as:
 - i) inversion point data (percentage water cut);
 - ii) emulsion viscosity at downhole operating conditions over predicted pump life;
 - iii) emulsion forming tendency;
 - 2) foamy oil behaviour, such as that affecting annular fluid level;
 - 3) other fluid types and concentrations, such as diluent, corrosion/scale inhibitor, completion fluid, dispersants and injection points in the wellbore.

5.3.4 Compatibility with related well equipment and services

5.3.4.1 General

The user/purchaser shall specify related well equipment and service considerations that can impact the compatibility of the proposed component for the well such as material requirements, dimensional limitations, transportation, and installation restrictions, to ensure that the component conforms to the intended application.

5.3.4.2 Accessory equipment and well operation

The following topics shall be considered for the application:

- a) dimension of chemical injection tubing/string line and injection point such as above pump, below pump, annulus, tubing string;
- b) surface instrumentation dimension and location such as above or below pump as applicable;
- c) surface equipment dimensions, location relative to the pump and attachment to the pump such as by pass systems, clamps, shrouds, pod, tail pipes, backflow valves, swages;
- d) well intervention limitations such as; maximum allowable pump length, maximum coiled tubing diameter;
- e) packer type, location in the wellbore relative to ESP assembly;
- f) casing gas venting scheme such as vented to atmosphere, vented to production flow line, no venting;

- g) other completions related equipment that might impact the deployment and/or operation of the ESP system.

5.4 User/purchaser selections

5.4.1 General

[Table 1](#) provides the compiled list of the selection criteria for ESP components that shall be selected by the user/purchaser. The grades can vary by component as selected by the user/purchaser. Guidelines on the selections available is provided in [5.4.2](#), [5.4.3](#) and [5.4.4](#).

Table 1 — User/purchaser grade selections

Component	Selected grades								
	Design validation (Annex A)			Functional evaluation (Annex C)			Quality control (7.4)		
	V1	V2	V3	F1	F2	F3	Q1	Q2	Q3
Bolt-on discharge				a	a	a			
Pump and gas handlers									
Bolt-on intake					a	a			
Mechanical gas separators						a			
Seal chamber sections									
Motor									
Cable, MLE and pothead									
Assembled ESP system	Annex B^b			Annex E					
^a Unavailable sections.									
^b Indicates that component has no grade selections.									

5.4.2 Design validation

This document provides three design validation grades as indicated in [Table A.1](#), of which one shall be selected by the user/purchaser:

- V1: highest grade;
- V2: intermediate grade;
- V3: basic grade.

5.4.3 Component functional evaluation

The user/purchaser shall specify a component functional evaluation grade for each component as indicated in [Table 1](#). This document provides requirements for three functional evaluation grades, noting that some components can have fewer:

- F1: highest level of functional evaluation;
- F2: intermediate level of functional evaluation;
- F3: basic level of functional evaluation.

For assembled systems, guidelines for completing a functional evaluation are provided in [Annex E](#).

5.4.4 Quality grades

The user/purchaser shall specify one of the following three quality grades, which are detailed in [Clause 7](#):

- Q1: highest level of quality;
- Q2: intermediate level of quality;
- Q3: basic level of quality.

5.4.5 Shipping, handling and storage

The user/purchaser shall specify environmental conditions and projected storage duration as well as any special shipping and handling requirements for the components.

5.4.6 Operator's manual

The user/purchaser shall specify if an operator's manual for the ESP system as specified in [7.2.3](#) is required.

5.4.7 Subcomponent condition classifications in manufacture of components

The user/purchaser shall apply the following as it pertains to subcomponent classification use in the manufacture of components:

- All Q2 and Q1 specified equipment shall be manufactured using “new” subcomponents only.
- For Q3 specified equipment the subcomponent condition classifications shall be specified as either “new only” or “new and/or recertified” as specified in [Clause 9](#).

5.4.8 Additional documentation

The user/purchaser may specify additional documentation, testing, and acceptance criteria as necessary to meet their requirements.

6 Technical specification

6.1 General

The supplier/manufacturer shall prepare a technical specification, which responds to the requirements in the functional specification set forth by the user/purchaser or which identifies in detail where variance(s) to the requirements in the functional specification exist or are offered.

The technical specification comprises three classes of information relating to obligation for disclosure of these documents by the supplier/manufacturer to the user/purchaser:

- Public information: this information should be identified as such and provided without restrictions (e.g. an ASTM material specification and published performance curves).
- Confidential information: this information should be identified as such (e.g. an engineering drawing) and may be either provided or made available for inspection.
- Trade secrets: this information should be identified as such (e.g. a secret formula or process), in which there is no obligation to disclose it to the user/purchaser.

The timing of disclosure may be governed by agreement between the supplier/manufacturer and the user/purchaser, considering the development time required. The documentation and disclosure requirements of this clause are separate from the requirements of other (sub)clauses, e.g. [7.2](#).

The supplier/manufacturer shall document a summary of the technical specification response to the functional specification in accordance with [6.13](#).

Where a covered component or system includes a non-covered component, the inclusion of the non-covered component shall not cause the specified requirements or performance ratings of the component or systems as established under this document to be invalidated. The evidence supporting this shall be documented by the supplier/manufacturer. Components or systems not covered in this document can be addressed in other national or international standards.

This document 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 shall clearly and completely identify any variations from the requirements of this document.

6.2 Design criteria

6.2.1 General

The supplier/manufacturer shall demonstrate conformance to the design basis and performance rating(s) of the component as per [6.2.5](#) and [6.2.6](#). Manufacturing requirements are detailed in [Clause 7](#).

6.2.2 Design documentation

Documentation of the design process for each type, size and model of component shall at least include:

- a) design criteria with references to the essential variables considered when designing the component conforming to the requirements of the design basis;
- b) engineering drawings and bill of materials;
- c) applicable specifications and standards;
- d) validation testing procedures, acceptance criteria, and approved results (see [Annex A](#));
- e) design verification and acceptance criteria;
- f) published performance curves, where applicable;
- g) design changes and design change justifications.

6.2.3 Materials

6.2.3.1 General

Metallic and non-metallic materials shall be specified by the supplier/manufacturer and shall be appropriate for the requirements in the functional specification. The supplier/manufacturer shall have documented specifications for all materials in critical subcomponents. All materials used shall conform with these specifications.

Critical subcomponents include those whose function includes any of the following:

- containment of pumping pressure, e.g. pump housing, head, base, bolting;
- possible containment of well pressure, e.g. sealed vessels that well pressure can leak into in service and that can still contain well pressure after pulling;
- transmission of torque between the ESP components, e.g. shaft, coupling, housings, head and base;
- radial or axial support of rotating components, e.g. radial bearing, bearing;

- weight support, e.g. housing, head, base, body (of seal chamber section), bolting, tubing crossover;
- sealing element, e.g. o-ring, bag, mechanical shaft seal faces and bellows;
- power electrical conductors, e.g. conductors in cable, leads, magnet wire, terminals;
- primary power electrical insulation, e.g. insulation on cable, leads, magnet wire, terminals/connectors.

As an exception, material substitutions in validated equipment designs are allowed without validation testing, provided that the change in material does not constitute a substantive design change and that the supplier/manufacturer's material selection criteria are documented and approved by a qualified person and meet all other requirements of this document.

6.2.3.2 Metallic materials

6.2.3.2.1 General

The supplier's/manufacturer's specifications shall define for all metallic materials where applicable to the specific use of the material:

- a) chemical composition according to an applicable standard or to a supplier's/manufacturer's internal specification;
- b) chemical composition limits;
- c) mechanical property limits, to include as a minimum:
 - 1) tensile strength;
 - 2) yield strength;
 - 3) elongation;
 - 4) hardness.
- d) electrical properties:
 - 1) resistivity or conductivity.
- e) magnetic properties:
 - 1) magnetic permeability;
 - 2) core loss.

6.2.3.2.2 Welds, brazing, and soldering

Welds, brazing and soldering shall be specified appropriate to the material, function, and service of the component and/or assembly. The supplier's/manufacturer's specification shall include the applicable parameters of the process and the resulting joint, including but not limited to:

- a) industry standards applied to the welding procedure, process, method, etc. (e.g. ASME BPVC Section IX or AWS B2.1/AWS B2.1M);
- b) standard weld symbols;
- c) basic process;
- d) filler metal;
- e) preparation, such as joint dimensions, tolerance, and contour;

- f) process parameters, such as temperature, amperage, polarity, heat treatment;
- g) final parameters, such as dimensions, tolerance, contour, and defect criteria.

6.2.3.3 Coatings or surface treatments

Coatings or surface treatments shall be in response to the operating environment specified in the functional requirements. Coatings and surface treatments addressed by this subclause are limited to those that provide performance enhancements to erosion, anti-friction and corrosion of subcomponent materials, which are designed to be in direct contact with production fluids as specified in the design basis. The supplier's/manufacture's specifications shall specify, where applicable, the characteristics and acceptance criteria of the coatings or surface treatments including but not limited to:

- a) basic coating type, trade name or surface treatment composition;
- b) corrosion and/or chemical resistance;
- c) hardness;
- d) minimum and maximum coating thickness;
- e) roughness;
- f) application process;
- g) bond strength;
- h) coupon testing;
- i) defect criteria, e.g. holidays.

6.2.3.4 Non-metallic materials

6.2.3.4.1 Polymers

The supplier's/manufacture's specifications shall define for all polymer materials where applicable to the specific use of the material:

- a) type of polymer;
- b) mechanical property limits:
 - 1) tensile strength, new and aged;
 - 2) elongation at rupture, new and aged;
 - 3) durometer (hardness) or modulus;
 - 4) thermal conductivity;
 - 5) thermal expansion coefficient;
 - 6) minimum and maximum recommended service temperature.
- c) electrical properties:
 - 1) volume resistivity;
 - 2) dielectric constant;
 - 3) dielectric strength;

- 4) dissipation factor at 60 Hz.
- d) fluid compatibility.

6.2.3.4.2 Ceramics

The supplier's/manufacturer's specifications shall define for all ceramic materials where applicable to the specific use of the material:

- a) ceramic type, name and grade;
- b) chemical composition;
- c) mechanical properties:
 - 1) grain size;
 - 2) density;
 - 3) hardness;
 - 4) transverse rupture strength;
 - 5) compressive strength;
 - 6) fracture toughness.
- d) thermal properties:
 - 1) thermal expansion coefficient;
 - 2) thermal conductivity.
- e) electrical properties:
 - 1) volume resistivity;
 - 2) dielectric constant;
 - 3) dielectric strength;
 - 4) dissipation factor at 60 Hz.
- f) minimum and maximum recommended service temperature.

6.2.3.4.3 Motor fluid

The supplier's/manufacturer's specifications shall define for the motor fluid:

- a) viscosity/temperature curve;
- b) density;
- c) flash point;
- d) coefficient of thermal expansion;
- e) pour point;
- f) dielectric strength and testing standard utilized for measurement;
- g) minimum and maximum service temperature.

6.2.4 Dimensional information

6.2.4.1 Dimensional information for components

Dimensional information shall be provided for component(s) supplied, except cable (see [6.2.4.2](#)). For each component, the supplier/manufacturer shall specify:

- a) maximum component OD;
- b) component schematic, including external dimensional information;
- c) component mass (weight) and length as installed and shipped.

6.2.4.2 Dimensional information for cable

For the cable, the supplier/manufacturer shall specify:

- a) weight per unit length;
- b) profile and outer dimensions;
- c) shipping weight and dimensions, including reel;
- d) size of each conductor in terms of total diameter equivalent.

6.2.5 Component and assembled system design verification

Design verification shall be performed by the supplier/manufacturer to verify that the component and assembled system (if applicable) design conforms to the supplier's /manufacturer's design basis. Design verification activities are conducted to ensure that the design outputs meet the design basis input requirements. Design verification includes documented activities, such as review of design calculations, component testing and comparison with similar designs and historical records of defined operating conditions. Empirical methods and/or physical testing used in design verification shall be fully documented and supported with drawings and material specifications. All design verification documentation shall be included in the component design file and shall be approved by a qualified person other than the design's originator.

6.2.6 Component design validation

Design validation testing shall be performed to verify that the component design conforms to the component performance rating as per [Annex A](#). Design validation activities are conducted to ensure the component performance meets the intended application or use as defined by the supplier's/manufacturer's design basis. The design validation grade specifies the process of proving a design by testing to demonstrate conformity of the product to design requirements for each validation grade per [Annex A](#), which provides a detailed description of the three validation grades (V1, V2 and V3) in this document.

6.2.7 Component functional evaluation requirements

Functional evaluations shall be performed in accordance with [Annex C](#) and shall be approved by a qualified person to verify that each component manufactured meets the supplier's/manufacturer's documented requirements, technical specification and the functional specification. The results of these evaluations shall be documented and shall become a portion of the quality documentation for that component.

6.2.8 Assembled system functional evaluation

When selected by the user/purchaser, functional evaluation should be performed in accordance with [Annex E](#) and should be approved by a qualified person to verify that the assembled system meets

the supplier's/manufacture's documented requirements. The results of these evaluations should be documented and should become a portion of the quality documentation for that system.

6.2.9 Design changes

All design changes shall be documented and reviewed against the design verification and design validation to determine if the change is a substantive design change. A design that undergoes a substantive design change becomes a new design requiring design verification as specified in [6.2.5](#) and design validation as specified in [6.2.6](#).

Changes to a component identified as a substantive design change require design validation. Design change(s) shall be validated and verified through the same methods utilized for the original component or subcomponent. Where testing is performed on subcomponent(s), the test(s) shall simulate the design criteria conditions of the component at its rated limits. The supplier/manufacture shall document the detailed test results and analysis that demonstrate that the component or subcomponent(s) test adequately simulates the required range of design criteria conditions.

6.3 Technical specification — All components

6.3.1 Technical characteristics

The component shall be compatible with related well equipment and services as specified in [Clause 5](#).

While installed and operated in accordance with the functional specification, the component shall perform in accordance with the functional specification.

6.3.2 Performance rating

6.3.2.1 Shaft power rating

The supplier/manufacture shall specify the shaft power rating, where applicable, at the reference speed and temperature, typically reported as horsepower at 60 Hz (3 500 r/min) or 50 Hz (2 918 r/min). The shaft power rating shall be determined through validation testing as outlined in [6.2.6](#) and detailed in [Annex A](#).

6.3.2.2 Shaft coupling rating

The supplier/manufacture shall specify the shaft coupling rating, where applicable, at the reference speed and temperature, typically reported as horsepower at 60 Hz (3 500 r/min) or 50 Hz (2 918 r/min). The shaft coupling power rating shall be determined through validation testing as outlined in [6.2.6](#) and detailed in [Annex A](#).

6.4 Technical specification — Bolt-on discharge

6.4.1 General

The supplier/manufacture shall prepare the technical specification for the bolt-on discharge that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.4.2 Technical characteristics for the discharge

The discharge shall serve as a connection between the top of the ESP pump section and the well production tubing.

6.4.3 Performance ratings

The supplier/manufacturer shall provide the following performance characteristics in accordance with [Annex A](#):

- a) the maximum recommended flow capacity rating of the bolt-on discharge;
- b) the pressure rating of the bolt-on discharge.

6.4.4 Scaling of design validation

Scaling of design for bolt-on discharge is not allowed.

6.5 Technical specification — Pump and gas handler

6.5.1 General

The supplier/manufacturer shall prepare the technical specification for the pump and gas handler that responds to the functional requirements. The supplier/manufacturer shall provide to the user/purchaser the component data as defined in [7.2](#).

6.5.2 Technical characteristics for the pump and gas handler

The pump shall move fluid against a differential pressure.

The gas handler shall move fluid against a differential pressure and/or condition the fluid to change the properties or characteristics of the fluid.

Requirements for bolt-on intake and bolt-on discharge do apply when integral to the pump or gas handler.

6.5.3 Performance ratings

The supplier/manufacturer shall provide the following performance characteristics in accordance with [Annex A](#):

- a) the design performance curves – water only;
- b) the maximum GVF rating of the pump and gas handler;
- c) the pump stage thrust;
- d) the housing pressure rating.

6.5.4 Scaling of design validation

Scaling of design for the pump and gas handler is not allowed. Changes to the number of stages in a given pump housing is not considered scaling.

6.6 Technical specification — Bolt-on intake

6.6.1 General

The supplier/manufacturer shall prepare the technical specification for the bolt-on intake that responds to the functional requirements. The supplier/manufacturer shall provide to the user/purchaser the component data as defined in [7.2](#).

6.6.2 Technical characteristics for the bolt-on intake

The bolt-on intake shall:

- a) provide a flow path from the well bore to the inlet of the pump, gas handler or gas separator;
- b) contain a shaft to transmit torque and thrust.

6.6.3 Performance ratings

The supplier/manufacture shall provide the maximum flow capacity and pressure rating of the bolt-on intake in accordance with [Annex A](#).

6.6.4 Scaling of design validation

Scaling of design for the bolt-on intake is not allowed.

6.7 Technical specification — Mechanical gas separators

6.7.1 General

The supplier/manufacture shall prepare the technical specification for the mechanical gas separator that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.7.2 Technical characteristics

The mechanical gas separator shall:

- a) separate free gas from the fluid entering the ESP pump or gas handler section and vent to bypass the pump or gas handler;
- b) contain a shaft to transmit torque and thrust.

Requirements for bolt-on intake also apply when it is integral to the mechanical gas separator.

6.7.3 Performance ratings

The supplier/manufacture shall provide the mechanical gas separator performance curve in accordance with [Annex A](#).

6.7.4 Scaling of design validation

Scaling of design for the mechanical gas separator is not allowed.

6.8 Technical specification — Seal chamber sections

6.8.1 General

The supplier/manufacture shall prepare the technical specification for the seal chamber section that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.8.2 Technical characteristics

The seal chamber section shall:

- a) prevent contamination of the ESP motor with well fluid;

- b) provide a means for compensating for changes in the volume of motor fluid due to changes in temperature and pressure;
- c) provide a means for regulating pressure differential between the interior and exterior pressures of the seal chamber section in keeping with the volume expansion and contraction limits;
- d) handle axial thrust generated by the pump and motor, as required by design.

When the seal chamber section contains the shaft, the shaft shall provide a means for transferring the required torque and, where applicable, thrust.

6.8.3 Performance ratings

The supplier/manufacture shall provide the following performance characteristics for the seal chamber section in accordance with [Annex A](#):

- a) the volume contraction capacity;
- b) the operation deviation limits;
- c) the thrust bearing load capacity;
- d) the minimum operating speed for the thrust bearing;
- e) the horsepower requirement.

6.8.4 Scaling of design validation

Scaling of design for the seal chamber section is not allowed.

6.9 Technical specification — Motors

6.9.1 General

The supplier/manufacture shall prepare the technical specification for the motor that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.9.2 Technical characteristics

The motor shall convert input electrical power to the required torque needed to rotate all coupled ESP components at the required design frequency.

6.9.3 Performance ratings

The supplier/manufacture shall provide the following performance characteristics in accordance with [Annex A](#):

- a) the motor voltage for minimum current;
- b) the motor performance parameters:
 - 1) motor amperage;
 - 2) speed;
 - 3) torque;
 - 4) input kilowatts;
 - 5) efficiency;

- 6) power factor;
- 7) winding temperature rise at 100 % rated output power.
- c) the minimum and maximum internal motor operating temperature limits;
- d) the locked rotor current, torque and power factor values.

6.9.4 Scaling of design validation

Scaling of the design of the motor is allowed in accordance with [A.3.7.4](#)

6.10 Technical specifications — Power and motor lead extension cable

6.10.1 General

The supplier/manufacture shall prepare the technical specification for the power cable and MLE cable, hereafter referred to as “cable” that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.10.2 Technical characteristics

The cable shall:

- a) conduct electricity from the surface to the downhole motor;
- b) insulate the voltage supplied to the downhole motor.

6.10.3 Performance ratings

The supplier/manufacture shall provide the following performance characteristics in accordance with [Annex A](#):

- a) the cable voltage rating;
- b) the cable temperature rating;
- c) the cable ampacity coefficients;
- d) the cable conductor size;
- e) the cable acceptable minimum bending radius rating.

