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Petroleum and natural gas industries — Pipeline transportation systems

AMENDMENT 1: Complementary requirements for the transportation of fluids containing carbon dioxide or hydrogen

Industries du pétrole et du gaz naturel — Systèmes de transport par conduites

AMENDEMENT 1: Exigences complémentaires relatives au transport de fluides contenant du dioxyde de carbone ou de l'hydrogène

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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 2, *Pipeline transportation systems*.

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Petroleum and natural gas industries — Pipeline transportation systems

AMENDMENT 1: Complementary requirements for the transportation of fluids containing carbon dioxide or hydrogen

2 Normative references

Add the following documents:

> ISO 27913, *Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems*
>
> API Spec 5L, 46th edition (2018), *Specification for Line Pipe*

5.2 Categorization of fluids

Add the following paragraph at the end of the subclause:

> For category E fluids containing carbon dioxide exceeding the limit specified in G.1 the requirements in Annex G shall apply
>
> For category E fluids containing hydrogen exceeding the limit specified in H.2, Annex H shall apply.

8.1.6 Shear-fracture toughness

Designate the existing NOTE as NOTE 1 and add the following new NOTE:

> NOTE 2 ISO 27913 provides guidance on determining the fracture-toughness requirements for the arrest of running shear fractures in carbon dioxide pipelines.

Annex G

Add the following annex after Annex F.

Annex G
(normative)

Requirements for the transportation of fluids containing carbon dioxide

G.1 General

This annex provides requirements for the transportation of fluids consisting overwhelmingly of carbon dioxide.

NOTE Industry-accepted interpretation of “overwhelmingly CO_2” required by the London Convention and Protocol which came into force in February 2007 is 95 % molar fraction.

G.2 General design consideration

When designing pipeline systems for the transportation of fluid containing overwhelmingly CO_2, the following specific properties of carbon dioxide shall be considered:

— asphyxiant and mildly toxic;

— non-flammable;

— odourless;

— heavier than air;

— highly corrosive in the presence of free water;

— transportable in both gas or dense phase in manageable pressure and temperature regimes having adequate margin with respect to the phase envelope to avoid two-phase flow during normal operation;

— significant impact of impurities on the thermodynamic properties and the potential hazards;

— more susceptible to running shear fracture than conventional natural gas, especially if carbon dioxide is transported in dense phase.

NOTE Carbon dioxide is not classified as toxic under the Globally Harmonized System of Classification and Labelling of Chemicals. However, carbon dioxide is considered to be sufficiently toxic to be classified as a category E fluid as defined in Table 1 (see Reference [8]).

G.3 Requirements

Pipeline transportation systems designated for the transportation of the fluid defined in G.1 shall conform to the requirements specified in this document for category E substances and with the requirements of ISO 27913.

Annex H

Add the following annex after the newly-added Annex G, before the Bibliography.

Annex H
(normative)

Requirements for the transportation of fluids containing hydrogen

H.1 General

This annex provides requirements for the transportation of fluids containing hydrogen in quantity exceeding the limits specified in H.2.

H.2 Limit of application

The requirements specified in this annex shall apply to fluids with hydrogen content equal to or in excess of the minimum for exposing the pipeline system materials to the risk of hydrogen embrittlement or people, environment and assets to hazards different from those considered for category D substances and other category E substances.

NOTE The hydrogen content limit specified above can depend on several factors (metallurgy, pressure, temperature, contaminants, etc.) to be evaluated for the specific project case. A molar fraction of 2 % has historically been used as a limit below which no requirements additional to those specified for category D substances and other category E substances apply. Laboratory testing indicates that hydrogen can have an effect on the material properties at lower concentrations.

H.3 General design consideration

When designing pipeline systems for the transportation of fluid containing hydrogen, the following specific properties of hydrogen shall be considered:

— highly flammable;

— easily ignited and auto-ignited;

— burning with flame almost invisible in day light;

— easy to permeate and leak;

— promoting steel embrittlement;

— increasing in temperature when expanding.

NOTE An overview of the properties of hydrogen and related basic safety concerns, hazards and risks is provided in ISO/TR 15916.

H.4 Materials

H.4.1 Materials requirements

Materials shall conform to the requirements in Clause 8 and the following.

— Line pipe shall conform to ISO 3183 with product specification level PSL2 or to equivalent line pipe specification in case of repurposing of existing pipelines.

— Line pipe steel grade shall not exceed L485.

— ISO 3183 or API Spec 5L, 46th edition (2018), Annex G shall apply.

— Non-metallic materials and metals other than line pipe carbon steel shall be verified for compatibility with hydrogen.

NOTE 1 By way of example, EN 10208-2:2009 or API Spec 5L with adequate supplementary requirements and ISO 3183-2:1996 or ISO 3183-3:1999 are linepipe specifications that can be considered as equivalent to ISO 3183 for the purpose of this annex in the case of repurposing existing pipelines to hydrogen transportation.

