PUBLICLY AVAILABLE SPECIFICATION

ISO/PAS 12835

First edition
2013-12-15

Qualification of casing connections for thermal wells

Qualification des raccordements de boîtiers pour les puits thermiques

Reference number
ISO/PAS 12835:2013(E)

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Published in Switzerland

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Foreword

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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 documents 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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 5, *Casing, tubing and drill pipe*.

Introduction

This Thermal Well Casing Connection Evaluation Protocol (TWCCEP) provides procedures for assessment and thereby enables evaluation of suitability of threaded casing connections for service in intermediate or production casing strings of thermal recovery wells. The TWCCEP defines such wells as those with operating temperatures that cyclically vary between minimum values appreciably below 180°C and maximum values that range from 180°C to 350°C, in which the casing string is cemented and the primary axial loading is strain-based.

Throughout this document, a casing connection subject to evaluation is referred to as candidate connection. A candidate connection denotes a product with unique design features and production specifications for size, weight, and component materials (including pin, box, and interfacial components).

The TWCCEP assesses the candidate connection's galling resistance, structural integrity and sealability under loads typical for connection assembly and thermal-well service. The TWCCEP does not address impacts of external pressure, incomplete lateral pipe support, rotational fatigue, formation-induced shear, or environmentally-induced corrosion or cracking.

The TWCCEP's evaluation procedure includes analysis and full-scale testing. In the analysis, worst-case combinations of the connection geometry and material properties are determined and specifications for test specimens are derived. In the full-scale tests, those specimens are subjected to loading representative of thermal well operations. While the TWCCEP aims to enable a statistically significant full-scale test, it does not demand a rigorous check of a true statistical placement of the tested sample responses relative to field connection performance, and thus inherently assumes that the test specimens are representative of subsequent field connections. For this reason, only connections with the same design parameters as the candidate connection should be considered representative of the connection assessed under this protocol.

The extensive effort involved in replicating thermal well field conditions in a laboratory environment limits the extent of physical testing that can reasonably be undertaken in an evaluation program. This protocol balances technical rigor and practicality to provide a baseline level of confidence in the candidate connection's performance. Connection users should consider the scope of this evaluation and appropriate additions to address operation-specific conditions. Successful field use of a connection meeting the requirements of this protocol does not preclude an operator's need to employ appropriate product quality assurance measures and field operating practices.

The TWCCEP is the culmination of a thorough review of factors contributing to performance of casing connections in thermal well applications. This protocol has been developed using input from operators' descriptions of field practices, manufacturers' feedback on connection design and production, available literature, knowledge of past connection qualification programs, and additional analytical and experimental work performed in support of the protocol development. The TWCCEP is intended to be maintained and refined as new findings surface.

Qualification of casing connections for thermal wells

1 Scope

ISO/PAS 12835 is intended for assessment of casing connections for those field applications in which the design of the casing-connection system is strain-based, and in which primary axial loading is on the casing-connection system driven by constrained thermal expansion, and in which that primary loading exceeds the casing-connection system's yield envelope. Consequently, ISO/PAS 12835 should be considered as a protocol that is complementary to ISO 13679, which applies to classic elastic-design applications.

ISO/PAS 12835 describes the structure of the Thermal Well Casing Connection Evaluation Protocol (TWCCEP) and provides guidelines for its use by new or repeat TWCCEP users, whose familiarity with the TWCCEP provisions might vary. Clause 6 describes fundamental assumptions adopted in the TWCCEP.

NOTE The term "user" refers to a party that uses the TWCCEP in a connection evaluation program. That party might or might not be the same party as a later user of the evaluated connection in a field application.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the cited edition applies. For undated references, the latest editions of the reference documents apply.

