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Integrated model in Carbon Capture and Storage: Flow Assurance Challenges and Case Studies

Sun Xinghua[1], Wang Bing[2], Cai Xingxing[3]

1,2,3 Schlumberger (China) Investment Co., Ltd., Beijing, 100020

(*Sun Xinghua: XSun15@slb.com)

ABSTRACT

Carbon Capture and Storage (CCS) is intended to capture CO_2 created during the combustion of fossil fuels used in the production of thermal energy, chemical plants, and natural gas decarbonization process. Typically, pipeline transportation is often used to transport and store CO_2 underground. Over the following ten years, there will be an increase in demand for carbon capture technology, CO_2 pipeline transportation, and CO_2 underground storage.

In terms of pipeline transportation efficiency and safety, dense phase or supercritical phase are typically chosen. This paper uses KBC Multiflash 7.3 to compare the physical characteristics of fluids with various components under various equations of state. It is discovered that utilizing EOS-CG as the equation of state to describe fluid properties is a more conservative approach. This paper also analyzes transportation conditions of CO_2 with a small amount of impurity under different injection rates, compares the differences in pressure and temperature, liquid hold up, hydrate and CO_2 corrosion using the multiphase flow transient simulator OLGA as the primary simulation tool, along with its special pressure-enthalpy (PH) flash algorithm.

Keywords: Equation of State; Flow instability; Flow Assurance; OLGA

1. INTRODUCTION

Carbon capture can be used in a process, like the decarbonization of natural gas. In power plants, cement plants, or steel smelting plants, CO_2 can also be removed from flue gases; certain steel smelting plant manufacturers are already experimenting with carbon capture technology in high-temperature kilns. In Japan, CO_2 is taken straight out of the air. Due to the low CO_2 concentration in the air. Carbon capture technique can be implemented using a variety of decarbonization technology. Processes like membrane separation, adsorption, and absorption are frequently used to capture carbon.

When CO_2 leaves the carbon capture unit at upstream, it may be transported by pipeline, ship, or vehicles. Flow assurance concerns for pipeline transportation exist in daily production and operation and include:

1. Leakage risk: The operating condition for medium and long - distance CO_2 transportation pipelines is frequently over the critical pressure. If there is a leak, the environment and public safety could suffer greatly. When maintaining and operating CO_2 transportation pipes, it is crucial to take appropriate measures to prevent and detect leaks.

2. Risk of temperature drop: when fluid passes through the valve, the Joule-Thompson effect will cause low temperature issues, and low temperatures will impact the material's low temperature brittleness.

3. Hydrate danger: the presence of stratigraphic water in a CO_2 injection well may result in hydrate risk, and the presence of free water in a CO_2 transportation pipeline increases the risk of corrosion.

4. Erosion risk: Continuous operation might cause wear issues and wall thickness thinning in CO_2 transportation lines.

2. THERMODYNAMICS OF CARBON DIOXIDE WITH IMPURITY

Different carbon suppliers may provide the carbon source, and typically, different carbon sources comprise various fluid components. The critical point has a substantial impact on the whole production system and operation window, distinct fluid components have distinct critical points (critical temperature & critical pressure). As a result, choosing the right equation of

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state is crucial when describing the fluid's physical characteristics.

2.1 Equation of State Selection and Comparation

Characterizing the physical features is essential for CO_2 transportation and injection projects. For describing the thermal properties of CO_2 with impurity, GERG 2008 and EOS-CG are more frequently mentioned.

In this paper, below equation of state will be discussed and compared:

- PRA

PRA is a cubic EoS. There is some evidence that this method provides improved volumes (densities) compared to RKS.

- RKS

RKS is a cubic EoS. There is some evidence that this method provides improved fugacity compared to PR and PR78.

- GERG 2008

GERG 2008 is an industry-standard high-accuracy model for mixtures of natural gas components. The model includes appropriate BIPs for all components in the GERG reference list. The model performs best for mixtures that do not involve strong specific interactions, and for any of the pure reference substances. The mixture model is applicable to systems that do not contain free water. GERG 2008 equation (Vahedi et al, 2011), but this has limitations on the number and type of components.