NOTE 2 ISO/TR 15916 provides some indications of metallic materials susceptibility to hydrogen embrittlement and their suitability for hydrogen service.

NOTE 3 ISO 11114-2, ISO/TR 15916 and EIGA IGC Doc 121/14 provide guidance for the selection of non-metallic materials compatible with hydrogen.

H.4.2 Recommended material properties

The material should have the following properties.

— Line pipe steel should be treated for inclusion shape control.

— Line pipe chemical composition should be in accordance with ISO 3183 or API Spec 5L, 46th edition (2018), Table H.1.

— Hardness of line pipe and steel components should be ≤ 250 HV10 in parent metal, heat affected zone and weld metal in factory made and field welds.

Consideration should be given to HIC testing.

NOTE An ALARP (as low as reasonably practicable) approach can help in deciding the application of the recommended properties to newly built pipelines by balancing effort, time and money spent to apply the requirement and the benefit achieved. This approach most often leads to fulfilment of the recommended properties.

H.5 Design factors

H.5.1 Hoop stress basic design factors

The hoop-stress design factor f_{h} to be used in Formula (3) shall be determined in accordance with Formula (H.1):

$$f_{\mathrm{h}} = f_{\mathrm{hH2}} \times H_f \quad \text{(H.1)}$$

where

f_{hH2} is the base hoop design factor for the transportation of fluids with hydrogen content exceeding the limit specified in H.2, which shall be:

— 0,55 for offshore pipelines;

and if Annex B is applicable (see B.1):

— 0,55 for on land pipelines in location classes 1 to 4;

— 0,45 for on land pipelines in location class 5.

H_f is the performance factor depending on MAOP and steel grade, which shall be obtained from Table H.1.

Table H.1 — Performance factors, H_f

Line pipe steel grade	MAOP [MPa][a]						
	6,89	13,79	15,17	16,55	17,93	19,31	20,68
L360	1,000	1,000	0,954	0,910	0,880	0,840	0,780
L415	0,874	0,874	0,834	0,796	0,770	0,734	0,682
L450	0,832	0,832	0,794	0,758	0,733	0,699	0,649
L485	0,776	0,776	0,742	0,706	0,684	0,652	0,606

[a] Interpolation may be used to calculate H_f for intermediate values of MAOP.

NOTE ASME STP-PT-006 provides the rationale for the factors reported in this table.

H.5.2 Hoop stress enhanced design factors

The hoop stress design factors specified in Table 3 and in Table B.2 if Annex B is applicable, may be used provided line pipe material conforms to the requirements specified in H.4.1 and the following.

— Line pipe steel and welds shall have fracture toughness adequate to ensure sufficient resistance to hydrogen embrittlement in the transported fluid environment, proven by dedicated testing.

— Line pipes shall conform with the following requirements, unless it is proven by dedicated testing, or testing of or field experience with similar and representative material, that line pipes have sufficient resistance to hydrogen embrittlement even though not conforming:

  — Line pipe steel shall be treated for inclusion shape control.

  — Line pipe chemical composition shall be in accordance with ISO 3183 or API Spec 5L, 46th edition (2018), Table H.1.

  — Hardness of line pipe and steel components shall be ≤ 250 HV10 in parent metal, heat affected zone and weld metal in factory made and field welds.

Properties of tested or field proven materials and testing methods and results shall be documented.

NOTE 1 ISO 11114-4 and ASME B31.12 provide criteria and testing methods to assess fracture toughness in fluids containing hydrogen.

NOTE 2 Comparison of manufacturing procedure specifications (MPSs) and welding procedure specifications (WPSs) is an effective way to assess similarity and representativeness of the proven or tested material versus that actually used.

NOTE 3 Lower line pipe hardness can be necessary to comply with the 250 HV10 maximum hardness requirement in the girth weld.

NOTE 4 EPRG Hydrogen Pipelines Integrity Management and Repurposing Guideline White Paper provides information about the status of knowledge on hardness requirements.

H.5.3 Longitudinal stress

Longitudinal tensile stress shall not exceed the maximum allowable value specified for the hoop stress unless line pipe and welds conform to the material properties specified in H.5.2.

H.6 Fatigue

A fatigue analysis shall take into account the effect of hydrogen on fatigue crack growth.

The following shall be considered.

— Fatigue crack growth rate test data indicate that the rate of crack growth in hydrogen is of the order of 10 to 100 times higher than that in air. The difference depends upon the cyclic stress intensity factor range, ΔK, and the stress ratio, R (the ratio of the minimum stress to the maximum stress). The difference is larger at higher ΔK and smaller at lower ΔK. It increases as R increases. The rate of crack growth in hydrogen tends to that in air as ΔK decreases.

— The operational load cycles due to the variation in internal pressure can be greater in hydrogen service than in natural gas service, because of the implications of the different thermodynamic properties of hydrogen for the operation of a network (and, in particular, diurnal storage). This combined with reduced fatigue capacity of longitudinal seam welds can govern the wall thickness design.

