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Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems

Captage, transport et stockage géologique du dioxyde de carbone — Systèmes de transport par conduites

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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 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).

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This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation, and geological storage*.

This second edition cancels and replaces the first edition (ISO 27913:2016), which has been technically revised.

The main changes are as follows:

— the entire text has been editorially revised;

— normative references have been updated;

— a subclause about CO_2 stream flowrate and impurity measurement has been added;

— the level of impurities has been limited to 5 % and a set of 17 requirements are defined to ensure CO_2 stream pipeline integrity;

— Annex A has been added to show example compositions of CO_2 streams for gaseous and dense phase CO_2 streams which fulfil the requirements of this document;

— the latest findings in fracture arrest design have been included in Annex D;

— Annex F has been added to describe the decompression effects on pressure and temperature versus time.

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.

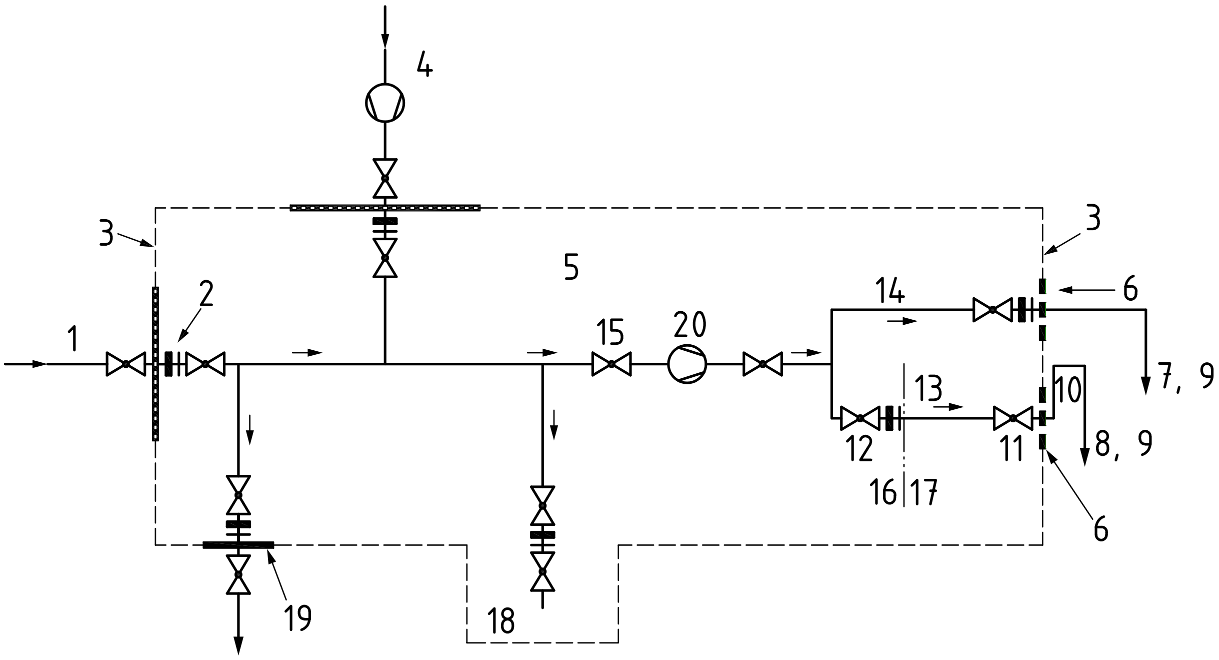
Introduction

Carbon dioxide (CO_2) capture, carbon dioxide use (CCU) and carbon dioxide storage (CCS) have been identified as key abatement technologies for achieving a significant reduction in CO_2 emissions to the atmosphere. Pipelines are likely to be the primary means of transporting CO_2 from the point-of-capture to storage sites (e.g. depleted hydrocarbon formations, deep saline aquifers), or to usage points (e.g. enhanced oil recovery or utilization) to avoid its release to the atmosphere. While there is a perception that transporting CO_2 via pipelines does not represent a significant barrier to implementing large-scale CCS, there is significantly less industry experience than there is for hydrocarbon service (e.g. natural gas). Furthermore, there are a number of issues that need to be adequately understood and associated risks that need to be effectively managed to ensure safe transport of CO_2. In a CCS or CCU context, there is a need for larger CO_2 pipeline systems in more densely populated areas and with CO_2 coming from multiple sources. Also, offshore pipelines for the transportation of CO_2 to offshore storage sites are likely to become common.

