Corrosion of Carbon Steel in Dense Phase CO_2 with Impurities

CO_2 Transport and Storage MYRP (1025033)

Ömer Doğan

FECM/NETL Carbon Management Research Project Review

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U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

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Team

- Ömer Doğan
- Zineb Belarbi
- MacKenzie Mark-Moser, Technical Portfolio Lead
- Ale Hakala, Senior Fellow, CTS MYRP Lead
- Mark McKoy, Technology Manager

ExxonMobil

- Neeraj Thirumalai
- Joe Jun
- Fang Cao

DNV

- Ramgo Thodla
- Jose Vera

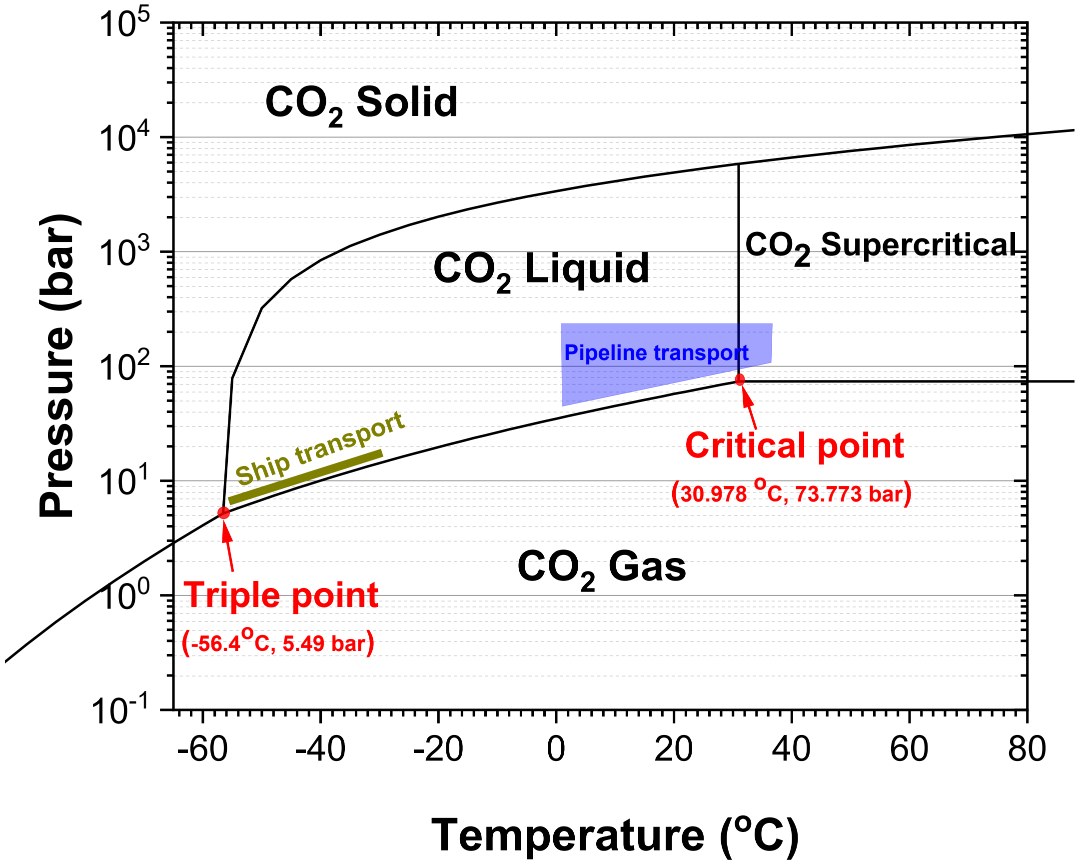
U.S. Department of Energy — Fossil Energy and Carbon Management

- Bob Smith, Program Manager
- Kevin Dooley, Program Manager

CO_2 Phase Diagram

These pipelines operate in the "dense phase" mode at ambient temperature and high pressure.

Pure CO_2 pressure-temperature diagram



However, impurities in the CO_2 stream can alter the phase diagram depending on the concentration and environmental factors.

if the critical temperature of the impurities is above that of CO_2 (e.g., H_2S and NO_2), the 2-phase region will be found below the critical temperature of the pure CO_2 and vice versa.

