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Petroleum and natural gas industries — Offshore platforms handling streams with high content of CO_2 at high pressures

Industries du pétrole et du gaz naturel — Plates-formes en mer traitant des courants à fort teneur en CO_2 à haute pression

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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 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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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*.

Introduction

In recent years, the oil industry has been facing challenges in developing and operating high-CO_2 content offshore fields. The CO_2-rich streams, separated from the produced natural gas, can be injected to enhance oil recovery from the reservoirs. Even in cases where the oil recovery increase is not so significant, operators have to consider the CO_2-rich stream compression and injection, in order to avoid its venting to the atmosphere.

Main concerns comprise surface safety system and material selection areas, which lack specific standards and regulations for this scenario. The commercial tools available, for instance, to model the dispersion of gases, need to be validated for CO_2 and CO_2/hydrocarbon mixtures, which have distinctive thermodynamic behaviour. This will affect the choice of materials and plant design.

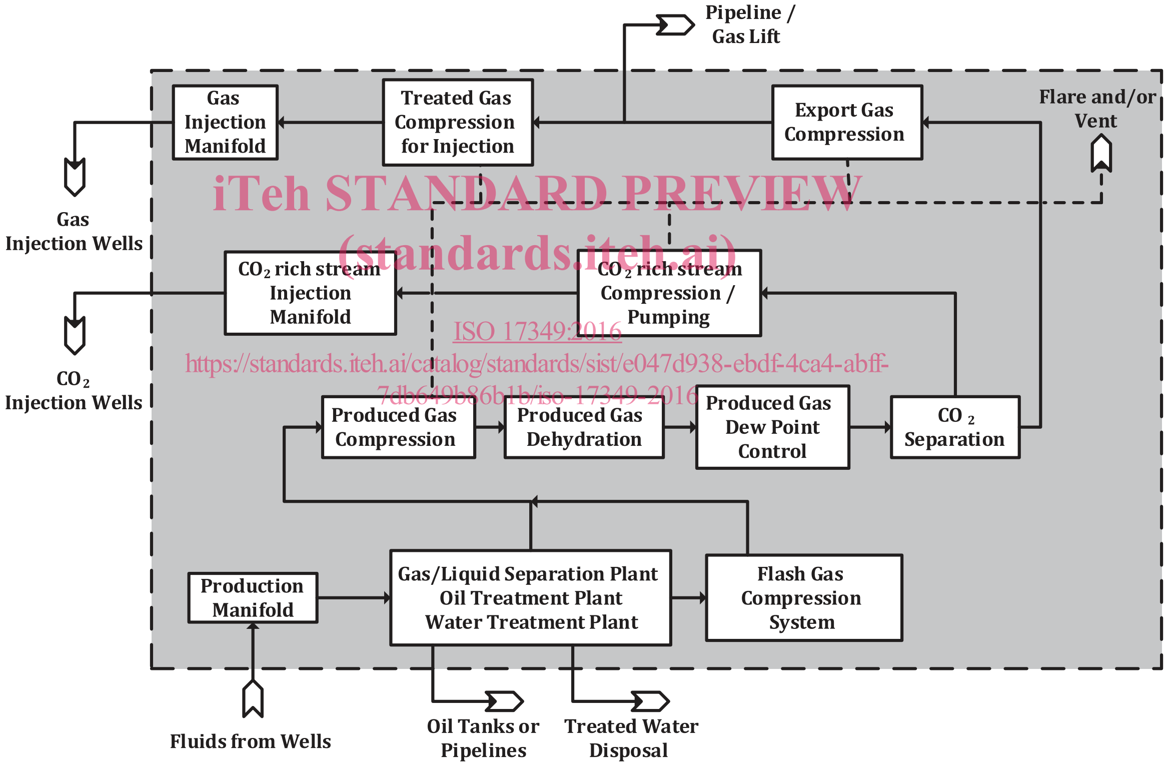
This International Standard addresses concepts and criteria for processing CO_2-rich streams, as a supplement to existing standards for offshore installations.

Petroleum and natural gas industries — Offshore platforms handling streams with high content of CO_2 at high pressures

1 Scope

This International Standard contains provisions for design of topside facilities for offshore plants handling CO_2-rich streams at high pressures; i.e. CO_2 molar concentration above 10 %. The surface systems include usual offshore process unit operations, as shown in Figure 1.

