Corrosion Inhibition in CO_2 Storage

Tim Myers

Centre de Recerca Matematica

Spain

The initial problem …

- Annual emissions have consistently risen since the industrial revolution: even after the Paris agreement in 2015 emissions continued to increase (with an exception due to COVID) reaching over 53 billion tonnes per year of greenhouse gases in 2024.
- At COP 30, 2025, one of the chief scientific advisers to the UN stated that 10bn tonnes of carbon dioxide needed to be removed from the air every year even to limit global heating to 1.7ºC above preindustrial levels (in tandem with drastic reductions in emissions).
- Removal technology is advancing, but then what?

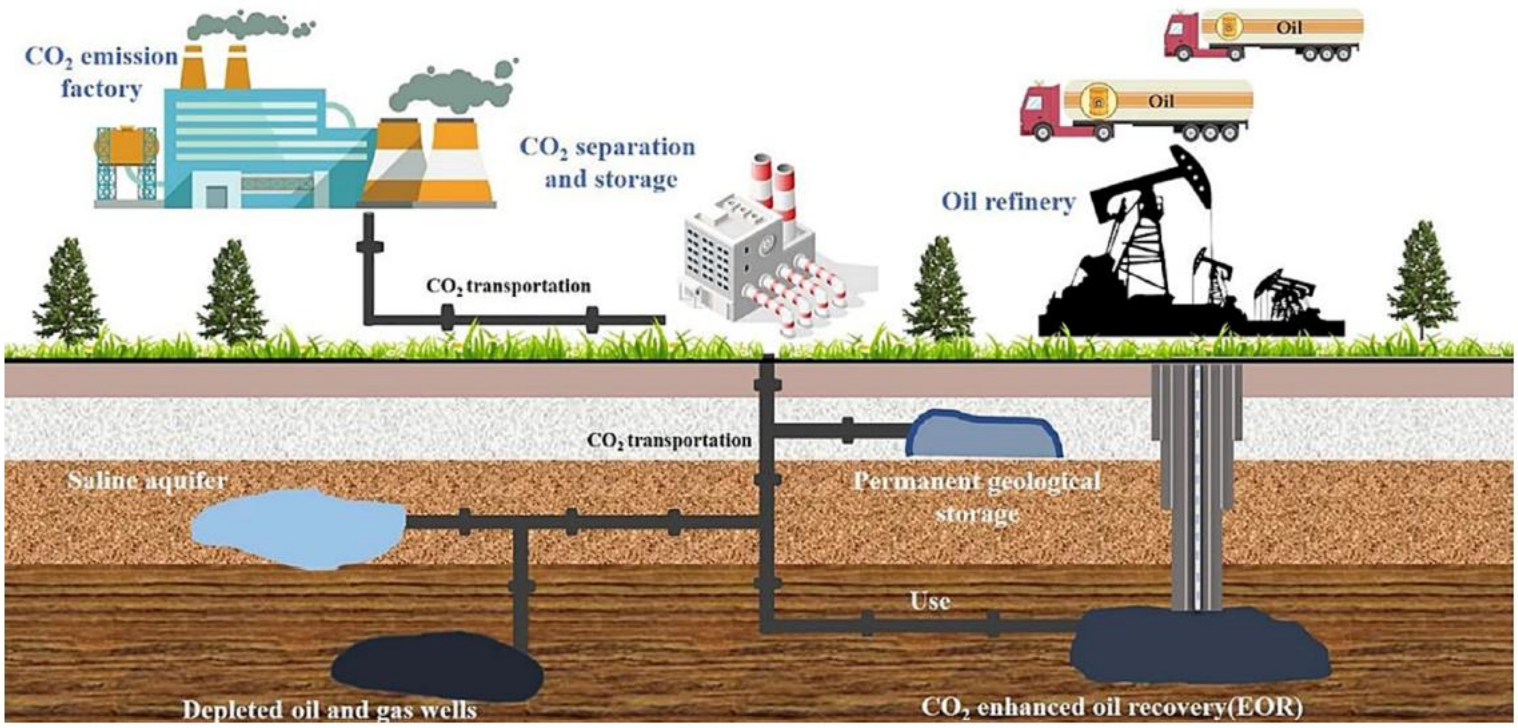
Carbon capture, utilisation, storage …

- Carbon capture and storage (CCS) is considered essential in the fight to achieve global net- zero emissions targets and limit the effects of climate change. A key difficulty concerns the storage and transport of CO2 after capture.

- Carbon Capture, **Utilization** and Storage (CCUS) technology has emerged as one of the major solutions to combat global climate change … CCUS technology is a new development of Carbon Capture and Storage (CCS) technology direction, not only to simply sequester CO2 but also to continue to put it into new production processes (fuels, chemicals, building materials and biomass (algae)).