6.10.4 Scaling of design validation

Scaling of the design of the cable is not allowed.

6.11 Technical specifications — Pothead

6.11.1 General

The supplier/manufacture shall prepare the technical specification for the pothead that responds to the functional requirements. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

6.11.2 Technical characteristics

The pothead shall:

- a) conduct electricity from the cable to the downhole motor;

- b) insulate the voltage supplied to the downhole motor;
- c) seal the connection to prevent motor contamination by well fluid.

6.11.3 Performance ratings

The supplier/manufacture shall provide the following performance characteristics in accordance with [Annex A](#):

- a) the pothead voltage rating;
- b) the pothead temperature rating;
- c) the pothead ampacity coefficients;
- d) the pothead differential pressure performance rating;
- e) the pothead thermal cycling performance rating.

6.11.4 Scaling of design validation

Scaling of the design of the pothead is not allowed.

6.12 Assembled ESP system – Additional requirements

6.12.1 General

When an assembled ESP system is supplied, the supplier/manufacture shall prepare additional technical specification information for the assembled ESP system which responds to the requirements in the functional specification set forth by the user/purchaser or identifies in detail where variance(s) to the requirements in the functional specification exist or are offered. The supplier/manufacture shall provide to the user/purchaser the component data as defined in [7.2](#).

The supplier/manufacture shall document a summary of the assembled ESP system technical specification response to the functional specification in accordance with [6.13](#).

6.12.2 Technical characteristics

The ESP assembled system shall be designed to convert input electrical power into hydraulic power to move fluid to a point.

6.12.3 System capabilities

6.12.3.1 System capabilities characteristics

The supplier/manufacture shall provide the following system capabilities characteristics in accordance with [Annex B](#):

- a) the axial strength and bending tensile load capability;
- b) the surface temperature rating;
- c) the maximum amperage rating;
- d) the dogleg severity limits;
- e) the maximum deviation limits which the ESP assembly may be run through and operating at;
- f) the installed operating temperature range;

- g) the maximum pressurization and depressurization rates;
- h) the input surface power required to the power cable at the wellhead;
- i) the assembled ESP system motor fluid percentage utilization of each seal chamber contraction capacity;
- j) the minimum and maximum operating speed.

6.12.3.2 Dimensional information

The supplier/manufacturer shall specify the following dimensional information for the assembled system and auxiliary components:

- a) effective diameter;
- b) system schematic;
- c) total mass (weight) with and without cable;
- d) total length;
- e) bending stress analysis based on the wellbore and other pertinent information supplied in the functional specification.

6.13 Technical specification response guideline – ESP components

Table 2 provides a general guideline as to how the supplier/manufacturer shall respond to the functional specification. Table 2 is intended to provide a summary of the supplier/manufacturer response and does not replace the requirement to provide documentation in accordance with 6.1.

Table 2 — Technical specification response guideline

Case/Scenario description:			
Component recommendations	Description	Model name	Part number
Bolt-on discharge			
Pump(s) 1			
Pump(s) 2			
Gas handler			
Mechanical gas separator			
Bolt-on intake			
Seal chamber section(s)			
Motor			
Motor lead extension			
Power cable			
Accessories			
Functional specification response	Conformance with functional specification	Description of functional specification(s) that cannot be met	
Bolt-on discharge	☐ Yes ☐ No		
Pump(s) 1	☐ Yes ☐ No		
Pump(s) 2	☐ Yes ☐ No		
Gas handler	☐ Yes ☐ No		
Mechanical gas separator	☐ Yes ☐ No		
Bolt-on intake	☐ Yes ☐ No		

Table 2 (continued)

Case/Scenario description:			
Component recommendations	Description	Model name	Part number
Seal chamber section(s)	☐ Yes ☐ No		
Motor	☐ Yes ☐ No		
Motor lead extension	☐ Yes ☐ No		
Power cable	☐ Yes ☐ No		
Assembled ESP system (if supplied)	☐ Yes ☐ No		

7 Supplier's/manufacture's requirements

7.1 General

This clause contains the detailed requirements to verify that each component manufactured meets the requirements of the technical specifications. Design validation performance rating requirements by component are addressed in [Annex A](#).

7.2 Documented information

7.2.1 General

The supplier/manufacture shall establish and maintain documented information that relates to the requirements of this document. Documented information shall be maintained to demonstrate conformance to specified requirements. All documented information shall be legible and may be in any type of media, such as hard copy or electronic.

All documented information shall be available and auditable by the user/purchaser within 14 days after request. The supplier/manufacture may limit availability and auditing of sensitive or proprietary documented information to visual, controlled access review only.

Design documents (see [6.2.2](#)), data and component data sheet(s) shall be retained for 10 years after date of last manufacture of that component.

Delivery and manufacturing related documentation shall be retained for 5 years after date of delivery and manufacture.

7.2.2 Delivery documentation

Documentation supplied at the time of delivery of each component to the user/purchaser shall at least include:

- identification by component, including ancillary equipment;
- name and address of supplier/manufacture and assembly location identification where component was assembled;
- serial number;
- parts number(s);
- nameplate values;
- dimensions and weights of each component;
- functional evaluation documentation according to the specified functional grade, including testing facility location;

- h) quality documentation according to specified quality grade;
- i) validation grade;
- j) design summary sheets for the application, where applicable;
- k) component internal fluids used, such as motor fluid type, pump preservation fluid.

7.2.3 Operator's manual

When required by [5.4.6](#), the operator's manual shall be supplied. The operator's manual shall contain the following information:

- a) name and address of supplier/manufacture;
- b) supplier/manufacture component identification;
- c) representative illustration(s) identifying major ESP components, significant dimensions and configurations, and details of the interface connections;
- d) handling and storage guidelines;
- e) pre-installation inspection and pre-service procedures;
- f) installation and removal guidelines;
- g) operating and troubleshooting guidelines, including precautions for safe and environmentally acceptable operation. [Annex F](#) provides information on recommended operating range.

7.2.4 Certificate of conformance

When required by the quality grade or the user/purchaser, certificates of conformance shall be supplied. The certificate of conformance shall state that the component meets the following requirements:

- a) quality grade;
- b) functional grade;
- c) validation grade.

The statement shall include the component identification and shall be approved by the supplier's/manufacture's designated qualified person.

7.2.5 Component data sheet

7.2.5.1 General

When required by the quality grade or the user/purchaser, a component data sheet shall be supplied. The component data sheet shall contain the information as specified in [7.2.5.2](#) for all components and additional information as specified in [7.2.5.3](#) to [7.2.5.10](#), where applicable.

7.2.5.2 All components

The supplier/manufacture shall provide the following information for all components:

- a) quality grade;
- b) validation grade;
- c) product identification by component including ancillary equipment;
- d) dimensions and weights, installed;

- e) shaft power rating, where applicable;
- f) radial bearing configuration description, such as bearing material type and spacing, where applicable;
- g) spline diameter and type, where applicable;
- h) materials for housings, shafts seals and fasteners, where applicable;
- i) external coating types used, where applicable;
- j) maximum operating temperature rating, where applicable;
- k) flange compatibility as defined by the supplier/manufacturer, where applicable;
- l) rotational direction (bi-directional or clockwise/counter-clockwise as viewed from the top), where applicable;
- m) shipping, handling and storage requirements for appropriate storage, environmental conditions and duration.

7.2.5.3 Bolt-on discharge

The supplier/manufacturer shall provide the following information for each type of bolt-on discharge to be supplied:

- a) connection specifications, such as thread type, size and weight;
- b) flow capacity rating;
- c) pressure rating.

7.2.5.4 Pump and gas handler

The supplier/manufacturer shall provide the following information for each type of pump and gas handler components supplied:

- a) design performance curves – water only;
- b) maximum GVF rating; water and air;
- c) NPSH requirement;
- d) pump stage thrust;
- e) housing pressure rating;
- f) pump construction;
- g) number of stages;
- h) stage type (axial flow stage, mixed flow stage, radial flow stage), name and material;
- i) pump stage coating type, where applicable.

7.2.5.5 Bolt-on intake

The supplier/manufacturer shall provide the following information for each type of bolt-on intake to be supplied:

- a) flow capacity rating;
- b) inlet screen material, opening size and total inlet area, where applicable.

7.2.5.6 Mechanical gas separator

The supplier/manufacturer shall provide the following information for each type of mechanical gas separator supplied:

- a) performance curve;
- b) inlet screen material, opening size and total inlet area, where applicable.

7.2.5.7 Seal chamber section

The supplier/manufacturer shall provide the following information for each type of seal chamber section supplied:

- a) volume contraction capacity;
- b) operating deviation limits;
- c) thrust bearing type, load capacity, rotational direction, and location, such as top or bottom;
- d) horsepower requirements;
- e) minimum operating speed or speed load curve for thrust bearing;
- f) total number and type of seal chamber sections;
- g) positive seal element material, where applicable;
- h) chamber sequence order from top to bottom and connection type between seal chambers (parallel or series);
- i) total number of mechanical shaft seals;
- j) total motor fluid volume;
- k) check valve operating pressure.

7.2.5.8 Motor

The supplier/manufacturer shall provide the following information for each type of motor supplied:

- a) motor performance parameters in accordance with [6.9.3](#) and [Annex A](#);
- b) motor voltage for minimum current at specified load and speed;
- c) motor operating internal temperature limits;
- d) locked rotor current, torque and power factor;
- e) nameplate horsepower, voltage, amperage and reference frequency;
- f) thrust bearing type, load capacity, rotational direction and location, such as top or bottom;
- g) radial bearing type;
- h) motor insulation voltage rating;
- i) motor type and fluid volume;
- j) connection type to the MLE, such as tape-in or plug-in.

7.2.5.9 Power and motor lead extension cable

The supplier/manufacturer shall provide the following information for each type of cable and MLE supplied:

- a) voltage rating;
- b) temperature rating;
- c) ampacity coefficients;
- d) conductor size;
- e) acceptable minimum bending radius rating;
- f) conductor type, such as solid, stranded or compact stranded, conductor coating, where applicable, and number of strands in case the conductor uses stranded cable;
- g) conductor shield material and thickness, where applicable;
- h) geometry (flat or round);
- i) insulation material(s) and thickness;
- j) barrier layer(s) material and thickness, where applicable;
- k) braid, where applicable;
- l) jacket(s) material, where applicable;
- m) armor material and construction details, such as thickness, width of wrap, contour (e.g. flat or convoluted), class of galvanization;
- n) maximum acceptable DC leakage value expressed in ampere/volt/length;
- o) minimum ambient temperature for handling;
- p) weight per unit length.

7.2.5.10 Pothead

The supplier/manufacturer shall provide the following information for each type of pothead supplied:

- a) voltage rating;
- b) temperature rating;
- c) ampacity coefficients;
- d) differential pressure cycling performance rating;
- e) thermal cycling performance rating;
- f) minimum ambient temperature for handling;
- g) connection type to the motor, such as tape-in or plug-in and motor series;
- h) housing material;
- i) sealing element material(s);
- j) conductor insulation material(s);
- k) conductor connection insulation material(s).

7.3 Component identification

7.3.1 Permanent identification

Each component, with the exceptions of the discharge head and shaft coupling(s), shall be permanently marked with the component's unique identifier, e.g. serial number.

Components manufactured with "re-certified" subcomponents shall be permanently marked with a unique identifier included as part of the component serial number.

The bolt-on discharge head shall be permanently identified with the material type and thread type.

Shaft coupling(s) shall be permanently identified with a part number.

7.3.2 Semi-permanent identification

Each component shall be semi-permanently identified according to the supplier's/manufacture's specifications with the following information:

- a) Pump and gas handler: stage name, number of stages, shaft material, pump construction, part number, unique identifier, series, configuration, housing material, shaft size, bearing material.
- b) Bolt-on intake: series, part number, shaft size, shaft material, bearing material, housing material.
- c) Mechanical gas separator: configuration, unique identifier, model, series, part number, shaft size, shaft material, bearing material, name (such as rotary), housing material.
- d) Seal chamber section: chamber configuration, motor fluid, model, part number, unique identifier, shaft material, housing material, series, positive seal element type and material, o-ring material, thrust bearing type (such as standard, high load), chamber type and sequence.
- e) Motor: series, horsepower, configuration, motor fluid, part number, unique identifier, shaft material, housing material, thrust bearing type (such as standard, high load), radial bearing material, voltage, current, frequency.
- f) Power and motor lead extension cable: part number, unique identifier, conductor size, length (for main power cable, length of cable to be indicated on cable reel; for motor lead extension cable, length to be indicated on removable tag or stamped on pothead housing).

7.4 Quality

7.4.1 General

The supplier/manufacture shall have documented quality control procedures implemented by qualified personnel to ensure that each component supplied/manufactured conforms to the supplier's/manufacture's applicable specifications drawings, procedures and standards. This requirement also applies to all sub-suppliers to the supplier/manufacture. This requirement applies to any component or subcomponent supplied as conforming to the requirements of this document.

Each supplier of components used in the assembled ESP system shall have quality systems implemented that validate conformity of each component to the specified requirements. Verifiable evidence of conformity to the requirements shall be documented and provided by the supplier/manufacture with the component in conformance with the selected quality grade. Component validation records shall conform to the supplier's/manufacture's data controls.

7.4.2 Quality grade requirements

The requirements in [Table 3](#) shall be implemented as specified in the referenced subclauses. [Table 3](#) specifies the percentage of components to be inspected for each purchase order with a minimum of 1.

Where the percentage of components inspected is less than 100 %, the supplier/manufacturer shall use a documented method for determining the sample size.

For [Table 3](#), 100 % refers to all components/subcomponents (not including common hardware) and not 100 % of the component/subcomponent itself (such as surface area).

For [Table 3](#), subcomponent by specified sample size refers to the percentage of subcomponents to be inspected per heat or batch lot with a minimum of 1. Where the percentage of subcomponents inspected is less than 100 %, the supplier/manufacturer shall use a documented method for determining the sample size.

Testing methods specified in [Table 3](#) are requirements to meet the quality grade. Conformance to the requirements of a higher quality grade automatically qualifies the final component for lower grades. These procedures include acceptance criteria for all manufactured components furnished to this document.

Table 3 — Quality grade requirements summary for ESP components/sub-components

Property	Q3	Q2	Q1
Material certificate (metals and non-metals) (see 7.5)	Per supplier/manufacturer	Subcomponents by specified supplier/manufacture sample size excluding: — common hardware — process materials (such as penetrants, solvents) — shipping materials/equipment	Per Q2 with 100 % for sub-components excluding: — common hardware — process materials (such as penetrants, solvents) — shipping materials/equipment
Coatings and surface treatments (see 7.6.2)	Per supplier/manufacturer	Per supplier/manufacturer	Subcomponents by specified sample size (hardness shall be measured using coupons and/or dedicated subcomponent test samples)
Non-destructive weld examination for welds (see 7.9.2.2)	Visual inspection (see 7.9.2.2)	Per Q3 with 100 % of components and subcomponents with magnetic particle or liquid penetrant or radiographic or ultrasonic per supplier/manufacture inspection type selection criteria.	Per Q2
Component and sub-component dimensional inspection (see 7.9.3)	Per supplier/manufacturer	Critical features as specified in 7.9.3.4 on components and subcomponents by specified sample size	Per Q2 with critical features as specified in 7.9.3.4 on 100 % of the components and subcomponents
Securing of stator laminations (see 7.9.4.1)	100 % of subcomponents	100 % of subcomponents	100 % of subcomponents
Securing of rotor laminations (see 7.9.4.2)	Subcomponents by specified sample size	Subcomponents by specified sample size	100 % of subcomponents
Electrical integrity (see 7.9.4.3)	100 % of subcomponents	100 % of subcomponents	100 % of subcomponents
Gas block test for power and motor lead extension cable (see 7.9.4.4)	Per supplier/manufacturer	Per supplier/manufacturer	One sample of each production run

Table 3 (continued)

Property	Q3	Q2	Q1
Documentation (see 7.2)	Per supplier/manufacturer	Per Q3 with component data sheet, certificate of conformance	Per Q2 with functional drawings that include external profiles/dimensions and a cut away view showing the internal subcomponents, operator's manual
Traceability	Per supplier/manufacturer	Per supplier/manufacturer	100 % per 7.7

7.5 Raw materials

When required by the quality grade or when specifically requested by the user/purchaser, raw material used in the manufacture of components and subcomponents shall have a material certification report to verify conformance to the chemistries and properties as stated in the supplier's/manufacturer's documented material specifications. All materials shall be provided by audited and approved material suppliers. Material certifications are not required for common hardware or shipping hardware.

7.6 Additional processes applied to components

7.6.1 Documentation

Documentation of the processes described in 7.6.2 and 7.6.3 shall conform to at least one of the following requirements when approved by a qualified person:

- certificate of conformance stating that the material and processes applied conform to the supplier's/manufacturer's documented specifications and acceptance criteria;
- material test report verifying that the materials and processes conform to the supplier's/manufacturer's documented specifications and acceptance criteria.

7.6.2 Coatings and surface treatments

Coatings and surface treatments shall be performed according to documented procedures or international or national standards that result in a component or subcomponent that meets the supplier's/manufacturer's acceptance criteria.

When required by the quality grade, the surface hardness shall be measured using coupons and/or dedicated subcomponent test samples, based on the supplier's /manufacturer's sampling program. When coupons are used, they shall be placed or selected to reflect known sources of potential process variation.

7.6.3 Welding

Welding and brazing procedures and personnel qualifications shall be in accordance with a national or international standard, such as ASME BPVC Section IX or AWS D1.1/AWS D1.1M. Material and practices not listed in these standards shall be applied using weld procedures qualified in accordance with a national or international standard, such as the methods of ASME BPVC Section IX, AWS B2.1/AWS B2.1M.

The supplier/manufacturer shall ensure that welding and brazing procedures are appropriate for the specific well application considering issues such as corrosion susceptibility and hydrogen embrittlement. The supplier/manufacturer shall have documented acceptance criteria for all welds. The supplier/manufacturer shall have a documented procedure approved by a qualified person for selecting the non-destructive weld inspection process used.

7.7 Traceability

For Q3 and Q2 quality grades, traceability shall be in accordance with supplier's/manufacture's documented procedures.

For Q1 quality grade, all subcomponents with the exception of common hardware, process materials (such as penetrants, solvents) and shipping hardware shall be traceable to their raw material heat(s) or batch lot(s) and shall have a unique identifier. The heat, batch and lot identification of subcomponents shall allow for traceability of the subcomponent to the point that it is installed into the finished component.

Traceability of components (e.g. pump, motor, seal section) is considered sufficient if the equipment meets the requirements of this document when it leaves the supplier's/manufacture's inventory as a finished component.

7.8 Calibration systems

Inspection, measuring and testing equipment used for acceptance shall be used only within its calibrated range and shall be identified, controlled, calibrated and adjusted at specific intervals in accordance with the manufacturer's procedures, not to exceed one year. The supplier's /manufacturer's procedures shall be based on an internationally recognized standard.

Technologies for inspection, measuring and testing with verifiable accuracies equal to or better than those listed in this document may be applied with appropriate documentation and when approved by qualified personnel.

Calibration intervals shall be established based on repeatability and degree of usage. Intervals may be lengthened or shortened based on documented repeatability, amount of usage and calibration history.

The ranges, calibrations, resolutions, reading capabilities, time-based increments and recording capabilities shall have a confirmed accuracy that allows each parameter used for acceptance to be measured to a level of accuracy that assures the conformance to the specified acceptance criteria. Each measured parameter shall be documented as directly as practical from the subcomponent, component or assembly under test. All measuring and instrumentation systems shall be calibrated as a fully operational system and shall be used only within their calibrated ranges that facilitate repeatable readings by a qualified person.

7.9 Examination and inspection

7.9.1 General

When specified by the supplier/manufacture or user/purchaser, NDE and inspections shall be performed and accepted according to the supplier's/manufacture's documented specifications. The supplier's/manufacture's documented specifications shall include the requirements specified in this subclause and acceptance criteria.

