Corrosion in CO_2 Transmission Pipelines Joint Industry Project (CCT JIP)

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RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY

Roadmap for CO_2 Transport Fundamental Research Workshop
February 2023

OHIO UNIVERSITY 1804

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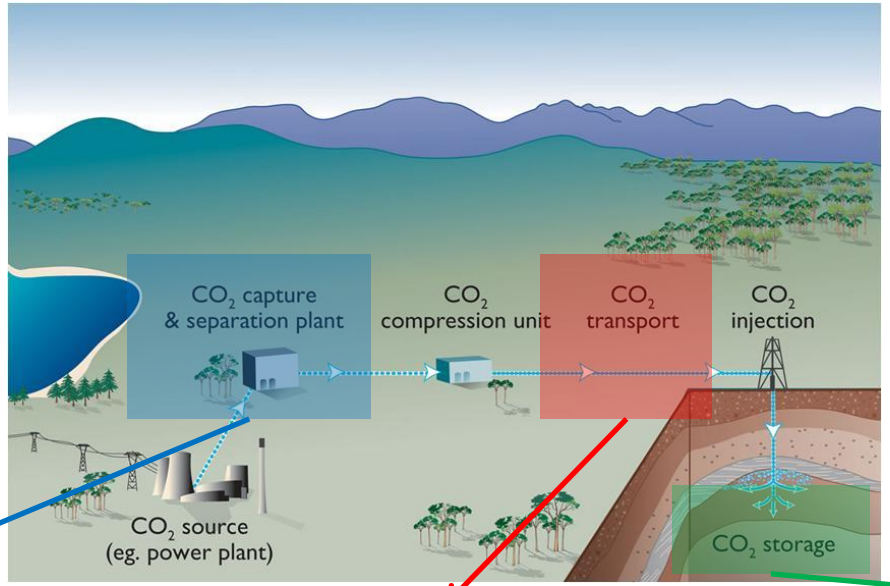
Introduction

Introduction

CO_2 Corrosion in CCS (Carbon Capture and Storage) Process



Source: http://www.co2crc.com.au/imagelibrary

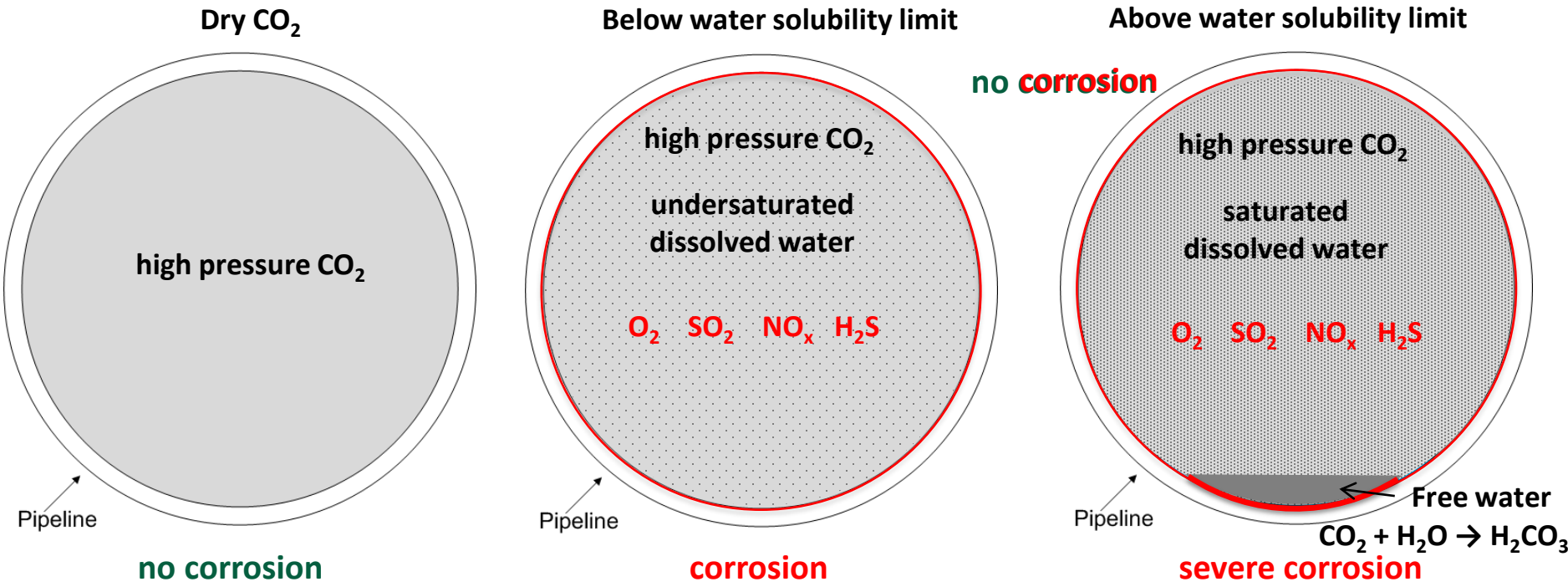
Corrosion of carbon steel in amine-based CO_2 capture plant