- EOS CG

EOS-CG is a high accuracy model for components associated with combustion of fossil fuels. EOS-CG is similar to GERG-2008 model described above. The EOS-CG model is recommended for mixtures associated with combustion of fossil fuels and carbon capture and storage.

- Span & Wagner (only for pure CO_2)[1]

Span & Wagner is considered the most appropriate when modelling pure CO_2, however when small quantities of impurities are present，Span & Wagner is not available. Span & Wagner equation of state is considered the most appropriate when modelling pure Carbon Dioxide (Aursand et al, 2012, Vahedi et al,2011), however when small quantities of impurities are present the use of this correlation is not available.

2.2 Fluid Composition Discussion

Multiflash 7.3 is used in this part to characterize physical properties. Four different fluid types, ranging from pure CO_2 to 15% impurity concentrations, will be taken into account in order to assess the various carbon sources. Detail compositions are displayed in Table 1.

Table 1: Fluid Components and EOS selections

EOS Selection	Fluid Components [mol %]		
0%	CH_4	N_2	CO_2
Span&Wagner	0%	0%	100%
GERG 2008	0%	0%	100%
EOS CG	0%	0%	100%
2% of Impurity	CH_4	N_2	CO_2
PRA	1%	1%	98%
RKS	1%	1%	98%
GERG 2008	1%	1%	98%
EOS CG	1%	1%	98%
5% of Impurity	CH_4	N_2	CO_2
PRA	2%	3%	95%
RKS	2%	3%	95%
GERG 2008	2%	3%	95%
EOS CG	2%	3%	95%
15% of Impurity	CH_4	N_2	CO_2
PRA	10%	5%	85%
RKS	10%	5%	85%
GERG 2008	10%	5%	85%
EOS CG	10%	5%	85%

2.3 PHASE ENVELOPE

2.3.1 Phase Behavior and Physical Property with Pure CO_2

The phase envelope for pure CO_2 is shown in Figure 1, including Span & Wagner, EOS-CG, and GERG 2008. For a single fluid, the form of the phase envelope is essentially the same. Table 2 illustrates the variation in the critical temperature and pressure, with more conservative results from Span & Wagner.

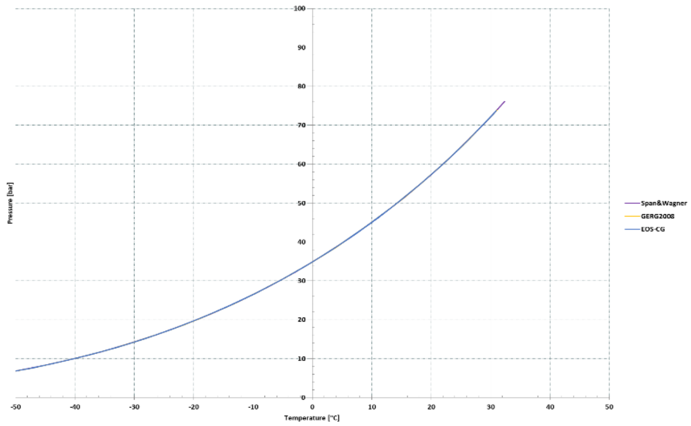

Figure 1 Phase Envelope for Pure CO_2

Table 2 Critical Pressure and Temperature Difference

EOS Selection	Critical Temperature [°C]	Critical Pressure [bara]
Span & Wagner	32.4	76.1
GERG 2008	30.7	73.3
EOS CG	31.0	73.7

2.3.2 Phase Behavior and Physical Property with Impurity

- Impurity content of 2%

The phase envelope for an impurity concentration of 2% is shown in Figure 2. We compare RKS, PRA, GERG 2008 and EOS-CG. The critical temperature and pressure are different, but the form of the phase envelope is essentially the same in Table 3. Because of its somewhat broader form and higher critical temperature and pressure than other shapes, EOS-CG results that are more conservative.