The objective of this document is to provide specific requirements and recommendations on certain aspects of safe and reliable design, construction and operation of pipelines intended for the large-scale transportation of CO_2 that are not already covered in existing pipeline standards such as ISO 13623, ASME B31.4, ASME B31.8, EN 1594, AS 2885 or other standards listed in the Bibliography. Existing pipeline standards cover many of the issues related to the design and construction of CO_2 pipelines. However, there are some CO_2-specific issues (e.g. fracture arrest, internal corrosion protection) that are not adequately covered in these standards but are addressed in this document. The purpose of this document is to cover these issues consistently. Hence, this document is not a standalone standard, but is written to be a supplement to other existing pipeline standards for natural gas or liquids for both onshore and offshore pipelines.

The system boundary (see Figure 1) between capture and transportation is the point at the inlet valve of the pipeline, where the composition, temperature and pressure of the CO_2 stream is within a certain specified range to meet the requirements for transportation as described in this document.

The boundary between transportation and storage or utilization is the point where the CO_2 stream leaves the transportation pipeline infrastructure and enters the downstream infrastructure, which can be permanent geological storage, utilization or buffer storage prior to shipping.



Key

1 source of CO_2 from capture (e.g. from power plant, industry; see ISO/TR 27912)
2 isolating joint
3 boundary limit
4 other source of CO_2
5 transportation system inside given in this document
6 boundary to storage facility or utilization
7 onshore storage facility
8 offshore storage facility
9 enhanced oil recovery
10 riser (outside transportation scope)
11 subsea valve (inside transportation scope)
12 beach valve
13 offshore pipeline
14 onshore pipeline
15 valve
16 landfall
17 open water
18 third party transport system
19 export to other uses than those of Keys 7, 8 and 9
20 intermediate compression or pumping

Figure 1 — Schematic illustration of the system boundaries of this document

Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems

1 Scope

This document specifies the requirements and recommendations for the transportation of CO_2 streams from the capture site to the storage facility where it is primarily stored in a geological formation or used for other purposes (e.g. for enhanced oil recovery or CO_2 use).

This document applies to the transportation of CO_2 streams by

— rigid metallic pipelines,

— pipeline systems,

— onshore and offshore pipelines for the transportation of CO_2 streams,

— conversion of existing pipelines for the transportation of CO_2 streams, and

— transportation of CO_2 streams in the gaseous and dense phases.

This document also includes aspects of CO_2 stream quality assurance, as well as converging CO_2 streams from different sources.

Health, safety and environment aspects specific to CO_2 transport and monitoring are also considered in this document.

Transportation of CO_2 via ship, rail or on road is not covered in this document.

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.

ISO 3183, *Petroleum and natural gas industries — Steel pipe for pipeline transportation systems*

ISO 20765-2, *Natural gas — Calculation of thermodynamic properties — Part 2: Single-phase properties (gas, liquid, and dense fluid) for extended ranges of application*

ISO/TR 27925, *Carbon dioxide capture, transportation and geological storage — Cross cutting issues — Flow assurance*

API SPEC 5L, *Line Pipe, 46th Edition, April 2018*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
aqueous phase
liquid phase composed predominantly of water and other impurities that are not dissolved in the gaseous or dense CO_2 phase

3.2
block valve
full-bore valve inserted into a pipeline to reduce the total volume of the *CO_2 stream* (3.4) that would be emitted in the case of planned or unplanned depressurization of that section or in the case of a pipeline rupture

3.3
bubble point pressure
pressure of the saturated liquid at a given composition and temperature

3.4
CO_2 stream
stream consisting overwhelmingly of carbon dioxide

Note 1 to entry: A carbon dioxide stream consists of usually more than 95 mol% CO_2.

3.5
corrosion allowance
additional wall thickness beyond that required by the mechanical design to compensate for any reduction in wall thickness by corrosion (internal/external) during the design operational life

3.6
critical point
highest temperature and pressure at which a pure substance (e.g. CO_2) can exist as a gas and a liquid in equilibrium

Note 1 to entry: For a multicomponent fluid mixture of a given composition, the critical point is the merge of the bubble point curve and the dew point curve.

