

Monitoring Breakdown Pressure Under Triaxial Loads with Cryogenic Fluids

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Outline

- Problem introduction
- Background
- Plan and experimental
- Preliminary results
- Conclusions and future work

Waterless/Cryogenic Shale Fracturing

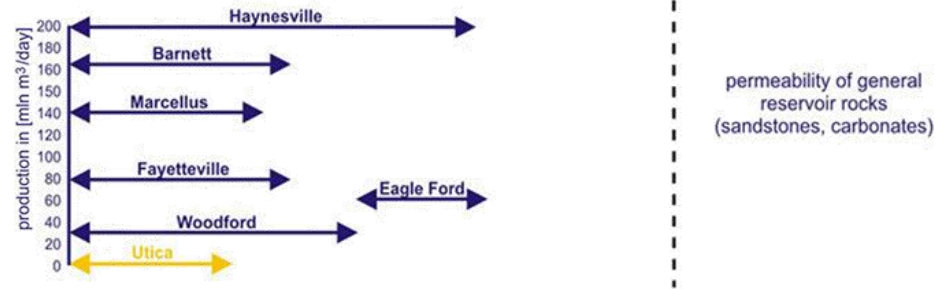
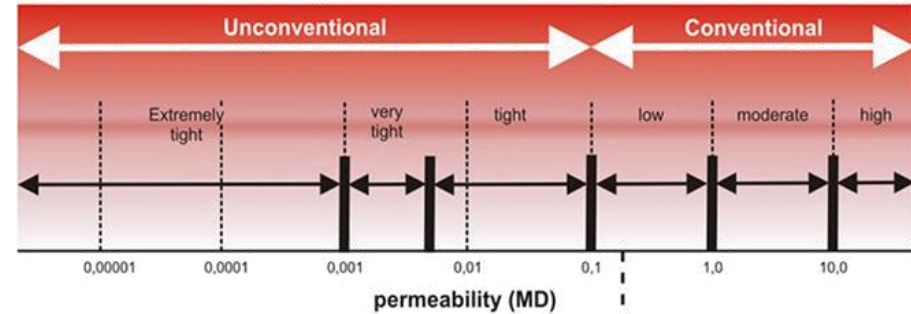
Disadvantages of aqueous fracturing:

- Liquid trapping.
- Water supply and disposal.
- Sensitive shale minerals:
 - › Smectite: swelling.
 - › Illite and Kaolinite: dispersion.



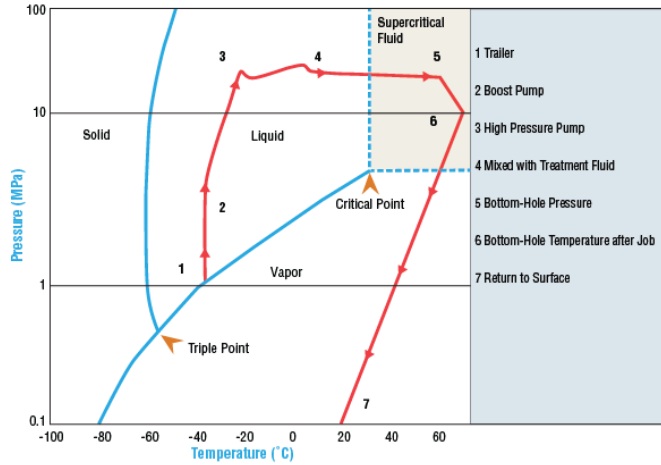
Advantages of cryogenic fracturing:

- Immediate flowback.
- No formation damage.
- Complex fractures.
- Thermal stress.



Six US shale basins producing in total 88% natural gas in respect of all productive shale formations. Modified after Dyrka, 2014.

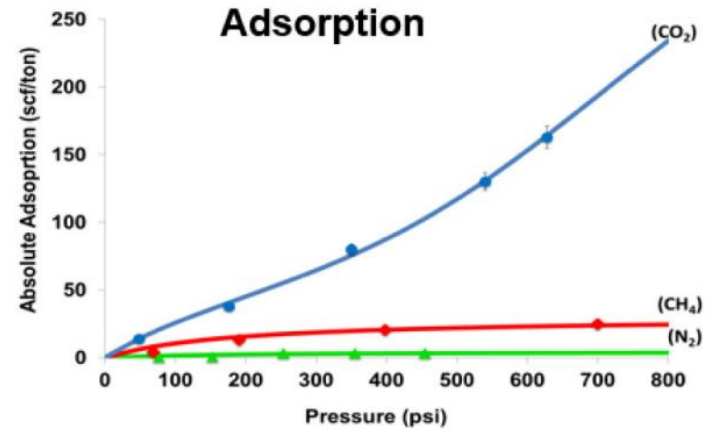
Waterless/Cryogenic Shale Fracturing, cont.