NDE instructions shall be detailed in the supplier's/manufacture's documented procedures and conform with this document. All NDE instructions shall be approved by a qualified ISO 9712 Level III examiner and performed by a qualified person. Personnel performing and accepting NDE shall be qualified in accordance with the supplier's/manufacture's procedures as a minimum for evaluation and interpretation. Personnel performing visual examinations shall have an annual eye examination in accordance with ISO 9712, as applicable to the discipline to be performed. As an alternative, the quality manager shall be authorized to qualify quality inspector's reading/observation capabilities based on pre-specified criteria (such as eye examination chart readings from a specified distance).

The inspection results shall be documented.

NOTE For the purposes of this provision, ASNT RP SNT-TC-1A is equivalent to ISO 9712.

7.9.2 Weld

7.9.2.1 General

Weld inspections shall be performed as specified by the quality grade and according to the requirements of this subclause.

7.9.2.2 Visual inspection

All visible welds shall be visually inspected and documented in accordance with the quality grade. The following features shall be considered unacceptable in the visual inspection of a weld:

- a) cracks in base or filler metal;
- b) inclusions;
- c) surface defects.

The implementation of visual inspection requires documented procedures that include specific acceptance criteria and with approved and documented results. Visual inspection requires that 100 % of the accessible/visible surfaces to be inspected.

7.9.2.3 Radiographic inspection

Radiographic inspections shall meet the requirements of a national or international standard, such as ASTM E94. Acceptance criteria shall be in accordance with a national or international standard, such as ASME BPVC, Section VIII, Division I, UW-51 or ASME B31.3.

7.9.2.4 Ultrasonic inspection

Ultrasonic inspections shall meet the requirements of a national or international standard, such as ASME BPVC Clause V, (Nondestructive Examination), Article 5. Acceptance criteria shall be in accordance with a national or international standard, such as ASME BPVC, Clause VIII, Division 1, Appendix 12.

7.9.2.5 Magnetic particle inspection

Magnetic particle inspection shall be in accordance with a national or international standard, such as ISO 10893-5 or ASTM E709.

7.9.2.6 Liquid penetrant inspection

Liquid penetrant inspection shall be in accordance with a national or international standard, such as ISO 10893-4 or ASTM E165.

7.9.3 Component and subcomponent dimensional inspection

7.9.3.1 General

Components and subcomponents shall be dimensionally inspected in accordance with the quality grade to assure conformance with the supplier's/manufacturer's design criteria and specifications.

7.9.3.2 Shaft straightness

The supplier/manufacturer shall have documented procedures performed by qualified personnel for shaft straightness to assure conformance with the supplier's/manufacturer's design criteria and specifications prior to final assembly. The documentation of the final straightness measurements shall be provided to the user/purchaser.

7.9.3.3 Stator bore straightness

The supplier/manufacture shall have documented procedures performed by qualified personnel for stator bore straightness to assure conformance with the supplier's/manufacture's design criteria and specifications prior to final assembly. The documentation of the final straightness measurements shall be provided to the user/purchaser.

7.9.3.4 Critical dimensional features

This subclause addresses the minimum required characteristics of critical dimensional features to aid the supplier/manufacture and user/purchaser in making decisions. Critical dimensional features shall include those features necessary for reliable function of the equipment and will be documented by the supplier/manufacture using documented procedures and approved by a qualified person.

Critical dimensional features shall at least consist of the following:

- a) shaft straightness;
- b) stator bore minimum drift diameter;
- c) rotor OD/ID;
- d) alignment fit dimensions controlling mating and moving parts;
- e) dimensions associated with rotating clearances, such as bearings, stage sealing fits;
- f) length dimensions controlling stack up tolerances;
- g) o-ring groove diameters;
- h) surface finish for sealing surfaces;
- i) external diameters, when critical for the application;
- j) keyways and splines (via gages);
- k) housing and barstock threads required for sealing and/or alignment;
- l) geometric dimensioning and tolerances where deemed important.

Features that do not require dimensional inspection include:

- pump stage flow path;
- common hardware;
- tapes;
- motor laminations;
- process materials, such as penetrants, solvents;
- encapsulation materials;
- shipping hardware and materials.

The supplier/manufacture may deem other dimensions to be critical based on the unique nature of the design.

7.9.4 Construction features

7.9.4.1 Securing of stator laminations

The supplier/manufacturer shall have documented procedures performed by qualified personnel to secure the stator laminations inside the stator housing from rotating under full voltage starting conditions. The supplier/manufacturer shall have a documented quality check procedure performed by a qualified person to verify the laminations have been secured.

7.9.4.2 Securing of the rotor laminations

The supplier/manufacturer shall have documented procedures performed by qualified personnel to secure the rotor end rings from shifting or loosening under starting or steady state operating conditions. The supplier/manufacturer shall have a documented quality check procedure performed by a qualified person to verify the rotor end rings have been secured.

7.9.4.3 Electrical integrity

Throughout the manufacture of the stator, cable and pothead, the supplier/manufacturer shall have documented procedures performed by qualified personnel to ensure the electrical integrity.

7.9.4.4 Gas block test for stranded power cable and motor lead extension

The supplier/manufacturer shall have documented procedures performed by qualified personnel to ensure a gas block test conforming to IEEE Std 1018 or IEEE Std 1019 is performed on the manufactured section of stranded power cable and stranded motor lead extension.

7.10 Manufacturing non-conformance

The supplier/manufacturer shall establish and maintain documented procedures to ensure that a component or subcomponent that does not conform to specified requirements is prevented from being delivered or installed. This control shall provide for the identification, segregation, evaluation, documentation and disposition of a non-conforming component or subcomponent.

Non-conforming components or subcomponents dispositioned for rework shall be reinspected to the same requirements as the original component or subcomponent. Non-conforming components or subcomponents dispositioned for use as-is are acceptable for Q2 and Q3 quality grades provided that the dispositioned component or subcomponent is evaluated and approved by a qualified supplier/manufacturer person. For Q1, use as-is also requires approval of a qualified user/purchaser person. Responsibility for review and authority for disposition of non-conforming components and subcomponents shall be specified by the supplier's/manufacturer's documented procedures.

7.11 Component functional testing

Functional evaluation testing shall be successfully performed by the supplier/manufacturer on each component manufactured in accordance with this document. Functional test results shall be documented, dated, and signed by qualified personnel performing the test. The testing details and acceptance criteria shall be specified by the supplier's/manufacturer's documented procedures. Functional evaluation testing shall conform to requirements of [Annex C](#).

8 Shipping, handling and storage

8.1 General

Components shall be handled, stored and shipped according to the documented processes and specifications of the supplier/manufacturer to prevent deterioration. Components shall be packaged for transport according to supplier's /manufacturer's documented specifications to prevent damage from

normal handling and contamination. All material provided for transport shall be clearly identified for removal prior to use. API RP 11S3 provides guidelines for appropriate practices of component handling.

8.2 Storage

Components shall be stored in conformance with the guidelines provided in the component data sheet to prevent damage or deterioration under environmental conditions specified in the functional requirements.

For components that have been stored for prolonged periods, or that have been stored under environmental conditions that are outside those specified in the user functional requirements, the user/purchaser shall consult with the supplier/manufacturer to determine the shelf life of the components.

9 Subcomponent condition classifications in manufacture of components

Components supplied in accordance with the requirements of this document shall include new or recertified subcomponents or a combination of new and recertified subcomponents as specified by the user/purchaser in the functional specification.

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023

Annex A (normative)

Design validation performance rating requirements by component

A.1 General

This annex specifies the validation grade requirements which include multiple individual validation procedures(s), process(s) and test(s) and provides the supplier/manufacturer requirements for establishing the performance ratings as specified in [Clause 6](#). The supplier/manufacturer shall document the validation test procedures and results in a design validation file conforming to the requirements of [7.2](#). The design validation file shall contain test results that validate the design and shall be reviewed and approved by a qualified person other than the originator. This review shall confirm that, as a minimum, all of the design validation requirements of this document have been met. All testing shall be performed to conform to the requirements of [Clause 7](#) and the document procedures that include acceptance criteria with the results approved by a qualified person.

Ratings shall be established at performance identified during the validation testing process.

NOTE Results from design validation testing are not necessarily directly applicable for prediction of downhole performance during operation.

A.2 Design validation grades

This document provides three grades of design validation for the components:

- V1: Highest grade – Validation grade V1 applies to a component that satisfies the applicable functional, technical and manufacturing requirements of this document. The V1 design validation file shall include all of the design validation assumptions, calculations, evaluations, test results and other supporting documentation used to validate the design.
- V2: Intermediate grade – Validation grade V2 applies to a component that satisfies the applicable functional, technical and manufacturing requirements of this document. The V2 design validation file shall include all of the design validation assumptions, calculations, evaluations, test results and other supporting documentation used to validate the design. Validation grade V2 is a designation provided to accommodate use of the supplier's/manufacturer's existing and established design validation practices and documentation of performance to ensure all the components satisfies the requirements of this document.
- V3: Basic grade – Validation grade V3 applies to a component that satisfies the applicable functional, technical and manufacturing requirements of this document. The V3 design validation file has no specific requirements of the design validation assumptions, calculations, evaluations, test results and other supporting documentation used to validate the design. Validation grade V3 is a designation provided to accommodate that documentation of design validation of the applicable component may be determined from previously documented experience gained from manufacture of a component and/or internal design basis documentation. For validation grade V3, it is expected that existing information in the design validation file will be made available to satisfy the requirements of this document.

Previous documentation or testing applicable to existing components shall be accepted at its relevant grade. Components qualified to higher grades of design validation shall be considered qualified for lower grades of design validation.

Verifiable historical data shall include a minimum of 20 installations of at least one continuous year of acceptable performance each. Components provided as V2 shall additionally conform to [6.2.9](#) (design changes).

Table A.1 — Design validation grade requirements

ESP component	Requirement	V3	V2	V1
All, where applicable	Shaft power rating	No specific requirements	Per supplier/manufacturer	As per A.3.1.1
	Shaft coupling rating	No specific requirements	Per supplier/manufacturer	As per A.3.1.2
Bolt-on discharge head	Maximum flow capacity rating	No specific requirements	Per supplier/manufacturer	As per A.3.2.1
	Pressure rating	No specific requirements	As per A.3.2.2	As per A.3.2.2
Pump and gas handler	Design performance curves – water only	No specific requirements	Per supplier/manufacturer	As per A.3.3.2
	Maximum GVF rating	No specific requirements	Per supplier/manufacturer	As per A.3.3.3
	Pump stage thrust	No specific requirements	Per supplier/manufacturer	As per A.3.3.4
	Housing pressure rating	No specific requirements	As per A.3.3.5	As per A.3.3.5
Bolt-on intake	Maximum flow capacity rating	No specific requirements	Per supplier/manufacturer	As per A.3.4
Mechanical gas separator	Design performance curve	No specific requirements	Per supplier/manufacturer	As per A.3.5
Seal chamber section	Volume contraction capacity	No specific requirements	Per supplier/manufacturer	As per A.3.6.2
	Operation deviation limits	No specific requirements	As per A.3.6.3	As per A.3.6.3
	Thrust load bearing capacity	No specific requirements	Per supplier/manufacturer	As per A.3.6.4
	Minimum operating speed for thrust bearing	No specific requirements	Per supplier/manufacturer	As per A.3.6.5
	Horsepower requirement	No specific requirements	As per A.3.6.6	As per A.3.6.6
Motor	Motor performance parameters	No specific requirements	As per A.3.7.2.2	As per A.3.7.2.2
	Motor voltage for minimum current	No specific requirements	As per A.3.7.2.3	As per A.3.7.2.3
	Scaling of design validation	No specific requirements	As per A.3.7.4	As per A.3.7.4
	Motor operating internal temperature limits	No specific requirements	As per A.3.7.5	As per A.3.7.5
	Locked rotor current, torque and power factor	No specific requirements	Per supplier/manufacturer	As per A.3.7.6

"No specific requirements" indicates that the supplier/manufacturer has no requirement to provide any component design validation/design verification documentation or documented and verified historical use of the component in an environment justifiably similar to that of the functional specification.

"per supplier/manufacturer" requires either component design validation/design verification documentation availability or documented and verified historical use of the component in an environment justifiably similar to that of the functional specification. Each document requires verification by a qualified person.

Table A.1 (continued)

ESP component	Requirement	V3	V2	V1
Power cable and MLE	Voltage rating	No specific requirements	Per supplier/manufacturer	As per A.3.8.2.5
	Temperature rating	No specific requirements	Per supplier/manufacturer	As per A.3.8.2.5
	Ampacity coefficients	No specific requirements	Per supplier/manufacturer	As per A.3.8.2.4
	Conductor size	No specific requirements	Per supplier/manufacturer	As per A.3.8.2.2
	Acceptable minimum bending radius rating	No specific requirements	Per supplier/manufacturer	As per A.3.8.2.3
Pothead	Voltage rating	No specific requirements	Per supplier/manufacturer	As per A.3.9.2
	Temperature rating	No specific requirements	Per supplier/manufacturer	As per A.3.9.2
	Ampacity coefficients	No specific requirements	Per supplier/manufacturer	As per A.3.9.3
	Differential pressure performance	No specific requirements	Per supplier/manufacturer	As per A.3.9.4
	Thermal cycling performance	No specific requirements	Per supplier/manufacturer	As per A.3.9.5
"No specific requirements" indicates that the supplier/manufacturer has no requirement to provide any component design validation/design verification documentation or documented and verified historical use of the component in an environment justifiably similar to that of the functional specification. "per supplier/manufacturer" requires either component design validation/design verification documentation availability or documented and verified historical use of the component in an environment justifiably similar to that of the functional specification. Each document requires verification by a qualified person.				

A.3 Method for determining performance ratings

A.3.1 For all components

A.3.1.1 Shaft power rating

A.3.1.1.1 General

The supplier/manufacturer shall specify the shaft power rating at the reference speed and reference temperature and the maximum rated operating temperature, typically reported as horsepower.

A.3.1.1.2 Method

Verification of shaft power rating shall be through physical testing that at least includes:

- a minimum of ten samples from the same or multiple heat lot(s) for each specific diameter used for physical testing;
- performance of a pull test on five of the samples in accordance with ASTM E8, in which samples are machined only for connection requirements to the test equipment and all samples are machined per the supplier's/manufacturer's test specimen drawing;
- performance of torsion testing on five of the samples, in which samples are machined with all production features, such as splines, keyways, locating grooves, and all samples are machined per the supplier's/manufacturer's test specimen drawing;

- d) chemical and mechanical specifications that fall within the material requirements of the supplier/manufacturer.

Scaling of physical testing is permitted based on the following conditions:

- 1) selection of three diameters of each alloy for physical testing, in which for proper scaling, the minimum, maximum and mean diameter materials with the same production features are selected;
- 2) performance of physical testing of the samples;
- 3) performance of theoretical analysis by finite element analysis or equivalent analysis method against the test sample's actual dimensions and material properties;
- 4) Comparison of the results of the physical testing and theoretical analysis by calculating the ratio of the torsional yield between the theoretical and physical results, in which the yield point is determined by plotting an angle versus torque graph to show the transition from linear to plastic deformation and taking the standard 0,2 % offset on this curve;
- 5) scaling to other diameters is only permitted, if the theoretical versus physical torsional yield ratio varies less than 5 %.

The theoretical or physical torque at the torsional yield point is converted to horsepower. The shaft power rating shall be calculated by applying a temperature correction factor, based on a yield strength degradation versus temperature curve, which is determined either from data provided by source supplier or by physical testing and approved by a qualified person. The supplier/manufacturer may elect to apply additional de-rating correction factors to this calculation, which shall be specified in the design validation documentation.

A.3.1.1.3 Calculation

The shaft power rating shall be calculated using [Formula \(A.1\)](#) or [Formula \(A.2\)](#).

$$P_s = C_{\text{load}} (\tau \times v) / 9\,549 \quad (\text{metric units}) \quad (\text{A.1})$$

$$P_s = C_{\text{load}} (\tau \times v) / 63\,025 \quad (\text{US customary units}) \quad (\text{A.2})$$

where

C_{load} is de-rating factor, such as temperature and design margin;

P_s is shaft power rating expressed in kW or HP;

v is rotational speed expressed in r/min;

τ is torque at yield point expressed in N-m or in/lb.

A.3.1.1.4 Documentation and reporting

The following data shall be documented:

- a) material certification data, diameter, and machined features;
- b) unique identifiers and type descriptions of the test equipment and instrumentation.

The following data shall be documented during the test:

- a) for pull test sample, per ASTM E8:
 - 1) ultimate tensile strength;
 - 2) yield strength;

- 3) % elongation;
- 4) de-rating factors applied.
- b) for torsional test samples:
 - 1) ultimate tensile strength;
 - 2) yield strength;
 - 3) angle of twist (rad);
 - 4) de-rating factors applied.

A.3.1.2 Shaft coupling rating

A.3.1.2.1 General

The supplier/manufacturer shall specify the coupling rating at the reference temperature and the maximum rated operating temperature, typically reported as horsepower.

A.3.1.2.2 Method

Verification of the spline diameters and materials shall be through physical testing that at least includes:

- a) a minimum of five samples from the same lot for a diameter and spline type;
- b) performance of torsion testing on the five samples, in which all samples are manufactured per the supplier's/manufacturer's specification:
 - 1) prepare short sections of shafting, splined for the coupling to be tested, where shaft length is the minimum required for the test fixture/system;
 - 2) select the shaft material to match the intended rating of the coupling;
 - 3) insert the two shafts into the coupling and apply torque until either the shaft yields or the coupling fails:
 - if a shaft yields (per [A.3.1.1.2](#)), the coupling is to be rated at the same horsepower rating as the shaft that yielded;
 - if the coupling fails (such as by fracturing, splitting, deformation), the coupling is to be rated at 66 % of the horsepower at the torque failure point.
- c) chemical and mechanical specifications that fall within the material requirements of the supplier/manufacturer.

The shaft coupling rating shall be calculated by applying a temperature correction factor, based on a yield strength degradation versus temperature curve, which is determined either from data provided by source supplier or by physical testing and approved by a qualified person. The supplier/manufacturer may elect to apply additional de-rating correction factors to this calculation, which shall be specified in the design validation documentation.

A.3.1.2.3 Calculation

The shaft coupling power rating shall be calculated using [Formula \(A.3\)](#) or [Formula \(A.4\)](#).

$$P_{sc} = C_{load} (\tau \times v) / 9\,549 \quad (\text{metric units}) \quad (\text{A.3})$$

$$P_{sc} = C_{load} (\tau \times v) / 63\,025 \quad (\text{US customary units}) \quad (\text{A.4})$$

where

C_{load} is de-rating factor, such as temperature and design margin;

P_{sc} is shaft coupling power rating expressed in kW or HP;

v is rotational speed expressed in r/min;

τ is torque at yield point expressed in N-m or in/lb.

A.3.1.2.4 Documentation and reporting

The following data shall be documented:

- a) material certification data, part number, unique identifier (where applicable), spline diameter and type;
- b) unique identifiers and type descriptions of test equipment and instrumentation;
- c) torque applied, angle of twist (rad), de-rating factors applied.

A.3.2 Bolt-on discharge

A.3.2.1 Maximum flow capacity rating

The supplier/manufacture shall provide the maximum recommended flow capacity rating of the bolt-on discharge. The supplier/manufacture shall have a documented process that supports the reported maximum recommended flow capacity. Flow capacity shall be reported as a maximum rate and maximum velocity.

A.3.2.2 Pressure rating

Design validation shall be performed to a documented procedure and successfully completed to the supplier's /manufacturer's established acceptance criteria for each size, type and pressure rating. The pressure rating shall be the value of the maximum allowable difference of internal less external pressure.

A.3.3 Pump and gas handler

A.3.3.1 Specifications

The supplier/manufacture shall specify the pump performance curves (catalogue curves), the maximum GVF at the intake, and the housing pressure rating of the pump and gas handler components.

A.3.3.2 Standard test fluids

Reference fluids shall be used for testing. Gas used for testing shall be air or nitrogen. Specific gravity of the test fluids are measured/calculated at intake conditions.

A.3.3.3 Design performance curves – water only

A.3.3.3.1 General

Design performance curves shall be prepared showing the head, shaft input power, and efficiency as a function of flow rate. The performance curves shall be created by testing at a target rotational speed of either 2 916 r/min ($\pm 3\%$) or 3 500 r/min ($\pm 3\%$).