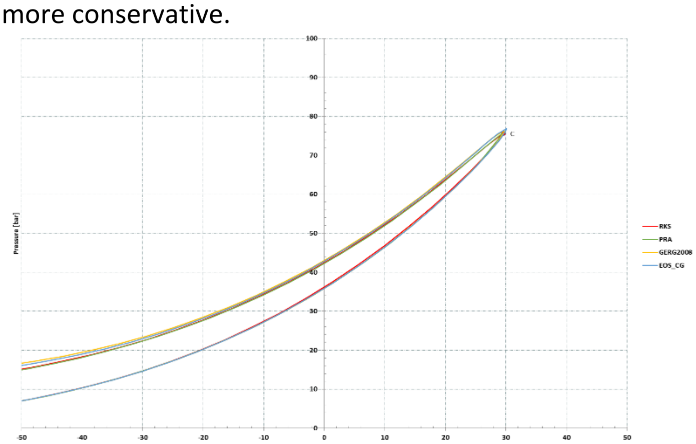

Figure 2: Phase Envelop for 2% Impurity Fluid

Table 3: Critical Pressure and Temperature Difference

EOS Selection	Critical Temperature [°C]	Critical Pressure [bara]
RKS	29.6	75.6
PRA	29.6	75.7
GERG 2008	29.7	76.4
EOS CG	30.1	76.9

- Impurity content of 5%

The phase envelope for an impurity concentration of 5% is shown in Figure 3. We compare RKS, PRA, GERG 2008 and EOS-CG. Figure 3 shows a somewhat different shape for the phase envelope; EOS-CG has a broader two-phase envelope, which indicates that its operation window to prevent two-phase flow is narrower than that of other EOS. Critical pressure is a little higher than other EOS even though the critical temperature is almost the same.

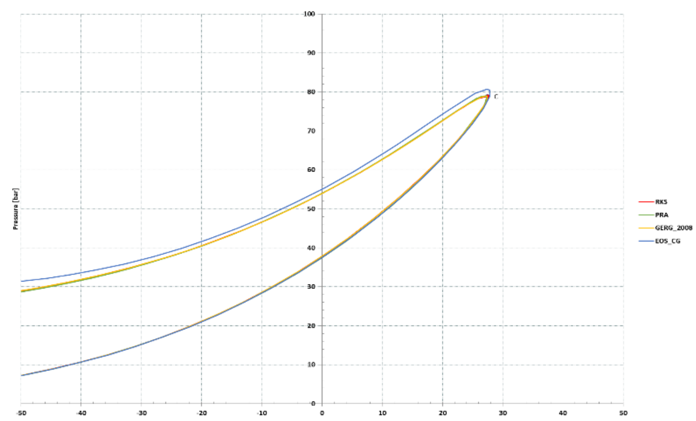

Figure 3: Phase Envelop for 5% Impurity Fluid

Table 4: Critical Pressure and Temperature Difference

EOS Selection	Critical Temperature [°C]	Critical Pressure [bara]
RKS	27.4	78.9
PRA	27.3	79
GERG2008	27.4	78.9
EOS CG	27.8	80.54

- Impurity content of 15%

The phase envelope for an impurity concentration of 15% is shown in Figure 4. Additionally compared are RKS, PRA, GERG 2008 and EOS-CG. EOS-CG has a broader phase envelope shape than other EOS for temperatures over 10 °C, and GERG-2008 has a wider phase envelope shape than other EOS for temperatures below 10 °C. EOS-CG has a little higher critical temperature and pressure than other EOS, as seen in Table 5.

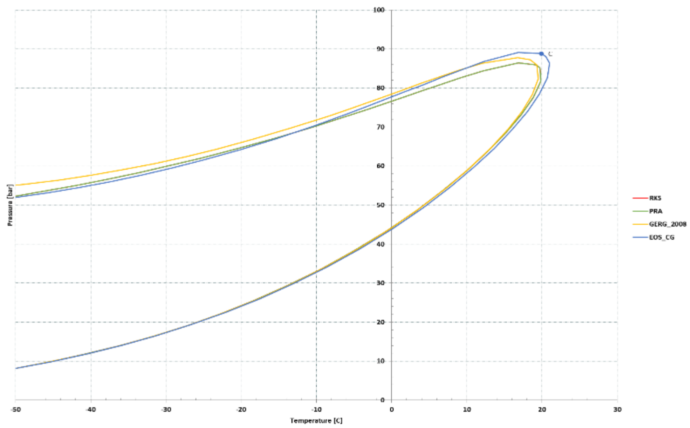

Figure 4: Phase Envelop for 15% Impurity Fluid

Table 5: Critical Pressure and Temperature Difference

EOS Selection	Critical Temperature [°C]	Critical Pressure [bara]
RKS	19.26	85.97
PRA	19.26	85.97
GERG2008	18.41	87.30
EOS CG	19.91	88.85