Phase behavior changes for CO₂ during fracturing treatment (Watts, 2014)



Instable CO₂ induced fracture (Bennour et al., 2015)



CO₂ adsorption compared to other gases at different pressures (Aljamaan, 2015)

No full understanding of cryogenic fracturing:

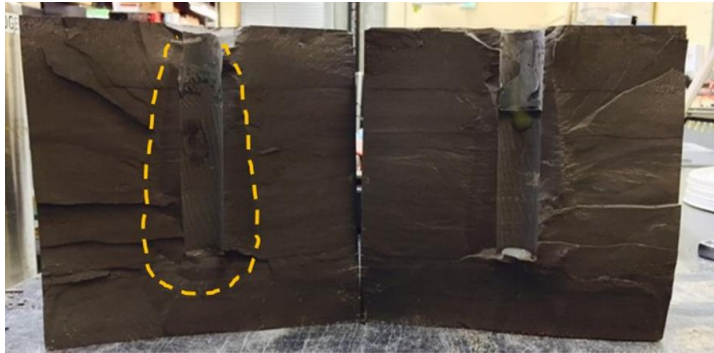
- Phase behavior during fracturing.
- Fracture evolution and rheology.
- Breakdown pressure.
- Fracturing at reservoir conditions: HPHT.
- Carbon Dioxide:
 - › Adsorption.
 - › Supercritical/liquid.

Cryogenic Fracturing Background

Tight sandstone and shale fracturing using liquid N₂ (Wang et al., 2016):

Experiment:

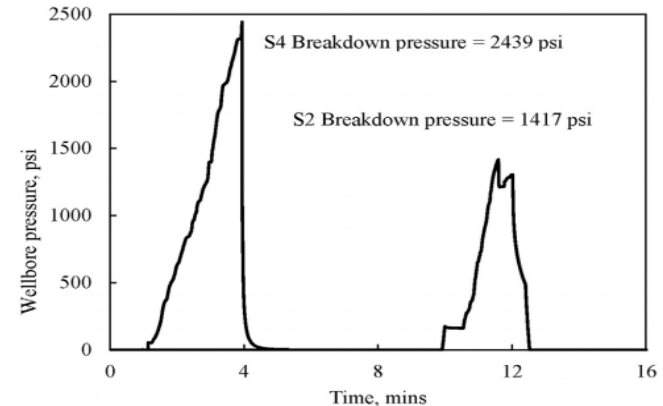
- 17 cm cubic samples.
- L-N₂ injected multiple times before fracturing.
- Triaxial stresses applied.



Fracture face of a fractured sample

Results:

- Permeability decreased as the sample warmed up.
- 42% decrease in breakdown pressure.



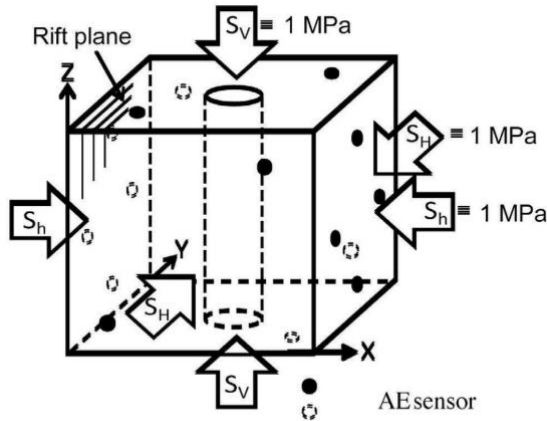
S2 lower breakdown pressure because of multiple N₂ injections prior to fracturing

Cryogenic Fracturing Background

Granite fracturing using L-CO₂ and supercritical CO₂: (Ishida et al., 2012)