The presence of impurities will affect the solubility limit of water

Therefore, the corrosion behavior of carbon steel

Impurities in CO_2 streams

Recommended Composition Limits for CO_2 Streams

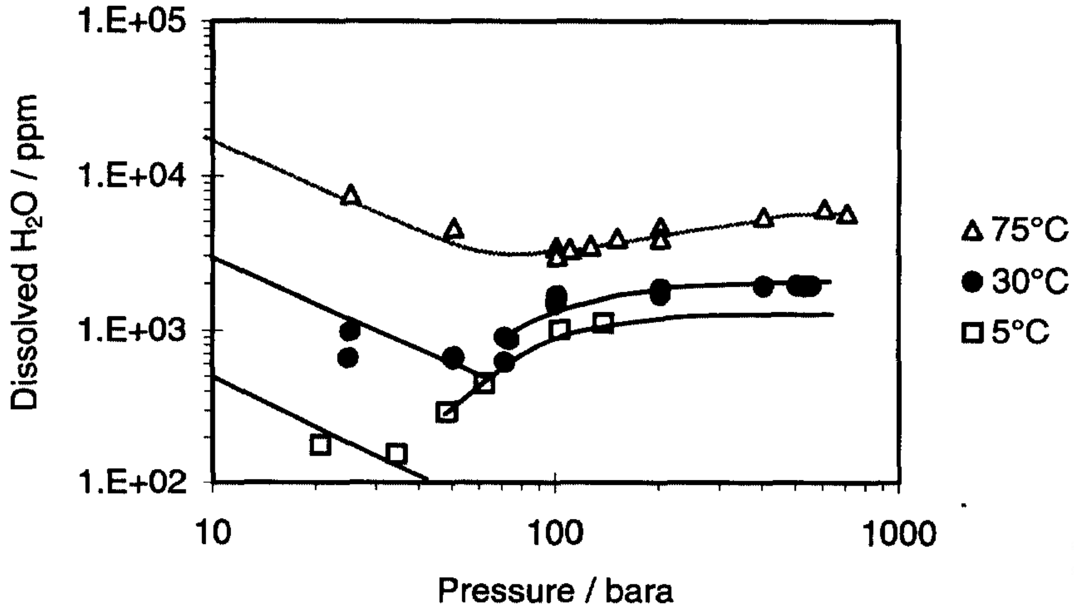
Component	Unit[a]	Carbon Steel Pipeline		EOR		Saline Reservoir Sequestration		Saline CO_2 and H_2S Cosequestration	
		Concept	Literature Range	Concept	Literature Range	Concept	Literature Range	Concept	Literature Range
CO_2	vol%	95	90–99.8	95	90–99.8	95	90–99.8	95	20–99.0
H_2O	ppmw[c]	300	20–650	300	20–650	300	20–650	300	20–650
N_2	vol%	4	0.01–7	1	0.02–2	4	0.01–7	4	0.01–7
O_2	vol%	4	0.01–4	0.01	0.001–1.3	4	0.01–4	4	0.01–4
Ar	vol%	4	0.01–4	1	0.01–1	4	0.01–4	4	0.01–4
CH_4	vol%	4	0.01–4	1	0.01–2	4	0.01–4	4	0.01–4
H_2	vol%	4	0.01–4	1	0.01–1	4	0.01–4	4	0.01–4
CO	ppmv[d]	35	10–5000	35	10–5000	35	10–5000	35	10–5000
H_2S	vol%	0.01	0.002–1.3	0.01	0.002–1.3	0.01	0.002–1.3	75	10–77
SO_2	ppmv	100	10–50,000	100	10–50,000	100	10–50,000	100	10–50,000
NO_x	ppmv	100	20–2500	100	20–2500	100	20–2500	100	20–2500
NH_3	ppmv	50	0–50	50	0–50	50	0–50	50	0–50

[a] Maximum unless otherwise noted.
[b] Immediately dangerous to life and health.
[c] Parts per million by weight.
[d] Parts per million by volume.
[e] Not enough information.