Corrosivity of transported CO_2 with impurities

Corrosion of wellbore steels in high pressure CO_2/brine environments.

Introduction

Corrosion Problem in CO_2 Transport Pipelines



Gaps and Challenges

Gaps and Challenges

What we do know…

- Dry CO_2 does not corrode carbon steel.
- Aqueous corrosion rate of carbon steel is very high under high pressure CO_2 conditions.
- Aqueous corrosion mechanisms in high pressure CO_2 are similar to those in low pressure CO_2 conditions.
- Negligible corrosion occurs at water-undersaturated and water-saturated conditions in pure dense phase CO_2.
- Corrosion occurs at water-undersaturated conditions in dense phase CO_2 with the presence of impurities (O_2, SO_2, NO_2, H_2S, etc.).
- Localized corrosion occurs at water-unsaturated conditions in dense phase CO_2 with the presence of impurities and some flow.

Gaps and Challenges

What we don't know…

- **How impurities affect the H_2O solubility/acid formation in a dense CO_2 phase.**
- **The effect of impurities on corrosion in a dense CO_2 phase.**
- **The effect of pressure, temperature and flow.**
- **Long-term corrosion behavior of carbon steel in a dense CO_2 phase (at constant impurities concentration).**
- **Mechanisms of uniform and localized corrosion in dense phase CO_2 with impurities.**

Gaps and Challenges

What we need to build…

- **A thermodynamic model for predicting H_2O behavior in dense phase CO_2 with impurities**
- **Mechanistic model that can predict the rate of corrosion of steel in dense phase CO_2 and in aqueous phase with impurities, that accounts for the effect of all key variables such as: concentrations, pressure, temperature, flow, etc.**

Corrosion in CO_2 Transmission Pipelines (CCT) JIP

Objective and Goals

Objective: Identify and quantify the key issues which impact corrosion of materials specifically relating to the integrity of structures for the CO_2 transport pipelines.

Goals:

- To understand the effect of a wide range of impurities (O_2, SO_2, NO_2, H_2S, etc.) on **the water/acid solubility and the speciation** in dense phase CO_2.
- To develop a **thermodynamic model** for predicting the water/acid solubility and the speciation in dense phase CO_2 in the presence of impurities.
- To determine impact of **environmental parameters (pressure, temperature, flow, and impurity types and concentrations)**, both individually and synergistically, on **steel corrosion** in both dense phase CO_2 and aqueous phase in the presence of impurities.
- To develop a **mechanistic model** to predict the corrosion processes in order to help determine facility lifetime.