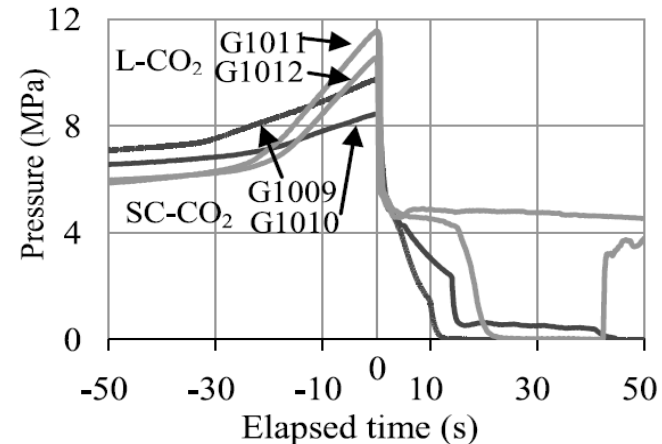
Experiment:

- 8'' cubic samples.
- L-CO₂: 2 samples.
- Supercritical CO₂: 2 samples.
- 1MPa confined pressure.



Results:

- S-CO₂: lower breakdown pressure.
- S-CO₂: wavelike fracture with secondary branches.
- Larger fracture areas than water.



Cryogenic Fracturing Background

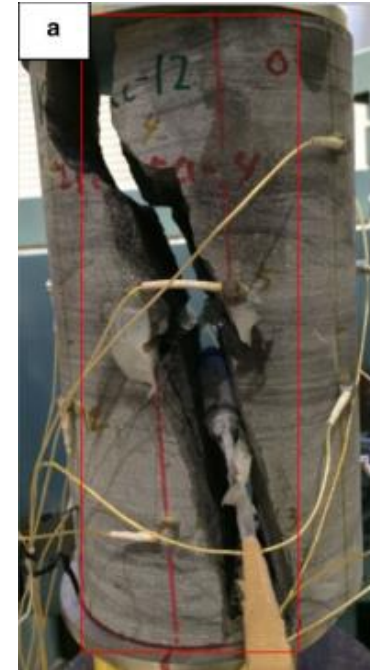
Shale fracturing using L-CO₂ compared to water and oil: (Bennour et al., 2015)

Experiment:

- 6.7" long, 3.35" diameter.
- 11 samples: 4 L-CO₂, 4 water and 3 oil injected.
- Uniaxial load: 0,1 and 3 MPa.

Results of L-CO₂:

- Fracture independency of loading and bedding.
- Tilted vertical fractures: 10-30 degrees.
- Unstable fracture extension.



0 MPa axial loading



3 MPa axial loading

Cryogenic Fracturing Background

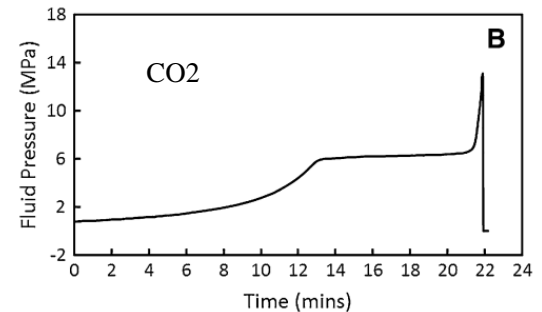
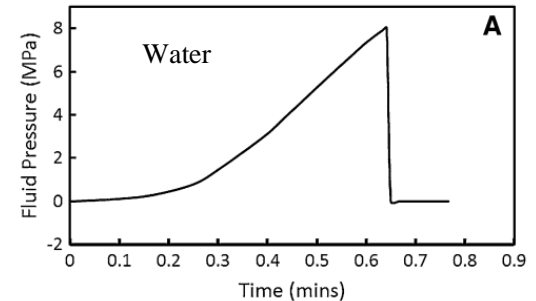
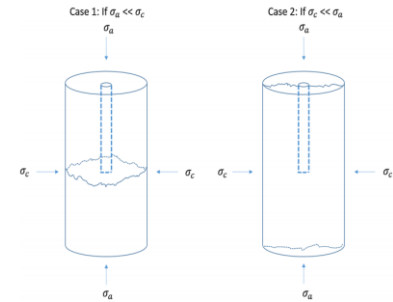
Shale fracturing using G-N₂, G-CO₂ and water: (Xiang et al., 2015)

Experiment:

- 2" * 1" cores.
- Triaxial load different configuration:
- Longitudinal or transverse.