Note 2 to entry: The critical point can be established with the *critical pressure* (3.7) and the *critical temperature* (3.8).

3.7
critical pressure
vapour pressure at the *critical temperature* (3.8)

Note 1 to entry: The critical pressure for pure CO_2 is 7,38 MPa.

3.8
critical temperature
pure substance temperature above which liquid cannot be formed simply by increasing the pressure

Note 1 to entry: The critical temperature of pure CO_2 is 304,13 K (equivalent to 30,98 °C).

Note 2 to entry: For *CO_2 streams* (3.4), phase transitions can still occur above critical temperature.

3.9
dense phase
<engineering> CO_2 or *CO_2 streams* (3.4) in the single-phase fluid state above a density of 500 kg/m^3

Note 1 to entry: For more details on the dense phase, refer to ISO/TR 27925.

3.10
dew point pressure
pressure on the saturated vapour line

3.11
ductile fracture
shear fracture
mechanism which takes place by the propagation of a crack or stress-raising features, linked with a considerable amount of local plastic deformation

3.12
environmental cracking
brittle fracture of a normally ductile material in which the corrosive effect of the environment is causing the embrittlement

3.13
flow assurance
engineering discipline that is required to understand the behaviour of fluids inside pipelines, at flowing and static conditions

Note 1 to entry: The flow assurance provides input to design activities, such as pipeline design or risk analysis and operating philosophy development.

3.14
fracture arrestor
crack arrestor
additional pipeline component that can be installed around portions of a pipeline designed to resist propagating fractures

3.15
hydraulic capacity
maximum flow rate achievable in a system for a given pressure loss and given mechanical and operating constraints

3.16
in-line inspection
ILI
operation of sending an inspection tool inside a pipeline for the purposes of maintenance procedures such as pipeline cleaning, liquid removal, corrosion detection

3.17
internal coating
layer to reduce internal roughness and minimize friction pressure loss on the inside of the pipeline

3.18
maximum allowable operating pressure
MAOP
highest possible pressure to which the equipment or system may reasonably be exposed locally during operation

3.19
minimum design temperature
lowest possible temperature to which the equipment or system may reasonably be exposed locally during installation and operation

3.20
multi-phase flow
co-existence of more than one fluid phases (e.g. gas and *dense phases* (3.9) or two dense phases) in the same location of the pipeline

3.21
non-condensable component
component that, when pure, can be in gaseous form at possible CO_2 equilibrium conditions throughout the CO_2 value chain

EXAMPLE N_2, Ar, H_2, CO, CH_4, O_2 (excluding CO_2).

3.22
operating envelope
limited range of parameters over which operations result in safe and acceptable performance of the equipment or system

3.23
pipeline commissioning
activities associated with the initial filling and pressurization of the pipeline system with the fluid to be transported

3.24
pipeline dewatering
removal of water after hydraulic testing of the pipeline system

3.25
rapid gas decompression
phenomenon brought about by pressurized fluid migrating at a molecular level into a polymer and then being released suddenly causing failure of polymeric materials

3.26
saturation pressure
saturation vapour pressure
pressure of a vapour which is in equilibrium with its liquid at a given temperature applicable to pure CO_2

Note 1 to entry: For a *CO_2 stream* (3.4) containing impurities, the saturation pressure can either be the pressure on the saturated liquid line [*bubble point pressure* (3.3)] or the pressure on the saturated vapour line [*dew point pressure* (3.10)]. For CO_2 streams, both pressures are different for a given temperature.

3.27
short-term storage reserve
accumulation of the fluid in a pressurized section of a pipeline additional to the fluid that is extracted from the pipeline, for the purpose of temporary storage of that fluid

3.28
single phase
flow of CO_2 or a *CO_2 stream* (3.4) in a gas or a *dense phase* (3.9), but not in any combination of them

3.29
threat
activity or condition that alone or in combination with others has the potential to cause damage or to produce another negative impact if not adequately controlled

3.30
triple point
temperature and pressure at which the three phases (gas, liquid and solid) of a substance coexist in thermodynamic equilibrium

3.31
vent station
installation from which the contents of the pipeline or a section of pipeline between *block valves* (3.2) can be vented

3.32
network code
set of rules that are operational terms and conditions and agreed by either operators or governments, or both, under which a CO_2 stream system is required to operate safely and in a way that allows the objectives of each party to be realised

Note 1 to entry: Figure 1 shows where the network code becomes relevant for different system operators.