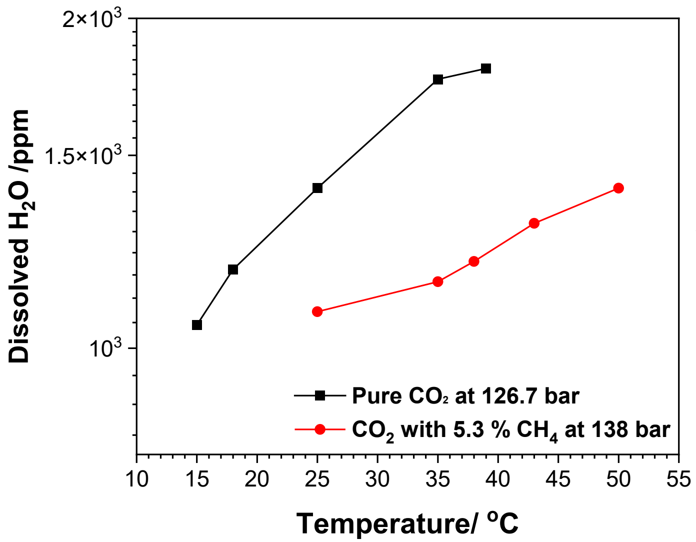
Shirley, Pamela, and Myles, Paul. *Quality Guidelines for Energy System Studies: CO2 Impurity Design Parameters*. United States: N. p., 2019. Web. doi:10.2172/1566771.

Water solubility in CO_2

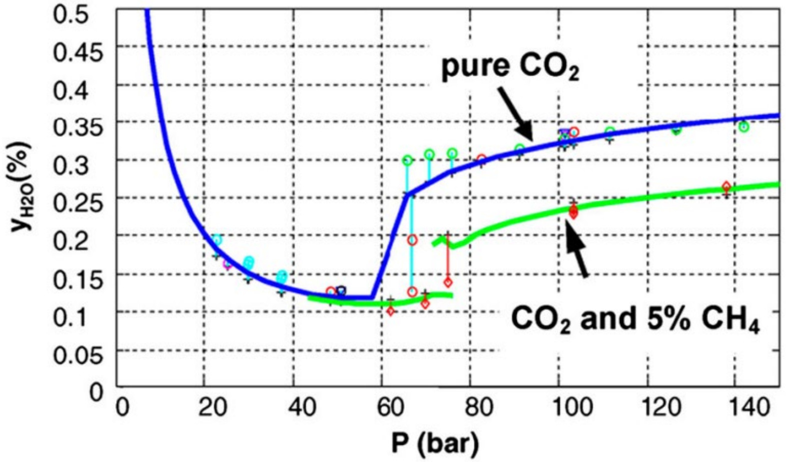
Amount of water that can be contained in CO_2 as a function of pressure and temperature



R. Wiebe, J. Gaddy, J. Am. Chem. Soc. 3, (1941):p. 475.
K.Y. Song, SPE Paper No. 18583 (Houston, TX: SPE International, 1988)



K.Y. Song, R. Kobayashi, SPE Formation Evaluation (1987) :p. 500.
M. B. King, A. Mubarak, J. D. Kim, T. R. Bott, J. Supercrit. Fluids 5, (1992) :p. 296