This International Standard is applicable only to topside facilities of fixed and floating oil and gas production offshore units up to the last barrier, such as an ESDV. Subsea production systems and Cryogenic CO_2 separation are not covered.



NOTE This example is within the scope of this International Standard.

Figure 1 — Example of a Process Flow Diagram (in grey zone)

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 edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies..

ISO 13702, *Petroleum and natural gas industries — Control and mitigation of fires and explosions on offshore production installations — Requirements and guidelines*

ISO 15156 (all parts), *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production*

ISO 21457, *Petroleum, petrochemical and natural gas industries — Materials selection and corrosion control for oil and gas production systems*

ISO 23936-1, *Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 1: Thermoplastics*

ISO 23936-2:2011, *Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 2: Elastomers*

API STD 521, *Pressure-relieving and Depressuring Systems, API Standard, January 2014*

3 Terms and definitions

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

3.1
compressibility factor
Z
thermodynamic property for modifying the ideal gas law to account for the real gas behaviour

3.2
corrosion resistant alloy
CRA
alloy intended to be resistant to general and localized corrosion by oil field environments that are corrosive to carbon steels

[SOURCE: ISO 15156-1:2015, 3.6]

3.3
dense phase
fluid state (supercritical or liquid) above critical pressure

3.4
equation of state
EOS
thermodynamic equation describing the state of matter under a given set of physical conditions

3.5
free water
water not dissolved in the CO_2-rich stream

Note 1 to entry: This can be pure water, water with dissolved salts, water wet salts, water glycol mixtures or other mixtures containing water.

3.6
gas-assisted flare
flare with gas assistance system in order to increase gas net heating value

3.7
high-velocity tip flare
flare with gas exit velocities higher than 122 m/s

3.8
high-velocity vent
vent with gas exit velocities higher than 150 m/s

3.9
hydrate
solid, crystalline compound of water and light hydrocarbons or CO_2, in which the water molecules combine with the gas molecules to form a solid

3.10
CRA clad
metallic coating of CRA in which the bond between the parent metal and liner is metallurgical

3.11
low-velocity tip flare
flare with gas exit velocities lower than 122 m/s

3.12
low-velocity vent
vent with gas exit velocities lower than 150 m/s

3.13
minimum design temperature
minimum temperature below which the application limits for the materials involved are exceeded

3.14
platform
complete assembly, including structure, topsides, foundations and stationkeeping systems

[SOURCE: ISO 19900:2013, 3.35]

3.15
rapid gas decompression
RGD
depressurization
explosive decompression
rapid pressure-drop in a high pressure gas-containing system which disrupts the equilibrium between external gas pressure and the concentration of gas dissolved inside any polymer, with the result that excess gas tries to escape from the solution at points throughout the material, causing expansion

[SOURCE: ISO 23936-2:2011, 3.1.10]

3.16
supercritical phase
fluid state above critical pressure and temperature

3.17
topsides
structures and equipment placed on a supporting structure (fixed or floating) to provide some or all of a platform’s functions

Note 1 to entry: For a ship-shaped floating structure, the deck is not part of the topsides.

Note 2 to entry: For a jack-up, the hull is not part of the topsides.

Note 3 to entry: A separate fabricated deck or module support frame is part of the topsides.

[SOURCE: ISO 19900:2013, 3.52]

3.18
triple point
temperature and pressure where CO_2 exists as a gas, liquid and solid simultaneously

4 Abbreviated terms

AIV	acoustically induced vibration
BLEVE	boiling liquid expanding vapour explosion
BDV	blow down valve
CH_4	methane
CO_2	carbon dioxide
CCR	central control room
CRA	corrosion resistant alloy
EERS	evacuation, escape and rescue strategy
EOS	equation of state
ESD	emergency shut down
FES	fire and explosion strategy
GDU	gas dehydration unit
H_2S	hydrogen sulfide
HC	hydrocarbon
HP	high pressure
HSE	health, safety and environment
IDLH	immediately dangerous to life or health
LP	low pressure
MMSCF	million standard cubic feet gas (60 °F and 1 atm)
NHV	net heating value
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
Pa	ambient pressure
Pc	critical pressure
PEL	permissible exposure limit
PHA	Preliminary Hazard Analysis
ppmv	parts per million, volumetric basis
PR	Peng-Robinson EOS
PR-HV	Peng-Robinson EOS modified by using mixing rule of Huron-Vidal and Peneloux factor