Scope of Work

Key Mechanistic Stages in Dense Phase CO_2 Corrosion

Operating condition:
- C_{H2O} < Solubility Limit
- Presence of Impurities (SO_2, NO_2, H_2S, O_2)

Upset condition:
- C_{H2O} > Solubility Limit
- Presence of Impurities (SO_2, NO_2, H_2S, O_2)

➢ **Initial stages**
- Water/acid droplet or layer formation

➢ **Intermediate stages**
- Chemical reactions in the electrolyte.
- Chemical/Electrochemical reactions at the steel surface
- Nucleation of corrosion products at the steel surface

➢ **Final stages**
- Growth and transformation of corrosion products

- **Effect of impurities**
- **Effect of droplet volume**
- **Effect of pressure and temperature**
- **Effect of flow**
- **Uniform/localized corrosion**

Scope of Work

The CCT JIP investigates effects of a wide range of impurities (H_2O, O_2, SO_2, NO_2, H_2S, etc.), in particular combinations, on both thermodynamic properties and corrosion behavior. The research is divided into three main parts:

- Part 1. Thermodynamic study.
- Part 2. Corrosion study.
- Part 3. Model development.

Part 1. Thermodynamic Study

- **Develop a thermodynamic model of solubility of water/acid and speciation in dense phase CO_2 in the presence of impurities like SO_2, NO_2, H_2S and O_2.**
  - Task 1-1: Perform a systematic experimental study to investigate the solubility and the conditions under which the impurities react to form acids.
  - Task 1-2: Employ molecular simulations to study the homogeneous and heterogeneous nucleation of water (on metal surface or around impurities) in the dense phase CO_2 environment.
  - Task 1-3: Develop a thermodynamic model by fitting the studied conditions (Topic 1A).

Part 2. Long-Term Corrosion Study

- **Evaluate long-term corrosion behavior under water unsaturated dense phase CO_2 in the presence of various impurities.**
  - Task 2-1: Glass cell experiments
  - Task 2-2: Autoclave experiments
  - Task 2-3: Flow loop experiments

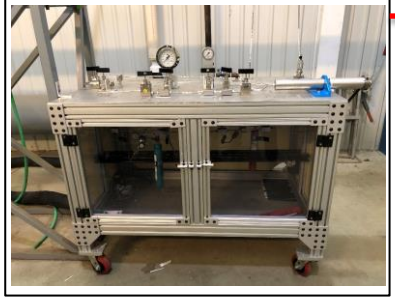
Part 3. Corrosion Modeling

- **Develop a mechanistic model, which can predict the rate and mechanism of corrosion of steel in dense phase CO_2 with impurities.**
  - The data from the experimental part of the study will be used to focus and guide the modeling effort.
  - The thermodynamic model developed in Part 1 will be connected to the corrosion model.
  - The existing model of CO_2 corrosion in the ICMT (MULTICORP™, TOPCORP™, and WELLCORP™) will serve as a good platform for building the basic model needed in this study.
  - Extending the model to much higher CO_2 pressures and adding the effect of impurities on corrosion behavior is the main focus when constructing the new model envisioned in this task.

