Simulation of a full-scale CO$_2$ fracture propagation test

Stéphane Dumoulin, Gaute Gruben, Morten Hammer, Svend Tollak Munkejord
SINTEF, Trondheim, Norway
10th Trondheim CCS Conference, 2019-06-19
Outline

• Background
• Experimental
• FE-CFD model
• Results
• Conclusions
• Further work
Background

• CCS is one of the necessary measures to reduce CO$_2$ emissions

• Important to design and operate CO$_2$-transport systems in safe and economical way

• Running-ductile fracture (RDF) may be triggered e.g. by corrosion or third-party damage to pipeline

• Governed by ‘race’ between decompression wave in fluid inside the pipe, and fracture-propagation velocity
  – If depressurization wave faster, pressure at fracture tip will decrease and RDF will arrest
  – Otherwise RDF may continue for long distances, with economical and human loss
Background

5-10 times more energy stored in dense phase CO$_2$ than natural gas

→ Challenging for existing design methods

Methane


CO$_2$

Background

- Typically higher pressure at the crack-tip
- Higher pressure downstream the crack-tip
Background

- Two-Curve Method + CO₂ = Uncertainties
- Need full-scale testing
- Valid only in restricted domain!
- Better understanding of the phenomenon is needed!
Background

**SINTEF coupled FE-CFD code**

- Developed over several years by an interdisciplinary team
- Includes more physics than analytical solutions
- A validated code can:
  - Be applied as a design tool
  - Give insight into RDF problem
  - Reduce uncertainties in traditional design methods

Experimental

**Full scale tests presented at IPC 2016***

- 24"/19.1 mm telescopic set-up, 7 sections + reservoirs
- CO₂ mixture (N₂, CH₄, H₂):
  - 150 barg / 15 °C
  - Saturation pressure 89 barg

* A. Cosham, D. G. Jones, K. Armstrong, D. Allason, J. Barnett
IPC2016-64456 Analysis of a dense phase carbon dioxide full-scale fracture propagation test in 24 inch diameter pipe
FE-CFD code

- LS-DYNA FEA framework
- In-house CFD solver (user load sub.)
- Structure: Pipe, shell elements
- BC: Backfill, SPH particles
- Loading: Escaping CO₂, 1D Eulerian grid
FE-CFD model

Geometry, IC and BC

Symmetry in set-up and results

→ Model East direction only
FE-CFD model

Steel material

- Work hardening curves estimated from $R_{p02}$ and $R_m$
- Fracture parameter determined from FEA of Charpy tests

A. Liessem et al. (2007) ISOPE
**FE-CFD model**

**Backfill material**
- Backfill: on-site boulder clay, no data
  - Apply data for clay found in literature
  - Mohr-Coulomb model

![Mohr-Coulomb model diagram](image)
FE-CFD model

Loading with CO$_2$

- Peng-Robinson EOS, saturation pressure 83.4 barg
Results

Simulation of full-scale test

COOLTRANS Full-Scale

Time - 0
Results

Simulation of full-scale test

[Graph showing crack speed and pressure over crack position]
Results

Simulation of full-scale test
Conclusions

• Good agreement between simulation and experiment, but more validation work needed
• The simulation agrees well with the experiment in the low and medium toughness sections
• A slower deceleration in crack velocity in the high-toughness section
• Using the DWTT test in fracture calibration might increase the accuracy in the high-toughness section
• >50% energy dissipated in the backfill, <3% along the crack path
Further work

- Objective: Improve accuracy and computational efficiency for calculation of thermophysical properties of mixtures
- Hybrid interpolation scheme developed
- Needs to be implemented in coupled model and tested
- Assess sensitivity of coupled model/RDF to EOS
Thank you for your attention

Questions?

Acknowledgement: This publication has been produced with support from the NCCS Centre, performed under the Norwegian research programme Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Aker Solutions, Ansaldo Energia, CoorsTek Membrane Sciences, EMGS, Equinor, Gassco, Krohne, Larvik Shipping, Norcem, Norwegian Oil and Gas, Quad Geometrics, Shell, Total, Vår Energi and the Research Council of Norway (257579)
FE-CFD model

Steel material

- Scaling of fracture parameter for larger shell elements
FE-CFD model

Steel material

• Scaling of fracture parameter for larger shell elements
Results

Energy dissipation

Energy distribution, full-scale sim.