For CO_2 with impurities, it is possible to observe that:

1. Two-phase region increasingly widens as impurity contents rise. The working zone will get smaller as the impurity percentage rises when the fluid must be carried in a single phase. The shapes of the phase envelopes of RKS, PRA, GERG 2008, and EOS - CG are more similar.
2. With regard to critical temperature and pressure, EOS CG has the highest values. When EOS-CG is selected for fluid property characterization, more conservative results can be attained.

The density of the fluid and its viscosity are comparable when the fluid is in the supercritical phase. Table 6 shows the fluid model information.

Table 6: Detail Information for impurity fluids

EOS Selection	CH_4 [mol %]	N_2 [mol %]	CO_2 [mol %]	Critical Temperature [°C]	Critical Pressure [bara]
EOS CG	10%	5%	85%	19.91	88.85

At pressure = 95 bara, Figure 5 shows the density and viscosity vary with temperature. Density and viscosity are comparable to liquid and gas, respectively.

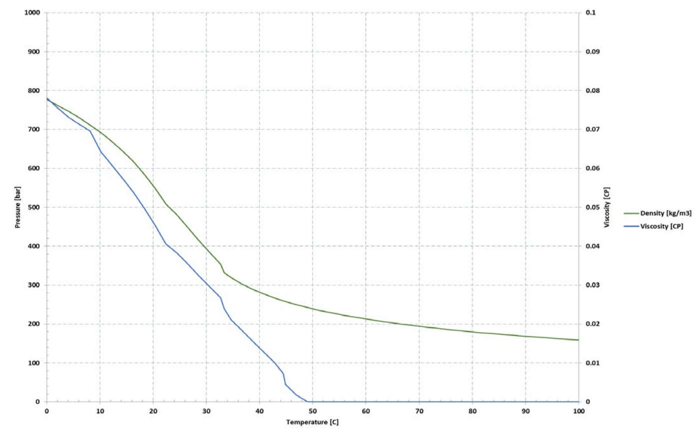

Figure 5: Fluid property vary with temperature @ pressure = 95 bara

3. *INTEGRATED MODEL DESCRIPTION*

The subsea pipeline and tubing will be used to deliver CO_2 from the platform to the reservoir. The fluid components for the current study are shown in Table 7. Table 8 displays the injection rate at various phases, ranging from 35,000 kg/h to 45,000 kg/h.

Table 7:Fluid Component for Integrated Model

Component	Mole Fraction [%]
METHANE	3
ETHANE	0.5
PROPANE	0.3
CO_2	95
H_2O	1.2

Table 8: Injection rate with time

Year	Injection Rate [kg/h]
2023	35000
2024	40000
2025	45000

In this study, PH Flash is specifically considered in model settings using OLGA 2022.1[3], the primary multiphase transient simulation tool. Figure 6 depicts the integrated model, which includes a 2500 m-long TVD and a subsea pipeline with a length of 7.5 km and a riser of 170 m.

Figure 6: Integrated OLGA Model – from Platform to Bottom Hole

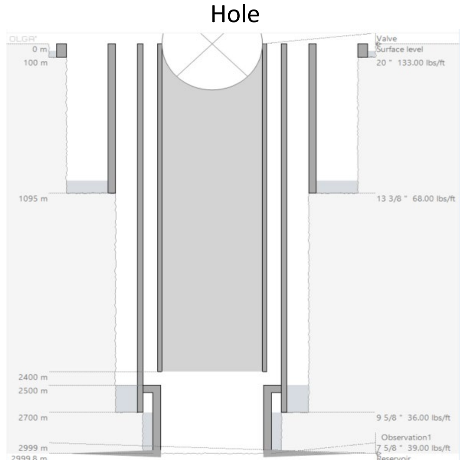

Figure 7: The injection of OLGA Well Model

3.1 *Pressure and Temperature Profile*

The pressure profile for a subsea pipeline and wellbore is shown in Figures 8 and 9 with different injection rate. The max pressure in the subsea pipeline is below the critical pressure (75.22 bara), and back pressure in the subsea pipeline likewise rises as the injection rate increases but remains below MAOP = 80 bara for subsea pipeline. Wellbore pressure profile is in the dense gas phase and above the critical pressure.