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

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

ASTM E21, *Standard Test Methods for Elevated-Temperature Tension Tests of Metallic Materials*

ASTM E831-06, *Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*

ISO 9001, *Quality management systems — Requirements*

ISO 11960, *Petroleum and natural gas industries — Steel pipe for use as casing and tubing for wells*[1)]

ISO 13679:2002, *Petroleum and natural gas industries — Procedures for testing casing and tubing connections*[2)]

3 Terms and definitions

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

3.1
ambient temperature
ambient temperature in the facility where a physical testing task is executed

1) Based on API Specification 5CT.

2) Based on API Specification 5C5.

3.2
application severity level
connection loading specifications assumed to be representative for a range of operational conditions, which determine the scope of analysis and testing required by the evaluation procedure (3.15) for those operational conditions

3.3
assigner
party that commissions an evaluation program (3.16)

3.4
average string strain
average axial strain along the controlled elongation interval (3.13) of a specimen string (3.37)

3.5
bend test specimens
subset of candidate connection specimens (3.8) subjected to the optional bending evaluation (3.6) per the TWCCEP evaluation procedure (3.15)

3.6
bending evaluation
analysis and physical testing conducted to determine a candidate connection's (3.7) sensitivity to casing curvature

3.7
candidate connection
casing connection product that is being evaluated by the TWCCEP, and is uniquely defined by its design features and production specifications with respect to size, weight, and component materials

3.8
candidate connection specimens
a set of connection specimens (3.11, 3.12) that is representative of a candidate connection's (3.7) design and features, and is provided for an evaluation program (3.15) of that candidate connection (3.7)

3.9
casing pup
short piece of casing pipe cut from a mother joint

3.10
connection
single design-specific assembly of pin and box and interfacial component(s)

3.11
connection specimen (for threaded and coupled connections)
two connections consisting of a single coupling and two casing pups (3.9) with pin ends joined by that coupling

3.12
connection specimen (for integral connections)
one connection consisting of one casing pup (3.9) with a box end and one casing pup (3.9) with a pin end

3.13
controlled elongation interval
portion of a specimen string (3.37), along which the elongation is measured and controlled

3.14
effective string length
portion of the total length of a specimen string (3.37) that is assumed to deform appreciably under mechanical forces in the thermal cycle test (3.44)

3.15
evaluation procedure
set of analytical and testing tasks required by the TWCCEP to assess performance of the candidate connection specimens (3.8)

3.16
evaluation program
execution of the TWCCEP to assess performance of a candidate connection (3.7)

3.17
evaluation report
collectively, all documents prepared by an evaluator (3.18), according to applicable TWCCEP reporting requirements, that describe an evaluation program's (3.16) execution history and results

3.18
evaluator
party that performs analytical and testing tasks required by an evaluation procedure (3.15)

3.19
excluded connection
connection (3.10) that has been evaluated in a TWCCEP full-scale test but whose performance has been excluded from comparison with threshold performance requirements (3.45)

3.20
galling
cold welding of contacting material surfaces followed by tearing of metal during subsequent sliding

3.21
high cycle temperature
targeted highest temperature in the thermal cycle test (3.44)

3.22
inspection report
collectively, all documents prepared by an inspector (3.23), according to applicable TWCCEP reporting requirements, that describe compliance of the executed evaluation program (3.16) with TWCCEP requirements

3.23
inspector
party that verifies compliance of the executed evaluation program (3.16) with requirements of the TWCCEP

3.24
interfacial component(s)
design-specific component(s) of a connection (3.10) applied to the pin and box either during their manufacturing (e.g. coatings) or during the connection assembly (e.g. thread compound)

3.25
limit-strain specimens
subset of candidate connection specimens (3.8) subjected to the limit-strain test (3.26) per the TWCCEP evaluation procedure (3.15)

3.26
limit-strain test
tension test, to structural failure, of the limit-strain specimens (3.25)

3.27
low cycle temperature
targeted lowest temperature in the thermal cycle test (3.44)

3.28
make-break specimens
subset of candidate connection specimens (3.8) subjected to multiple make-ups and break-outs per the TWCCEP evaluation procedure (3.15)