- CCUS systems involve a large number of metal pipes and equipment, which are at risk of corrosion. Internal corrosion accounts for more than 50% of incidents and is the most common form of failure in the industry

CO2 movement



There is a little too much oil industry in this …

Carbon capture, utilisation, storage …

The combination of water with CO2, as well as with common exhaust gas impurities such as SOx and NOx, can lead to the formation of carbonic, sulfuric, and nitric acids, which corrode transport and storage vessels. To combat this, there is a strong push to understand and thus reduce the corrosive effects …

Corrosion

Corrosion is defined as the destructive attack of a material by reaction with its environment

Corrosion inhibitors are chemical substances that are added to aggressive environments in small concentrations to decrease the corrosion rate. These substances can react with either a metal surface or its surroundings providing protection to the surface,

It has been observed that corrosion inhibitors generally work by forming an adsorbed film.

Corrosion inhibitors can be introduced into the aggressive environment in a single application or continuously by gradual and controlled additions. The single addition is possible in static systems where friction is negligible. Gradual addition is necessary for systems where variation in flow degrades the integrity of the protective film.

Carbon capture, utilisation, storage …

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Current corrosion mitigation strategies rely heavily on the use of large volumes of chemical inhibitors to create protective films that form a barrier against corrosive attack. In addition to the financial costs, there are serious concerns about the toxicity and degradability of existing inhibitor formulations, as well as the lack of effective inhibitors for use at the high temperatures required to effectively exploit sustainable energy sources, such as geothermal engineering. This has motivated significant research worldwide aimed at creating the next generation of sustainable inhibitors.

Supercritical CO2

If want to focus on a particular component …

Supercritical CO_2 is how CO2 is often transported. It is becoming an important commercial and industrial solvent due to its role in chemical extraction, in addition to its relatively low toxicity and environmental impact. The relatively low temperature of the process and the stability of CO_2 also allows compounds to be extracted with little damage or denaturing. In addition, the solubility of many extracted compounds in CO_2 varies with pressure, permitting selective extractions.

Water is a major cause of corrosion in supercritical CO2 transport tubes. Numerous investigations have proven that supercritical CO2 in the absence of water is not corrosive to pipelines. When the water content is smaller than its solubility in supercritical CO2 the corrosion of pipeline materials gradually increases with the growth of water content.

Mathematical modelling

Current models mainly appear to focus purely on isotherms.

A single, simple model takes the form

$$\frac{\partial \theta}{\partial t} = k_a c(\theta_m - \theta) - k_d \theta ,$$

Langmuir isotherm

$$\theta_e = \frac{k_a c_e \theta_m}{k_a c_e + k_d},$$

This quantifies the final state of the inhibitor, i.e. how much is adsorbed in equilibrium.
But what does this tell me about the time-dependent process?
How do we adapt for multiple chemicals? With flow?

Mathematical modelling

The level appears to be rather low … One of the few papers discussing progression of corrosion

Ma et al Process Safety and Environmental Protection 171 (2023)

3.1.2. Linear corrosion rate model

The linear corrosion rate model is a deterministic model that assumes that the corrosion rate grows linearly with time (Li et al., 2022b). Its form is relatively simple, as shown in Eq. (1).

$$D(t) = D_0 + \dot{D}t \tag{1}$$

Where, $D(t)$is the corrosion depth over time, t is the time interval, D_0 is the corrosion depth at the initial time, and $\dot{D}$ is the corrosion rate.

When there is only one set of ILI data, the initial time can be regarded as zero or the moment of third-party interference or coating peeling off (Vanaei et al., 2017). When a pipeline has at least two ILI data collected at different times, the corrosion rate can be calculated with Eq. (2).

$$\dot{D} = \frac{dT_2 - dT_1}{t_2 - t_1} \tag{2}$$

Corrosion inhibition

- Corrosion inhibition in industrial systems requires a combination of components, typically at least five, which has led to a vast array of inhibitor formulations. A poor understanding of the corrosion process, coupled with a lack of systematic optimization methodologies, has resulted in the commercial adoption of suboptimal inhibitor formulations.

- Whilst models exist, they are generally tackled numerically, consequently, the main objectives of this project will be to develop and analyse accurate corrosion inhibition models and combine them with experimental data to determine their parameters and optimize their efficiency.

Goals

- To understand how corrosion and inhibition is modelled
- Then, to advance the theoretical understanding of corrosion inhibition through developing a validated mathematical model for corrosion inhibition
- To use the models to help understand and optimize corrosion inhibition

(I have sent some literature which includes experimental data)

Suggested strategies

Analyse/develop models for isotherms/kinetics

1. Literature! (Lots of work, primarily for transporting oil)
2. Isotherm for single component (not just Langmuir)
3. Isotherms for multiple components
4. Kinetic versions – not steady-state
5. Static – 1D fluid diffusion with adsorption at boundary
6. Moving – Diffusion + advection with adsorption

Enjoy yourselves!!!