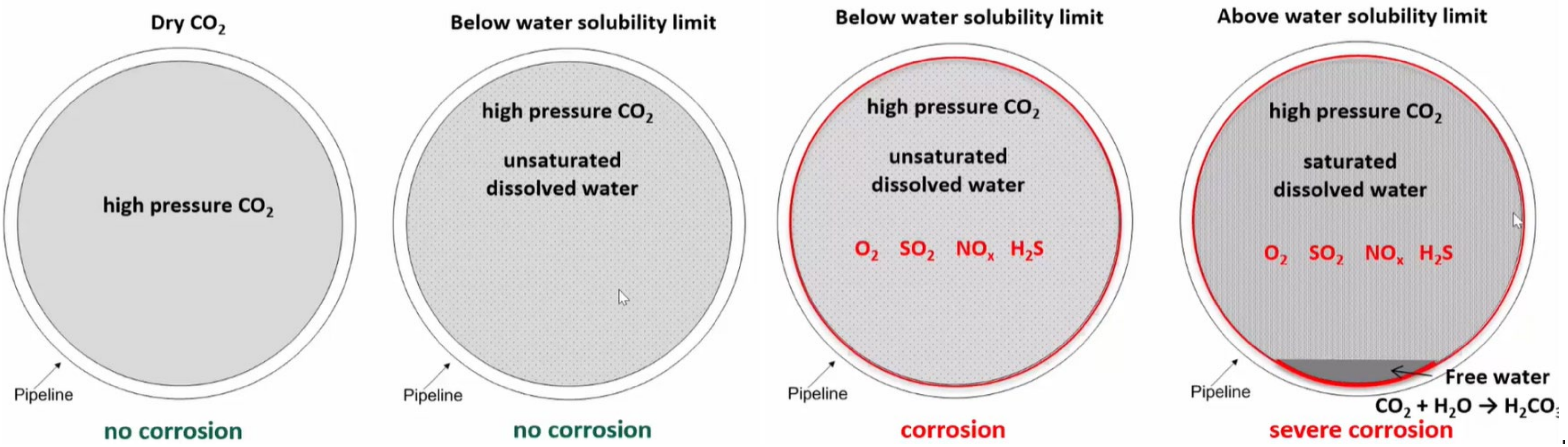


Water solubility in pure CO_2 and in a CO_2–CH_4 mixture at 25°C

Xiang et al., State-of-the-art overview of pipeline steel corrosion in impure dense CO2 for CCS transportation: mechanisms and models, Corrosion Engineering, Science and Technology, 52:7, 485-509,

Internal corrosion of pipeline steel

Impact of impurities on phase boundaries and reactions in CO_2 and corrosion of carbon steel



Nesic et al. Ohio University

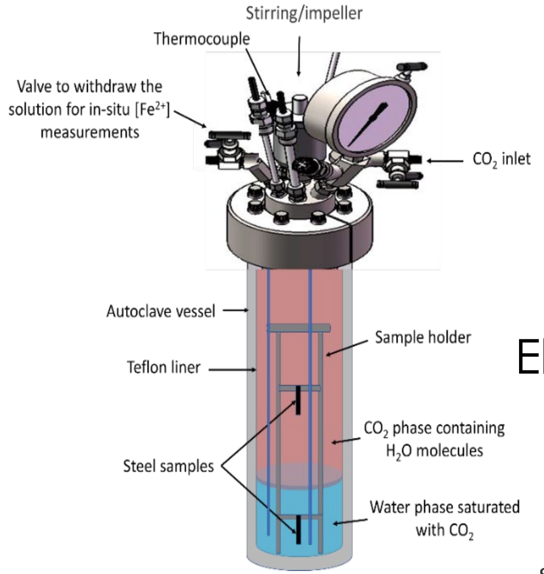
Corrosion in dense phase CO_2 in the presence of water and other impurities

- Investigate the effect of impurities (e.g., CO, O_2, H_2, NO_x, SO_x) on the corrosion of pipeline carbon steel under dense phase CO_2 in electrochemical and immersion autoclaves using weight loss and electrochemical methods.

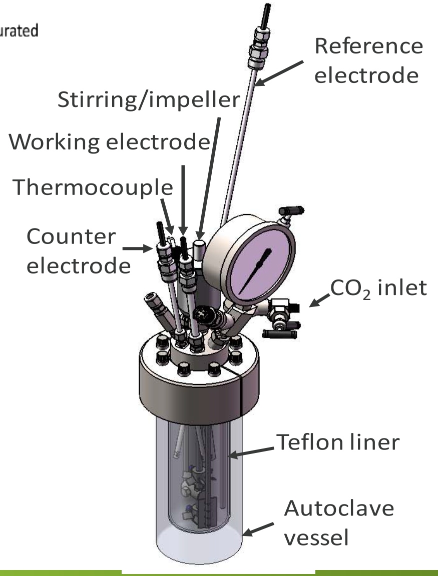
- The team will investigate improving the test setup by adding capabilities to continuously or periodically measure impurity content in the autoclaves, injecting impurities to replenish those consumed in corrosion reactions, and detecting acid dropout.

- The post-exposure analysis of the coupons will characterize corrosion mechanisms, including localized corrosion and corrosion products, using SEM, EDS, XRD, and Kelvin probe.