3.29
make-up support pin
pin component of candidate connection (3.7) with seal removed, used to support a coupling's open end during make-up and break-out of that coupling's opposite end

3.30
material coupon
cylindrical section of pipe from which material strip specimens (3.31) are cut

3.31
material strip specimen
longitudinal steel strip cut from a material coupon (3.30) and machined for use in mechanical property characterization tests

3.32
prior evaluation data
set of data acquired in a connection performance assessment carried out by analysis and/or physical tests prior to issuance of this protocol and/or according to a procedure/protocol different than the TWCCEP evaluation procedure (3.15)

3.33
program roles
collective reference to the roles of assigner (3.3), supplier (3.39), evaluator (3.18) and inspector (3.23)

3.34
repairable galling
galling that can be repaired according to a supplier's (3.39) field-repair procedure for a candidate connection (3.7)

3.35
severe galling
galling that cannot be repaired according to a supplier's (3.39) field-repair procedure for a candidate connection (3.7)

3.36
specimen
used in commentary and/or descriptive context, denotes a generic reference to a connection specimen (3.11, 3.12) or to a material strip specimen (3.31)

3.37
specimen string
collective reference to a single connection specimen (3.11, 3.12) and/or an in-series assembly of two or more connection specimens (3.11, 3.12) in a thermal cycle test (3.44)

3.38
substantially qualified party
person/company possessing technical skills and experience necessary to perform a task, as designated by the assigner (3.3) and the supplier (3.39)

3.39
supplier
party that manufactures a candidate connection (3.7)

3.40
tensile strain threshold
tensile strain value that a connection specimen (3.11, 3.12) is expected to survive during a limit-strain test (3.26)

3.41
test specimen
used in commentary and/or descriptive context, denotes a generic reference to a connection specimen (3.11, 3.12) that is provided for a full-scale test

3.42
thermal cycle
used in commentary and/or descriptive context, denotes a temperature excursion from a low initial temperature to a high maximum temperature and back to the low initial temperature

3.43
thermal cycle specimens
subset of candidate connection specimens (3.8) subjected to the thermal cycle test (3.44) per the TWCCEP evaluation procedure (3.15)

3.44
thermal cycle test
thermo-mechanical test of connection specimens (3.11, 3.12), in which several thermal cycles are applied between the low cycle temperature (3.27) and the high cycle temperature (3.21)

3.45
threshold performance requirements
set of connection performance criteria that candidate connection specimens (3.8) must satisfy in order for a candidate connection (3.7) to be considered as having met TWCCEP minimum performance requirements

4 Abbreviations, symbols and illustrations of selected definitions

4.1 Abbreviations

Terms defined in Table 1 denote abbreviations used for descriptive purposes.

Table 1 — List of abbreviations

ASL	application severity level
BF	fast box taper
BS	slow box taper
CSS	cyclic steam stimulation
CTE	coefficient of thermal expansion
FEA	finite element analysis
max.	maximum
min.	minimum
PF	fast pin taper
PS	slow pin taper
SAGD	steam assisted gravity drainage

TC	threaded-and-coupled
TWCCEP	thermal well casing connection evaluation protocol
TF(WGS)	final make-up torque for specimen with WGS configuration
TF(WGT)	final make-up torque for specimen with WGT configuration
TF(WSC-M)	final make-up torque for specimen with WSC configuration and multiple make-ups
TF(WSC-S)	final make-up torque for specimen with WSC configuration and single make-up
TF(WST-M)	final make-up torque for specimen with WST configuration and multiple make-ups
TF(WST-S)	final make-up torque for specimen with WST configuration and single make-up
WGS	worst-case tolerance combination for galling in seal
WGT	worst-case tolerance combination for galling in threads
WSC	worst-case tolerance combination for sealability in compression at high temperature
WST	worst-case tolerance combination for sealability in tension at low temperature

4.2 Symbols

Terms defined in Table 2 denote variables, which depend on the selected application severity level (ASL) and other protocol options, procedural calculations, and interim results.

