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CO_2 Transportation with Pipelines - Model Analysis for Steady, Dynamic and Relief Simulation

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Perspective

This paper presents some topics about CO_2 transportation in pipelines from an industrial point of view. In particular the point of view of process and flow-assurance design activities required for:

- feasibility studies,
- preliminary design
- FEED (Front-End Engineering Design)

Summary

Main points:

- Some peculiar characteristics of CO2
- Simulation of CO2 rich mixtures vs pure CO2 streams
- Commercial simulators
- Standard equations of state
- GERG equation of state
- Two transport cases
- A pipeline depressurization case

“Carbon dioxide or CO_2 capture and storage”,

often defined by its acronym CCS,

is the term used to describe a set of technologies aimed at capturing carbon dioxide emitted from industrial and energy-related sources before it enters the atmosphere, by compressing and injecting it underground in secure geological formations.

This paper analyses the thermodynamic methods required for a reliable simulation of steady state as the initial requirement for the subsequent calculation of relief conditions (flow rate, pressure and temperature) as a preliminary critical step to the calculation the dispersion effects

The point of view is that of an engineering company which should carry out the engineering evaluation of various alternatives and prepare a final design.

These projects are usually carried out by means of commercially available process simulators:

- HYSYS,
- AspenPlus,
- ChemCad, etc.

and fluid-dynamics simulators (1D CFD):

- OLGA,
- LedaFlow, etc.

The selection of suitable equations of state is very important step in the design of a CCS project due to the impact in many areas from

- steady state and dynamic simulation,
- HSE risk evaluation
- including pipeline depressurization

either during planned operations or in case of unforeseen events.

In these fields the use of commercial simulators such as

- HYSYS (Aspen Technology or Honeywell versions) and
- AspenPlus

is a common practice.

Standard cubic equations of state as the

- Soave-Redlich-Kwong SRK and
- Peng-Robinson PR

are proposed as default choices and are usually assumed (without any sound foundation) to produce reliable results.

For the simulation of pure CO_2 transport, one of the leading fluid-dynamics simulation software (OLGA) has recently introduced the use of the Wagner equation (Span and Wagner, 1996).

But from the simulation point of view this equation is far from being a benefit since it applies to pure CO2 only and pure CO2 streams are not common at all.

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For CCS design the GERG-2004 equation of state, developed and published (Kunz et al., 2007) as a research project supported by the “Groupe Européen de Recherches Gazières” appears to be a much better choice.

This project was funded by European natural gas industry for the evaluation of the thermodynamic properties of natural gases and other mixtures of natural gas components for the basic engineering, performance assessment of existing plants, gas metering, transmission, and storage.

Most of the standard natural gas applications, such as gas transmission and storage, are located in the "classical" natural gas region, i.e. the gas phase at temperatures from 250 K to 350 K and pressures up to 30 MPa, this range is of main interest for the calculation of thermodynamic properties and is addressed by this new equation.

To reproduce experimental values, for both pure components and mixtures, within experimental errors, the GERG-2004 equation uses a larger number of regressed parameter with respect to cubic equations of state

The GERG-2004 equation of state is explicit in the Helmholtz free energy with density and temperature as independent variables.

$$a(\rho, T) = a^0(\rho, T) + a^r(\rho, T)$$

The level of complexity of the equation can be guessed by noting that it uses up to 110 parameters to define the pure fluid behaviour and 89 binary coefficients for each component-component interaction.

Calculation presented in the following slides have been performed using XPSIM (eXtended Process SIMulator, 2013) a software for process simulation and flow-assurance studies.

XPSIM in addition to the standard cubic equations such as **SRK** and **PR**, allows the selection of other complex equations of state including the GERG model.

From a numerical solution point of view, the simulation of pure components using temperature and pressure as independent variables (TP plane) presents a discontinuous phase change from vapour to liquid

Property	Value
Critical temperature	30.97 °C
Critical pressure	73.773 bar
Triple point temperature	-56.6 °C
Triple point pressure	5.18 bar
Acentric factor	0.22394