Immersion Autoclaves



Electrochemical Autoclaves



Corrosion studies in dense phase CO_2 with impurities

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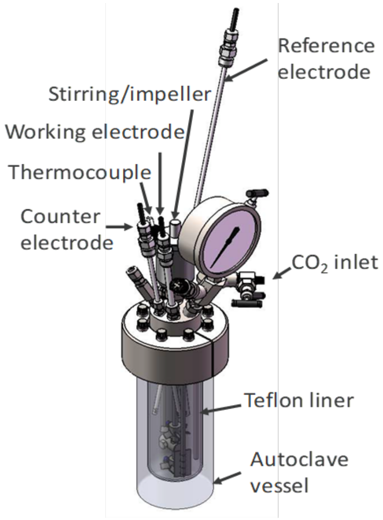
Electrochemical reaction autoclaves

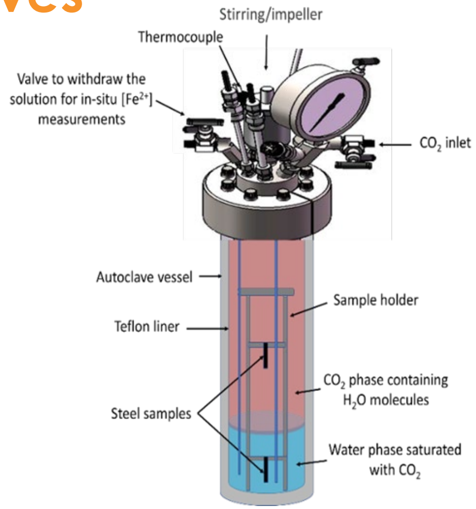


Operational conditions

Autoclave made of Hastelloy 276 with 3 electrode configuration.

- For up to 5000 psi
- Temperature: 25°C to 300°C
- Available gases:
  - SO_2 12%+O_2 23.5%+CO_2 ; SO_2 12%+CO_2 ; H_2S 4%+CO_2
  - CO_2; O_2+CO_2
  - H_2, N_2, Ar
- Rotation speed up to 600 rpm (1.25 m/s, Re=15611 at 40°C)
- High-temperature and high-pressure pH probe
  - High Pressure ZrO_2-based pH probe (85 To 250 °C; for up to 4000 psi)
  - High Pressure Glass-based pH Probe (2 To 80 °C ; 0 to 3000 psi)

Immersion autoclaves



Operational conditions

- Autoclave made of Hastelloy 276; Ni alloys; Stainless steel.
- For up to 5000 psi
- Temperature: 25°C to 250°C
- Available gases:
  - SO_2 12%+O_2 23.5%+CO_2 ; SO_2 12%+CO_2 ; H_2S 4%+CO_2
  - CO_2; O_2+CO_2
  - N_2, Ar
- Rotation speed up to 600 rpm (1.25 m/s, Re=15611 at 40°C)
- In-situ measurements of ions concentration (Fe^{2+}, Cr^{2+}, …)
- Gas and liquid phase sample holders

Collaborators

ExxonMobil

- advanced characterization and microanalysis of selected samples
- donate carbon steel materials for corrosion testing at NETL
- contribute to the discussion of experiments design/conditions and share any relevant experience and corrosion testing results with NETL
- conduct complementary autoclave corrosion tests of dense phase CO2 with impurities

DNV

- perform corrosion tests under varying conditions to characterize the effect of water drop out during operational upsets
- investigate the impact of deposits, left on the steel surface after water dissolution in sCO2, on the ability to retain water and sustain corrosion under hygroscopic conditions

Project Timeline

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Evaluation of the risk of corrosion in dense phase CO_2 in the presence of aqueous/acid phase (continuous or droplets) and other impurities

Tasks	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Literature review	■											
Establish test methodologies and obtain steel samples	■											
Determine general corrosion rates of carbon steel in aqueous/acid phase with SOx and NOx	■	■	■	■	■							
Determine general corrosion rates of carbon steel in aqueous/acid phase with additional impurities					■	■	■	■				
Corrosion mechanisms of select steels	■	■	■	■	■	■	■	■	■	■	■	■
Project kick-off and progress meetings	■		■		■		■		■			■

Project Kick-off: June 14, 2024

Any Questions?

Ömer Doğan
Technical Portfolio Lead
Advanced Energy Materials
Structural Materials Team
Office: (541) 967-5858
Email: omer.dogan@netl.doe.gov

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