Table 2 — Symbols

CTE_a	average coefficient of thermal expansion
ρ_{MAX}	maximum test curvature
D	casing outside diameter
$\Delta\varepsilon_{LL}$	strain increment for application in the limit-strain test
$\Delta\rho$	curvature increment
$ETTE_a$	average residual post-cycle strain
L_{CEI}	length of controlled elongation interval
L_p	unsupported pup length (pup length excluding make-up loss, i.e. pin-box overlaps at each end)
$LTTS$	lower-bound temperature strain increment
$SLCF$	strain-length compensating factor
SRI	temperature range strain increment
$SSP(T)$	saturated steam pressure at temperature T
t	casing wall thickness
T	temperature
T_{amb}	ambient temperature
T_{hc}	high cycle temperature

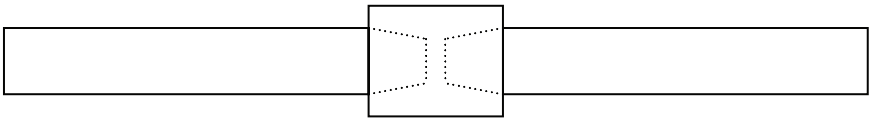
T_{lb} lower-bound temperature for a given application severity level

T_{lc} low cycle temperature

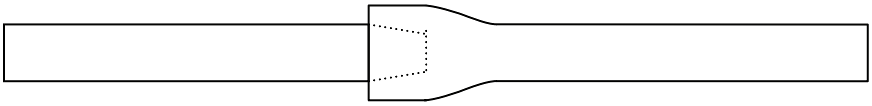
T_{ub} upper-bound temperature for a given application severity level

4.3 Illustrations of selected definitions

Figure 1 illustrates a connection specimen (3.11, 3.12). Figure 1 a) shows a connection specimen for a threaded-and-coupled (TC) connection (3.11), and Figure 1 b) shows a connection specimen for an integral connection (3.12). A threaded-and-coupled connection specimen consists of one coupling and two casing pups (3.9), and contains two connections (two leak paths). An integral connection specimen consists of one pin-end pup and one box-end pup, and contains one connection (one leak path).



a) Threaded-and-coupled connection specimen



b) Integral connection specimen

Figure 1 — Illustration of connection specimens

When full-scale testing is conducted on strings containing multiple connection specimens assembled in series, some casing pups are shared by two adjacent connection specimens (which might be either threaded and coupled or integral). Each such shared casing pup is considered to consist of two halves, with each half belonging to the connection specimen that includes the corresponding pin end or integral box end. Figure 2 illustrates an example of a string assembly with four connection specimens. For consistency with TWCCEP requirements for a thermal cycle test (3.44), in which a four-specimen string (3.37) assembly may be used, the example in Figure 2 shows Specimens 3, 4, 5, and 6. For threaded and coupled connection specimens, the two specimen leak paths can be distinguished by the specimen number and letters "A" and "B" referring to each specimen side.

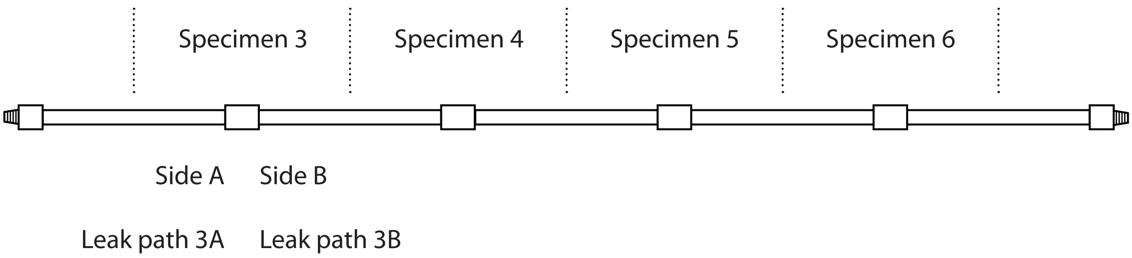


Figure 2 — Illustration of connection string assembly

5 Program flowchart

Figure 3 illustrates five main components (blocks) of a TWCCEP program (3.16). A detailed description of the TWCCEP blocks and tasks is provided in Clause 10.