Results of CO₂:

- Highest breakdown pressure
 - › Injection rate 5 times water
- Complex fracturing patterns



Cryogenic Shale Fracturing

Goals:

- Fracture behavior for different fluids.
- Effect of fracturing fluid on breakdown pressure.
- Difference between SC-CO₂ and L-CO₂.
- Impact of confining and axial load on breakdown pressure.

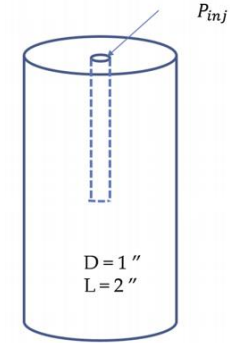
Monitoring experiment:

- CT imaging.
- Axial load.
- Confining pressure.
- Pore pressure.

Research Plans

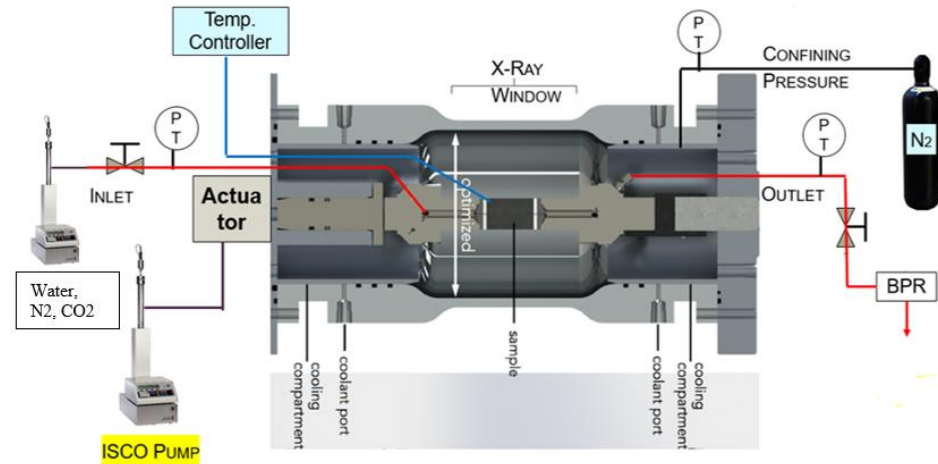
Sample preparation:

- 2” length 1” diameter cores.
- Vertical 1” length 1/8” diameter hole.



Experiment setup:

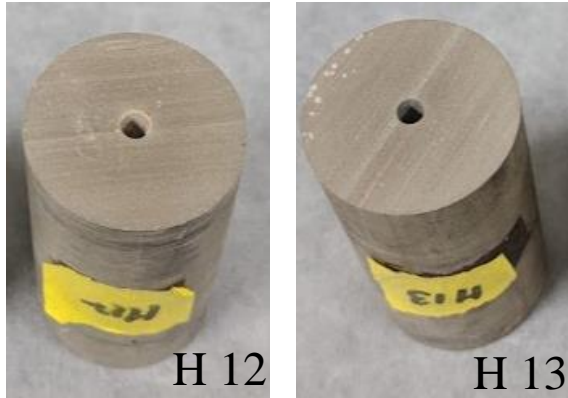
- Main component: Glatz's HPHT apparatus.
- Pressure transducer: PTX 1400.
- Temperature gauge: K-type.
- ISCO pump connected to actuator.
- Temperature control: OMEGA.



Setup schematic

Experimental work

Sample preparation:



Green River shale formation
Depth: 2340 ft
Core dimensions: 1.9" * 1"
Hole dimensions : 0.9" * 1/8"