A.3.3.3.2 Test points

Tests shall be performed on a minimum of three different pump sections, in three different housing lengths.

A test point includes direct measurements of discharge and intake pressure, flow rate, and data required to correct test fluid to standard conditions. The data to be recorded for correcting fluid to standard conditions shall include shaft torque, rotation speed, and intake fluid temperature.

For each pump section, starting at zero flow, a minimum of seven test points shall be taken, at approximately equal flow intervals, with the last point being recorded at a flow which results in test open flow. Then, starting at test open flow, a minimum of seven test points shall be taken, at approximately equal flow intervals, with the last point being recorded at zero flow rate. This test shall be performed a minimum of three times.

A.3.3.3.3 Calculations

Formulae (A.5) to (A.16) shall be used to generate the pump performance curve and shall be documented per A.3.3.3.4.

Head:

$$H = (p_o - p_i) \times 101\,970 / \rho_f \quad (\text{metric units}) \quad (\text{A.5})$$

$$H = (p_o - p_i) \times 144 / \rho_f \quad (\text{US customary units}) \quad (\text{A.6})$$

Shaft power:

$$P_m = (v \times \tau) / 9\,549 \quad (\text{metric units}) \quad (\text{A.7})$$

$$P_m = (v \times \tau) / 5\,252 \quad (\text{US customary units}) \quad (\text{A.8})$$

Fluid power:

$$P_f = (H \times Q \times \rho_f) / 8\,810\,348 \quad (\text{metric units}) \quad (\text{A.9})$$

$$P_f = (H \times Q \times \rho_f) / 8\,463\,627 \quad (\text{US customary units}) \quad (\text{A.10})$$

Efficiency:

$$E = 100 \times P_f / P_m \quad (\text{metric units}) \quad (\text{A.11})$$

$$E = 100 \times P_f/P_m \quad (\text{US customary units}) \quad (\text{A.12})$$

Flow rate adjustment:

$$Q_a = Q_n \times (v_r/v_n) \quad (\text{A.13})$$

Head adjustment:

$$H_a = H_n \times (v_r/v_n)^2 \quad (\text{A.14})$$

Thrust adjustment:

$$F_a = F_n \times (v_r/v_n)^2 \quad (\text{A.15})$$

Power adjustment:

$$P_a = P_n \times (v_r/v_n)^3 \quad (\text{A.16})$$

where

E Efficiency expressed in per cent;

F_a is the thrust adjustment;

F_n is the thrust at test r/min;

H is the head in height of water column expressed in m or ft;

P_a is the power adjustment;

P_f is the fluid power measured at pump discharge expressed in kW or HP;

P_m is the mechanical power demanded by the shaft measured at its driven end expressed in kW or HP;

P_n is the power at test r/min;

p_i is the pressure measured at pump intake expressed in MPa or psi;

p_o is the pressure measured at pump discharge expressed in MPa or psi;

Q is the flow rate measured at pump discharge expressed in m³/d or bbl/d;

Q_a is the flow rate adjustment;

Q_n is the flow rate at test;

v_n is the test revolutions expressed in r/min;

v_r is the reference revolutions expressed in r/min;

ρ_f is fluid density measured at pump discharge expressed in kg/m³ or lb/ft³;

τ is the torque applied to the pump shaft at the pump intake expressed in N-m or ft/lb.

A.3.3.3.4 Documentation and reporting

The following data shall be documented for each pump housing length tested:

- a) stage name, series, pump construction type, number of stages, and unique identifier (such as serial number);
- b) unique identifiers, calibration data and type descriptions of test equipment and instrumentation.

The following data shall be documented during the test, at each of the test points:

- a) intake pressure;
- b) discharge pressure;
- c) intake temperature;
- d) discharge temperature;
- e) flow rates;
- f) rotation speed;
- g) shaft torque.

All raw test data should be retained in the original units of measure.

Tests performed at the target rotation speed of 2 916 r/min shall be reported in metric units and tests performed at the target rotation speed of 3 500 r/min shall be reported in US customary units as shown below:

- head shall be reported in metres of water or in feet of water;
- flow rate shall be reported in cubic metres per day or in barrels per day;
- power shall be reported in kilowatts or in horsepower;
- thrust shall be reported in newtons or in pounds force.

Best fit curves for head and power versus flow shall be determined using all the test points corrected to reference r/min.

A graph of head and power versus flow, using the best fit curves and test points corrected to target r/min, shall be constructed as follows:

- The horizontal scale of the graph shall show flow rate at the bottom of the graph using a scale that allows the data on the graph to be easily viewed. The scale on this axis shall start at zero and shall allow representation of the whole curve.
- The vertical axis shall show head, power and efficiency using scales that allow the data on the graph to be easily viewed. The scales on these axes shall start at zero and shall allow representation of the whole curves.

The supplier/manufacturer shall report pump curves at both 2 916 r/min and 3 500 r/min. These pump curves can be generated using affinity laws extrapolated from actual tests performed at a different rotation speed, if required.

A.3.3.4 Maximum gas volume fraction rating – air and water

A.3.3.4.1 General

Maximum GVF shall be determined based upon test data at BEP and reference fluid properties. Maximum GVF rating shall be determined for each stage type, using the maximum number of stages as determined in [Table A.2](#), or for specific fixed length pump and gas handler designs.

Table A.2 — Maximum allowable differential pressure by pump housing outer diameter

Pump housing outer diameter		Maximum differential pressure at BEP & 100 % liquid	
cm	in	kPa	psi
<9,78	<3,85	1 379	200
9,79 to 11,68	3,86 to 4,60	2 068	300
11,69 to 15,24	4,61 to 6,00	3 447	500
15,25 to 20,32	6,01 to 8,00	2 758	400
>20,33	>8,01	3 447	500

A.3.3.4.2 Test points

The test points for each stage type or specific pump and gas handler design consist of the following steps:

- Tests shall be performed on a minimum of one pump/gas handler component.
- Tests shall be performed at a target rotational speed of both 2 916 r/min (± 3 %) and 3 500 r/min (± 3 %).
- Intake pressure shall be 1 400 kPa (± 5 %). Intake temperature shall be at reference fluid conditions or, alternatively, corrected to reference fluid conditions.
- The BEP flow rate shall be established ± 2 % by starting with the discharge choke closed and then opening it until the target rate is achieved and flow loop discharge pressure is stabilized (ensuring pressure measurement values do not vary by more than 5 % for a minimum of 2 minutes). The discharge choke position and rotational speed shall remain unchanged for the remainder of the testing steps.
- Gas is introduced until the free gas content at the intake (GVF) is 5 % (± 1 %). Data shall be documented after intake flow and pressure are stabilized (at values ± 5 %) for a minimum of 5 minutes.
- Additional gas is introduced to increase the intake GVF by an additional 5 % (± 2 %). Data shall be documented after flow is stabilized (at values ± 5 %) for a minimum of 2 minutes. The process is continued by increasing GVF by increments of 5 % (± 2 %) until pump differential pressure cannot be stabilized (at values ± 5 %) for a minimum of 2 minutes or head becomes zero.
- Steps a) to f) shall be performed at least three times to ensure repeatability of results. Repeatability of results is achieved, if the repeated test results are evaluated and documented as acceptable by a qualified person.
- The reported rating shall be the average of the test results from step g).

A.3.3.4.3 Calculations

The following calculations shall be made to generate the pump GVF rating and documented per [A.3.3.4.4](#).

The percentage of free gas is given in [Formula \(A.17\)](#):

$$V_f = (100)(Q_{Gi})/(Q_{Gi} + Q_{Li}) \quad (\text{A.17})$$

The gas volume fraction is given in [Formula \(A.18\)](#):

$$G = (Q_{Gi})/(Q_{Gi} + Q_{Li}) \quad (\text{A.18})$$

where

Q_{Gi} is the flow rate of gas at intake;

Q_{Li} is the flow rate of liquid at intake.

A.3.3.4.4 Documentation

The following pump and test fluid data shall be documented:

- a) stage name, series, pump construction type, number of stages, and unique identifier (such as serial number);
- b) unique identifiers, calibration data and type descriptions of test equipment and instrumentation;
- c) intake pressure;
- d) discharge pressure;
- e) intake liquid flow rate;
- f) intake gas flow rate;
- g) intake temperature;
- h) discharge temperature;
- i) shaft torque;
- j) rotation speed.

All raw test data shall be documented in the original units of measure.

Tests performed at the target rotational speed of 2 916 r/min shall be reported in metric units and tests performed at the target rotational speed of 3 500 r/min shall be reported in US customary units as shown below:

- differential pressure shall be reported in megapascal or in pounds per square inch;
- liquid flow rate shall be reported in cubic metres per day or in barrels per day;
- maximum GVF shall be reported as the GVF at the point at which pressure readings become unstable (fluctuate more than $\pm 5\%$).

The pump design performance curves shall be generated based on the data collected in this testing as per [A.3.3.3](#).

A.3.3.5 Pump stage thrust

A.3.3.5.1 General

Design performance curves shall be prepared showing the axial thrust for one pump stage as a function of flow rate, at both 2 916 r/min and 3 500 r/min, using reference fluid.

Test points shall be taken per [A.3.3.3.4](#) with the addition that pump shaft axial down thrust and flow rate shall be included in the data measurements and the tested pump construction is of compression type.

Documentation of data shall conform with [A.3.3.5.3](#), with the addition that the pump shaft cross sectional area shall be documented.

A.3.3.5.2 Calculation method

The total axial thrust measured at each test point shall be corrected to standard conditions and target rotational speed. This total axial thrust value divided by the number of pump stages shall result in the thrust value per stage for the compression type pump construction.

The pump shaft axial thrust generated by the differential pressure on the shaft shall be calculated at each test point by multiplying the pump differential pressure at that test point, corrected to standard conditions and target r/min, by the shaft cross sectional area. For vertical pump tests, the portion of pump shaft axial thrust contributed by the mass of the shaft and impeller assembly shall be computed and subtracted from each test point. For horizontal tests, this value shall be zero.

For floater type pump construction, the hydraulic portion of the pump thrust at each test point shall be calculated by subtracting the pump shaft axial thrust measured at the test point from the thrust values calculated for the compression type pump construction.

The single stage hydraulic portion of the pump thrust at each test point shall be calculated by dividing the hydraulic portion of the pump thrust by the number of pump stages.

A.3.3.5.3 Documentation

A graph of flow rate versus single stage hydraulic thrust, using data calculated per [A.3.3.5.2](#), shall be constructed so that the horizontal scale is identical to the graph of head and power versus flow for the tested pump stage type and the vertical axis shows stage thrust using a scale that allows the data on the graph to be easily viewable and provides representation of the entire thrust curve range.

A.3.3.6 Housing pressure rating

Design validation shall be performed to a documented procedure and successfully completed to the supplier's/manufacture's established acceptance criteria for each series, design and material configuration. Test results shall determine the maximum allowable difference of internal less external pressure that can be exerted on the housing, which results in the rating. The test results shall be approved by a qualified person other than the design engineer and the testing engineer. Scaling does not apply to housing pressure rating.

A.3.4 Bolt-on intake

The supplier/manufacture shall provide the maximum recommended flow capacity rating and pressure drop of the intake and shall have a documented process that supports the rating.

A.3.5 Mechanical gas separator

A.3.5.1 General

The supplier/manufacture shall prepare mechanical gas separator performance curves for design validation.

A.3.5.2 Standard test fluid conditions

Reference fluid shall be used for testing. Gas used for testing shall be air or nitrogen. Specific gravity of the test fluids are measured/calculated at intake conditions.

A.3.5.3 Test fixture

The testing fixture shall have the following features:

- a) The intake shall be isolated to assure all fluids pass through to the interior of the component and capable of maintaining a constant pressure of 689 kPa (100 psi) ± 5 %.
- b) The vents shall be isolated to assure all vented fluids are contained for measurement. The differential pressure between the intake pressure and the gas vent shall be not greater than 0,34 kPa (5 psi).
- c) The drive system shall be able to measure input power.
- d) The test fixture shall have a pumping method incorporated in order to generate the required flow rate and pressure through the device. The pumping method shall be either of the following:
 - the test fixture shall have a pump, which is to be connected to the discharge side of the gas separator that is capable of producing a maximum liquid flow rate greater than that of the mechanical gas separator and a differential pressure of 1 379 kPa (200 psi) ± 10 %;
 - a booster pump to provide inlet flow at the specified pressure provided that the flow rate it generates is not greater than the maximum water only capacity of the component being tested (per [A.3.5.4.2](#)).

A.3.5.4 Design performance curves

A.3.5.4.1 General

Design performance curves shall be prepared showing mechanical gas separator efficiency and horsepower as a function of intake free gas percentage at a constant intake liquid flow rate. The performance curves shall be created by testing at target rotational speeds of both 2 916 r/min (± 3 %) and 3 500 r/min (± 3 %) at the test intake pressure.

A.3.5.4.2 Water only test points

Testing shall be conducted with the reference fluid to prepare a water only performance curve per [A.3.3.3.2](#).

A.3.5.4.3 Gassy fluid test points

Test points shall be taken based on the following conditions and in enough quantity to fully define the curve being created:

- a) Intake pressure shall be at 689 kPa (100 psi) ± 5 % throughout testing at all rates;
- b) Intake liquid flow rates shall be of 20 %, 40 %, 60 %, 80 % and 100 % of maximum of the component;
- c) Intake free gas percentage shall start at 5 % and increase in increments of 5 % until the component gas separation efficiency is less than 20 %. The testing shall be performed at each of the five prescribed liquid flow rates.

A.3.5.4.4 Calculations

The calculation for percentage of free gas shall be per [Formula \(A.17\)](#). The calculation for P_m (in kW or HP) shall be per [Formulae \(A.7\)](#) or [\(A.8\)](#).

The calculation for mechanical gas separator efficiency shall be per [Formula \(A.19\)](#).

$$E_{MGS} = 100 \times Q_{GGE} / Q_{Gi} \quad (A.19)$$

where

Q_{Gi} is the gas flow rate at inlet;

Q_{GGE} is the gas out gas exit.

A.3.5.4.5 Documentation and reporting

- 1) The following data shall be documented:
 - a) the series;
 - b) construction type;
 - c) unique identifier;
 - d) test pump details, such as series, stage name, number of stages and construction.
- 2) The following data shall be documented during the test, at each of the test points:
 - a) inlet pressure;
 - b) gas exit pressure;
 - c) liquid exit pressure;
 - d) inlet, liquid flow rate;
 - e) inlet, gas flow rate.
- 3) The following data shall be documented or calculated during the test, at each of the test points:
 - a) component shaft torque;
 - b) component shaft rotation speed.
- 4) The following data shall be documented or calculated based on mass balance equations during the test, at each of the test points:
 - a) liquid exit, liquid flow rate;
 - b) liquid exit, gas flow rate;
 - c) gas exit, gas flow rate;
 - d) gas exit, liquid flow rate.

The gas separator design performance curves shall be generated based on the data collected in this testing as per [A.3.5.4](#) and shall be reported along with all the data documented and calculated in [A.3.5.4.5](#)

A.3.6 Seal chamber section

A.3.6.1 General

To establish the performance ratings of the seal chamber section, the supplier/manufacturer shall perform the specified actions.

A.3.6.2 Volume contraction capacity

A.3.6.2.1 General

This subclause specifies the method that determines seal chamber contraction capacity. Ratings provided shall be at both vertical orientation and at the component's maximum deviation limit as specified on the component data sheet.

A.3.6.2.2 Gravity chambers

A.3.6.2.2.1 General

For a chamber that relies on gravity to separate seal chamber fluid from well fluid, such as labyrinth-type chamber designs, calculations or computer-based solid modelling can be used to determine the contraction capacity of the chamber. The calculations or models used to determine the capacity are subject to the conditions described in [A.3.6.2.2.2](#) and [A.3.6.2.2.3](#).

A.3.6.2.2.2 Sweep volume

The sweep volume capacity of a chamber is defined as the total volume in the chamber less any inactive volumes which can exist due to the physical design of the chamber.

A.3.6.2.2.3 Contraction capacity while deviated

When calculating the contraction capacity of the chamber when at the component's maximum deviation limit, there can be features that affect the contraction capacity based on the component's polar orientation. If the orientation of these features cannot be controlled, the features shall be assumed to be in the orientation that results in the smallest contraction capacity for calculation purposes.

A.3.6.2.3 Positive seal chambers

Positive seal chambers, such as bags/bladders/bellows or pistons, use a physical barrier to separate the well fluid from the internal seal chamber fluid. For these chambers and for the purposes of this document, contraction capacity shall be determined using experimental methods subject to the following:

- a) The test fixture shall simulate a seal chamber section to support the positive seal element(s) and provide a path from the internal chamber volume through a check valve which is rated for the specific seal chamber section design. The test fixture and testing fluid(s) shall be maintained at a relatively stable temperature throughout the testing procedure.
- b) The chamber(s) internal volume shall be filled with an incompressible fluid that has a viscosity of less than or equal to 60 cP. The chamber(s) external volume shall be filled with an incompressible fluid that has a viscosity of less than or equal to 60 cP or, alternatively, with air or nitrogen at a sufficient pressure to ensure the internal chamber is sufficiently contracted.
- c) The chamber(s) internal volume shall be filled with additional fluid until such time that the internal pressure of the chamber causes the check valve to open. Once the check valve opens, the filling process is stopped by reducing the filling rate until such time that the check valve closes.
- d) The chamber(s) internal volume shall be emptied while the positive barrier is pressurized externally, until such a time that the differential pressure across the barrier reaches the supplier's/ manufacturer's specification for the maximum differential pressure rating for the specific seal chamber design.
- e) The expelled fluid volume from the internal chamber in step d) shall be measured and reported as the maximum contraction volume of the chamber.

- f) Single positive seal chambers shall be tested independently to determine its contraction capacity. Multiple positive seal chambers that are connected in parallel to increase the contraction capacity shall be tested together to determine the contraction capacity of the combined chambers.

A.3.6.3 Operating deviation limitations

The supplier/manufacturer shall have documented procedures and acceptance criteria to support that the seal chamber section can perform its designed function at the stated maximum deviation as indicated on the component data sheet.

A.3.6.4 Thrust bearing load capacity

A.3.6.4.1 General

The objective of the thrust bearing load capacity test is to verify the load rating in both the clockwise and counter-clockwise directions of a hydrodynamic axial thrust bearing when immersed in lubricating fluid. This test verification shall be performed for each combination of runner and bearing designs.

A.3.6.4.2 Test equipment and procedure

The supplier/manufacturer shall use the following test equipment and procedure:

- a) As a minimum, the test equipment shall comprise of a thrust bearing, a thrust runner, a shaft, equipment required to fix the runner to the shaft, a drive motor, a housing to contain test oil and hold test pressure, equipment to regulate test pressure, test temperature, and to monitor the test parameters.
- b) The test shall be conducted such that the motor fluid temperature within the test apparatus is at the rated maximum temperature of the seal chamber section as specified by the supplier/manufacturer or higher. The temperature shall be monitored by measuring the motor fluid temperature within the test apparatus and shall be maintained within a range of $\pm 2,5$ °C ($\pm 4,5$ °F) throughout the test.
- c) The test fluid shall be supplier's /manufacturer's specified motor fluid and shall have a viscosity no higher than 3 cP at the maximum test temperature.
- d) The test setup shall provide test fluid that is essentially free of debris and contaminants such as air or water throughout the test.
- e) The chamber pressure shall be between 96 kPa and 2,76 MPa (14 psia and 400 psia). The pressure shall be maintained within a 69 kPa (10 psi) range throughout a given test.
- f) The test shall be conducted at revolution speed between 2 916 r/min and 3 500 r/min.
- g) A minimum of three samples shall be tested. Each sample shall be tested in both clockwise and counter-clockwise rotational direction.
- h) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test, with the exception of modifications to allow for temperature measurements of bearing pads.
- i) An axial load equal to the required test load shall be applied. The sample shall be rotated for a minimum of 30 min.

A.3.6.4.3 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to support the thrust bearing load ratings as indicated on the component data sheet.

The bearing passes these test acceptance criteria if there is no evidence of fluid film breakdown as determined by visual inspection of the bearing surfaces and approval by a qualified person other than the one performing the test.