General principles adopted for the TWCCEP evaluation procedure (3.15) are described in Clause 6. It is strongly recommended that all users of this document and all parties responsible for a prospective use

of an assessed connection in a field application review Clause 6 and become aware of the assumption basis and procedural requirements specified by TWCCEP for the assessment tasks and data reporting.

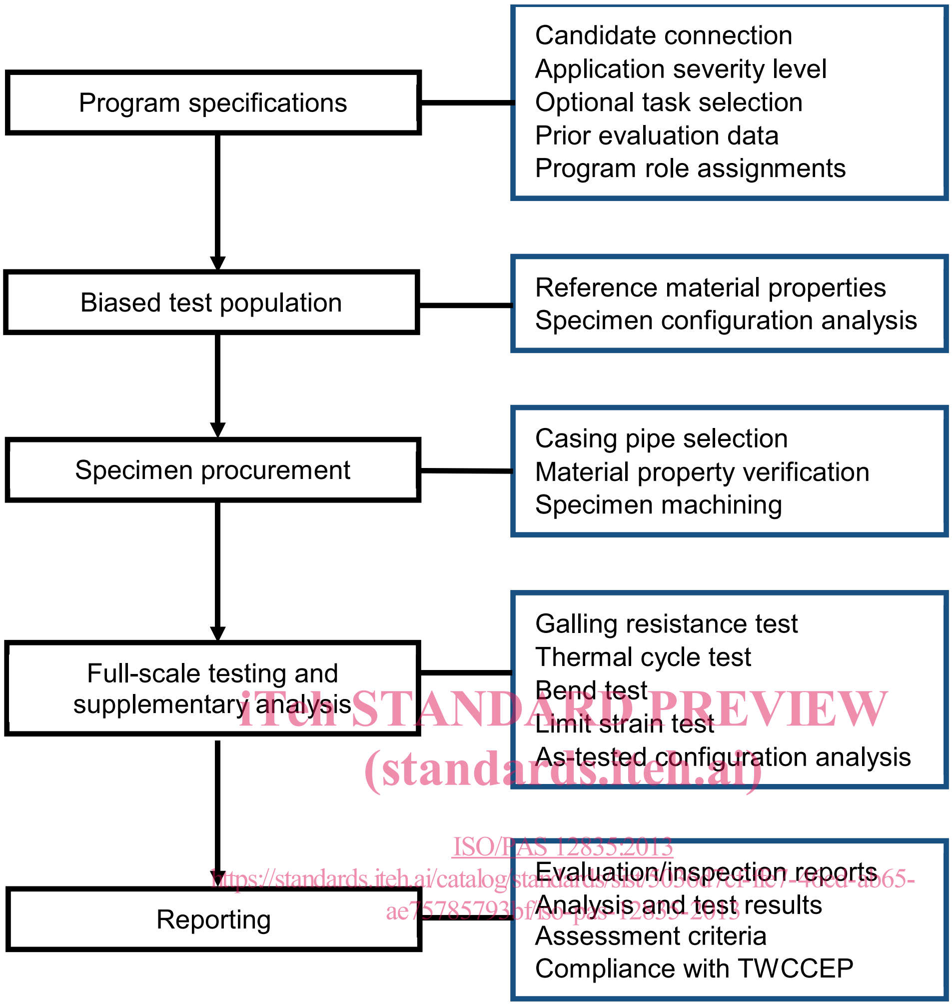

Program specifications
Candidate connection
Application severity level
Optional task selection
Prior evaluation data
Program role assignments
Biased test population
Reference material properties
Specimen configuration analysis
Specimen procurement
Casing pipe selection
Material property verification
Specimen machining
Full-scale testing and supplementary analysis
Galling resistance test
Thermal cycle test
Bend test
Limit strain test
As-tested configuration analysis
Reporting
Evaluation/inspection reports
Analysis and test results
Assessment criteria
Compliance with TWCCEP