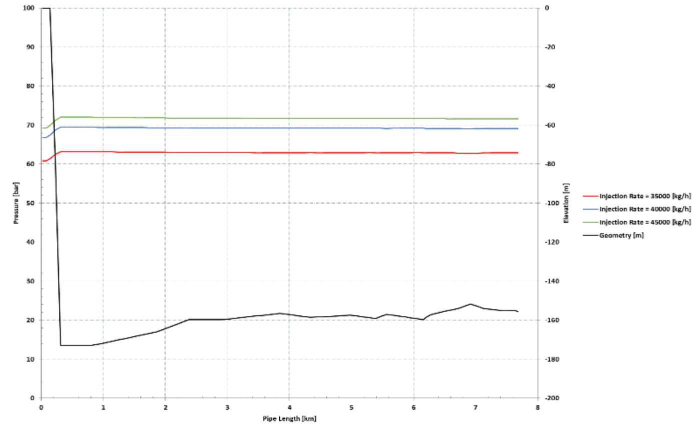

Figure 8: Pressure Profile for Pipeline

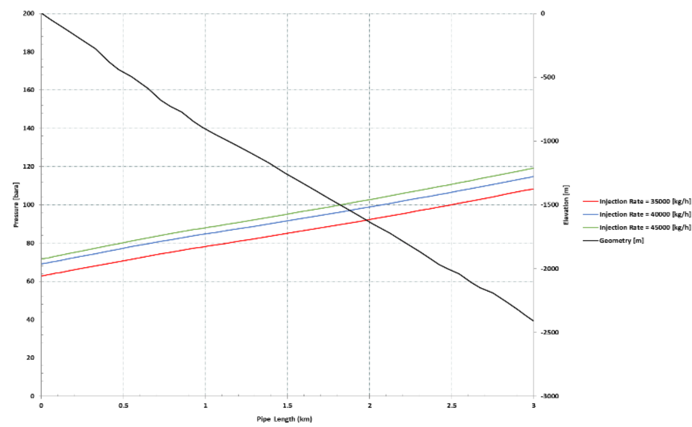

Figure 9: Pressure Profile for Wellbore

Temperature profiles for subsea pipeline and wellbore are shown in Figures 10 and 11. There is only one fully open valve at the wellhead in the integrated model, and there is no additional pressure or temperature loss down the subsea pipeline or wellbore. Subsea pipeline and wellbore temperature profiles are both over the critical temperature.