PR-SV Peng-Robinson-Stryjek-Vera EOS

PSV pressure safety valve

RGD rapid gas decompression

RO restriction orifice

SCF standard cubic feet

SVLE solid-liquid-vapour equilibrium

STEL short-term exposure limit

SRK Soave-Redlich-Kwong EOS

Tc critical temperature

TWA time weighted average

v_{max} maximum permitted velocity, expressed in m/s

Z compressibility factor

5 Overview of CO_2-rich streams behaviour

5.1 General

In an offshore plant design, CO_2-rich streams can be handled close to or above its critical pressure (dense phase) or above its critical pressure and temperature (supercritical phase).[8] In the latter, some of its properties are similar to that of a liquid (e.g. density) and other similar to that of a gas (e.g. viscosity). The physical and thermodynamic properties of the CO_2-rich streams will have an impact on issues like hydrate formation and depressuring.

The design of a plant handling CO_2-rich streams at high pressures should be conducted using an EOS supported by experimental data in the range of operations. Examples of this approach are shown in Annex A. If experimental data are not available, data from thermodynamic based models, including readily available EOS, should be used taking into account any related uncertainties therefore allowing for sufficient safety margins.

Particular attention should be given when performing simulations near the critical point due to strong variation on stream properties and uncertainty on the description of the existing phases. For that reason, equipment normal operation envelope should avoid critical point region.

5.2 Hydrate formation

CO_2-rich streams can present a potential risk for hydrate formation similar to sweet natural gas, if water is present (as free water or in gas phase).

For high pressures, CO_2 has an inhibitor effect on hydrate formation, since an increase on the CO_2 concentration shifts the hydrate equilibrium curve towards low temperatures, as it can be seen in Annex B.

Dehydration unit design should take into account all operational conditions, including low temperatures that might occur in process systems and pipeline segments downstream from the offshore plant. Special attention should be given to the fact that CO_2 tends to increase water-holding capacity at higher pressures.

For that reason, depending on CO_2 content in the stream, it is not safe to set a water dew point specification based on higher pressure requirements only, since water condensation can occur at lower pressures (see Figure B.1).

As a first approach, a margin of 10 °C on water dew point or a reduction down to 50 % of the water saturation content should be considered.

An example of moisture content specification for Dehydration Unit is presented in Annex C.

5.3 CO_2 solid formation

Solid formation can be observed in a CO_2-rich stream depending on temperature and pressure. Low temperatures that lead to solid formation can be achieved during planned and unplanned depressuring operations, for equipment maintenance purposes and emergency conditions as well. Annex D presents phase diagram for CO_2-rich streams and discusses solid formation based on experimental and theoretical calculations.

The influence of methane content in solid formation temperature can be found in Reference [9]. The frost point is presented for a CO_2-CH_4 mixture in a wide range of concentrations, showing that increasing CH_4 content shifts the frost point curve toward lower temperatures, as shown in Annex D.

According to References [9] and [10], there is an indication that solid formed from a CO_2-rich stream in low temperature operations may be considered as composed of pure CO_2. Therefore, in the absence of experimental data and specific phase diagrams for mixtures with the solid region represented, available phase diagrams for pure CO_2 may be used as conservative approach, in order to predict the low temperatures in which solid formation is expected in an offshore plant design.

Process plant design should take into account the predicted low temperatures with additional design margin in order to specify suitable mitigation measures to avoid or deal with solid formation. More details are presented in Clause 6.

5.4 Flow metering

Design of metering systems shall take into account the peculiarities of behaviour of CO_2-rich streams. Preferably, metering systems should be located in plant sections where physical and transport properties are stable and predictable, i.e. far from critical point or phase transitions. Depending on the process, this means some meters may be designed for gas phase, while others for liquid phase.[11]

Flow computers with input for composition as well as temperature and pressure online measurements using the AGA-8 method, commonly used for natural gas, may be extended to CO_2-rich streams as long as conditions guarantee gas phase.[12] AGA-8 method also shows good predictability of supercritical phase as shown in Annex A.