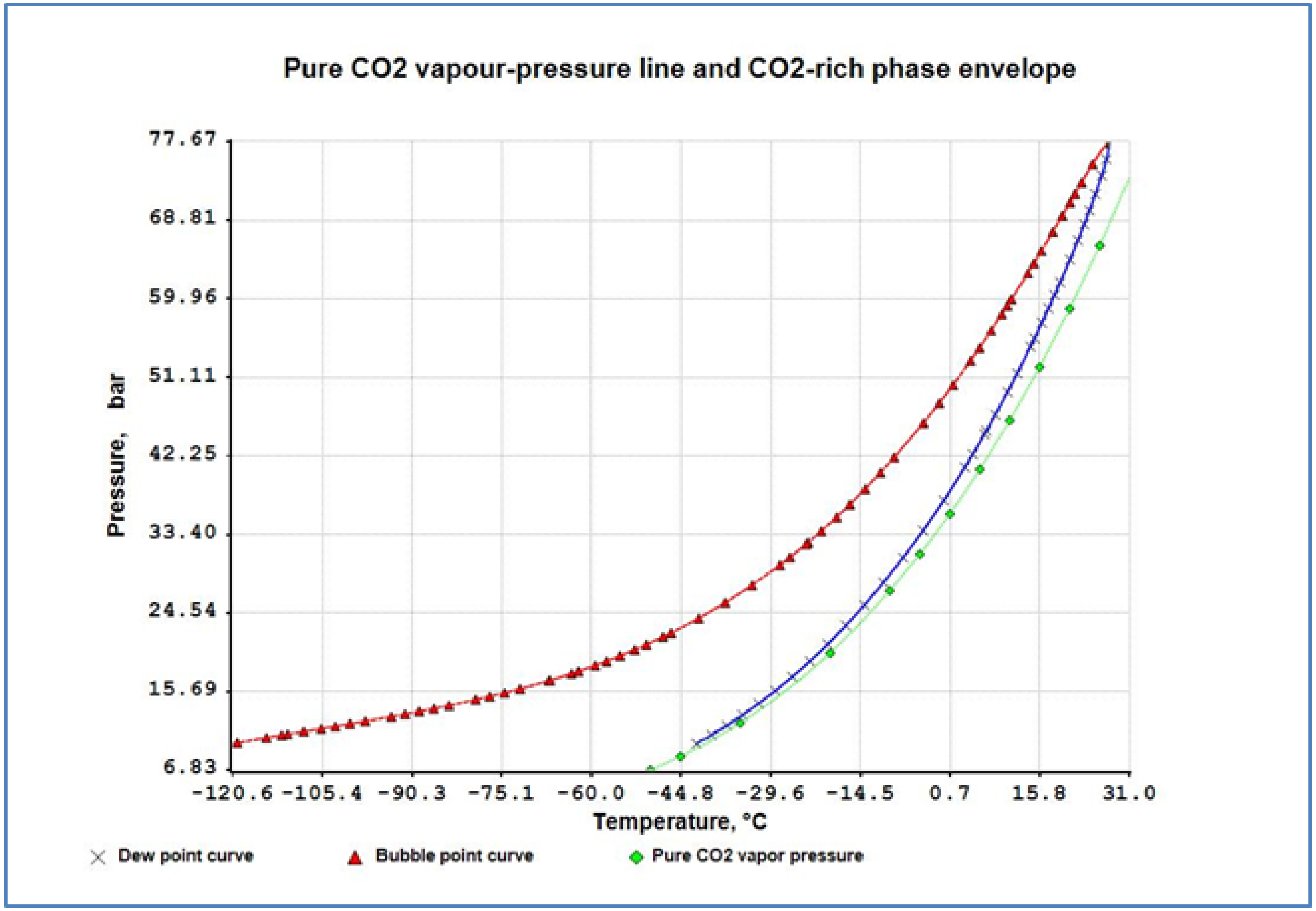
