TECHNICAL CONSIDERATIONS FOR CO2 PIPELINE TRANSPORT AND THE ROLE OF COMPOSITE CRACK ARRESTORS

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PHMSA

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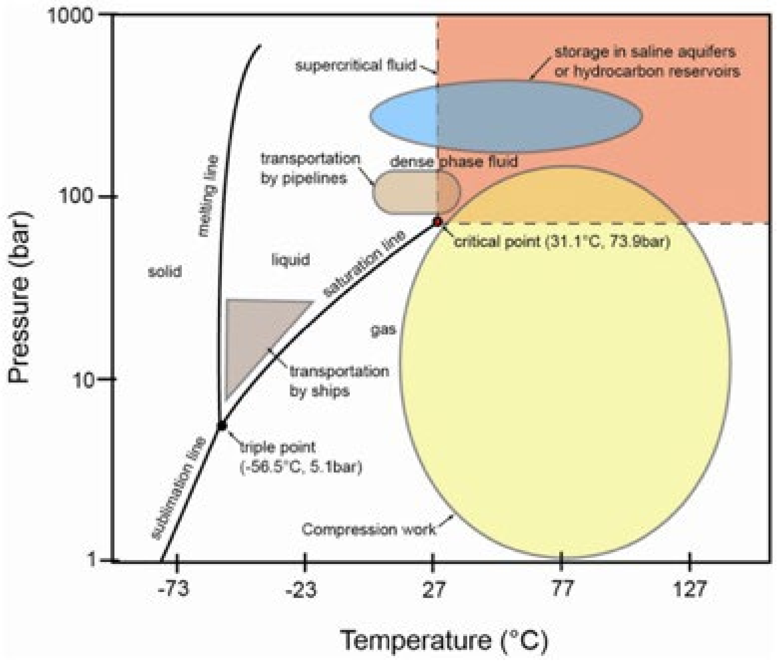
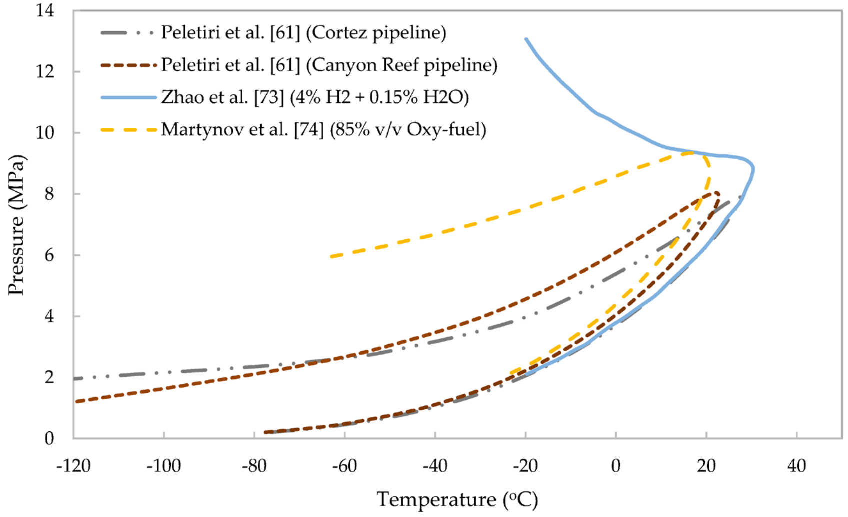
Content

- CO_2 pipeline transport overview
- Two main consideration
- What we know – what we don't know – GAPS
- Role of composite crack arrestors
- Where do we go from here