Testing shall be completed successfully on all three consecutive samples. If one of the sets of three samples fails original testing, then testing shall be performed with a new group of three samples.

A.3.6.4.4 Determination of thrust bearing test load

[Formula \(A.20\)](#) shall be used to determine the thrust bearing load:

$$L_t = ((L_0 \times 1,25) \times (v_n / 3\,500)(u_t/5)) \quad (\text{A.20})$$

where

- L_t is the test load;
- L_0 is the nominal load rating of bearing at 3 500 r/min and 5 cP lubricating fluid viscosity;
- v_n is the actual shaft rotational speed during test expressed in r/min;
- u_t is the actual lubricating fluid test viscosity (absolute) expressed in cP;
- 1,25 is the standard safety factor.

A.3.6.5 Minimum operating speed for thrust bearing

A.3.6.5.1 General

The objective of the minimum operating speed for thrust bearing test is to validate the ability of the axial thrust bearing to handle a nominal load at the minimum rated rotational speed in both clockwise and counter-clockwise rotational directions. This test validation shall be performed for each combination of runner and bearing designs.

A.3.6.5.2 Test equipment and procedure

The supplier/manufacturer shall use the following test equipment and procedure:

- a) The test equipment shall be per [A.3.6.4.2](#).
- b) The test shall be conducted at any temperature. The temperature shall be monitored by measuring the motor fluid temperature within the test apparatus and shall be maintained within a range of $\pm 2,5\text{ }^{\circ}\text{C}$ ($\pm 4,5\text{ }^{\circ}\text{F}$) throughout the test.
- c) The test fluid shall be supplier's /manufacturer's specified motor fluid and shall have a viscosity no higher than 3 cP at the maximum test temperature.
- d) The test setup shall provide test fluid that is essentially free of debris and contaminants, such as air or water, throughout the test.
- e) The chamber pressure shall be between 96 kPa and 2,76 MPa (14 psia and 400 psia). The pressure shall be maintained within a 69 kPa (10 psi) range throughout a given test.
- f) The test shall be conducted at the specified minimum frequency as dictated by the supplier/manufacturer. The speed shall be held to $\pm 0\text{ } \%$ / $\pm 2\text{ } \%$ tolerance throughout the duration of the test.
- g) A minimum of three samples shall be tested. Each sample shall be tested in both clockwise and counter-clockwise rotational direction.

- h) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test, with the exception of modifications to allow for temperature measurements of bearing pads.
- i) Initial load applied to the thrust bearing before start-up shall be no less than 445 N (100 lbf). Once the test speed is reached, an axial load equal to 2 224 N (500 lbf) (± 5 %) shall be applied. The load shall be maintained for a minimum of 30 min.

A.3.6.5.3 Test acceptance criteria

The supplier/manufacturer shall have requirements and documented procedures and acceptance criteria to verify the minimum operating speed as indicated on the component data sheet.

Testing shall be completed successfully on all three consecutive samples. If one of the sets of three samples fails original testing, then testing shall be performed with a new group of three samples.

A.3.6.6 Horsepower requirement

The supplier/manufacturer shall have requirements and documented procedures and acceptance criteria to validate the horsepower requirement as indicated on the component data sheet.

A.3.7 Motor

A.3.7.1 Motor performance

The objective of the motor performance test is to validate the motor performance parameters. This is accomplished by recording the motor amperage, speed, torque, input kilowatts, efficiency, power factor, and average winding temperature rise at 100 % of rated output power under specified test conditions. This test applies a load device to the motor, such as a dynamometer.

The test shall be performed in a controlled environment, where key input parameters ambient fluid temperature, ambient fluid flow rate, motor torque, input voltage, input power frequency are controlled and output parameters amperage, speed, input kilowatts, power factor, average winding temperature rise are measured.

A.3.7.2 Test procedures

A.3.7.2.1 General

This subclause provides the details of the motor performance and motor voltage for minimum current test procedures.

A.3.7.2.2 Motor performance test

To establish the motor performance parameters from [6.9.3](#), the motor shall be run in a test loop under the following conditions:

- a) The cooling fluid (water) shall be maintained between 60 °C and 71 °C [150 °F (± 10 °F)].
- b) The flow rate shall maintain a fluid velocity by the motor between 0,27 m/s and 0,34 m/s (0,9 ft/s and 1,1 ft/s).
- c) The input power frequency shall be 60 Hz (± 1 %) with voltage THD <5 %.
- d) The casing/liner in the immediate proximity of the motor shall not be larger than two times the diameter of the motor, and its diameter shall be reported.

The motor load shall be set at 100 % of rated output power, while energized at the voltage which yields the minimum current at 100 % output power. The motor shall operate for a minimum of one hour to

allow time for the fluid in the test loop and the internal motor temperature to stabilize prior to obtaining the performance parameters. The amperage, voltage, speed, torque, input kilowatts, power factor are measured and average winding temperature rise and efficiency are calculated. The average winding temperature rise is calculated according to the change in resistance of the stator winding between two states per [A.3.7.3](#). The efficiency is calculated according to [Formula \(A.21\)](#):

$$E = (((v \times \pi/30) \tau / (\beta \times 1\,000)) \times 100) \quad (\text{A.21})$$

where

- β is the input power expressed in kW;
- v is rotational speed expressed in r/min;
- τ is torque expressed in Nm.

The viscosity of the motor fluid used in the test shall be estimated and reported using the temperature-viscosity curve for the fluid and the internal operating temperature of the motor calculated as the ambient fluid temperature plus the average winding temperature rise. The minimum viscosity allowed with this viscosity estimation method during testing shall be 4 cP.

A.3.7.2.3 Motor voltage for minimum current

To verify the optimum motor voltage for a specified power output rating, the motor shall be run in a test loop under the conditions described in [A.3.7.2.2](#). The motor fluid used in the test shall be of the same fluid specification used for the motor performance test. The motor load is to be maintained at constant torque [calculated torque at 100 % output power assuming a rotation speed of 3 450 r/min (± 2 %)] or maintaining a constant power output of 100 % rated output power (± 2 %), while energized at varying voltages. The voltage shall be varied and at each voltage point the amperage shall be recorded and data plotted until the minimum input current point is determined. The voltage at which the current is minimized is the motor test voltage for the motor performance test in [A.3.7.2.2](#) and the motor voltage for minimum current in [6.9.3](#).

A.3.7.3 Motor winding temperature rise

A.3.7.3.1 General

The supplier/manufacture shall have requirements and documented procedures for validating motor winding temperature rise. The average temperature of a winding can be determined by comparing the DC resistance of the winding at a specific temperature with the DC resistance at the temperature before the winding is initially energized at the start of the test. This method utilizes the characteristic of the conductor material, where in the temperature range of interest, the winding resistance changes in direct proportion to the winding temperature. This validation test shall be performed using the following procedure:

- a) The first resistance measurement is taken before the motor is energized and loaded, with the winding temperature stabilized while immersed in the test fluid. The winding resistance may be taken between any two-line terminals, and the same two terminals are used throughout the test. The test fluid temperature shall also be recorded at this time.
- b) After the motor has been energized and loaded and stabilized per [A.3.7.2.1](#), the test fluid temperature shall be recorded again, and the motor shall be de-energized. At the moment the motor is de-energized, a timing device shall be started. Within 15 s after the motor shaft stops rotating or within one minute after the motor is de-energized, whichever can be achieved first, the first resistance reading and the time it is taken shall be recorded.
- c) An additional minimum of four winding resistance measurements along with the corresponding times of the measurements shall be recorded. These measurements shall be completed within the

next two minutes. Test fluid circulation and temperature shall be maintained constant in the test loop after de-energizing the motor.

- d) A curve shall be plotted of resistance versus time and the curve shall be extrapolated back to zero time to determine the resistance at the time of de-energization. The curve fit of the resistance data versus time shall have a sample coefficient of determination of 0,995 or greater. The average winding temperature rise shall then be determined according to [Formula \(A.22\)](#):

$$T_{aw} = [(R_f - R_b)/R_b \times (K + T_b)] - (T_f - T_b) \quad (\text{A.22})$$

where

- R_f is the resistance of the winding at the time of motor de-energization, determined from an extrapolation of the five consecutive resistance readings taken after de-energization expressed in ohms;
- R_b is the resistance of the winding before the test is started at a known stable temperature expressed in ohms;
- K is 234,5 for copper conductor;
- T_{aw} is the average winding temperature rise expressed in °C;
- T_f is the temperature of the test fluid at the time of motor de-energization expressed in °C;
- T_b is the temperature at the time R_b is taken expressed in °C.

A.3.7.3.2 Testing documentation

The following test information shall be documented:

- location of test;
- date of test;
- qualified person performing testing;
- motor description including model, serial number, nameplate power, voltage and ampere;
- reference fluid test temperature;
- motor fluid used in the test;
- test data results.

A.3.7.4 Scaling of design validation

Scaling of motors is allowed within a motor model and series by using per-unitized performance data provided that the supplier/manufacturer shall test at minimum three different sizes of motors within the model and series, the temperature rise is within ± 3 °C and other parameters as listed in [Table A.3](#) are within ± 3 % of the resulting testing values as prescribed in [Clause 6](#).

Table A.3 — Per unit motor performance parameters

Parameter	Per-unitized parameter
Efficiency	Percentage
Amperage	Percentage
Rotation speed	r/min
% Power Factor	Percentage
Winding Temperature Rise (°C)	Degree C

For grade V2, motor performance parameters and voltage for minimum current (see 6.9.3) may be validated using scaling of per-unitized performance data listed in Table A.3 obtained from testing a single motor size, provided the motor is a smaller motor than that being validated. Other conditions of motor scaling include:

- If a motor model, series and size is available in multiple voltage configurations, only one motor voltage configuration needs to be tested. The results shall be accepted for the other motor voltage configurations for that motor size.
- Any motor configuration available for the motor model and series and size, such as upper tandem, centre tandem, lower tandem and single, can be used for the purposes of determining the performance rating.
- Scaling is not permitted between motors which have different lamination geometry, such as differences in diameter, rotor/stator slot geometry.

Similar performance parameters can be expected on a per unit basis for motors constructed with equivalent magnet wire current density, ampere turns, lamination design and specification, output power rating per unit of rotor length and having the same materials of construction within the electromagnetic region. Table A.3 lists the per-unitized motor performance parameters.

The supplier/manufacturer shall have documented procedures and acceptance criteria in place for the scaling of motors. All scaled motors shall have data reviewed and verified by a qualified person and documented within the design files for the component.

A.3.7.5 Motor operating internal temperature limits

The supplier/manufacturer shall have documented procedures and acceptance criteria to support the minimum and maximum motor operating internal temperature limits as indicated on the component data sheet as approved by a qualified person.

A.3.7.6 Locked rotor current, torque and power factor

To establish the locked rotor current, torque and power factor, the motor shall be tested under the following conditions:

- The motor shaft shall be locked against rotation. The shaft locking mechanism shall include a torque measuring device.
- The motor voltage and frequency shall be determined by the supplier/manufacturer to achieve full nameplate current.
- The motor shall be energized under the above conditions, long enough to measure the motor amperage, torque and power factor.

A.3.8 Power and motor lead extension cable

A.3.8.1 General

This subclause includes the general cable rating and selection criteria for main power cable and MLE cables without pothead.

A.3.8.2 Cable ratings and selection criteria

A.3.8.2.1 General

The cable ratings and selection criteria, such as conductor size, voltage rating, temperature rating, chemical resistance and ampacity coefficients, shall be provided by the supplier/manufacturer. These ratings and selection criteria shall be validated by the supplier/manufacturer through documented procedures with acceptance criteria referencing established industry standards by SDOs, such as IEEE, ASTM, IEC and NEMA as reviewed and approved by a qualified person who is other than the person who developed the original rating and/or selection criteria.

A.3.8.2.2 Conductor size

The supplier/manufacturer shall validate the cable conductor size through dimensional and resistive testing per [Clause D.2](#) or [Clause D.3](#). The results shall be reviewed and approved by a qualified person.

A.3.8.2.3 Acceptable minimum bending radius rating

To determine the minimum bending radius rating of finished ESP downhole cable, the supplier/manufacturer shall use the following testing procedure:

- a) The cable sample length for this test may be any given length, however 40 % to 60 % of the sample length shall be held as a control sample which is to be maintained at the reference temperature (± 2 °C) and used for establishing a benchmark value. The remaining cable sample length shall be used for the bending test.
- b) The cable sample used for the bending test shall be cooled in a cold chamber to the minimum handling temperature of the cable for a minimum of 4 h.
- c) The sample shall be bent over a cylindrical mandrel for three full bending cycles within a maximum of 2 minutes from the time the sample is removed from the cold chamber. The bending cycle shall correspond to a 180° curve of the cable over the mandrel to one side and another 180° curve to the opposite side of the cable. For flat cable constructions, the cable shall be bent along the minor cable axis.
- d) The diameter of the mandrel shall be determined by minimum rated bend radius for the cable.
- e) After the bending test is completed, the cable sample shall remain at the reference temperature (± 2 °C) for a period of 24 h and shall then be subjected to tests as specified in [C.8.2](#). The test results are considered acceptable if the voltage breakdown value is within 90 % of same tests performed on the control sample.
- f) Testing shall be completed successfully on all three consecutive samples. If one of the sets of three samples fails original testing, then testing shall be performed with a new group of three samples.

A.3.8.2.4 Ampacity coefficient

A.3.8.2.4.1 General

The objective of the ampacity coefficient test is to validate the ampacity coefficient value of the cable.

A.3.8.2.4.2 Test equipment and procedures

The supplier/manufacturer shall use the following test equipment and procedures:

- a) As a minimum, the test equipment shall comprise of the cable and equipment necessary to maintain electrical integrity of the connection. Test equipment shall pass the specified current through the device and allow for equal current among phases. Conductor temperature shall be physically measured or derived through calculation based on resistance measurements.
- b) The sample length shall be a minimum of 30 cm (11,8 in).
- c) A minimum of three samples shall be tested. Samples may be modified for conductor temperature measurement purposes, provided the modification does not impact the performance of the sample.
- d) The test for the temperature rise shall be performed in air at atmospheric pressure and at the reference temperature (± 2 °C or $\pm 3,6$ °F).
- e) Each sample shall be tested at a minimum of two amperages. The upper and lower test amperages to be used for testing are listed in [Table A.4](#), to which the following applies:
 - separate test samples do not need to duplicate the exact amperages used to test previous samples;
 - the amperage can be DC or AC (RMS);
 - on a given test, all three conductors shall have equal amperage such that the phase furthest from the average amperage is no more than 1 % different than the average.

Table A.4 — Amperage test value by conductor size

Conductor size	Minimum upper amperage during test	Maximum lower amperage during test
2/0 AWG	190	47
1/0 AWG	151	38
1 AWG	118	30
2 AWG	94	24
25 mm ²	70	18
4 AWG	59	15
16 mm ²	45	12
6 AWG	37	10
10 mm ²	28	10

- f) The temperature of the air in the test chamber shall be monitored and adjusted so that the conductor temperature is within 10 °C (18 °F) of the maximum rated temperature of the cable.
- g) The test conditions are considered stable when the conductor temperature and air temperature change no more than 1 °C (1,8 °F) in 30 min.

A.3.8.2.4.3 Construction of ampacity coefficient

A curve showing the expected temperature rise versus amperage shall be constructed following the general form of temperature rise equals the ampacity coefficient multiplied by the square of the amperage in the device. The data points shall be curve fitted using a polynomial according to [Formula \(A.23\)](#):

$$\Delta T = c \times I^2 \quad (\text{A.23})$$

The value of c is the resulting ampacity coefficient.

A.3.8.2.4.4 Test acceptance criteria

The calculated ampacity coefficient shall not be greater than the rated value by more than 5 %. The coefficient of determination for the polynomial curve using the calculated coefficient and the experimental data should be at least 0,9.

A.3.8.2.5 Voltage rating and temperature rating**A.3.8.2.5.1 General**

The objective of the voltage and temperature rating test is to validate the voltage and temperature ratings of the cable.

A.3.8.2.5.2 Test equipment and sample preparation

The supplier/manufacture shall validate the voltage and temperature ratings of the power and MLE cable using the following procedure:

- a) As a minimum, the test equipment shall comprise the cable and test equipment necessary to age the cable under various conditions.
- b) A minimum of 12 samples shall be tested. Three or more samples shall be tested at each of the following conditions:
 - unaged;
 - aged in nitrogen at maximum temperature rating or higher;
 - aged in water at maximum temperature rating or higher;
 - aged in mineral oil IRM902 in accordance with ASTM D471 at maximum temperature rating or higher.

Additional samples and additional temperatures are acceptable.

- c) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test.
- d) The length of the aged cable samples for testing shall be of a length sufficient that the cable sample is a minimum of 30 cm long after any contaminated ends of the cable have been cut off and the ends have been prepared for discharge testing.
- e) The samples for aged testing shall be aged at the maximum operating temperature for the cable design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of $\pm 2,5$ °C ($\pm 4,5$ °F) throughout the test. Additional tests performed at temperatures other than the maximum rated temperature of the cable shall follow the same testing criteria of having nine aged samples (three samples aged in nitrogen, water and mineral oil).
- f) The pressure shall be greater than 700 kPa (101,5 psi) and less than 700 kPa (101,5 psi) above that which is sufficient to maintain water in liquid phase at the test temperature. The pressure shall be maintained at a single value, ± 100 kPa ($\pm 14,5$ psi), throughout the test, prior to increasing the temperature by heating. The pressure shall be maintained via a regulator or similar device.
- g) The aged samples shall age at the test temperature for a minimum of 28 d for all samples aged in nitrogen, water and mineral oil. If testing more than nine aged samples, shorter times are acceptable for additional samples.

A.3.8.2.5.3 AC discharge testing

The supplier/manufacturer shall validate the AC discharge of the power and MLE cable using the following procedure:

- a) All samples, new or aged, shall be tested to full discharge (failure) in the same manner:
 - the discharge test temperature shall be 20 °C (± 2 °C) (68 °F ($\pm 3,6$ °F));
 - the test atmosphere shall be water.
- b) The samples shall be prepared so that the cable ends are clean and well insulated from the electric ground and from the other phases. Following the aging tests, it is acceptable to cut away ends of cable that can be contaminated between the conductor and the insulation.
- c) A water tank shall be prepared which is designed so that the water within the tank is grounded. The sample shall be bent so that some part of the cable is totally immersed in water while the cable ends are kept out of water. AC voltage shall be applied to one phase while the other two phases, cable armor and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V/s. All phases of all samples shall be tested with the same voltage increase rate within ± 5 %.
- d) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phase and ground. The test shall be completed a second time to measure the full discharge on the second attempt.
- e) The process shall be repeated for all phases of a given sample.
- f) The process shall be repeated for all samples.

A.3.8.2.5.4 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to verify the voltage and temperature rating of the cable. These acceptance criteria shall at least include:

- a) established criterion for un-aged discharge (failure) voltage;
- b) demonstration that a full discharge (failure) voltage is greater than the voltage rating when exposed to maximum rated temperature for a minimum period of one year.

Documented accelerated testing methods are acceptable.

A.3.8.2.5.5 Documentation

The supplier/manufacturer shall have testing results reviewed and approved by a qualified person. At a minimum the following data shall be documented:

- a) cable model, type and lot or batch number;
- b) date of testing;
- c) test temperature;
- d) duration of aging;
- e) first and second breakdown voltage for each phase of each sample;
- f) accelerated test method used, if applicable.

A.3.9 Pothead

A.3.9.1 General

The supplier/manufacturer shall provide the rating of potheads.

A.3.9.2 Voltage rating and temperature rating

A.3.9.2.1 Test equipment and sample preparation

The supplier/manufacturer shall validate the voltage and temperature ratings of the pothead using the following procedure:

- a) As a minimum, the test equipment shall comprise of the pothead, an attached section of cable and a device that simulates the pothead to motor connection sealing interface and pressure equalization characteristics of a seal chamber section. Test equipment shall be used to age the equipment under various conditions.
- b) A minimum of 12 samples shall be tested. Three or more samples shall be tested at each of the following conditions:
 - unaged;
 - aged in nitrogen at maximum temperature rating or higher;
 - aged in water at maximum temperature rating or higher;
 - aged in mineral oil, i.e. IRM 902 per ASTM D471, at maximum temperature rating or higher.