L-CO₂



H13

Water



H12

SC-CO₂



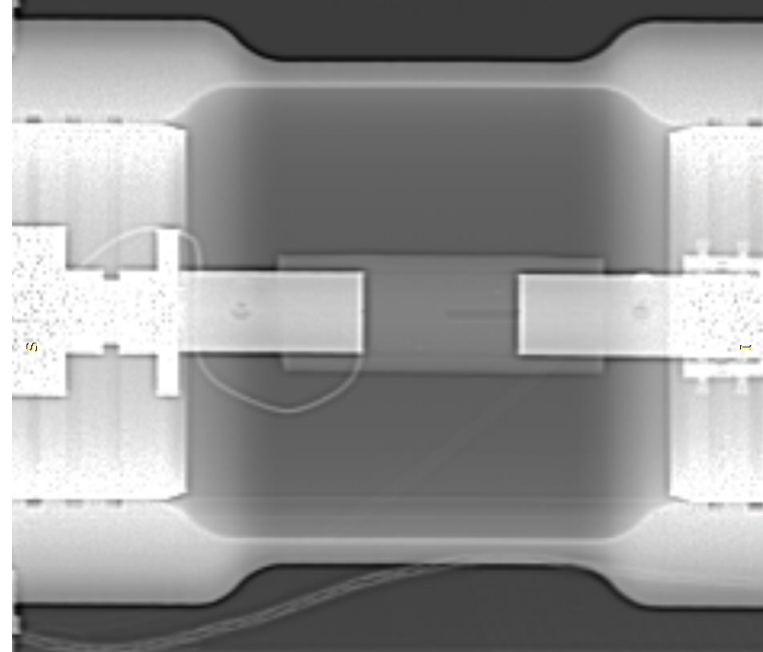
H11

Experimental work

Sample installation:



Core connected to upstream

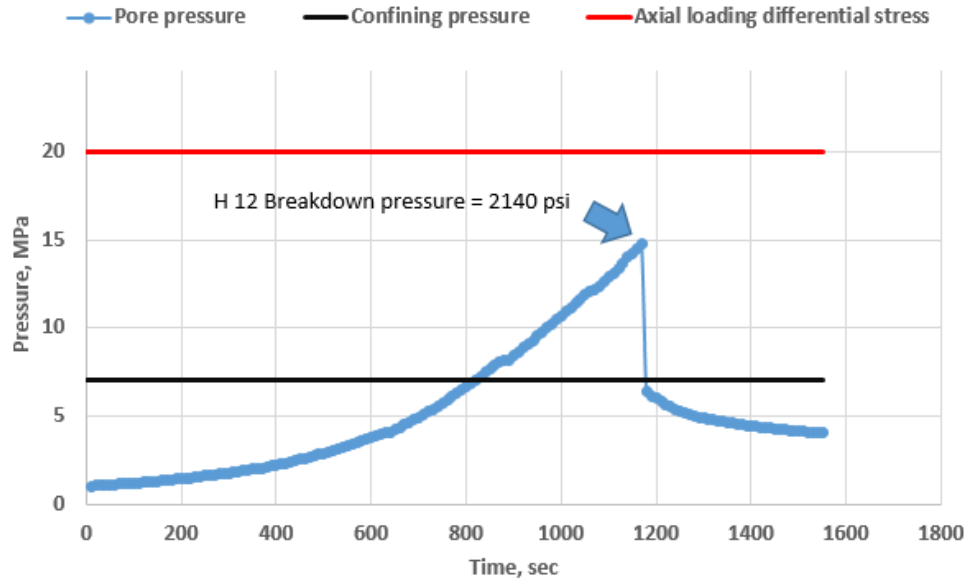


Core inside main component under triaxial load

Preliminary Results

H 12 (Water):

- Breakdown pressure:
 - 2140 psi (experimental)
 - 2300 psi (Xiang et al., 2015)



(Talal and Elliot, not published)