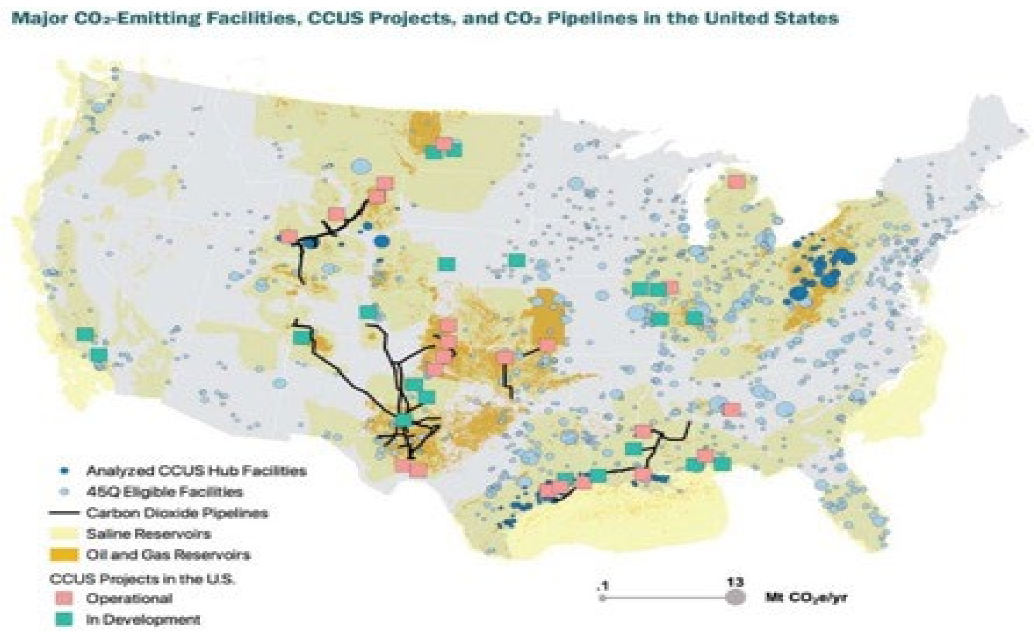


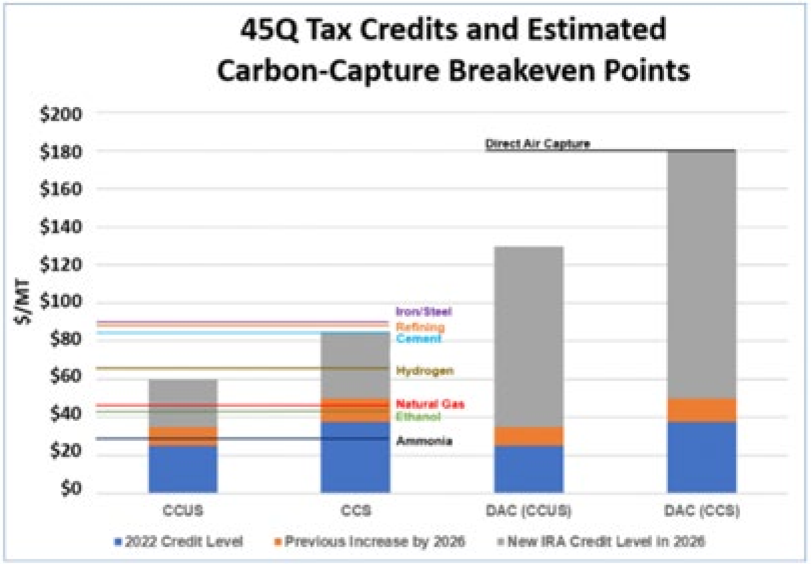


Peletiri, S.P.; Rahmanian, N.; Mujtaba, I.M. CO_2 Pipeline Design: A Review. *Energies* **2018**, *11*, 2184. https://doi.org/10.3390/en11092184

CO_2 Overview

- There are 16 carbon capture sequestration projects and potentially over 80 more in development in the USA
- There are 5200 miles of CO_2 pipelines in USA
- 166 CO_2-EOR operations running
- Currently, there is not a well-defined regulatory oversight for Dense Phase CO_2 transport. Design criteria are based on ASME B31.4/ 49 CFR 195
- Need to achieve over 65,000 miles of pipelines by 2050 to achieve net zero goals in the USA.