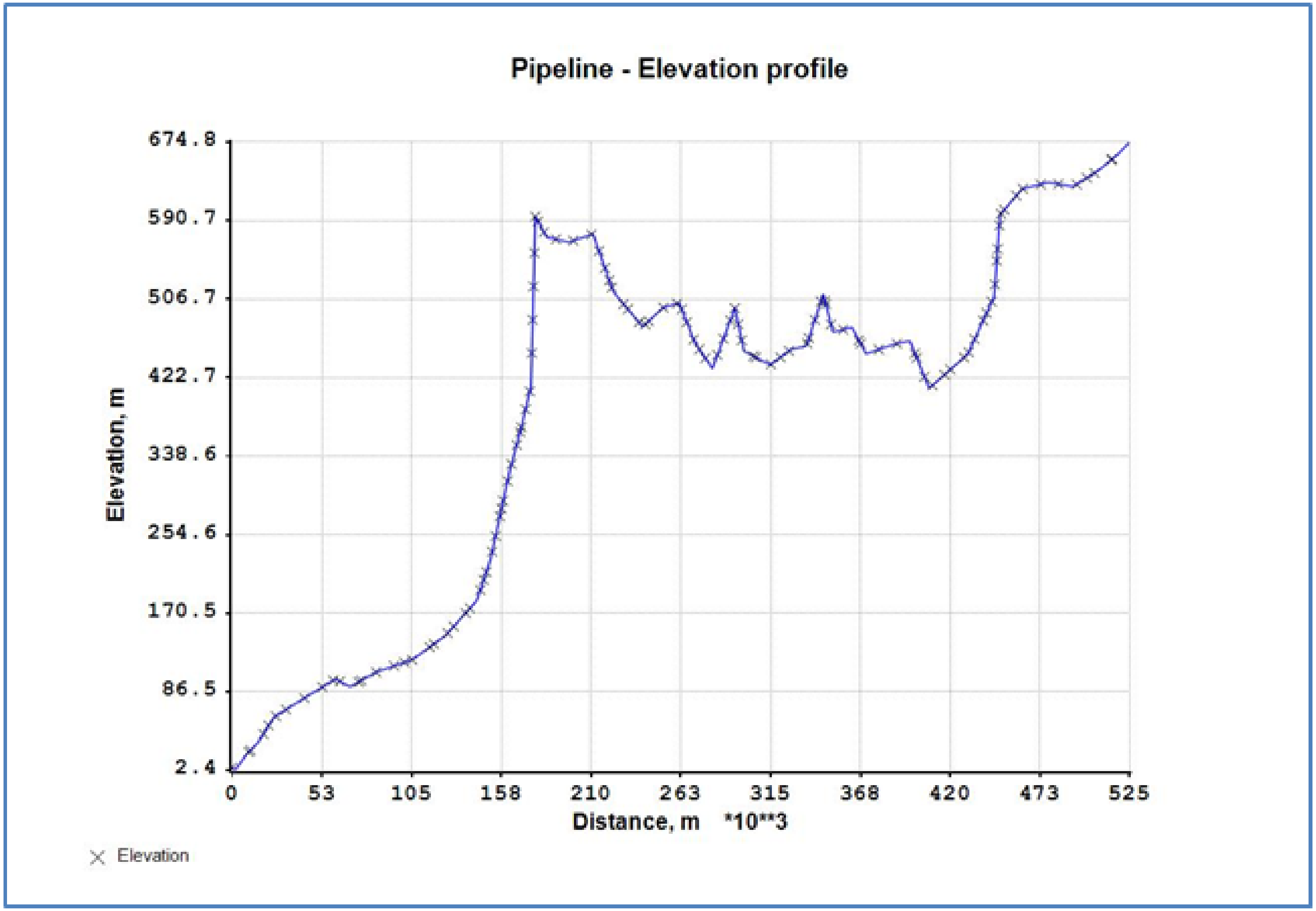


