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CO₂ corrosion rate calculation model

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Foreword

NORSOK is an acronym for the competitive position of the Norwegian continental shelf and comprise petroleum industry standards in Norway. The collaboration initiative in 1993 between the authorities and the petroleum industry initiated the development of NORSOK standards.

Reducing the project execution time and developing and operating cost for petroleum installations on the Norwegian shelf was the target.

The intention for the Petroleum industry is to develop and use standards providing good technical and cost effective solutions to ensure that the petroleum resources are exploited and managed in the best possible way by the industry and the authorities. The industry will actively contribute to the development and use of international standards in the global market.

The NORSOK standards shall:

- bridge the gap based on experiences from the Norwegian continental shelf where the international standards are unsatisfactorily;
- replace oil company specifications where possible;
- be available as references for the authorities' regulations;
- be cost effective;
- promote the Norwegian sector as an attractive area for investments and activities.

Developing new NORSOK standards and regular maintenance of existing standards shall contribute to maintain the competitiveness both nationally and internationally for the Norwegian petroleum industry.

The NORSOK standards are developed by experts from the Norwegian petroleum industry and approved according to the consensus principles as laid down by the guidelines given in this NORSOK directive.

The NORSOK standards are owned by the Norwegian Oil and Gas Association, the Federation of Norwegian Industries and the Norwegian Shipowners' Association. They are managed and published by Standards Norway.

Introduction

This NORSOK standard, which is a recommended practice, contains

- a computer program for corrosion rate calculations which is available for downloading from the NORSOK internet website (<http://www.standard.no>) or can be procured from Standards Norway,
- a user manual for the computer program. A description of the calculation model, the algorithms and the conditions for the corrosion rate calculations are given. In additions, methods and algorithms for calculation of essential input parameters to the corrosion rate calculations are given.

In the present Revision 3, the following changes have been made compared to Revision 2, June 2005:

4. Included that the model is not applicable when the H₂S partial pressure is higher than 0.05 bar, or when the ratio between the partial pressure of CO₂ and H₂S is less than 20. The model can lead to underprediction of the corrosion rate when the total content of organic acids exceeds 100 ppm and the CO₂ partial pressure is less than 0.5 bar, particularly in condensing systems. This is changed from Rev. 2, where the H₂S partial pressure limit was set to 0.5 bar in the computer program for corrosion rate calculations.
4. Removed the use of corrosion inhibitor efficiency.
Included reference with advice on practical use of the corrosion prediction model.
- 5.2. Included a warning that the model may be less conservative around 90 °C than at other temperatures.
- 5.3. / 7.1. Removed effect of corrosion inhibitors. Removed inhibitor efficiency as input parameter in Table 3.
- 7.2.2. Replaced "formation water" with "produced water". Replaced "Bicarbonate" with "Total alkalinity" in Table 6. Included "Acetic acid + Acetate" as new input parameter in Table 6.
- 8.1. Included a warning that the fugacity calculation is uncertain at total pressures above 250 bar.
- 8.2.1. Included description of calculation of pH in presence of organic acids.
- 8.2.2. Included equation for acetic acid dissociation and description of chemical reactions involving acetic acid.
- 8.2.3. Included equation for the dissociation constant for acetic acid.

In addition to these changes some typographical errors have been corrected. A database function has also been included in the computer program, enabling simultaneous calculation for a large number of cases.

1 Scope

This NORSOK standard presents a recommended practice for calculation of corrosion rates in hydrocarbon production and process systems where the corrosive agent is CO₂.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet the requirements of the referenced standards below.

2.1 Normative references

NORSOK M-001, Materials selection

3 Terms, definitions and symbols

3.1 Terms and definitions

3.1.1

can (possibility)

expression in the content of a document conveying expected or conceivable material, physical or causal outcome

3.1.2

may (permission)

expression in the content of a document conveying consent or liberty (or opportunity) to do something

Note 1 to entry: Permissions are expressed using the verbal forms specified in ISO/IEC Directives Part 2 clause 7.4 Table 5

3.1.3

shall (requirement)

expression in the content of a document conveying objectively verifiable criteria to be fulfilled and from which no deviation is permitted if compliance with the document is to be claimed

Note 1 to entry: Requirements are expressed using the verbal forms specified in ISO/IEC Directives, Part 2 clause 7.2 Table 3

3.1.4

should (recommendation)

expression in the content of a document conveying a suggested possible choice or course of action deemed to be particularly suitable without necessarily mentioning or excluding others

Note 1 to entry: Recommendations are expressed using the verbal forms specified in ISO/IEC Directives, Part 2 clause 7.3 Table 4.