Differential pressure flow meters such as orifice plates, Venturi or V-Cone are well suitable and robust, especially when working at very high pressures. Coriolis meters, being mass flow meters, are less susceptible to the variation of fluid properties or phase changes as long as no solids are formed but can be limited to operational pressures due to meter body construction.

Special care should be taken regarding changes in the CO_2-rich stream properties and potential flashing, so meter sizing and location should be properly selected.

6 Blow down, depressuring and relieving of plant and equipment

Temperature decrease observed in CO_2-rich streams during depressuring depends upon the initial and final pressures, initial temperature and stream composition.

In order to avoid brittle fracture, minimum temperatures achieved during an isenthalpic depressuring should be considered for material selection of let-down pressure devices (PSVs, BDVs, ROs) and for the entire low pressure system. Piping sections upstream the let-down pressure device can also be subjected to low temperatures and should be designed for co-incident high pressure at minimum temperature.

Apart from low temperature effects, designing relief systems of process plants (equipment or piping) should consider solid CO_2 formation, hydrate formation, adhesion and two-phase flow analysis.

Plant design should avoid operational conditions that lead to the triple point and solid formation in order to prevent plugging, piping erosion and vibration. Annex D presents examples of depressuring route in a phase diagram for CO_2-rich streams.

Designer should evaluate the following:

- control of blow down rate (such as manual assisted operations, restriction orifice or automatic control in steps);
- selection of backpressure of the blow down relief header higher than triple point and frost line. In this case proper transient studies should be carried out for a better evaluation of the whole relief system;
- avoiding pockets and minimizing bends in pipe segments downstream relief device up to main flare or vent header;
- main flare or vent header configuration to avoid potential plugging;
- use of heat tracing;
- application the full upstream pressure rating to the blow down systems in the event of risk of plugging.

For depressuring criteria, designer shall comply with API STD 521 requirements even in cases of non-flammable CO_2-rich streams.

ESD system design should consider proper installation of shutdown/isolation valves in order to limit inventory and thereby minimize trapped fluid amount and potential for incident escalation.

The risk of Rapid Gas Decompression (RGD) damages to non-metallic materials can impose limitations on the depressuring rate. This scenario should be included in the consequence analysis.

7 Flare and vent system configuration

7.1 General

Flare and Vent system design shall comply with API STD 521.

Design of CO_2-rich streams flare and vent systems shall consider the following aspects, as a minimum:

- CO_2-rich streams composition and respective minimum net heating values (NHVs);
- combustibility (flare);
- safe gas dispersion (vent);
- CO_2 solid formation (see Clause 5);
- temperature profile during depressuring (see Clause 6 and Clause 8);
- selection of metallic and non-metallic materials (see Clause 8).

7.2 System selection

Possible flare and vent system configurations are described in Table E.1.

In case of H_2S present in CO_2-rich streams, flaring should be preferred instead of venting. For flare systems, design should comply with H_2S destruction temperature, as low NHV streams have lower flame temperature. For vent systems, design shall warrant proper H_2S dispersion due to hazard and safety aspects.

Flaring gases with low NHV influences ignition stability and can cause flame extinction. Header and disposal segregation between low and high NHV releases may be considered as an option.

For streams with NHV lower than 7,5 MJ/Sm^3 (200 BTU/SCF), which corresponds approximately to a 75 % (molar) CO_2 mixture with methane, vent or gas-assisted low-velocity tip flare should be used. Minimum NHV shall be ensured in flare systems to allow flammability and combustion efficiency at the flare tip, by mixing assistance fuel gas from a reliable source to CO_2-rich streams being relieved. The capacity of assistance fuel gas should be designed for the worst-case scenario.

For streams with NHV higher than 7,5 MJ/Sm^3 (200 BTU/SCF) and lower than 28,1 MJ/Sm^3 (800 BTU/SCF), high-velocity tip flares are not recommended. The use of such tip compared with low velocity one shall be carefully evaluated. Manufacturer guarantee is required in case the high-velocity tip will be used.

For high-velocity tip flares, a typical minimum NHV gas mixture to be burned is 28,1 MJ/Sm^3 (800 BTU/SCF). This corresponds approximately to a 25 % (molar) CO_2 mixture with methane.