Figure 1: Pure Carbon Dioxide vapour pressure line and CO2-CH4 mixture

Base case

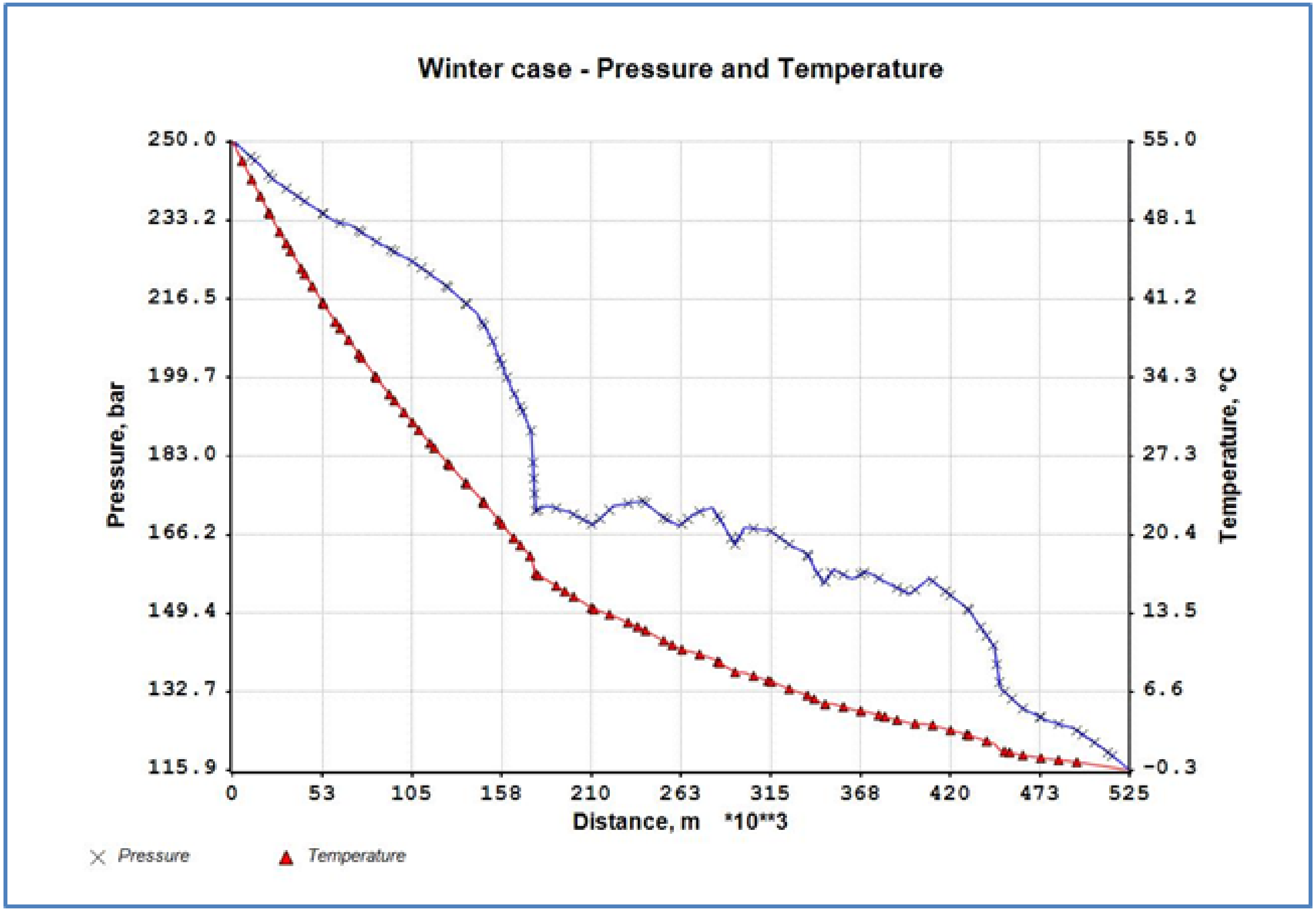
Pipeline length:	525 km
Diameter	0.463 m
Flowrate	600000 kg/h
Inlet Temperature	55 °C
Inlet Pressure	250 bar

Delivery target pressure: about 120 bar


Pipeline - Elevation profile
674.8
590.7
506.7
422.7
338.6
254.6
170.5
86.5
2.4
Elevation, m
0
53
105
158
210
263
315
368
420
473
525
Distance, m *10**3
Elevation

Equation	Final Pressure bar	Final Temp °C
GERG	116.08	0.32
LK	115.92	-0.30
SRK	115.47	-0.07
PR	116.31	-0.26