before

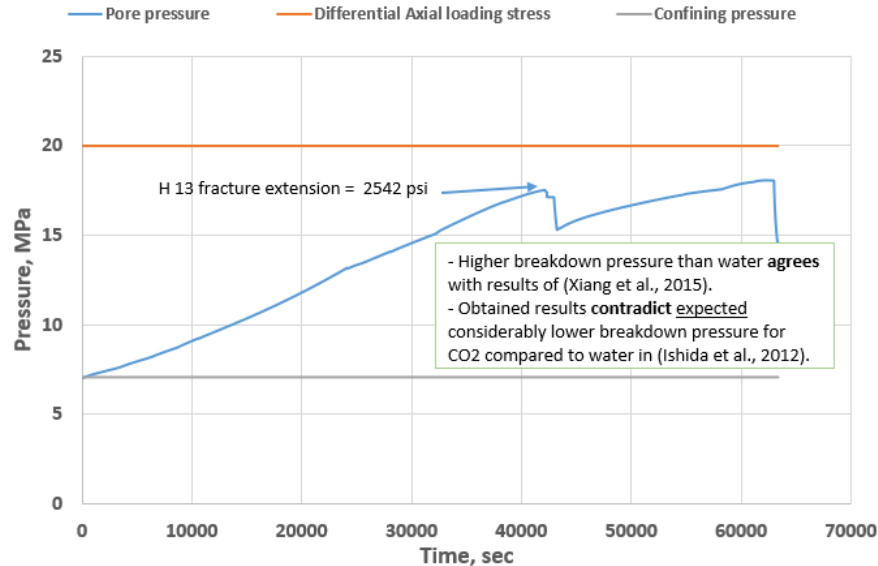
after

Stanford University

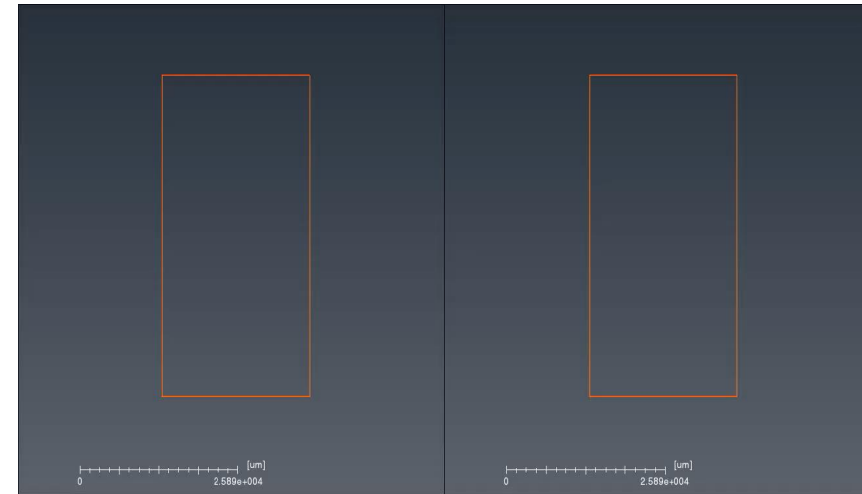
Preliminary Results

H 13 (L-CO₂):

- Fracture extension pressure: 2542 psi (experimental)
- Breakdown pressure: 1993 psi (Xiang et al., 2015)



(Talal and Elliot, not published)



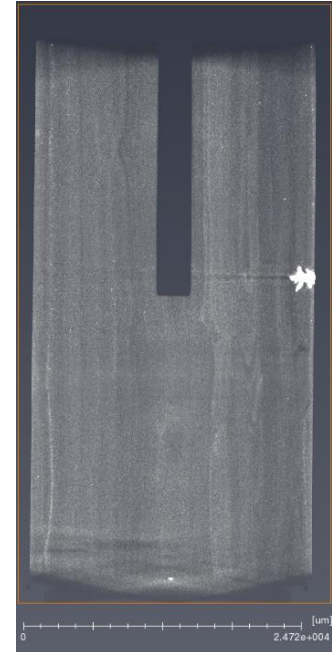
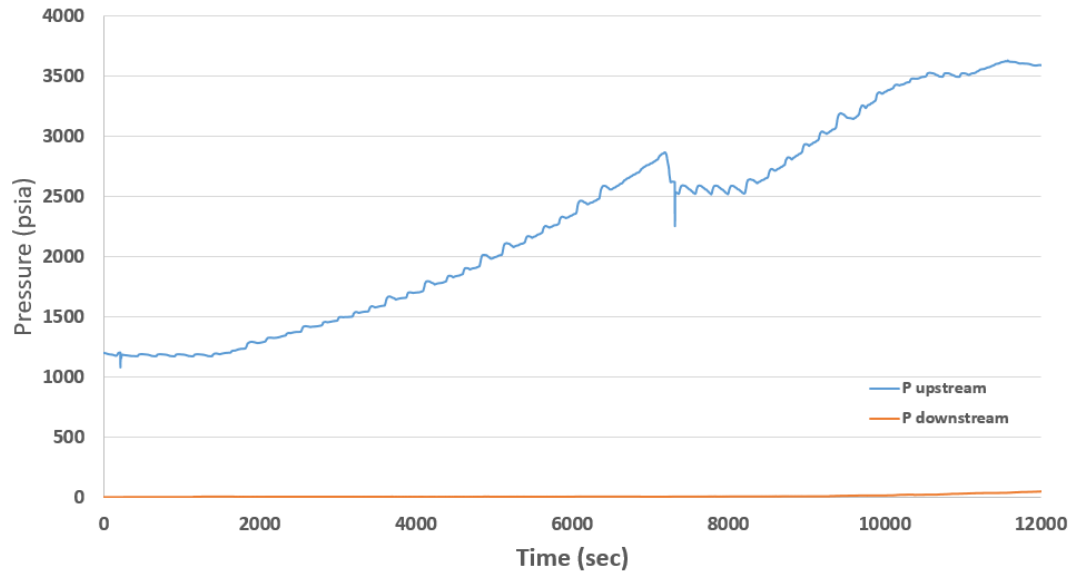
before

after

Preliminary Results

H 11 (SC-CO₂):