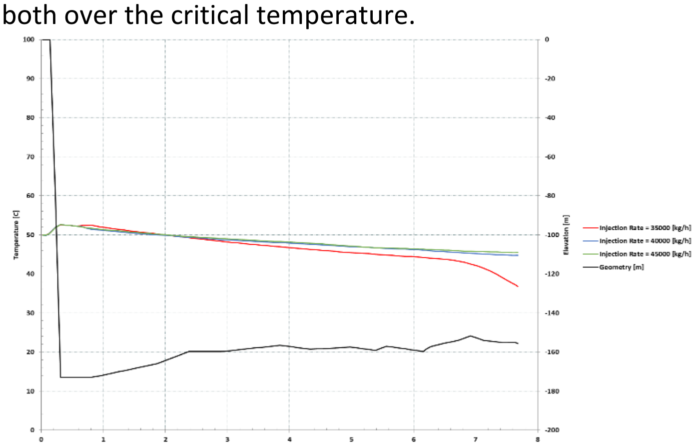

Figure 10: Temperature Profile for Subsea Pipeline

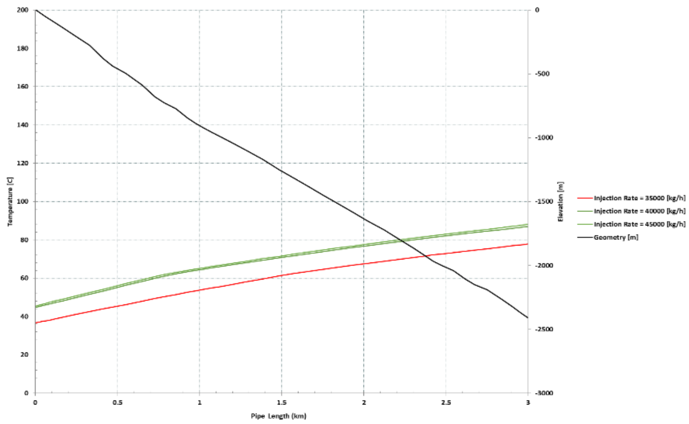

Figure 11: Temperature Profile for Wellbore

3.2 Liquid Hold Up

Figures 12 and 13 depict the liquid hold up for subsea pipeline and wellbore, respectively. The subsea pipeline is in the single phase (gas phase) and the pressure is below the critical pressure. If the pressure is above the critical pressure, the wellbore is in the dense gas phase.

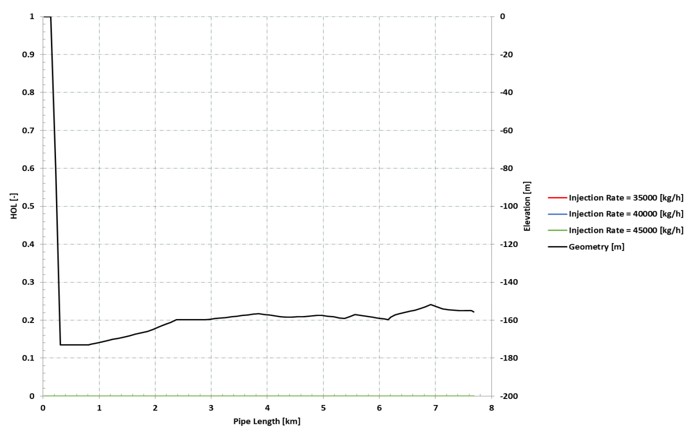

Figure 12: Liquid Hold up for Subsea Pipeline

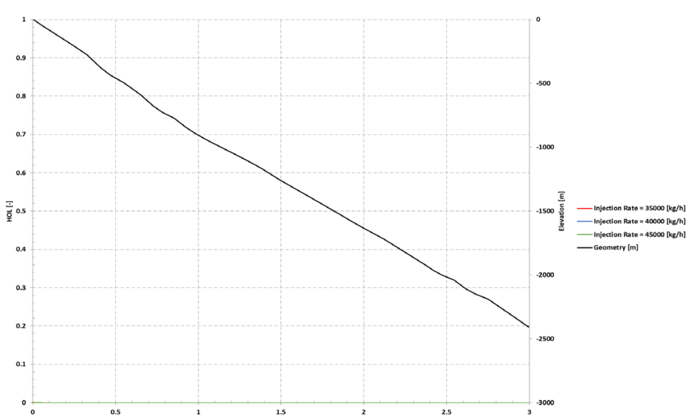

Figure 13: Liquid Hold up for Wellbore

3.3 Hydrate Risk

Figure 14 displays the phase envelope, the hydrate line where hydrates of types I and II form, and the water line. When operating normally, there is no crossover between water line and P&T profile, no free water dropout, and no hydrate risk for the wellbore or subsea pipeline. Both the wellbore model and the subsea pipeline are in single phase.

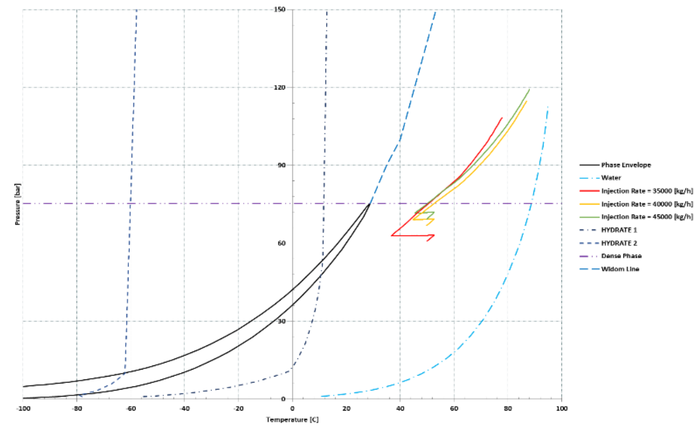

Figure 14: Phase Envelope

3.4 Corrosion Risk

For corrosion consideration, 3 corrosion models in OLGA are selected and compared.