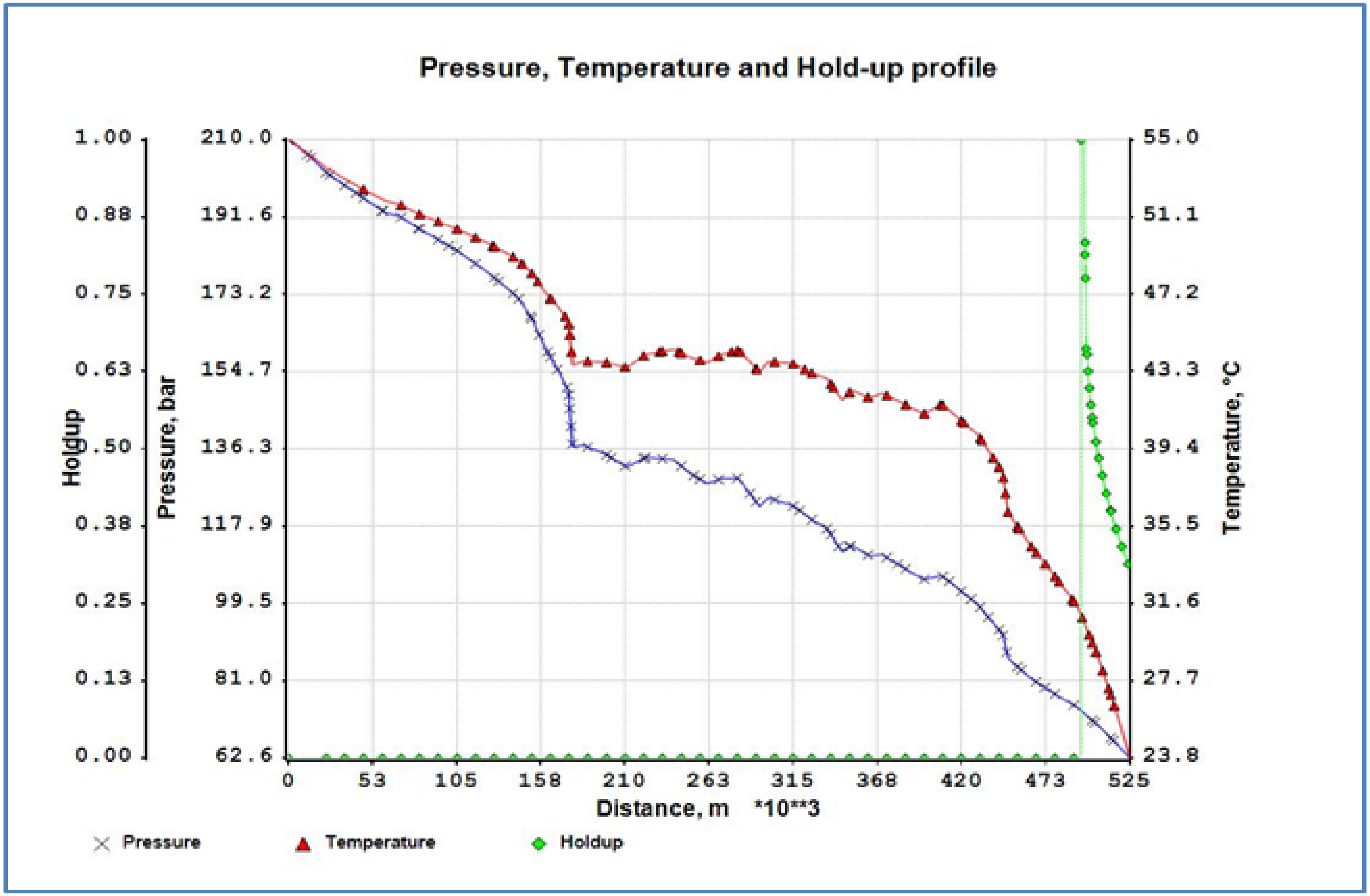
Table 2: Carbon-dioxide transport results (winter case)


Winter case - Pressure and Temperature
Pressure, bar
250.0
233.2
216.5
199.7
183.0
166.2
149.4
132.7
115.9
Temperature, °C
55.0
48.1
41.2
34.3
27.3
20.4
13.5
6.6
-0.3
0
53
105
158
210
263
315
368
420
473
525
Distance, m *10**3
Pressure
Temperature

Inlet pressure set at 210 bar

Case	Equation	Final Pressure, bar	Final Temperature, °C	Vapour Fraction
1	GERG, k=SRK	62.61	23.84	0.4545
2	LK, k=SRK	63.40	24.39	0.4697
3	SRK	53.81	17.36	0.4881
5	PR, k=PR	59.50	21.64	0.4397