7.3 System configuration

7.3.1 Flare

For units dealing with CO_2-rich streams, alternative flare system for low NHV and/or low temperature may be considered in additional to typical HP and LP systems.

The ignition of CO_2-rich streams requires a high energy ignition source. Such condition can be achieved by increasing the number of pilot burners in relation to minimum requirements of pilot manufacturers' recommendations as detailed in ISO 25457.

To ensure combustion, special attention shall be given to flare tip velocities. It is important to take into account the following considerations: Low-velocity flares are those designed for and operated with an exit tip velocity lower than the maximum permitted velocity, v_{max}, as determined by the Formula (1), limited to 122 m/s (400 ft/s).

$$\log_{10}\left(v_{max}\right) = (NHV + K1) / K2 \qquad (1)$$

where

v_{max} is the maximum permitted velocity, expressed in m/s;

$K1$ is the constant equal to 28,8;

$K2$ is the constant equal to 31,7;

NHV is the net heating value, expressed in MJ/Sm^3.

The method to determine the maximum permitted velocity v_{max} is shown in Reference [13].

As a rule, maximum permitted velocity calculated from Formula (1) will dictate flare tip area equivalent diameter. Effects of low temperature on flame stability can be countered by lowering velocity or adding assistance gas. Flare tip design will be dictated by flare tip suppliers and experimental evidence should be required for all critical relief scenarios and/or unproven solutions. Interaction with flare tip suppliers is recommended from the early phases of design.

Designer should evaluate noise and acoustically induced vibration (AIV) aspects.

Flare thermal design shall comply with API STD 521, following recommendations about admissible total radiation fluxes over the working areas, without the need of any heat shield in the unit.

Dispersion simulations are necessary for defining the following designing aspects: flare length, height, position and orientation due to dominant wind directions. The snuffed flare scenario should be one of those covered by dispersion studies, especially considering that low temperature releases are less likely to ignite.

7.3.2 Vent

Vent tip location shall be assessed based on dispersion studies, practical safety zones, noise, acoustically induced vibration (AIV) and thermal radiation in case of accidental ignition scenario.

Dispersion simulations, including evaluation of the CO_2 plume, are necessary for defining the following designing aspects: vent length, height, position and orientation due to dominant wind directions. The final location of the outlet orifices shall ensure that the low flow discharges be adequately dispersed.

As a general recommendation, the vent tip should be pointing 45° from the horizontal plane in the direction away from working areas. Some protection against rain may be provided.

When designing the vent system, consideration should be given to the formation of solid CO_2 due to low temperatures downstream of blow down/relief valves. If solid CO_2 formation is possible, the vent design should minimize the potential for blockage.

High-velocity vents are recommended whenever possible, in order to reduce potential CO_2 or hydrate plugging, solid adhesion and improve gas dispersion.

8 Materials

8.1 Corrosion

8.1.1 General

Internal corrosion can be a significant risk to the carbon steel piping and equipment integrity dealing with CO_2-rich streams in presence of free water. Free water combined with high CO_2 partial pressure is likely to lead to high corrosion rates. As discussed is Annexes B and C, water can be less likely to drop out from vapour phase CO_2-rich streams when compared to natural gas.

The presence of H_2S in combination with free water will have a significant effect on the corrosion rate. The possibility of oxidizing species ingress in the presence of H_2S can induce elemental sulfur deposition leading to higher corrosion rates.

Materials selection shall comply with ISO 21457. Physicochemical and corrosion models used for internal corrosion evaluation should take into account considering high CO_2 contents and high pressures.

Piping, fittings and equipment with fluids containing H_2S shall be evaluated according to ISO 15156 (all parts).

Pipe segments and other parts of the system that can have stagnant conditions (pockets) should be evaluated carefully for internal corrosion.

8.1.2 Internal corrosion control by dehydration

In general, for carbon steel piping and equipment no internal corrosion protection is required providing that free water in the CO_2-rich streams be avoided through a strict water content control procedure. This consideration should be used downstream of the dehydration system. Moisture content monitoring should be considered as part of piping and equipment design and operation.

Upset conditions and downtimes shall be taken into account. This can include dehydration system failure and dehydration off-spec when specifying critical systems where significant failure cannot be tolerated.