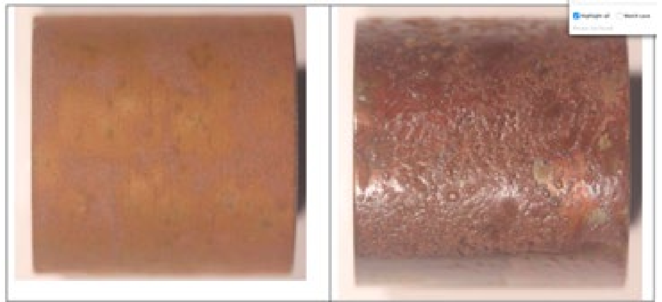
Two Main Technical Considerations for CO_2 Transport

- There is a need for a well-defined oversight.
- Two primary technical challenges are:
  - Ensure that line pipes are fabricated with sufficient material toughness to arrest a ductile fracture (CVN, DWTT, QA/QC)… **otherwise, ensure the pipeline system is designed against ductile fracture propagation.**
  - Ensure CO_2 corrosion does not occur due to water and impurities within the system … **Otherwise, ensure the pipeline system is designed with a mitigation/barrier under upset conditions or that upset conditions are accounted for as part of the design.**

When could ductile fracture propagation occur?

The likelihood that an impact occurs at the pipe body rather than a weld section is significantly greater.

When could acid corrosion occur?



a) DnV 4_3 NO: 50 °C , 500 ppmv H_2O, 200 ppm NO, 500 ppmv O_2

b) DnV 3_3 NO:After exposure 4 °C, 500 ppmv H_2O, 200 ppm NO, 500 ppm O_2

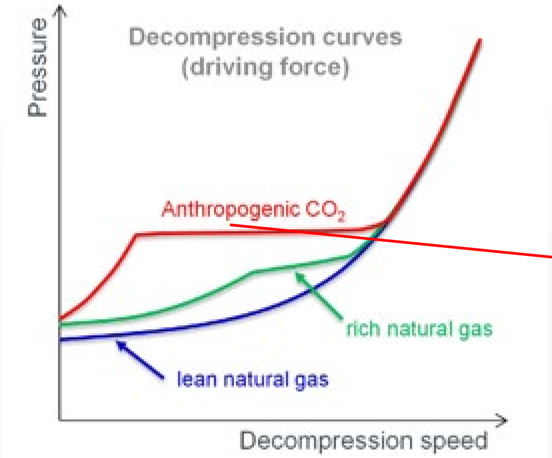
The likelihood that acid corrosion occurs is significantly greater under upset conditions than under steady state conditions.

Example Risk Rating Matrix

	Consequence →				
People	Minor skills impact.	Minor impact to capability	Unavailability of core skills affecting services.	Unavailability of critical skills or personnel	Protracted unavailability of critical skills/people.
People	Minor injury or first aid treatment	Injury requiring treatment by medical practitioner	Major injury / hospitalization	Single death and/or multiple major injuries	Multiple deaths
Information	Compromise of information otherwise available in the public domain.	Minor compromise of information sensitive to internal or sub-unit interests.	Compromise of information sensitive to this organisation operations.	Compromise of information sensitive to organisational interests.	Compromise of information with significant ongoing impact.
Property & Equipment	Minor damage or vandalism to asset.	Minor damage or loss of <5% of total assets	Damage or loss of <20% of total assets	Extensive damage or loss <50% of total assets	Destruction or complete loss of >50% of assets
Reputation	Local mention only. Quickly forgotten. Freedom to operate unaffected. Self-improvement review required	Scrutiny by Executive, internal committees or internal audit to prevent escalation Short term local media concern. Some impact on local level activities	Persistent national concern. Scrutiny required by external agencies. Long term 'brand' impact.	Persistent intense national public, political and media scrutiny. Long term 'brand' impact. Major operations severely restricted.	International concern, Governmental Inquiry or sustained adverse national/international media. 'Brand' significantly affects organisational abilities.
Financial	1% of Project or Organisational Annual Budget	2-5% of Project or Organisational Annual Budget	5-10 % of Project or Organisational Annual Budget	> 10% Project or Organisational Annual Budget	> 30% of Project or Organisational Annual Budget
Capability	Minimal impact on non-core business operations. The impact can be dealt with by routine operations.	Some impact on business areas in terms of delays, systems quality but able to be dealt with at operational level	Impact on the organisation resulting in reduced performance such that targets are not met. Organisations existence is not threatened, but could be subject to significant review or changed ways of	Breakdown of key activities leading to reduction in performance (eg. service delays, revenue loss, client dissatisfaction, legislative breaches). Survival of the project/activity/organisation is threatened	Critical failure(s) preventing core activities from being performed. The impact threatens the survival of the project or the organisation itself.