Additional samples and additional temperatures are acceptable.

- c) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test.
- d) The equipment shall be subjected to vibration at 1 g and 60 Hz in a radial direction for a period of not less than 6 h before use in the test. During the vibration conditioning procedure, the equipment does not have to be filled with fluid and may be vibrated at any temperature. The equipment shall not be modified after exposure to the vibration.
- e) The samples for aged testing shall be aged at the maximum temperature rating for the pothead design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of $\pm 2,5$ °C ($\pm 4,5$ °F) throughout the test. Additional tests performed at temperatures other than the maximum rated temperature of the pothead shall follow the testing criteria of having nine aged samples (three samples aged in nitrogen, water and mineral oil).
- f) The pressure shall be greater than 700 kPa (101,5 psi) gauge pressure and less than 700 kPa (101,5 psi) gauge pressure above that which is sufficient to maintain water in liquid phase at the test temperature. The pressure shall be maintained at a single value, ± 100 kPa (14,5 psi), throughout the test, prior to increasing the temperature by heating and the pressure shall be maintained via a regulator or similar device.
- g) The aged samples shall age at the test temperature for a minimum of 28 d for all three samples each aged in nitrogen, water and mineral oil. If testing more than nine aged samples, shorter times are acceptable for additional samples.

A.3.9.2.2 AC discharge testing

The supplier/manufacturer shall validate the AC discharge of the pothead using the following procedure:

- a) All samples, new or aged, shall be tested to full discharge (failure) in the same manner:

- the discharge test temperature shall be 20 °C (± 2 °C) (68 °F ($\pm 3,6$ °F));
- the test atmosphere shall be air with a humidity content less than 30 % relative saturation.
- b) All aged samples shall undergo inspection or other testing method to confirm if there has been any fluid contamination into the sealing areas of the pothead. If the pothead sealing is found to have failed and the pothead is contaminated, the sample may not be used for discharge testing.
- c) The samples shall be prepared so that the cable ends and pothead terminals are clean and well insulated from the electric ground and from the other phases. Following the aging tests, it is acceptable to cut away ends of cable that are contaminated inside the insulation.
- d) Voltage shall be applied to one phase while the other two phases, cable armor, pothead housing and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V per second. All phases of all samples shall be tested with the same voltage increase rate within ± 5 %.
- e) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phases and ground. The test shall be completed a second time to measure the full discharge on the second attempt.
- f) The process shall be repeated for all phases of a given sample.
- g) The process shall be repeated for all samples.

A.3.9.2.3 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to verify the voltage and temperature rating of the pothead. These acceptance criteria shall at least include:

- a) established criterion for un-aged discharge (failure) voltage;
- b) demonstration that a full discharge (failure) voltage is greater than the voltage rating when exposed to maximum rated temperature for a minimum period of one year.

Documented accelerated testing methods are acceptable.

A.3.9.2.4 Documentation

The supplier/manufacturer shall have testing results reviewed and approved by a qualified person. At least the following data shall be documented:

- a) pothead model, type and lot or batch number;
- b) date of testing;
- c) test temperature;
- d) duration of aging;
- e) first and second breakdown voltage for each phase of each sample;
- f) accelerated test method used, if applicable.

A.3.9.3 Ampacity coefficients

A.3.9.3.1 Test equipment and procedures

The supplier/manufacturer shall validate the ampacity coefficient rating of the pothead using the following procedure:

- a) As a minimum, the test equipment shall comprise the pothead, a device that simulates the motor connection, and equipment necessary to maintain electrical integrity of the connection. Test equipment shall pass specified current through the device and allow for equal current among phases. A minimum of one conductor temperature inside the pothead shall be physically measured or derived through calculation.
- b) A minimum of three samples shall be tested. Samples may be modified for conductor temperature measurement purposes provided the modification does not impact the performance of the sample.
- c) The test fluid for the temperature rise test shall be water. The water in the test fixture shall circulate to maintain a constant temperature around the test equipment throughout the test.
- d) Each sample shall be tested at a minimum of two amperages, subject to the conditions specified in [Table A.4](#).
- e) Separate test samples do not need to duplicate the amperages used to test previous samples.
- f) The amperage can be DC or AC (RMS).
- g) On a given test, all three conductors shall have equal amperage such that the phase furthest from the average is no more than 1 % different than the average.
- h) The temperature of the test fluid shall be modified so that the conductor temperature is within 10 °C of the maximum rated temperature of the pothead. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus.
- i) The pressure shall be no greater than 700 kPa (101,5 psi) above the pressure necessary to maintain water in liquid phase at test fluid temperature.
- j) The test conditions are considered stable when the conductor temperature and fluid temperature change no more than 1 °C (1,8 °F), and the test pressure changes no more than 20 kPa (2,9 psi) in 30 min.

A.3.9.3.2 Construction of ampacity coefficient

A curve showing the expected temperature rise versus amperage shall be constructed per [A.3.8.2.4.3](#).

A.3.9.3.3 Test acceptance criteria

The acceptance criteria shall be per [A.3.8.2.4.4](#).

A.3.9.4 Pothead differential pressure cycling performance

A.3.9.4.1 Test equipment and procedure

The supplier/manufacturer shall validate that the pothead is capable of experiencing the rated pressure cycling performance using the following procedure:

- a) As a minimum, the test equipment shall comprise of:
 - the pothead and a device that simulates the motor connection;
 - a housing to contain test fluid exterior to the pothead/motor simulator and maintain and measure pressure;

- a housing to contain test fluid interior to the simulator and maintain and measure pressure;
- a device to measure temperature.

NOTE The motor simulator does not require electrical integrity, it is only a test to determine the ability to seal.

- b) A minimum of three samples shall be tested.
- c) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test.
- d) The equipment shall be subjected to vibration at 1 g and 60 Hz in a direction consistent with radial direction on the ESP when attached, for a period of not less than 6 h before use in the test. The equipment shall not be modified or repaired after exposure to the vibration.
- e) The test shall be at the maximum operating temperature for the pothead design. The temperature shall be monitored by measuring the test fluid temperature within the test apparatus and shall be maintained within a range of $\pm 2,5\text{ }^{\circ}\text{C}$ ($\pm 4,5\text{ }^{\circ}\text{F}$) throughout the test.
- f) The test shall use two test fluids. The fluid outside the device under test shall be water. The fluid inside the device under test shall be motor fluid with a viscosity of no more than 8 cP at test temperature. The two fluids shall be immiscible and clearly show contamination in either direction.
- g) The test setup shall ensure that the test fluids are essentially free of debris and contaminants, such as air or water, throughout the test.
- h) The test pressures shall be greater than 206,8 kPa (30 psia) and sufficient to maintain water in liquid phase. The pressure(s) shall be changed throughout the test to achieve pressure cycles. It is acceptable to change either pressure outside the pothead/motor connection or the pressure inside the connection to change the pressure differential across the connection.
- i) Once the stabilized test temperature is achieved, the maximum internal differential pressure shall be applied to the connection and held for a minimum of 5 min. After the hold period, the pressure differential shall be changed to result in the maximum negative pressure differential rating. The rate of pressure change shall be no more than 6,9 kPa (1 psi) per second. The maximum negative pressure differential shall be held for a minimum of five minutes. After the hold period, the differential pressure shall be changed until it reaches the maximum internal differential pressure rating. The rate of pressure change shall be no more than 6,9 kPa (1 psi) per second. The process shall be repeated to reach the rated number of pressure cycles or for 100 total cycles, whichever is greater.

A.3.9.4.2 Test acceptance criteria

The supplier/manufacture shall have documented procedures and acceptance criteria to validate the pothead differential pressure cycling performance rating as indicated on the component data sheet.

Testing shall be completed successfully on all three consecutive samples. If one of the sets of three samples fails the testing, then a testing shall be performed with a new group of three samples.

A.3.9.5 MLE pothead thermal cycling performance

A.3.9.5.1 Test equipment and procedure

The supplier/manufacture shall validate the MLE pothead rated thermal cycling performance as reported on the component data sheet using the following procedure:

- a) As a minimum, the test equipment shall comprise of:
 - the MLE pothead and a device that simulates the motor connection;

- a housing to contain test fluid exterior to the pothead/motor simulator and maintain and measure pressure;
- a housing to contain test fluid interior to the simulator and maintain and measure pressure;
- a device to measure temperature.

NOTE For the purposes of this test, motor simulator does not require electrical integrity.

- b) A minimum of three samples shall be tested.
- c) The samples used for testing purposes shall be standard equipment and shall not have any modifications that can affect their performance in the test.
- d) The equipment shall be subjected to vibration at 1 g and 60 Hz in a direction consistent with radial direction on the ESP when attached, for a period of not less than 6 h before use in the test. The equipment shall not be modified after exposure to the vibration.
- e) The test shall use two test fluids. The fluid outside the device under test shall be water. The fluid inside the device under test shall be motor fluid with a viscosity of no more than 8 cP at test temperature. The two fluids shall be immiscible and clearly show contamination in either direction;
- f) The test setup shall ensure that the test fluids are essentially free of debris and contaminants, such as air or water, throughout the test.
- g) The test pressures shall be greater than 206,8 kPa (30 psia) and sufficient to maintain water in liquid phase. The exterior pressure shall be maintained greater than the interior pressure with a pressure differential equivalent to the maximum negative pressure differential rating of the MLE pothead throughout the test.
- h) Once the maximum test temperature is reached, the temperature shall be held for a minimum of 5 min. After the hold period, the temperature shall be decreased until the temperature equals the minimum temperature for the thermal cycle rating. The rate of temperature change shall be no more than 1 °C (1,8 °F) per minute. The minimum temperature shall be held for a minimum of 5 min. After the hold period, the temperature shall be increased until it reaches the maximum temperature rating. The rate of temperature change shall be no more than 1 °C (1,8 °F) per minute. The process shall be repeated to reach the rated number of thermal cycles.

NOTE The purpose of this test is only to determine the ability to seal at the rated temperature range.

A.3.9.5.2 Test acceptance criteria

The supplier/manufacturer shall have documented procedures and acceptance criteria to validate the MLE pothead rated thermal cycling performance as reported on the component data sheet. These acceptance criteria shall at least include the absence of leakage in either direction across the seal and the ability to hold the rated pressure differential in both directions.

Testing shall be completed successfully on all three consecutive samples. If one of the sets of three samples fails the testing, then a testing shall be performed with a new group of three samples.

Annex B **(normative)**

Requirements for determining performance capabilities as an assembled system

B.1 General

This annex provides the supplier's/manufacturer's requirements for establishing performance capabilities and related testing of the assembled ESP system. Testing shall be performed:

- a) in accordance with the requirements of [Clause 7](#);
- b) in accordance with an approved procedure with specified acceptance criteria;
- c) on calibrated equipment;
- d) by a qualified person.

Testing results shall be documented and shall be approved by a qualified person other than the person who performed the testing.

All testing shall be in accordance with the requirements of [7.2](#), [7.3](#), [7.4](#), [7.6](#) and [7.8](#) and to document procedures which include acceptance criteria with the results approved by a qualified person.

NOTE Results from design validation testing are not necessarily directly applicable for prediction of downhole performance during operation.

B.2 Method for determining system capabilities

B.2.1 Axial strength and bending tensile load

The supplier/manufacturer shall specify the axial strength, in terms of both maximum allowable tensile load and maximum allowable compressive load that the ESP system may be exposed to per the functional specification. Axial strength of the assembly under bending moment forces shall be determined by performing a stress analysis calculation. This stress analysis calculation shall be performed and reviewed by a qualified person.

B.2.2 Surface temperature rating

The supplier/manufacturer shall specify the minimum and maximum well site ambient temperature conditions under which the ESP system may be installed. This rating shall be established based upon documented historical record of field installations and performance and/or full-scale testing.

B.2.3 Amperage rating for the assembled ESP system

The supplier/manufacturer shall specify the maximum amperage rating for the assembled ESP system during operation, including start-up conditions. This rating shall be determined by the supplier's/manufacturer's calculations based on the environment as specified by the functional specification. The supplier/ manufacturer shall specify the component that limits the rating.

B.2.4 Dog leg severity limits for the assembled ESP system

The supplier/manufacture shall provide the dogleg severity limits for the assembled ESP system determined using stress analysis calculations. The stresses in the ESP system shall be calculated. Both the stress value and the maximum allowable stress value for the ESP assembly shall be provided at:

- a) the most severe dogleg point in the well survey from the surface to the pump setting depth;
- b) the ESP assembly setting depth.

B.2.5 Deviation limits for the assembled ESP system

The supplier/manufacture shall provide the maximum deviation angles reported as the number of degrees from vertical which the ESP assembly may be installed through and at which the ESP may be operated.

B.2.6 Minimum, maximum and differential operating environment temperature capability for the ESP assembly

The supplier/manufacture shall specify the minimum, maximum and differential operating environment temperature capability for the assembled ESP system during operation, including start-up conditions. This capability limit shall be determined by the supplier's/manufacture's calculations based on the environment as specified by the functional specification. The supplier/manufacture shall specify the component(s) that limit(s) the capability of the assembled system. The differential operating environment temperature rating for the seal chamber section shall be calculated based on full contraction capacity utilization of the upper most chamber of the seal chamber section.

B.2.7 Maximum pressurization and depressurization rates

The supplier/manufacture shall specify the maximum pressurization and depressurization rates for the assembled ESP system during operation, including start-up conditions. These rates shall be determined by the supplier's/manufacture's calculations based on the environment as specified by the functional specification. The supplier/manufacture shall specify the component(s) that limit(s) the rate values.

B.2.8 Power requirements

The supplier/manufacture shall calculate the required input power in kVA and kW at the wellhead to properly operate the assembled ESP system within the environment specified by the functional specification. The calculations shall include the motor kVA/kW requirements at the motor input terminals, and the additional requirements due to the losses in the cable and motor lead extension. This information shall be provided to the user/purchaser in response to the functional specification. The value reported shall not consider any kW losses due to harmonic distortion.

B.2.9 Assembled ESP system motor fluid percentage utilization of each seal chamber contraction capacity

For each seal chamber or set of parallel chambers, the supplier/manufacture shall report the percentage of nominal motor fluid contraction capacity that is used when the ESP system cools from the expected maximum ESP operating temperature to the expected minimum well static temperature (when the ESP is not operating) as specified in the functional specification.

To determine the oil volume relevant for a given chamber or set of parallel chambers, the calculations shall include:

- a) the volume of the motor fluid in the motor(s);
- b) the volume of oil in any of the seal chambers below the given chamber;
- c) any additional volume of oil in additional component or device below the given chamber.

For a gravity-type chamber, the calculations shall also include the total volume of the chamber itself. For a positive seal type chamber, or set of parallel seal chambers, the volume shall also include the motor side of the positive chamber when the positive seal device experiences maximum internal differential pressure.

For the purpose of the calculations, the entire volume of motor fluid shall be considered to be either

- a) at the estimated internal operating temperature of the motor for the application, or
- b) based on documented evidence of actual temperatures of the motor oil in the motor and seal.

The calculated contraction shall be the change in volume of the motor fluid that results between the estimated internal motor operating temperature and the minimum expected bottom-hole temperature of the well. This contraction volume shall be divided by the rated capacity for the chamber type or set of parallel chambers and corrected for operating deviation where applicable.

B.2.10 Minimum operating speed for assembled system

The supplier/manufacture shall have a documented process to determine the minimum operating speed for the assembled ESP system for the environment specified in the functional specification. The supplier/manufacture shall consider conditions, such as pumping fluid to surface, lubrication of bearings, motor fluid circulation, minimum start/break frequency and downhole gauge requirements.

B.2.11 Maximum operating speed for assembled system

The supplier/manufacture shall have a documented process to determine the maximum operating speed for the assembled ESP system for the subsurface environment specified in the functional specification. The supplier/manufacture shall consider conditions, such as exceeding component ratings, erosional velocities and well drawdown limitations.

Annex C (normative)

Functional evaluation: single component

C.1 General

This annex contains requirements for the functional evaluation procedures that verify the ability of an ESP component to conform to the functional specification. Up to three functional grades are specified, depending on the component. Each component shall perform within the acceptance criteria specified. The results of each functional evaluation shall be documented and shall be approved by a qualified person.

The failure of a component to conform to any specified criteria requires the functional evaluation to be halted. The functional evaluation testing may then be restarted at the beginning after the component is corrected. In the case a supplier's/manufacture's specified testing system anomaly does not cause detrimental effect on the component, the testing can continue from the point of interruption. Testing anomalies/interruptions shall be documented in the testing results.

All testing shall be in accordance with the supplier's/manufacture's documented procedures and shall be performed by a qualified person. This testing shall be performed prior to delivery and/or transfer of ownership to the user/purchaser. All testing shall be performed in accordance with 7.2, 7.3, 7.4, 7.6 and 7.8 and to document procedures which include acceptance criteria with the results approved by a qualified person.

Previous documentation or testing applicable to existing components shall be accepted at its relevant grade. Components qualified to higher grades of functional evaluation shall be considered qualified for lower grades of functional evaluation.

"in conformance with supplier's/manufacture's specifications and acceptance criteria" requires component functional evaluation documentation availability as well as documented processes and procedures as approved by a qualified person.

C.2 Bolt-on discharge head

There are no functional evaluation requirements or grades for the bolt-on discharge head.

C.3 Pump and gas handler

Table C.1 outlines the three functional evaluation grades for the pump and gas handler component(s).

Table C.1 — Functional evaluation grades for pump and gas handler

	F3	F2	F1
Hydraulic evaluation	In accordance with API RP 11S2	Per F3, with two additional test points taken: 1. between minimum operating limit and BEP 2. between BEP and maximum operating limit	Per F2 with pass/fail criteria at ± 3 % tolerance on flow and head, and ± 5 % tolerance on power, a minimum of 93 % of published efficiency

Table C.1 (continued)

	F3	F2	F1
Mechanical – shaft extension, shaft end play and shaft side play	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	Per F3	Per F3
Mechanical – shaft total indicator run-out	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	Per Clause C.9	Per Clause C.9
Vibration	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	In accordance with API RP 11S8 with the following exemptions: — for component outer diameter <15,24 cm (6 in): maximum velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s) [0,137 g rms], for horizontal testing is 0,396 cm/s (0,156 in/s) [0,107 g rms] — for component outer diameter ≥15,24 cm (6 in): maximum velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s) [0,172 g rms]. All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz.	Per F2

C.4 Bolt-on intake

There is one functional evaluation grade for the bolt-on intake. The requirement is to functionally evaluate the shaft rotation, shaft extension, shaft end play and shaft side play in conformance with supplier's/matrixufacturer's specifications and acceptance criteria.

C.5 Mechanical gas separator

[Tables C.2](#) outlines the two functional evaluation grades for the mechanical gas separator.

Table C.2 — Functional evaluation grades for mechanical gas separator

	F2	F1
Mechanical – shaft rotation	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	Per F2
Mechanical – shaft extension, shaft end play and shaft side play	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	Per F2

Table C.2 (continued)

	F2	F1
Mechanical – shaft total indicator run-out	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Per Clause C.9
Mechanical – rotor	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Rotor subcomponents shall be dynamically balanced per supplier's/manufacturer's specifications and acceptance criteria.
Vibration	In conformance with supplier's/manufacturer's specifications and acceptance criteria	In accordance with API RP 11S8 with the following exemptions: — for component outer diameter <15,24 cm (6 in): maximum velocity amplitude for vertical test is 0,508 cm/s (0,200 in/sec) [0,137 g rms], for horizontal testing is 0,396 cm/s (0,156 in/s) [0,107 g rms] — for component outer diameter ≥15,24 cm (6 in): maximum velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s) [0,172 g rms]. All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz. Supplier/manufacturer shall have a documented procedure to ensure that shaft radial support bearings are adequately lubricated during vibration testing.

C.6 Seal chamber section

[Table C.3](#) outlines the three functional evaluation grades for the seal chamber section. If the seal chamber section is integral to motor, [Clause C.8](#) applies.