4 Symbols and abbreviated terms

4.1 Symbols

A_C	cross-section area of the notched-bar impact specimen equal to 80 mm^2	mm^2
C_v	Charpy V-notch absorbed energy value of the pipeline steel measured in the transverse direction	J
D	outer diameter of the pipe	mm
E	Young's modulus	MPa
P	pressure	MPa
P_s	bubble point pressure at given temperature and CO_2 stream composition	MPa
R	average pipe radius	mm
t	wall thickness of the pipe	mm
t_{min}	minimum wall thickness	mm
t_{minDP}	minimum wall thickness against internal pressure	mm
t_{minHS}	minimum wall thickness against hydraulic shock	mm
t_{minDF}	minimum wall thickness against fracture propagation	mm
T	temperature	°C
σ_f	flow stress	MPa

4.2 Abbreviated terms

BTEX	collective term for the highly volatile aromatic hydrocarbons benzene, toluene, ethylbenzene and xylene
BTCM	Battelle Two Curve Method
CCS	carbon dioxide capture and storage
CCU	carbon dioxide capture and utilization
DEG	diethylene glycol
EOR	enhanced oil recovery
ILI	in-line inspection
IMP	integrity management plan
MAOP	maximum allowable operating pressure
MEG	monoethylene glycol
SSC	sulphide stress cracking
TEG	tri-ethylene glycol

NDMA N-nitrosodimethylamine, also known as dimethylnitrosamine (DMN)

NMEA N-methylethanolamine

NDEA N-nitrosodiethylamine

NDELA N-nitrosodiethanolamine

NPIP N-nitrosopiperidine

NOMor N-nitrosomorpholine

PCDD polychlorinated dibenzodioxins

PCDF polychlorinatedfurans

5 Properties of CO_2, CO_2 streams and the mixing of CO_2 streams that influence pipeline transportation

5.1 General

According to ISO 20765-2, pure CO_2 and CO_2 streams have properties that can be very different from those of hydrocarbon fluids and can influence all stages of the pipeline life cycle. The thermodynamic and chemical behaviours of pure CO_2 have been explored throughout literature (e.g. see Reference [50]). In the usual operating envelope for CCS or CCU, the temperature and pressure vary and are project-specific. CO_2 can be in the gaseous or dense phase. There can be a large change in properties when crossing a phase boundary and for this reason, normal operation close to the phase boundaries should be avoided if possible.

In case multi-phase flow cannot be avoided for any reason, it should be given special consideration during design, commissioning, operation and decommissioning (see References [25] and [52]).

Subclauses 5.2 and 5.3 provide information for the designer and pipeline operator on how to decide on the correct parameters to be used to avoid negative impacts on the pipeline integrity.

Impurities within the CO_2 stream affect the phase envelope and can result in negative impacts on the pipeline operation and integrity. As part of the design process, limits shall be specified for the maximum levels of impurities within the CO_2 stream, and robust measurement equipment shall be installed to monitor the composition against this specification prior to its entry into the pipeline. For more information, refer to Annex A.

5.2 Pure CO_2

5.2.1 Thermodynamics

The thermodynamic properties of CO_2, particularly the saturation pressure, shall be taken into account because they have a significant impact on the design and operation of the pipeline. For a dense phase pipeline, the maximum saturation pressure resulting from isentropic expansion from within the operating envelope shall be used as the principal parameter in the design against running ductile fractures as described in 8.1.6. For gaseous transport, refer to 8.1.5.

The potential for inaccuracies in saturation pressure prediction and fluid properties should be taken into account when evaluating the design and operational philosophy of a CO_2-transport system, and when applying a margin of error to the maximum saturation pressure as a design criterion is recommended.

5.2.2 Chemical reactions and corrosion

With pure CO_2, there are no chemical reactions or internal corrosion in the pipeline.