- No fracturing up to 3500 psi
- Downstream pressure +230 psi overnight
- Axial loading: 20 MPa → 30 MPa



before

Conclusions:

- Water fracturing resulted in similar results to literature.
- L-CO₂ fracture extension pressure is higher than water breakdown pressure.
- SC-CO₂ breakdown pressure is higher than water.

Lessons learned:

- Teflon-nickel-teflon jacketing minimizes leakage.
- Viton sleeves swell and are not reusable.

Future work:

- Fracturing using N₂.
- Behavior difference between L-CO₂ and SC-CO₂.
- Influence of temperature on fluids behavior during fracturing.
- Impact of triaxial loads on breakdown pressure.

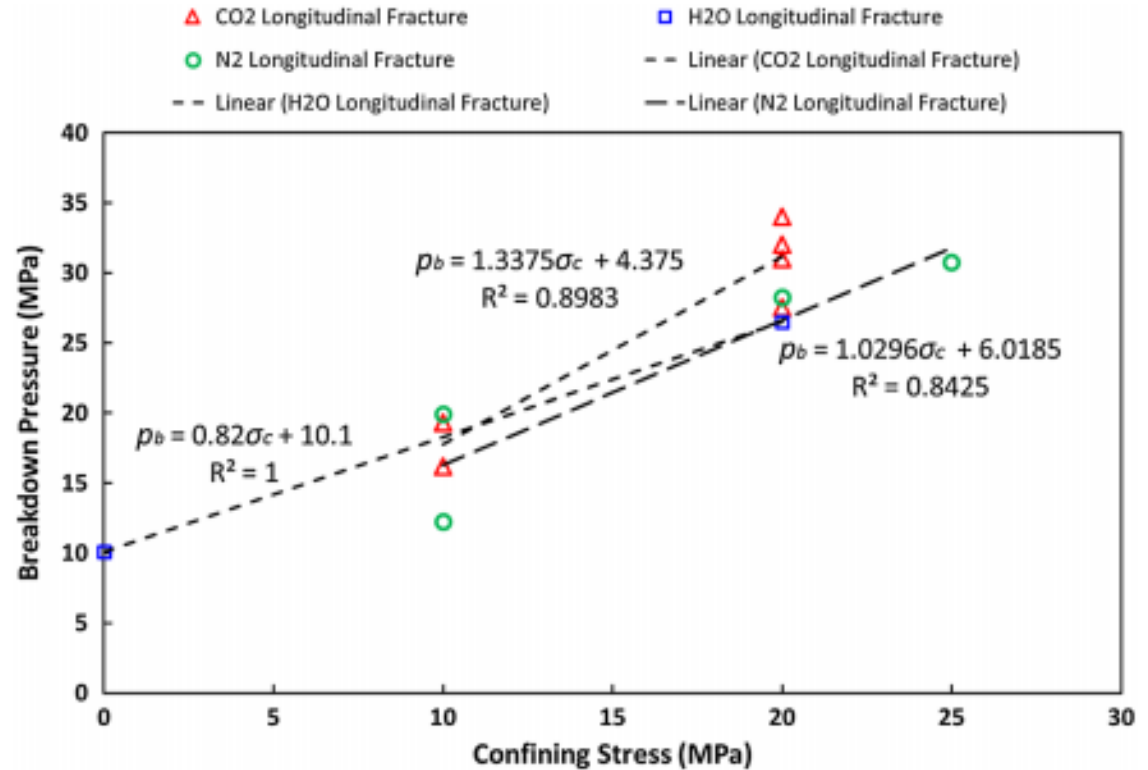
Acknowledgement

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- Saudi Arabian Cultural Mission (SACM)
- SUPRI-A affiliates

Thank You!