Table C.3 — Functional evaluation grades for seal chamber section

	F3	F2	F1
Hydrostatic evaluation – positive seal elements, relief valves, mechanical seals, housing joints	In accordance with API RP 11S7	Per F3	Per F3 and including a pressure bleed off test during the air test using a pressure gauge to ensure pressure holds for a minimum of 5 min
Mechanical – power loss, shaft extension, shaft end play and shaft side play	In accordance with API RP 11S7	Per F3	Per F3 and loaded power loss per supplier's/manufacturer's specifications and acceptance criteria
Mechanical – shaft total indicator run-out	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Per F3	Per Clause C.9

Table C.3 (continued)

	F3	F2	F1
Seal fluid - dielectric	In conformance with supplier's/manufacturer's specifications and acceptance criteria	In conformance with supplier's /manufacturer's specifications and acceptance criteria	Per F2
Vibration	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Per API RP 11S8 with the following exemptions: — for component outer diameter <15,24 cm (6 in): maximum velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s) [0,137 g rms], for horizontal testing is 0,396 cm/s (0,156 in/s) [0,107 g rms] — for component outer diameter ≥15,24 cm (6 in): maximum velocity amplitude for vertical and horizontal testing is 0,635 cm/sec (0,250 in/s) [0,172 g rms]. All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz.	Per F2

C.7 Motors

C.7.1 Functional evaluation

[Table C.4](#) outlines the three functional evaluation grades for the motor.

Table C.4 — Functional evaluation grades for motors

	F3	F2	F1
Hydrostatic evaluation – pressure test for leaks (vacuum or pressure)	In conformance with supplier's /manufacturer's specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical – standard idle/coast, kW	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Supplier/manufacturer shall perform testing in conformance with supplier/manufacturer specifications and acceptance criteria	Per F2
Mechanical – load test	No requirement	No requirement	Per A.3.7
Electrical functional evaluation testing – insulation resistance test, high potential test, dielectric oil breakdown, phase imbalance	Per C.8.2	Per F3	Per F3

Table C.4 (continued)

	F3	F2	F1
Mechanical – shaft extension, shaft end play and shaft side play (if applicable)	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	Per F2
Vibration	In conformance with supplier's/matrixufacturer's specifications and acceptance criteria	In accordance with API RP 11S8 with the following exemptions: — for component outer diameter <15,24 cm (6 in): maximum velocity amplitude for vertical test is 0,508 cm/s (0,200 in/s) [0,137 g rms], for horizontal testing is 0,396 cm/s (0,156 in/s) [0,107 g rms] — for component outer diameter ≥15,24 cm (6 in): maximum velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s) [0,172 g rms]. All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz.	Per F2

C.7.2 Electrical functional testing procedure

The purpose of the electrical functional testing procedure is to verify the electrical integrity of the manufactured ESP motor. This test is typically performed at no load conditions. The test procedure shall be per supplier's/matrixufacturer's established procedures and acceptance criteria which, as a minimum, conforms to the following:

- All electrical connections shall be clean.
- Phase-to-phase resistance shall be measured by balancing within ± 3 % of the average of the resistance of all three phase-to-phase measurements.
- An insulation resistance test from phase to ground shall be performed for all three phases. Motor winding phases may be tied together or tested separately. The motor housing temperature shall be between 10 °C and 40 °C and shall be recorded. The supplier/matrixufacturer shall have established acceptance criteria for either current leakage or minimum resistance.
- High potential test of insulation system from phase to ground shall be performed for all three phases using a direct current test voltage of $(1,5 \times \{\text{nameplate voltage}\} + 1\,000) \times 1,7$. Motor winding phases may be tied together or tested separately. The motor housing temperature shall be between 10 °C and 40 °C and shall be recorded. The supplier/matrixufacturer shall have established acceptance criteria for either current leakage or minimum resistance.
- Following motor rotational testing, an insulation resistance test shall be performed in accordance item c). The motor housing temperature shall be at a minimum of 40 °C and shall be recorded. The

supplier/manufacture shall have established acceptance criteria for either current leakage or minimum resistance.

- f) The dielectric strength of oil shall be tested in accordance with ASTM D877 or ASTM D1816. Oil shall successfully test to a dielectric strength of a minimum of 20 kV direct current. This test shall be performed as the last step in the testing process. The oil sample shall be taken from the motor base end.

C.8 Cable and MLE

C.8.1 Functional evaluation

[Table C.5](#) outlines the three functional evaluation grades for the cable and MLE.

Table C.5 — Functional evaluation grades for cable and MLE

	F3	F2	F1
Electrical – insulation resistance test and high potential test for EPDM or polyethylene insulated cable	In conformance with supplier's/manufacture's specifications and acceptance criteria	In accordance with API RP 11S6, IEEE Std 1018 or IEEE Std 1019	Per F2
Electrical – insulation resistance test and high potential test for other insulation types	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per F3	Per F3
Electrical – conductor resistance	In conformance with supplier's/manufacture's specifications and acceptance criteria	Per D.3.4 and Clause D.4	Per F2
Electrical – insulation discharge	No requirement	No requirement	Full alternating current discharge test (see C.8.2)
Electrical – minimum allowable bending radius insulation discharge	No requirement	No requirement	Full alternating current discharge test per ANSI/NEMA WC 53/ICEA T-27-581

C.8.2 Insulation AC discharge test

C.8.2.1 General

The purpose of the insulation AC discharge test is to determine the voltage at which the insulation of an insulated conductor breaks down or fails. This test shall be performed by meeting the following requirements:

- three samples shall be selected from the length of finished cable to be tested to full discharge (failure) in the same manner;
- the discharge test temperature shall be 20 °C (±2 °C) (68 °F (±3,6 °F));
- the test atmosphere shall be water;
- the samples shall be prepared so that the cable ends are clean and well insulated from the electric ground;
- a water tank shall be prepared which is designed so that the water within the tank is grounded.

C.8.2.2 Testing procedure

The insulation alternating current discharge shall be validated using the following procedure:

- a) The sample shall be bent so that some part of the cable is totally immersed in water while the cable ends are kept out of water. AC voltage shall be applied to one phase while the two other phases are shorted to each other and the cable armor and, if applicable, metallic or semi-conductive sheath or layer are short-circuited to ground. The voltage shall start at zero and be increased at a rate of no more than 1 000 V per second. All phases of all samples shall be tested with the same voltage increase rate within $\pm 5\%$.
- b) The voltage shall be increased until a short circuit occurs and there is conductance between the tested phase and ground. The test shall be completed a second time to measure the full discharge on the second attempt.
- c) Repeat the test on the other two samples.
- d) Record the sample information and insulation breakdown voltages.
- e) Testing results shall be interpreted within the limits set by the supplier/manufacturer.

C.9 Measuring shaft runout

C.9.1 General

The purpose of the measuring shaft runout procedure is to specify the method for measuring shaft total indicator runout (TIR) on the top and bottom ends of ESP components. This procedure applies to the following components:

- pump or gas handler;
- seal chamber section;
- intake;
- mechanical gas separator.

This procedure does not apply to components with less than two journal bearings on the shaft.

If the construction of some components does not allow easy access to both ends of the shaft, only one end shall be measured.

This procedure measures the total indicator runout at the ends of a shaft that is (typically) supported by journal type bearings that have a relatively loose fit. Measurement results shall be within the limits set by the supplier/manufacturer. The total indicator runout measured is twice the actual shaft deflection.

C.9.2 Procedure

The measuring shaft runout procedure is as follows:

- a) The component shall be supported on a flat surface that gives even support along the entire length of the component or on moveable stands that support the component at the two quarter points.
- b) A dial indicator base shall be mounted on the exterior of the component or on another stationary surface, as close to the end as practical. The indicator base may be magnetic or a clamp type. The indicator measurement precision shall be 0,02 mm or 0,001 in.
- c) The indicator probe shall be positioned such that it contacts the major diameter of the shaft splines. Shaft spline types, shaft extension and indicator configurations can vary considerably. A qualified person experienced in measuring shaft runout should supervise and approve the test setup.

- d) Working from the end of the component that is opposite of the indicator setup, the shaft shall be slowly rotated 360° while an observer notes the maximum deflection of the indicator. Components for which only one end of the shaft is accessible and short components, such as bolt-on intakes, require special care in rotating the shafts to avoid false readings.
- e) Steps a) to d) shall be repeated for the other end of the shaft, if applicable.
- f) Total indicator runout for the component shall be reported for each end of the shaft.

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023

Annex D (normative)

Cable reference information

D.1 General

This annex covers detailed information and references pertaining to copper power cable conductors.

D.2 Metric conductors

D.2.1 Conductor properties

Unless otherwise specified, conductor sizes specified in metric sizes shall meet the requirements of IEC 60228 for conductor dimensions, resistance, resistance testing and temperature correction.

D.2.2 Metric cable conductor dimension table

[Table D.1](#) provides cable conductor dimensions for common cable construction types. [Table D.1](#) shall be used to provide conductor size ratings per [A.3.8.2.2](#).

Table D.1 — Cable conductor min and max dimensions for common metric sizes

Conductor				Nominal weight		Maximum diameter of conductor					
Size	Area					Solid (class 1)		Stranded (class 2)		Stranded compact (class 2)	
Trade name	cmil	in ²	mm ²	lb/kft	kg/km	in	mm	in	mm	in	mm
10 mm ²	19 644	0,015 5	10	59,7	88,5	0,146	3,7	0,165	4,2	0,157	4,0
16 mm ²	31 109	0,024 8	16	95,6	140	0,181	4,6	0,209	5,3	0,205	5,2
25 mm ²	49 305	0,038 8	25	149,2	222	0,224	5,7	0,260	6,6	0,256	6,5

D.2.3 Metric conductor resistance tables

[Table D.2](#) provides cable conductor nominal resistance values for common cable construction types. [Table D.2](#) shall be used to confirm quality for various conductor sizes per [D.2.1](#).

Table D.2 — Common copper metric conductor resistance values at 20 °C

Conductor size	Maximum conductor resistance values at 20 °C							
	Solid (class 1)				Stranded, circular or compacted (class 2)			
	Bare		Coated		Bare		Coated	
Trade name	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
10 mm ²	0,558	1,83	0,561	1,84	0,558	1,83	0,561	1,84
16 mm ²	0,351	1,15	0,354	1,16	0,351	1,15	0,354	1,16
25 mm ²	0,222	0,727	0,224	0,734	0,222	0,727	0,224	0,734

Table data were sourced from reference documents and further requirements in [D.2.1](#).

[Table D.3](#) shows the resistance values of the same cables at 25 °C. This is for simplicity when comparing them to the values found in the references that use 25 °C as the reference temperature.

Table D.3 — Common copper metric conductor resistance values at 25 °C

Conductor size	Maximum conductor resistance values at 25 °C							
	Solid				7-Wire stranded or compact			
	Bare		Coated		Bare		Coated	
Trade name	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
10 mm ²	0,571	1,87	0,574	1,88	0,571	1,87	0,574	1,88
16 mm ²	0,359	1,18	0,362	1,19	0,359	1,18	0,362	1,19
25 mm ²	0,227	0,74	0,229	0,75	0,227	0,74	0,229	0,75

Table data were sourced from reference documents and further requirements in [D.2.1](#).

D.3 AWG conductors

D.3.1 AWG conductor dimensions

D.3.1.1 General

Unless otherwise specified, conductor sizes specified in AWG sizes shall meet the requirements in this subclause.

D.3.1.2 Solid conductors

Solid conductors shall be in accordance with ASTM B258.

D.3.1.3 7-wire stranded conductors

7-wire stranded conductors shall be in accordance with ASTM B8.

D.3.1.4 7-wire compact stranded conductors

7-wire compact stranded conductors shall:

- be in accordance with ASTM B496 for sizes of AWG 2 and smaller;
- have a diameter of 92 % of the ASTM B8 requirements for the equivalent AWG size for sizes larger than AWG 2.

D.3.1.5 AWG cable conductor dimension table

[Table D.4](#) provides cable conductor dimensions for common cable construction types. [Table D.4](#) shall be used to provide conductor size ratings per [A.3.8.2.2](#).

Table D.4 — Cable conductor nominal dimensions for common AWG sizes

Conductor				Nominal weight		Nominal diameter of conductor					
Size	Area					Solid		7-Wire stranded		7-Wire compact	
AWG	cmil	in ²	mm ²	lb/kft	kg/km	in	mm	in	mm	In	mm
6 AWG	26 240	0,020 6	13,3	79,4	118	0,162	4,11	—	—	—	—
4 AWG	41 740	0,032 7	21,1	126	188	0,204	5,19	0,232	5,89	0,213	5,41
2 AWG	66 360	0,052 1	33,6	206	306	0,258	6,54	0,292	7,42	0,268	6,81
1 AWG	83 690	0,065 7	42,4	260	386	0,289	7,35	0,328	8,33	0,298	7,57
1/0 AWG	105 600	0,082 9	53,5	319,2	475	—	—	0,368	9,35	0,337	8,56
2/0 AWG	133 100	0,104 5	67,4	402,7	599	—	—	0,414	10,8	—	—

Conductor					Nominal weight		Nominal diameter of conductor				
Size	Area					Solid		7-Wire stranded		7-Wire compact	
AWG	cmil	in ²	mm ²	lb/kft	kg/km	in	mm	in	mm	In	mm
6 AWG	26 240	0,020 6	13,3	79,4	118	0,162	4,11	—	—	—	—
4 AWG	41 740	0,032 7	21,1	126	188	0,204	5,19	0,232	5,89	0,213	5,41
2 AWG	66 360	0,052 1	33,6	206	306	0,258	6,54	0,292	7,42	0,268	6,81
1 AWG	83 690	0,065 7	42,4	260	386	0,289	7,35	0,328	8,33	0,298	7,57
1/0 AWG	105 600	0,082 9	53,5	319,2	475	—	—	0,368	9,35	0,337	8,56
2/0 AWG	133 100	0,104 5	67,4	402,7	599	—	—	0,414	10,8	—	—

D.3.2 AWG copper conductor resistance

D.3.2.1 Solid bare conductors

Solid bare conductors shall be in accordance with ASTM B3.

D.3.2.2 Solid tin coated conductors

Solid tin coated conductors shall be in accordance with ASTM B33.

D.3.2.3 Solid lead coated conductors

Solid lead coated conductors shall be in accordance with ASTM B189.

D.3.2.4 7-wire stranded bare conductors

7-wire stranded bare conductors shall be in accordance with ASTM B8, Class A stranded conductors.

D.3.2.5 7-wire stranded tin coated conductors

For 7-wire stranded conductors where each individual wire is tin coated, the nominal resistance of the overall conductor shall be one seventh the resistance of an individual coated wire in accordance with ASTM B33.

D.3.2.6 7-wire stranded lead coated conductors

For 7-wire stranded conductors where each individual wire is lead-coated, the nominal resistance of the overall conductor shall be one seventh the resistance of an individual coated wire in accordance with ASTM B189.

D.3.2.7 7-wire compact stranded non-coated conductors

7-wire compact stranded non-coated conductors shall be in accordance with ASTM B496.

D.3.2.8 7-wire compact stranded tin coated conductors

For 7-wire compact stranded conductors where each individual wire is tin-coated, the nominal resistance of the overall conductor shall be one seventh the resistance of an individual tin-coated wire in accordance with ASTM B33.

D.3.2.9 7-wire compact stranded lead coated conductors

For 7-wire compact stranded conductors where each individual wire is lead-coated, the nominal resistance of the overall conductor shall be one seventh the resistance of an individual coated wire in accordance with ASTM B189.

D.3.2.10 AWG conductor resistance tables

[Table D.5](#) provides nominal copper cable conductor resistance values for common AWG cable construction types. [Table D.5](#) shall be used to confirm quality for various conductor sizes per [D.3.1](#).

Table D.5 — Nominal AWG copper conductor resistance values at 20 °C

Conductor size	Nominal conductor resistance values at 20 °C									
	Solid					7-wire stranded or compact				
	Bare		Coated			Bare		Coated		
AWG	Ω/kft	Ω/km	Ω/kft	Ω/km	CF	Ω/kft	Ω/km	Ω/kft	Ω/km	CF
6 AWG	0,395 2	1,297	0,406 7	1,334	0,971 6	-	-	-	-	-
4 AWG	0,248 5	0,815	0,255 7	0,839	0,971 6	0,253 0	0,830 0	0,263 1	0,863 1	0,961 6
2 AWG	0,156 3	0,513	0,160 9	0,528	0,971 6	0,159 0	0,522 0	0,165 3	0,542 8	0,961 6
1 AWG	0,123 9	0,407	0,127 5	0,418	0,971 6	0,127 0	0,417 0	0,130 7	0,429 2	0,971 6
1/0 AWG	0,098 3	0,322	0,100 6	0,330	0,976 6	0,100 0	0,328 0	0,102 9	0,337 6	0,971 6
2/0 AWG	0,077 9	0,256	0,079 8	0,262	0,976 6	0,079 5	0,261 0	0,081 8	0,268 6	0,971 6

Table data sourced from reference documents and further requirements in [D.3.2.1](#) to [D.3.2.9](#).

[Table D.6](#) shows the resistance values of the same cables at 25 °C. This is for simplicity when comparing them to the values found in the references that use 25 °C as the reference temperature.

Table D.6 — Nominal AWG copper conductor resistance values at 25 °C

Conductor size	Nominal copper conductor resistance values at 25 °C							
	Solid				7-Wire stranded or compact			
	Bare		Coated		Bare		Coated	
AWG	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km	Ω/kft	Ω/km
6 AWG	0,402 8	1,322	0,414 6	1,360	-	-	-	-
4 AWG	0,253 3	0,831	0,260 7	0,855	0,257 9	0,846	0,268 2	0,880
2 AWG	0,159 3	0,523	0,164 0	0,538	0,162 1	0,532	0,168 6	0,553
1 AWG	0,126 3	0,415	0,130 0	0,426	0,129 5	0,425	0,133 2	0,438
1/0 AWG	0,100 2	0,329	0,102 6	0,336	0,101 9	0,334	0,104 9	0,344
2/0 AWG	0,079 4	0,261	0,081 3	0,267	0,081 0	0,266	0,083 4	0,274

Table data were sourced from reference documents and further requirements in [D.3.2.1](#) to [D.3.2.10](#).

D.3.3 Resistance and temperature for copper AWG conductors

D.3.3.1 General

Temperature correction on resistance or conductivity of cable conductors shall be in accordance with temperature coefficients found in ASTM B193, based on conductor material and conductivity factor.

D.3.3.2 Temperature correction factor table for copper AWG conductors

[Table D.7](#) shows the correction factors to correct measurements from measured temperature to 20 °C and the correction factors to calculate the nominal resistance at service temperature based on the value at 20 °C. The conductivity factors from the [Table D.4](#) shall be used to determine the appropriate correction factor.

To use these correction factors, [Formulae \(D.1 and D.2\)](#) apply:

$$R_{20} = R_T * T_{CF} \quad (D.1)$$

$$R_T = R_{20} * (1 / T_{CF}) \quad (D.2)$$

where

R_{20} Resistance at 20 °C, measured or calculated;

R_T Resistance at temperature T ;

T_{CF} temperature correction factor from temperature T to 20 °C;

$(1/T_{CF})$ temperature correction factor from 20 °C to temperature T .