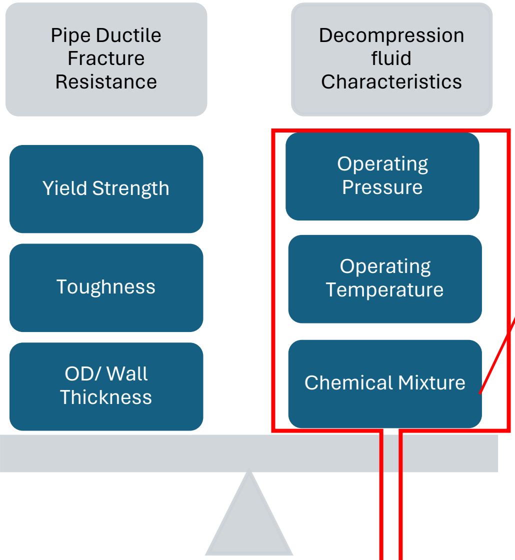
Likelihood	Qualitative Likelihood	Quantitative Likelihood		Insignificant	Negligible	Moderate	Extensive	Significant
↑	Is expected to occur in most circumstances	Has occurred on an annual basis in this organisation in the past or circumstances are in train that will cause it to happen	Almost Certain	6	7	8	9	10
↑	Will probably occur in most circumstances	Has occurred in the last few years in this organisation or has occurred recently in other similar organisations or circumstances have occurred that will cause it to happen in the next few years	Likely	5	6	7	8	9
↑	Might occur at some time	Has occurred at least once in the history of this organisation or is considered to have a 5% chance of occurring in the next	Possible	4	5	6	7	8
↑	Could occur at some time	Has never occurred in this organisation but has occurred infrequently in other similar organisations or is considered to have a 1% chance of occurring in the next	Unlikely	3	4	5	6	7
↑	May occur only in exceptional circumstances	Is possible but has not occurred to date in any similar organisation and is considered to have very much less than a 1% chance of	Rare	2	3	4	5	6

Ductile Fracture Propagation Work (Quick background)



DNV RP F104

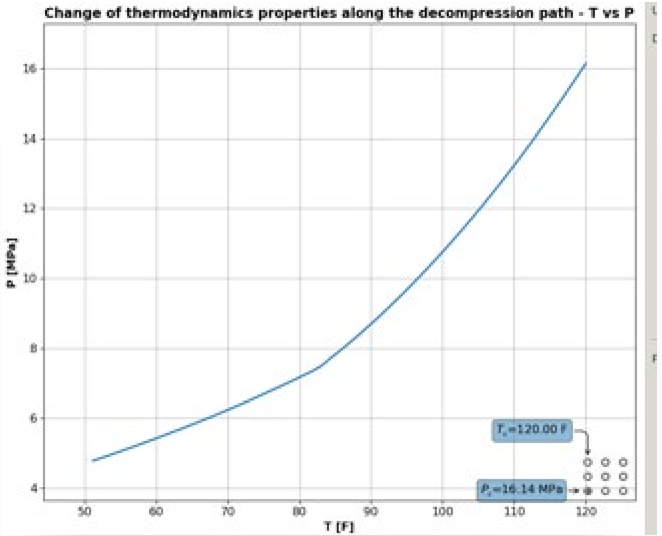
Results from large-scale running ductile fracture tests have been used for new design requirements for crack arrest in CO_2 pipelines.