The analysis may be based on either the characteristic fatigue resistance (normally given as S-N curves, i.e. stress amplitudes versus number of cycles to failure) or a fracture mechanics fatigue life assessment.

NOTE ASME B31.12 and IGEM/TD/1 Edition 6 Supplement 2 give (different) recommendations on fatigue crack growths for steels in gaseous hydrogen. IGEM/TD/13 Edition 2 Supplement 1 recommends that a factor of fifty (50) is applied to the S-N curves in BS 7608. The basis of the S-N curves in BS 7608 is similar to that of the curves in EN 1993-1-8 and IIW-1823-07.

H.7 Flanges and valves

The small molecular size of hydrogen and its proneness to leak either to the environment in case of flanges or to both the environment and from one side to the other in case of valves shall be considered.

Flanges and other mechanical connectors should be avoided and if this is not possible, they shall be minimised in number as much as possible.

Easy access for inspection and maintenance shall be ensured.

Flanged joints and valves shall be tested for fugitive emissions.

Valve actuators shall be designed to avoid being a possible source of ignition.

NOTE EIGA IGC Doc 121/14 provides recommendations to minimize the risk of leaks from valves.

H.8 Safety evaluation

Hydrogen is a category E fluid and is subject to the requirements for public safety stated elsewhere in this document (5.6, 6.2.1.2, Annex B and Annex E).

Although the thermal hazard radius from an ignited release is smaller than that for a natural gas pipeline with the same outside diameter and MAOP, hydrogen is more hazardous than natural gas for a number of reasons, including:

— potentially reduced tolerability to third-party damage and defects because of hydrogen embrittlement;

— increased ignition probability due to lower ignition energies required and larger range in flammable concentrations;

— increased flame speed and potential for deflagration-to-detonation transition (DDT) at much shorter distances;

— potential for overpressures resulting from explosion, especially in confined space or in case of delayed ignition;

— potentially higher volumetric leak rate, faster spread of a gas cloud, and longer jet lengths;

— poor visibility of flame in daylight for small fires (large fires are visible and have similar heat flux).

These factors shall be taken into account in determining the population density in accordance with B.3 and performing frequency and consequence analysis in accordance with E.7 and E.8 accounting for the possibility of hydrogen embrittlement.

Table B.7 provides mitigation measures for third-party damage that can be taken into consideration in the safety evaluation.

H.9 Repurposing

Existing pipelines may only be converted to hydrogen service, provided they are re-qualified for such service in accordance with the requirements described in this document.

The repurposing shall follow a pre-defined process that includes the following topics:

— initiation: the decision to repurpose the selected pipeline and specification of applicable references; a 'management of change' process shall be employed;

— requirement definition: transport capacity, operational parameters, and composition;

— review of available technical documentation: design (including material data), construction, inspection and repair, operational data and history;

— integrity assessment: based on the current pipeline integrity status and operating history also considering intended future service with special focus on influence of hydrogen on the material properties;

— hydraulic assessment: validating the transport premises and pressure requirements definition, also considering the outcomes of integrity assessment, including identification of modifications needed for pumps or compressors stations;

— safety evaluation: any changes in the safety as a result of a new fluid and the need for venting requirements; the safety evaluation shall be carried out in accordance with Annex E;

— re-assessment: integrity re-assessment considering influence of hydrogen on the material properties and defining the required modifications;

— documentation of the above;

— implementation of the actions identified in the process steps above.

If the available pipeline data and information are inadequate, (e.g. missing, partial or out of date), they shall be complemented and integrated with dedicated inspection and testing campaigns as necessary to conform to this annex, e.g. visual inspection/external survey, in-line inspection, cathodic protection survey, non-destructive and destructive testing. Any approaches or assumptions made to deal with limited available data shall be reasonably conservative.

Principles of reliability-based limit state design methods may be applied to manage the uncertainties related to limited availability of pipeline data and assess the best testing frequency.

Reliability-based limit-state design methods shall not be used to replace the requirements in H.5.1, H.5.2 and H.5.3 as applicable for the maximum permissible hoop stress due to fluid pressure.

Engineering critical assessment (ECA) in accordance with accepted industry practices such as BS 7910 may be applied for integrity assessment. ECAs shall be documented. All input data and assumptions made during the assessment shall be included in the documentation. In case it is not possible to prove and document the conformity of the pipeline material to the requirements specified in H.4.1, the MAOP shall not exceed 13,79 MPa or the value corresponding to 30 % SMYS hoop stress, whichever is lower.

NOTE 1 ISO 16708 provides recommendations, framework and principles for the application of reliability-based limit state design methods.

NOTE 2 EPRG Hydrogen Pipelines Integrity Management and Repurposing Guideline White Paper provides clarification guidance on integrity management of pipelines transporting hydrogen.