Please do not hesitate to ask questions!

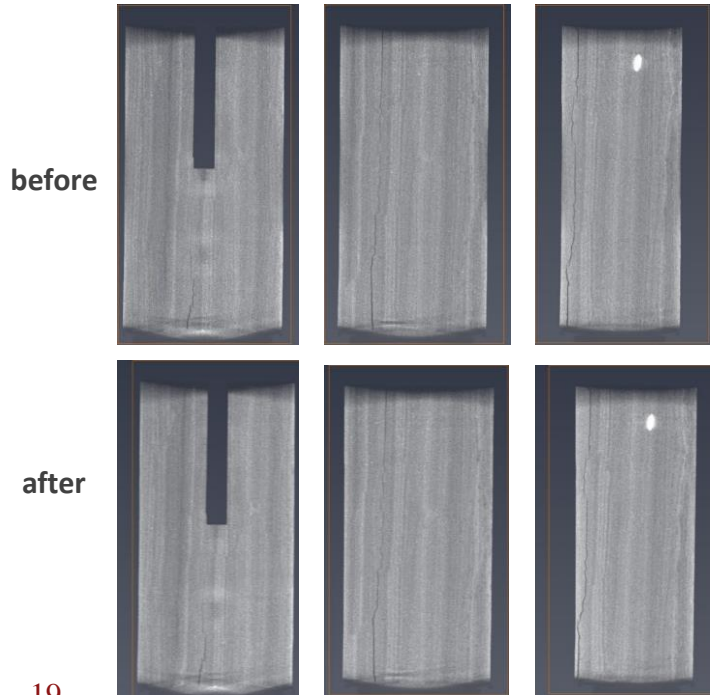
Fig. 7 Breakdown pressure as a function of confining stress (Case 2: longitudinal fracture)



Preliminary Results

H 13 (L-CO₂):

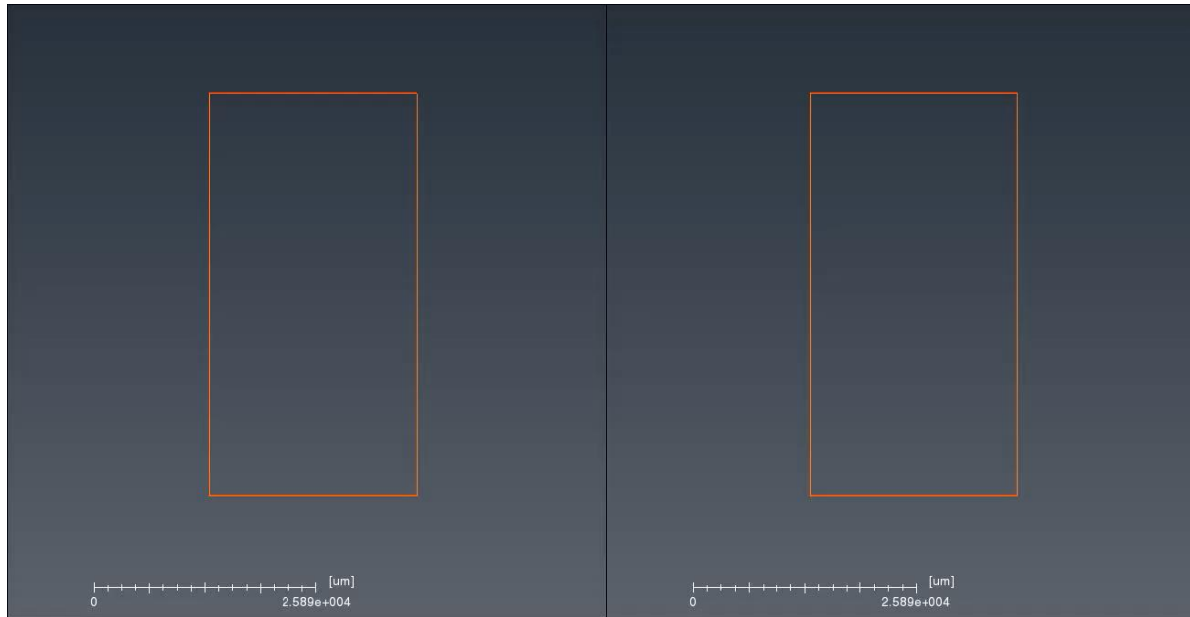
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Preliminary Results

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before

after