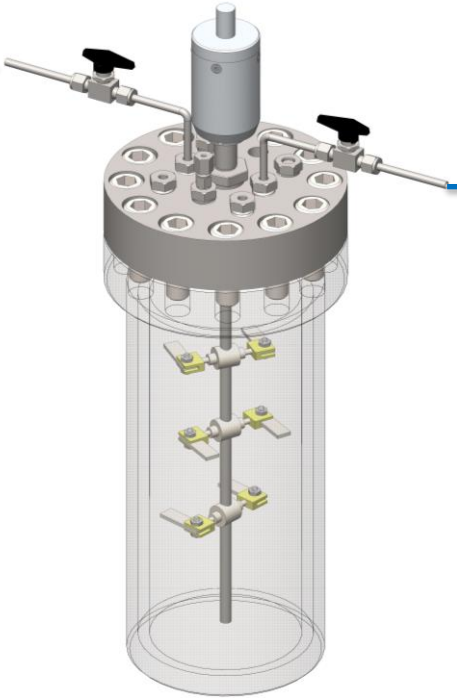
Equipment

Experimental Setup: Autoclave

Impurity injection system



HP syringe pump



Cavity enhanced laser absorption

H_2O: 0 ~ 6000 ppm_v
H_2S: 0 ~ 300 ppm_v
O_2: 0 ~ 2000 ppm_v

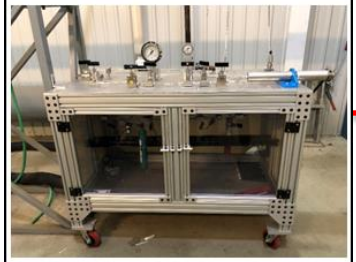
Quantum cascade laser

NO_2: 0 ~ 1000 ppm_v
NO: 0 ~ 1000 ppm_v
SO_2: 0 ~ 900 ppm_v

Equipment

Experimental Setup: HPHT Thin Channel Flow Cell (TCFC)

Impurity injection system



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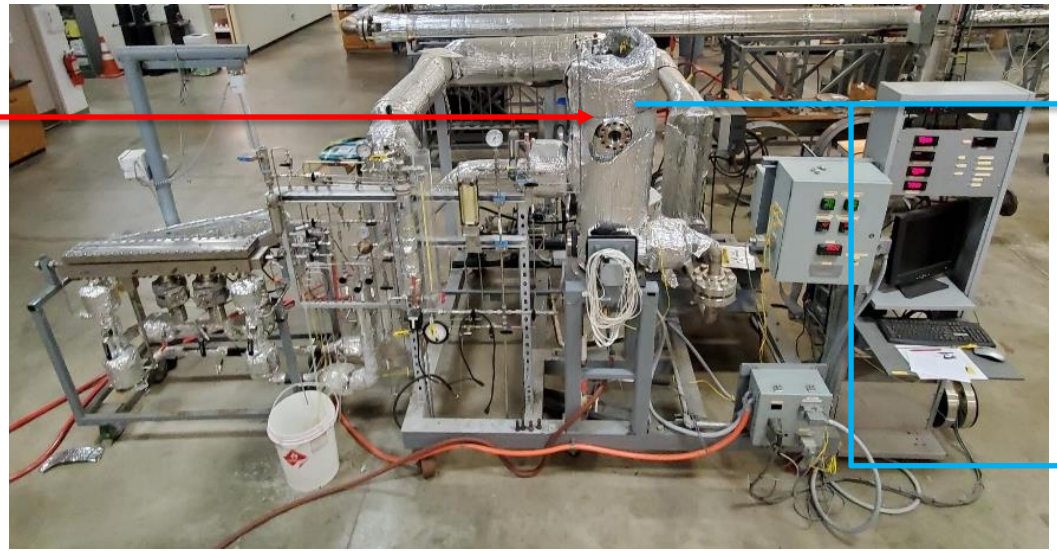

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CCT JIP Sponsors

1. BP
2. Chevron
3. ConocoPhilips
4. Enbridge
5. Equinor
6. EVRAZ North America
7. ExxonMobil
8. Occidental Oil Company
9. Shell
10. Tenaris

- *Duration: 3 years*
  January 2023 – December 2025
- *Budget: $50,000 / year / company*

Kinder Morgan, Saudi Aramco, Petrobras, Petronas, TotalEnergies showed their interest

Key Takeaways and Next Steps

Key Takeaways

- Thermodynamic and corrosion prediction models which can predict the water solubility/acid formation and corrosion of carbon steel in dense phase CO_2 environments with impurities covering various scenarios for CO_2 transportation pipelines.

- An improved understanding of the thermodynamic behavior of dense phase CO_2 in the presence of different impurities.

- An improved understanding of the corrosion behavior of carbon steel in dense phase CO_2 with impurities.

- A scientific and engineering basis for establishing safe CO_2 specifications.

- Education of students and broader engineering communities regarding the corrosion of CO_2 transmission pipelines.

Next Steps

- Mitigation of corrosion:
  - Corrosion inhibitors
  - Corrosion resistant alloys (CRAs)

- Effect of other impurities (glycol or alcohol) and low temperature.

- Effect of upset conditions.

- Establish safe CO_2 specifications considering the risk of corrosion.

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2/21/2023

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