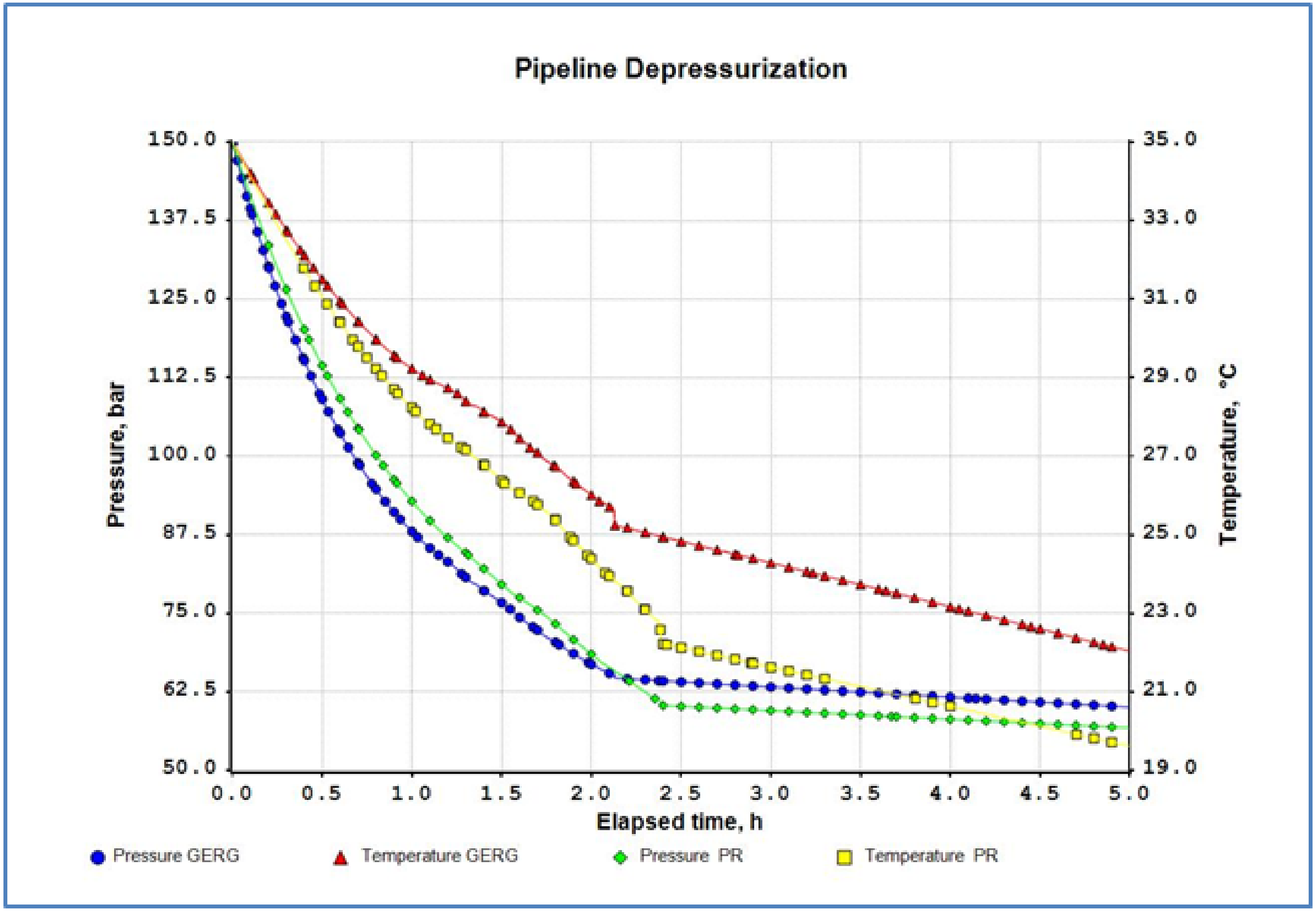
Table 3: CO_2 transport – Summer case with 2-phase flow


Pressure, Temperature and Hold-up profile
Holdup
1.00
0.88
0.75
0.63
0.50
0.38
0.25
0.13
0.00
Pressure, bar
210.0
191.6
173.2
154.7
136.3
117.9
99.5
81.0
62.6
Temperature, °C
55.0
51.1
47.2
43.3
39.4
35.5
31.6
27.7
23.8
0
53
105
158
210
263
315
368
420
473
525
Distance, m *10**3
Pressure
Temperature
Holdup

Pipeline depressurization

Pipeline length:	4 km
Diameter	24 inches
Initial Temperature	35 °C
Initial Pressure	150 bar

Leak (or PSV) diameter 50 mm


Pipeline Depressurization
150.0
137.5
125.0
112.5
100.0
87.5
75.0
62.5
50.0
Pressure, bar
35.0
33.0
31.0
29.0
27.0
25.0
23.0
21.0
19.0
Temperature, °C
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Elapsed time, h
Pressure GERG
Temperature GERG
Pressure PR
Temperature PR

Conclusion

The use of traditional equation of states such as the Peng-Robinson (PR) and Soave-RK (SRK) equations of state can generate questionable results that can produce wrong design choices.

This is particularly true when the fluid reaches the two-phases region and enthalpic effects become important.