Table D.7 — Cable conductor temperature correction factors for copper AWG conductors

Temperature		Multiplication factors to...						
		correct measurement to 20 °C, based on conductivity factors (T_{CF})				correct 20 °C value to service temperature, based on conductivity factors ($1/T_{CF}$)		
		100	97,66	97,16	96,16	100	97,66	97,16
°C	°F	unitless	unitless	unitless	unitless	unitless	unitless	unitless
0	32	1,085	1,083	1,083	1,082	0,921	0,923	0,924
10	50	1,041	1,040	1,040	1,039	0,961	0,962	0,962
15	59	1,020	1,020	1,019	1,019	0,980	0,981	0,981
20	68	1,000	1,000	1,000	1,000	1,000	1,000	1,000
25	77	0,981	0,981	0,981	0,981	1,020	1,019	1,019
30	86	0,962	0,963	0,963	0,964	1,039	1,038	1,038
35	95	0,944	0,946	0,946	0,946	1,059	1,058	1,057
40	104	0,927	0,929	0,929	0,930	1,079	1,077	1,076
45	113	0,911	0,912	0,913	0,914	1,098	1,096	1,096
50	122	0,895	0,897	0,897	0,898	1,118	1,115	1,115
55	131	0,879	0,882	0,882	0,883	1,138	1,134	1,134
60	140	0,864	0,867	0,867	0,869	1,157	1,154	1,153
65	149	0,850	0,853	0,853	0,855	1,177	1,173	1,172
70	158	0,836	0,839	0,840	0,841	1,197	1,192	1,191
75	167	0,822	0,826	0,826	0,828	1,216	1,211	1,210
80	176	0,809	0,813	0,814	0,815	1,236	1,230	1,229
85	185	0,797	0,800	0,801	0,803	1,255	1,250	1,248
90	194	0,784	0,788	0,789	0,791	1,275	1,269	1,267
100	212	0,761	0,765	0,766	0,768	1,314	1,307	1,306
120	248	0,718	0,723	0,724	0,726	1,393	1,384	1,382
140	284	0,680	0,685	0,686	0,688	1,472	1,461	1,458
160	320	0,645	0,650	0,652	0,654	1,550	1,538	1,535
180	356	0,614	0,619	0,621	0,623	1,629	1,614	1,611
200	392	0,586	0,591	0,593	0,595	1,707	1,691	1,688
220	428	0,560	0,566	0,567	0,569	1,786	1,768	1,764
240	464	0,536	0,542	0,543	0,546	1,865	1,845	1,840
260	500	0,515	0,520	0,522	0,524	1,943	1,922	1,917
280	536	0,495	0,500	0,502	0,504	2,022	1,998	1,993
300	572	0,476	0,482	0,483	0,486	2,100	2,075	2,070

D.3.4 Conductor resistance test

D.3.4.1 General

Testing of the cable to determine its conductor resistance value shall be per ASTM B193.

D.3.4.2 Allowable resistance

The resistance of single conductor and multiple-conductor parallel-lay cable shall be no more than the 102 % of the appropriate value in [Table D.2](#) or [Table D.5](#) (as appropriate) corrected to test temperature per [D.3.3.2](#).

The resistance of multiple-conductor twisted assembly cable shall be no more than the 104 % of the appropriate value in [Table D.2](#) or [Table D.5](#) (as appropriate) corrected to test temperature per [D.3.3.2](#).

D.4 Other conductor configurations

Conductor configurations other than those in [D.2](#) and [D.3](#) shall be in accordance with an appropriate standard or other requirement that consider dimensions and resistance. These conductor configurations shall be evaluated based upon supplier's/manufacturer's procedures and evaluation criteria and shall be implemented by a qualified person.

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023

Annex E (informative)

Functional evaluation guideline — Assembled ESP system

E.1 General

The supplier/manufacture should provide verifiable evidence that the components offered can be effectively assembled and operated as a system to meet the requirements of the application as specified by the user/purchaser. This should be determined through the series of tests as described in this annex and additional evaluations performed by a qualified person(s) assigned for the assembled ESP system evaluation.

The user/purchaser should select the desired system functional evaluation grade. Testing parameters, acceptance criteria and order of the testing should be agreed between the user/purchaser and the supplier/manufacture before performing the tests, as applicable to the project requirements. The objective of these tests is to verify the compatibility of the components, operational performance of the assembled system as designed and system integration interfaces.

Testing should be performed:

- a) in accordance with the requirements of [Clause 7](#);
- b) in accordance with an approved procedure with specified acceptance criteria;
- c) on calibrated equipment;
- d) by a qualified person.

Calibration certificates should be presented prior to the start of the system functional evaluation. Testing results should be documented and approved by a qualified person other than the person who performed the testing.

The assembled ESP system to be subjected to functional evaluation tests should comprise only components that have successfully completed their respective component functional evaluation tests as per [Annex C](#).

E.2 Mechanical compatibility test

The mechanical compatibility test verifies the mechanical compatibility and interface of the ESP system components. This test may be performed horizontally or vertically in the supplier's/manufacture's facility. The user/purchaser should specify the components that are required for this test. During the testing, all equipment selected (ESP and auxiliary equipment) should be mechanically coupled and flanges fully secured. For components with rotating shafts, shaft end play and rotation should be verified after mechanical make-up of each component in the assembly. This test is considered successful if all mechanical connections can be made up without damage and shaft settings (where measurable) are within the supplier's/manufacture's specifications and the shafts of the entire assembly rotate freely. Rotation of the assembly shafts can be verified visually or by measuring voltage generation from the motor while turning the upper most shaft in the made-up assembly.

E.3 Stack-up test

The objective of the stack-up test is to verify the ESP system assembly and installation procedure is safe and fit for purpose. This test should be performed with the ESP system placed vertically. The pump is

not started in this test. The stack-up test can mimic the rig floor activity. Unexpected “hold-up” points and clearance issues should be considered in this test.

Evaluation of the activities on the rig floor allows the user/purchaser to find strengths and weaknesses in the procedure. This test can be extended by the user/purchaser to include operations, such as running through hanger profile, assembling electric penetrators in the ESP packer, set and release of ESP packer.

The information from this test can be used to refine the mechanical compatibility test and aid understanding of how the ESP system is handled and assembled such as where to spot spoolers, hang goosenecks and minimizing hazards.

E.4 System integration test (SIT)

E.4.1 General

The purpose of the SIT is to verify the performance of a complete system and to identify any deviation that could lead to early failures. For the purpose of this test, the equipment utilized for test should be specified by the user/purchase as follows:

- a) ESP components: these components should be either the specific serial numbered components intended for installation or components of the same model and design.
- b) ESP cable: upon user's/purchaser's request, this cable should be either the specific serial numbered cable intended for installation, cable of the same model and design, a load cell and/or electrical cable system simulator to mimic the cable system electrical characteristics, or a combination thereof.
- c) Power equipment, such as ASD, transformers, control systems: This equipment should be either the specific serial numbered equipment intended for installation, equipment of the same model and design, other equipment that is suitable for the purposes of the test, or a combination thereof.

E.4.2 Assembled ESP system functional evaluation grade

The user/purchaser should specify an assembled ESP system functional evaluation grade detailed in [Table E.1](#). This document provides requirements for the following three functional evaluation grades:

- F1: highest level of functional evaluation;
- F2: intermediate level of functional evaluation;
- F3: basic level of functional evaluation.

E.4.3 Requirements

To ensure the system as a whole operates as designed and meets specification, the ESP should be functionally operated as per user's/purchaser's requirements, such as target flow rates, power supply frequency, operating frequencies and test fluids. The duration of the evaluation of the ESP system should be specified by the user/purchaser. The elapsed time should start immediately after achieving stable head and horsepower readings. Heat build-up should be avoided at the test fluid.

The ESP system under test should include its respective downhole sensor.

During the SIT, the following parameters should be measured and documented:

- a) intake and discharge temperatures;
- b) intake and discharge pressures;
- c) voltage and current RMS values at wellhead/wellhead penetrator and at power supply output;
- d) power supply frequency;

- e) downhole sensor measurements;
- f) mechanical torque and speed at pump's shaft.

Upon user's/purchaser's request, a torque cell should be used to directly measure the mechanical torque demanded by the pump's shaft. This approach provides more accurate data than the alternative of estimation or indirect measurement based on rotation and electric current.

After the last hydraulic evaluation test, the supplier/manufacturer may remove the torque cell. From this point, the SIT should proceed for the remainder of the duration.

Upon user's/purchaser's request, the SIT should be performed with the ESP string placed in a dummy well.

E.4.4 SIT procedure

At every time interval specified by the user/purchaser, the tests listed in [Table E.1](#) should be performed as a minimum. The testing results should be documented and approved by a qualified person other than the person who performed the testing.

Table E.1 — Functional evaluation grades for SIT

	F3	F2	F1
Hydraulic evaluation	In conformance with supplier's /manufacturer's specifications and acceptance criteria	Per F3 with two additional test points taken: 1. between minimum operating limit and BEP 2. between BEP and maximum operating limit	Per F2 with pass/fail criteria at ± 3 % tolerance on flow and head, and ± 5 % tolerance on power, and a minimum of 93 % efficiency as compared to published values
Vibration	In conformance with supplier's/manufacturer's specifications and acceptance criteria	Per API RP 11S8 with the following exemptions: — for component outer diameter $< 15,24$ cm (6 in): maximum velocity amplitude for vertical test is 0,508 cm/s (0,200 in/sec) [0,137 g rms], for horizontal testing is 0,396 cm/s (0,156 in/s) [0,107 g rms] — for component outer diameter $\geq 15,24$ cm (6 in): maximum velocity amplitude for vertical and horizontal testing is 0,635 cm/s (0,250 in/s) [0,172 g rms]. All vibration spectrums shall be taken over a frequency range of 0 Hz to 600 Hz	Per F2

The supplier/manufacturer in consultation with the user/purchaser should develop a rigorous test procedure to demonstrate the system is fit for purpose through a series of tests that force the system

into alarm and trip scenarios. These scenarios may be created within the ESP control system and/or externally, depending on their nature, such as operation, ESD or other control safety interlocks and interdependencies. If the power supply is housed in module, then air pressure and volume should be verified to ensure conformance to design requirements.

E.4.5 Analysis after SIT

E.4.5.1 General

After the conclusion of the SIT, the ESP string should be dismantled. Each single component should be subjected to an analysis as described in [E.4.5.2](#) to [E.4.5.6](#), according to the respective grade specified at its component functional evaluation documentation.

E.4.5.2 Pump and gas handler

The pump and gas handler should be subjected to the functional evaluation as specified in [Table C.1](#), excluding hydraulic evaluation and vibration.

E.4.5.3 Bolt-on intake

Independent of the chosen SIT functional evaluation grade, the bolt-on intake should functionally evaluate the shaft rotation, shaft extension, shaft end play and shaft side play in conformance with the supplier's/manufacture's specifications and acceptance criteria.

E.4.5.4 Mechanical gas separator

The mechanical gas separator should be subjected to the functional evaluation as specified in [Table C.2](#), excluding vibration.

E.4.5.5 Seal chamber section

The seal chamber section should be subjected to the functional evaluation as specified in [Table C.3](#), excluding vibration.

Dielectric oil should be sampled, at a minimum, from each seal chamber, at its lowest sampling port, with the string placed in a vertical position and in accordance with ASTM D923. No oil replenish should be made before sampling.

Upon user's/purchaser's request, the water content on those samples should be evaluated in accordance with ASTM D1533 to evaluate any water ingress during the SIT.

E.4.5.6 Motor

The motor should be subjected to the functional evaluation as specified in [Table C.4](#), excluding mechanical – standard idle/coast, kW; mechanical – load test; and vibration.

Dielectric oil should be sampled, at a minimum, from upper motor head and lower motor head and base, at its lowest sampling port, with the string placed in a vertical position and in accordance with ASTM D923. No oil replenish should be made before sampling.

Upon user's/purchaser's request, the water content on those samples should be evaluated in accordance with ASTM D1533 to evaluate any water ingress during SIT

E.5 Power test

The objective of the power test is to verify that the power supply equipment, as described at the technical specification, is appropriately sized to start and run the ESP motor to full load conditions when connected to the correct power cable system, or if the user/purchaser agrees a load cell and/or

electrical cable system simulator. The specific equipment to be utilized for this test should be per [E.4](#). If the motor designed for the application is unable to achieve 100 % motor load in the test conditions, an alternative larger pump can be required for test or a dynamometer can be substituted for the pump.

E.6 Calculating ESP system efficiency

The ESP system efficiency can be calculated as the total amount of hydraulic power imparted into the fluid by the ESP pump divided by the electrical power supply output at a measurement point prescribed by the user/purchaser (e.g. wellhead/wellhead penetrator). The calculation should incorporate all known PVT data to ensure best possible accuracy of the hydraulic power estimate used for the calculation.

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023

Annex F (informative)

Establishing recommended operating range of ESP system

F.1 General

This annex describes the factors to be considered for defining a recommended operating range (ROR) and establishes guidelines for creating the ROR. Some factors are application specific, while others shall apply to a certain stage design regardless of the application.

F.2 Considerations for ROR

F.2.1 Axial thrust forces

Axial thrust forces are application specific because, in addition to hydraulic stage design, thrust forces are affected by the fluid density, operating r/min and number of pump stages. These factors should be considered when comparing the generated axial thrust forces to the thrust bearing load limits, for which the following applies:

- Floater pumps: Axial thrust forces on floating pump impellers can cause excessive wear on thrust washers, especially when abrasive particles are present in the well fluid.
- Compression pumps: Axial forces on compression pump impellers are transferred to a thrust bearing, typically in the seal chamber section.
- Pumps with modular thrust bearings: Axial thrust forces are transferred to modular thrust bearings located in the pump section. Accelerated wear can occur on these bearings in excessive down thrust conditions, especially when abrasive particles are present in the well fluid.
- Pumps with hydraulic pistons for controlling axial thrust: Down thrust forces are equalized using a hydraulic piston in the top of the pump. Hydraulic piston size should affect the recommended operating range selection.

NOTE The ROR of a particular pump stage can vary depending on pump construction. A pump curve operating range can be extended beyond the efficient operating range of the pump depending on the thrust system supporting the pump, its construction type and thrust curve.

F.2.2 Flow and pressure limits

Application specific limits to ROR can include flow or pressure limits, such as a minimum flow required to cool the motor or a maximum pressure that needs not to be exceeded in the pump housing or maximum flow rate to prevent erosional velocities.

F.2.3 Power limits

Application specific limits to ROR can include constraints, such as motor input power limits, motor operating temperature or amperage limits, and component shaft power limits.

F.2.4 Shape of head/flow rate curve

Centrifugal pump head versus flow rate curves (per [A.3.3.2](#)) can show a droop, dip or flat region in the body of the head curve. When the head curve is flat or has a dip for a range of flow rates, the flow rate

of the pump can be unstable and therefore the pump ROR may be set to avoid operation in areas of the pump curve.

STANDARDSISO.COM : Click to view the full PDF of ISO 15551:2023

Annex G

(informative)

Example of user's/purchaser's ESP functional specification form

This annex provides a form, which can be used by the user/purchaser to assist in specifying the functional requirements of the ESP system as required in [Clause 5](#). This form is not necessarily inclusive of all requirements.

Company name		
Contact		
Case/Scenario description/Identifier:		
Technical specification response required:	Component(s) only ☐ Components and assembled system ☐	
Well information (required)		
Operating environment:	Coalbed methane ☐ Heavy oil ☐ Conventional oil ☐ Source water ☐ Other ☐	
Well type:	Vertical ☐ Directional ☐ Slant ☐ Horizontal ☐	
Well location:	Onshore ☐ Offshore ☐ Subsea ☐ Geographical location: _____	
Reservoir type:	Carbonate ☐ Shale ☐ Unconsolidated sandstone ☐ Coal ☐ Consolidated sandstone ☐	
Reservoir recovery process:		
	Aquifer drive ☐ Solution gas drive ☐ Water flood ☐ Coal dewatering ☐ Thermal ☐	
Enhanced oil recovery:	CO ₂ flood ☐ WAG ☐ Polymer flood ☐	
Existing or planned power supply details:		
	Generator ☐ Utility ☐ volts _____ Hz _____	
KVA/Amp supply limitations: _____		
Existing or planned surface equipment:		
	Switchboard ☐ 6-step ASD ☐ PWM ASD ☐ Filtered PWM ASD ☐ Medium voltage ☐	
Space restrictions ☐		
Well information (if available)		
Well Profile:	S-shaped ☐ U-shaped ☐ sinusoidal ☐ multilateral ☐	
Geothermal gradient/profile: please attach		
Previous production history: please attach		
Completion data (required) Units (circle one)		
Pump setting depth [PSD] (measured depth [MD])		m – ft
Pump setting depth [PSD] (true vertical depth [TVD])		m – ft
Existing or planned total well depth: TVD/MD	/	m – ft
Producing interval depth (top) TVD/MD	/	m – ft
Producing interval depth (bottom) TVD/MD	/	m – ft
Casing outside diameter		mm – in
Casing weight and grade		kg/m – lb/ft
Casing connection type		
Minimum drift diameter through wellhead to bottom of ESP assembly		mm – in
Tubing outside diameter		mm – in

Tubing weight		kg/m – lb/ft	
Tubing grade			
Tubing thread/type/size			
Completion type:	perforated casing ☐ hole ☐		
Sand control:	none ☐ slotted liner ☐ gravel pack ☐ sand screen ☐		
ESP system configuration:	single ☐ dual ☐ other ☐		
ESP deployment method:	conventional tubing ☐ coiled tubing ☐ wireline ☐		
Completion data (if available)	Units (circle one)		
Well deviation survey (please attach) or as a minimum:			
Inclination at pump setting depth		degrees	
Dogleg severity at pump setting depth		degrees/100 ft or degrees/30 m	
Maximum dogleg severity between wellhead and pump setting depth:		degrees/100 ft or degrees/30 m	
Tubing inner coating type and thickness (if applicable)			
Completion thermal characteristics such as heat transfer coefficients for completion, insulated tubing/annulus or flowing temperature profile (please attach)			
Completion diagram (please attach)			
Operating and production information	(required)	Units (circle one)	
Well inflow performance expressed as (please attach)			
— expected flow rate min/target/max as stock tank flow rate or pump discharge rate (BFPD – m ³ /day)			
— flowing pressure or fluid level at expected flow rate min/target/max for a specified depth (kPa – psi)			
— Gas volume fraction anticipated at expected flow rate min/target/max			
	Min	Target Max	
Stock tank production rate			m ³ /day - BFPD
Flowing pressure (at production rate)			kPa – psi
Flowing pressure reference depth (datum)			mTVD - ftTVD
Water cut			%
Tubing head pressure			kPa – psi
Casing pressure			kPa – psi
Bottom-hole temperature			°C – °F
Reservoir static pressure			kPa – psi
Reservoir static pressure reference depth			mTVD - ftTVD
Total producing gas oil ratio			sm ³ /sm ³ – scf/stb
Expected producing gas volume fraction			%
Maximum drawdown limitations			mTVD
Special operating conditions (such as heavy completion fluids, sand face control, delayed start up):			
Operation and production information (if available)			Units (circle one)
Sand cut			%
Wellhead flowing fluid temperature (range)			°C – °F

Flowing temperature at reference depth				°C – °F					
Reference depth				m - ft					
Slugging tendency?				Yes – No					
If yes, due to sand? gas? steam?									
Desired operating frequency range				Hz					
Desired operating frequency at target rate				Hz					
Please attach any materials, material requirements and dimensional limitations:									
Environmental compatibility (required)			Units (circle one) or list units used						
Oil density at standard conditions or API gravity									
Oil viscosity at standard conditions				cP					
Bubble point pressure at reservoir temperature				kPa – psi					
Solution GOR				sm ³ /sm ³ – scf/stb					
Water PH									
Water density									
Water salinity/chloride concentration				ppm					
Gas specific gravity									
CO ₂ (mole %)				H ₂ S (mole %)					
History of solids related problems such as plugging and erosion of downhole components? Yes ☐ No ☐									
If yes, please describe:									
Sand morphology (please attach) – refer to 5.3.3:									
Erosional velocity limit (if known):									
Scale tendencies anticipated? Yes ☐ No ☐ Foamy oil behaviour? Yes ☐ No ☐									
Paraffin deposition anticipated? Yes ☐ No ☐ Emulsions? Yes ☐ No ☐									
Asphaltene deposition anticipated? Yes ☐ No ☐									
If yes to any above items provide details (inversion point, emulsion viscosity data, water chemistry, etc.)									
Treating chemicals being injected in the well? Yes ☐ No ☐									
If yes, please describe:									
Operator manuals required? Yes ☐ No ☐									
Subcomponent condition classifications acceptable (for Q3 components only):									
New only ☐ New and/or re-certified: ☐									
Grade selections: Design validation, functional evaluation and quality control (required)									
Component	Selected grades								
	Design validation (See Annex A)			Functional evaluation (See Annex C)			Quality control (7.4)		
	V1	V2	V3	F1	F2	F3	Q1	Q2	Q3
	Bolt on discharge								
Pump and gas handlers									
Bolt on intake									