Note 2 to entry: In the negative form, a recommendation is the expression that a suggested possible choice or course of action is not preferred but it is not prohibited

3.2 Symbols

A	is the cross sectional area in m^2
$B_{(index)}$	is the constant used in viscosity calculation
$C_{(index)}$	is the concentration of component
CR_t	is the corrosion rate at temperature t in mm/year
D	is the pipe diameter in mm
F_{H_2O}	is the water mass flow in humidity calculations
F_{tot}	is the total mass flow in humidity calculations
$K_{(index)}$	is the equilibrium constant used in pH calculations
K_{SP}	is the equilibrium constant of iron carbonate
K_t	is the constant for the temperature t used in corrosion rate calculations
P	is the total system pressure in bar
Q_G	is the volumetric flow of gas in MSm^3/d
Q_L	is the volumetric flow of liquid (i.e. liquid hydrocarbons and water) in Sm^3/d
R	is μ_w/μ_o
Re	is the Reynolds number
S	is the wall shear stress in Pa
T	is the temperature given in Kelvin
T_c	is the temperature given in $^{\circ}\text{C}$
T_f	is the temperature given in $^{\circ}\text{F}$
T_{std}	is the temperature given in Kelvin at standard conditions ($60^{\circ}\text{F}/15,55^{\circ}\text{C}$)
Z	is the compressibility of the gas
a	is the fugacity coefficient
f	is the friction factor
f_{CO_2}	is the fugacity of CO_2 in bar
$f(\text{pH})_t$	is the the pH factor at temperature t
k	is the pipe roughness in m
I	is the ionic strength given in molar
p_{CO_2}	is the CO_2 partial pressure in bar
p_{H_2O}	is the H_2O vapour pressure in bar
t	is the temperature 5°C , 15°C , 20°C , 40°C , 60°C , 80°C , 90°C , 120°C or 150°C
u_G^S	is the superficial velocities of gas in m/s
u_L^S	is the superficial velocities of liquid in m/s
u_m	is the mixed velocity (m/s)
λ	is the liquid fraction
μ_o	is the viscosity of oil in Ns/m^2
μ_G	is the viscosity of gas in Ns/m^2
μ_L	is the viscosity of liquid in Ns/m^2
μ_m	is the mixed viscosity in Ns/m^2
μ_{relmax}	is the maximum relative viscosity (relative to the oil)
μ_w	is the viscosity of water in Ns/m^2
ρ_G	is the gas density in kg/m^3
ρ_L	is the liquid density in kg/m^3
ρ_m	is the mixed density in kg/m^3
ρ_o	is the oil density in kg/m^3
ρ_w	is the water density kg/m^3
ϕ	is the watercut at inversion point

4 Principles for use of the computer program

The corrosion rate equations included in this NORSOK standard describe the calculation model which shall apply, while the computer program itself is an optional aid which the users of the model may apply such that they possess an efficient tool to conduct corrosion rate calculations and parameter studies. This computer program is developed based on the corrosion rate model given as equations in this NORSOK standard and can be downloaded here: www.standard.no/M506-2017.

The computer program is an aid in CO₂ corrosion rate assessments, but the user of the computer program is responsible for the results and the final material selections and piping and equipment design. Therefore the user of the program shall perform a critical evaluation of all results and the applicability of these in each case. Corrosion rate calculation is only one element in a material selection process. Other essential factors are uncertainty in input data for corrosion rate calculations, construction and commissioning conditions, consideration of normal and upset operating conditions, actual corrosivity of produced fluids, scale, wax, inhibitor efficiency and geometry of corrosion attacks. These and other factors may influence the actual corrosion rates considerably, and be more important than any uncertainty in the corrosion rate calculations. As the computer program is distributed electronically and may be used on different computers and computer program versions, users of the computer program are sole responsible to verify that the computer calculations are in accordance with the equations in this NORSOK standard.

This NORSOK standard provides an introduction to the corrosion rate computer program. It also gives limitations and requirements to input parameters and results. Instructions for running the program are given in the help functions to the program.

The program covers only calculation of corrosion rates where CO₂ is the corrosive agent. It does not include additional effects of other constituents which may influence the corrosivity, e.g. contaminations of O₂, H₂S etc. If such constituents are present, which is common in e.g. produced water systems, these effects shall be evaluated separately. The model is not applicable when the H₂S partial pressure is higher than 0.05 bar, or when the ratio between the partial pressure of CO₂ and H₂S is less than 20. The model can lead to underprediction of the corrosion rate when the total content of organic acids exceeds 100 ppm and, at the same time, the CO₂ partial pressure is less than 0.5 bar, particularly in condensing systems.

Principles for materials selection are given in NORSOK M-001. The requirements in NORSOK M-001 shall be used when generating input data and when interpreting results from this NORSOK standard. It is important to note that this NORSOK standard and computer program may use or generate data which are outside the limits of NORSOK M-001. In case of conflict, NORSOK M-001 shall apply when selecting materials.

In previous versions of the model corrosion inhibitor efficiency was used, and the computer program calculated corrosion rate with effect of glycol or corrosion inhibitor in addition to corrosion rate without glycol or inhibitor. In the present version the use of corrosion inhibitor efficiency is removed, in order to be in line with the current version of NORSOK M-001, where the use of corrosion inhibitor efficiency is replaced by the inhibitor availability model.

Advice on practical use of the corrosion prediction model is given in ref. [1].