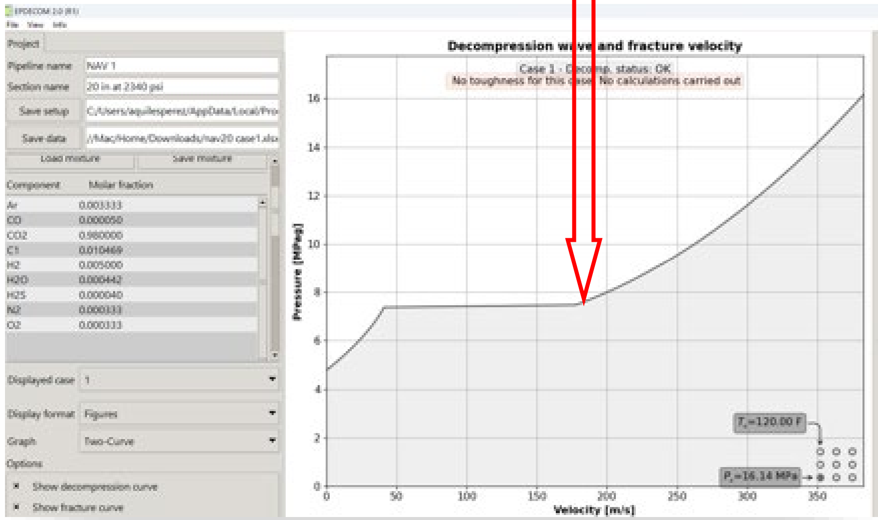


Impurities with higher molecular mass than CO_2 tend to lower the saturation pressure whereas, impurities with lower molecular mass tend to have an opposite effect.

For higher operating pressures, the corresponding effect of mixtures is not as significant.

Reducing the operating temperature also reduces the saturation pressure; however, considerations regarding **water drop out and corrosion issues** need to be considered when evaluating a lower operating temperature.





Alternative Fracture Control Methods

Crack arrestor

Figure 12. Leading Edge of Side B Clock Spring Arrester After Test 6-1.

Figure 4-21: Western Specialties Ultra-Wrap A and B-side repair overview post-test

- Crack arrestors or system components that could act as crack arrestors.
- Valve settings, bends, etc., are natural obstructions that can terminate a propagating crack.
- Composite crack arrestors could be part of a field joint installation process for CO_2 pipelines by providing additional hoop constraints to the pipe wall.
- Composite crack arrestor design requirements must be further validated to obtain regulatory approval – especially for dense-phase CO2.
- Field joint specifications are being developed to include composite crack arrestor technology during installation.

INTEGRITY MANAGEMENT PROGRAM
PIPELINE CO_2 TRANSPORT

Industry Type
- Direct Air
- Point Capture

Integrity program

- **Operating Risk** – Can we maintain safe operating parameters (pressure temperature, flow rate?)
- **Composition Risk -** Can we maintain impurity and water content within a safe margin?
- **Upset Conditions -** Can we maintain integrity during transient conditions (blowdown/ controlled decompression)?

Mitigation program

Mitigation of Operating Risk
-Internal Coatings?
-Crack Arrestors?
-CRAs

Mitigation of Composition Risk
-Chemical Inhibitors?
-??

Mitigation of Upset Conditions
-Material Selection
-Valve Selection
-Welding consumables

Monitoring program

- Monitoring of Operating Risk?
- Monitoring of Composition Risk ?
- Monitoring of Upset Conditions?

Current Gaps

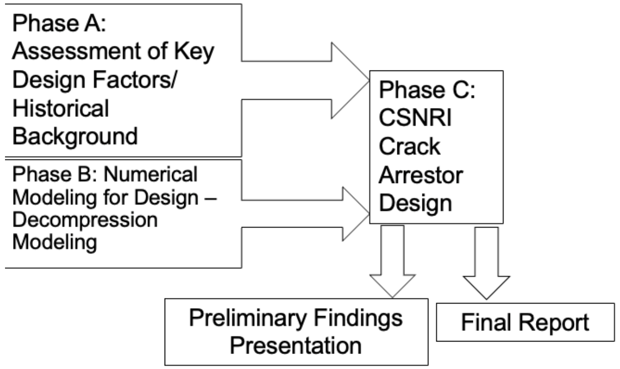
- EOS does not account for all potential mixtures from the various capture sources.
  - The EOS allows us to estimate the energy required to arrest a crack-saturation pressure.
  - Some EOS might be under or over-conservative in some scenarios.
  - An initial crack arrestor design methodology applicable to the CO_2 gas phase has been proposed. Validation needs to be performed.
  - An approved methodology and procedure for dense phase CO_2 crack arrestors has yet to be developed– part of FJC installation.
  - Repeatability and consistency during the manufacturing process are essential.