- CORR1 - NORSOK M506

  Given as a function of pH, temperature, CO_2 partial pressure, and wall shear stress, the NORSOK M-506 model calculates the corrosion rate.

- CORR2 - TOL IFE

  Top-of-line corrosion model takes these factors into account temperature, acetic acid concentration, and CO_2 partial pressure when calculating the amount of iron that can dissolve in condensed water.

- CORR3 - de Waard 1995

  The de Waard 95 model provides the corrosion rate as a function of liquid flow velocity, hydraulic diameter, and CO_2 partial pressure. de Waard 1995 and NORSORK M506 both take into account the solid iron carbonate coatings.

Figures 15 and 16 depict the rates of corrosion for three different corrosion models. Base on the rate of corrosion. The wellbore and subsea pipeline are not at risk of corrosion.

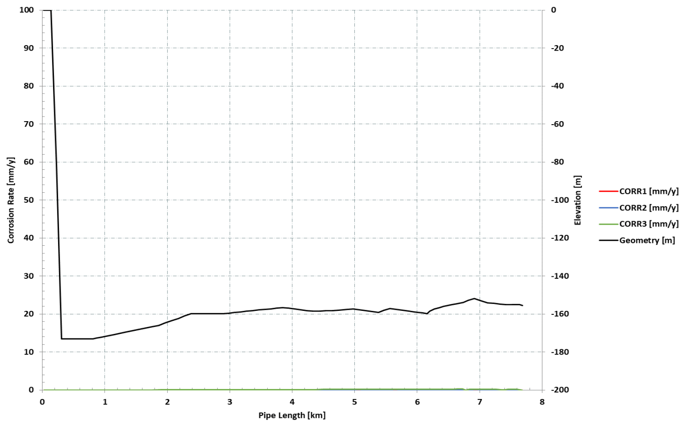

Figure 15: Corrosion Rate for Subsea Pipeline

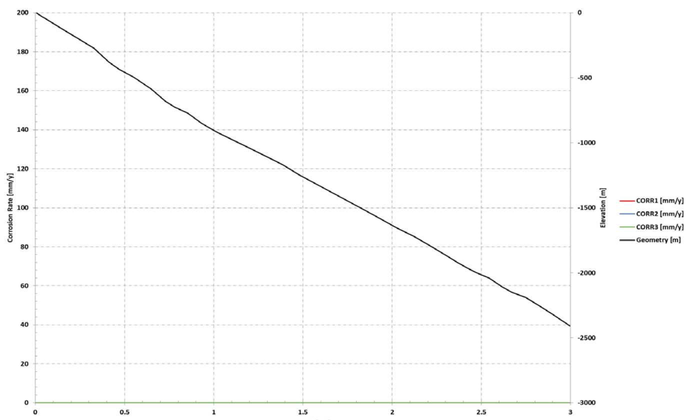

Figure 16: Corrosion Rate for Well

4. RESULTS

Trasient multiphase flow simulator for characterizing oil and gas fluids are constantly being improved to keep up with the needs of the energy transition. For CO_2 transportation pipelines with small contents of impurity, the fluid characterisation can handle pure carbon dioxide pipelines and includes equations of state to precisely forecast the physical properties, the two-phase regions. The development of the compositional tracking simulations to perform more rigorous simulations is a great help when needed, but there is still room for improvement in both simulation stability, use of more equations of state, and simulation speed.

In this paper, we discussed about the fluid property and flow assurance challenges for the integrated model in a steady state condition. Based on previous discussion, the subsea pipeline and wellbore are both in single phase, and we also consider the hydrate risk, corrosion risk. The next step is to properly account for these design elements and any associated operational concerns. This results in a system that is firmly constructed and can be operated safely throughout the project.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] “A new equation of state for carbon dioxide covering the fluid region from the triple-point temperature to 1100 K at pressure up to 800 MPa”, R.Span, W.Wagner.
[2] Multiflash 7.3 user manual help.
[3] OLGA 2022.1 user manual help.