Figure 3 — TWCCEP flowchart

6 Overview and fundamental assumptions of TWCCEP

6.1 General

This Clause contains an overview of fundamental assumptions adopted for the TWCCEP, which are provided to facilitate understanding and interpretation of TWCCEP's provisions and procedural requirements specified in later Clauses of this document.

6.2 Main TWCCEP features

6.2.1 Purpose of TWCCEP

The TWCCEP provides procedures for assessing suitability of threaded casing connections for intermediate or production casing strings for thermal recovery wells. Conducting an assessment of a candidate connection according to the TWCCEP provides data that can be interpreted by a user to complete evaluation of the candidate connection.

6.2.2 Applicability to service conditions

The TWCCEP applies to those field applications in which operational temperatures oscillate between a cold level, appreciably below 180°C, and a hot level, above 180°C, in which casing deformation is primarily driven by thermo-mechanical strain resulting from the above temperature excursions, and in which the casing body might or might not cyclically yield under the corresponding strain-driven loads.

Specifically, the TWCCEP applies to two thermal-recovery applications: Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS), in which thermal expansion of the casing string is constrained by cementing. The TWCCEP might also be used for qualifying connections for other extreme-service wells in which tubular undergo full-body yielding and for which deformation-tolerant design is desired; for example, wells in compacting reservoirs, steam-drive wells, geothermal wells, or some high-pressure, high-temperature wells.

6.2.3 Rationale for TWCCEP development

Lack of a standard connection evaluation procedure for thermal-well applications was the main rationale for developing the TWCCEP.

Loading of intermediate casing connections in thermally stimulated wells is very severe and of unique character. Prior to issuance of the TWCCEP, no other connection evaluation procedure had been adopted as an industry standard for those loading conditions. In particular, ISO 13679 provides procedures for evaluating casing and tubing connections only for elastic-design applications, in which the tubular-body stress state is assumed to remain elastic, and in which maximum operational temperatures do not generally exceed 180°C. Despite these fundamental differences, several similarities exist between the TWCCEP and ISO 13679. Where practical, such similarities are referred to in this document.

6.2.4 Subject of evaluation

A casing connection product subjected to an evaluation program is referred to as a candidate connection (3.7). A candidate connection denotes a product with unique design features and production specifications for size, weight, and component materials (including pin, box, and interfacial components (3.24)).

In general, one or more candidate connections can be assessed in an evaluation program. For simplicity, this document refers to a single candidate connection as a subject of evaluation. If two or more candidate connections are included in a single evaluation program, then all of the TWCCEP provisions apply to each candidate connection separately.

6.2.5 Application severity levels

The severity of field operating conditions varies. The TWCCEP distinguishes multiple ASLs, uniquely defined in terms of maximum operating temperature (see 9.3).

Temperature has been recognized as the primary variable influencing severity of pipe thermo-mechanical loading and the connection response to that loading, including sealability and structural performance. The following arguments support this assumption:

— constrained thermal expansion of cemented casing heated to the maximum operating temperature leads to pipe and/or connection yielding. The magnitude of the axial loads generated during heating (and also subsequent cooling during a well intervention), as well as the degree of post-yield deformation, strongly depend on the applied temperature range;

— in field service, applied internal pressures typically follow the saturated-steam relationship with temperature;

— properties of casing pipe and connection materials vary with temperature – the material yield strength typically decreases with temperature, and creep and relaxation effects become more pronounced at elevated temperatures;