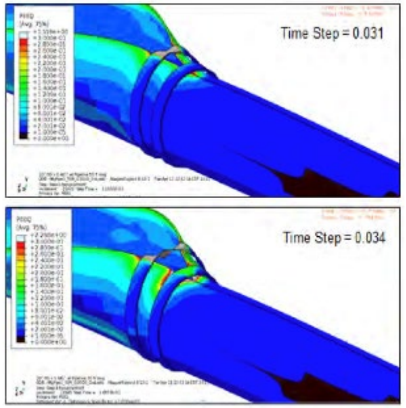
Role of composite Crack Arrestors on CO_2 Transport

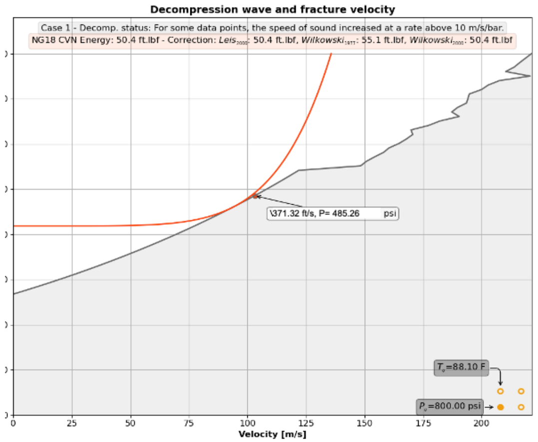
- It can be considered an added safety consideration, especially as part of the operation management analysis of dense-phase CO2 pipelines.
- It is necessary to evaluate and mitigate potentially hazardous conditions and consider whether to use crack arrestors depending on the class location type, as stated in ISO 136232.

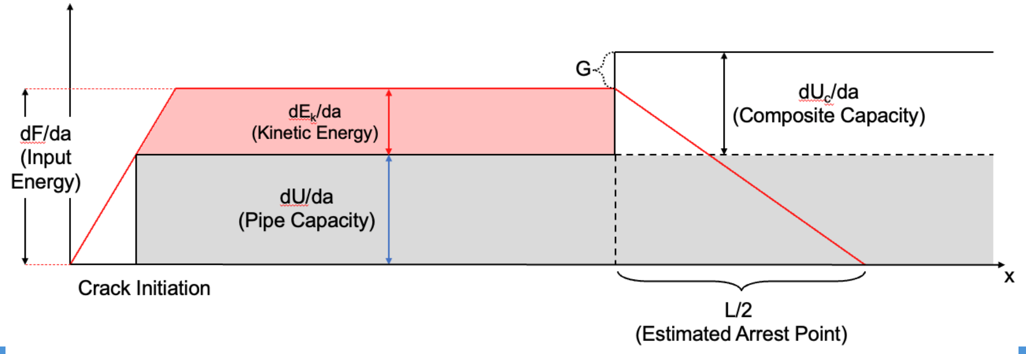
Crack Arrestors – Latest Work

- A methodology for composite crack arrestors has been developed and its promising technology to enhance safety of CO_2 pipelines.









There is plenty of Ongoing Initiatives

- API: SC5-TGLP-WI 4258: CO2 Pipelines
- DNV RP F104
- ISO 27913 – should be re-issued soon?

Summary of Material Concerns in CCUS Operations

- General corrosion allowances for new pipe steels in high-purity CO_2 environments
- Effect of impurities on corrosive liquid phase dropout
- Effect of phase separation on material resistance to fracture propagation.
- Corrosion mechanism evolution (uniform corrosion - pitting - crack initiation)
- Effects of corrosion on design allowances, decompression modeling input
- Ductile to brittle transition temperature and ductile fracture propagation.
- CO_2 transport is moving at a very rapid pace, with fracture control and corrosion mitigation being at the forefront of the technical challenges.

Where do we go from here?

- **Consistency and repeatability during the manufacturing process to ensure the pipe material can transport dense-phase CO2.**
- Create a risk classification (I, II, III, IV, V) of CO_2 with impurities based on capture locations such as ethanol plants, refineries, steel production, etc.
- Full-scale testing – based on risks:
  - Burst test.
  - Flow loop test.
  - Shock tube test.
- Composite crack arrestors for dense phase CO_2.
- Develop a facility (government) funded for testing and qualification of pipeline equipment for CO_2 transport.
- Other ideas?

Thank you!