Injection Of Flue Gas Improves CO_2 Permeability And Storage Capacity In Coal: A Promising Technology
SPE-210419-MS

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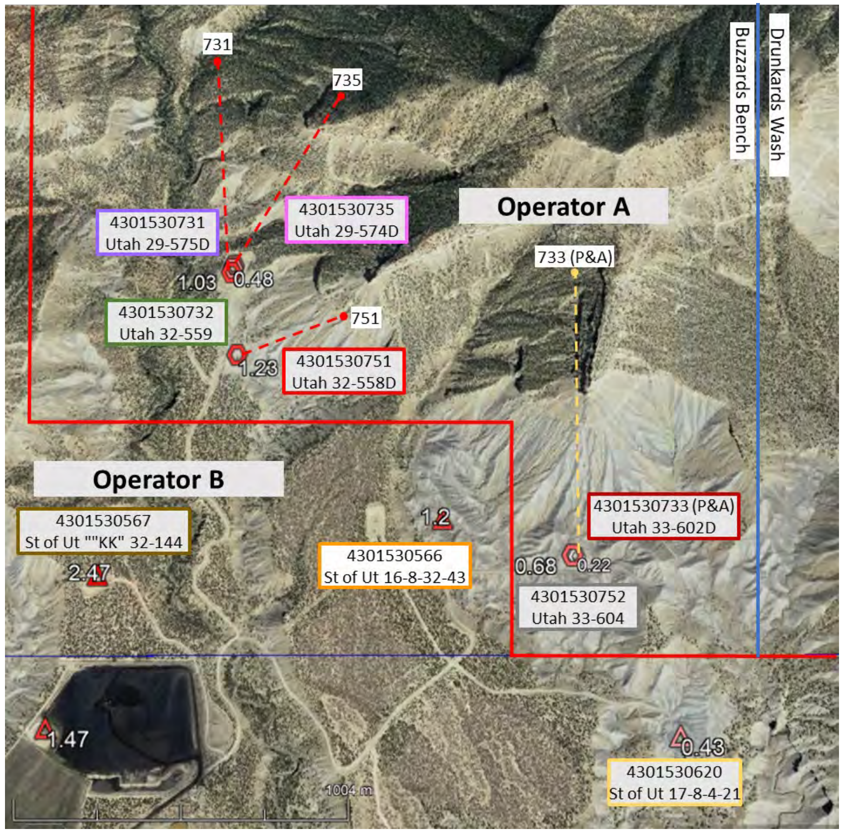
Objective

- Identify a potential site for field testing for injection of flue gas
- Experimental bench-scale results with **flue gas** in **coal** indicate:

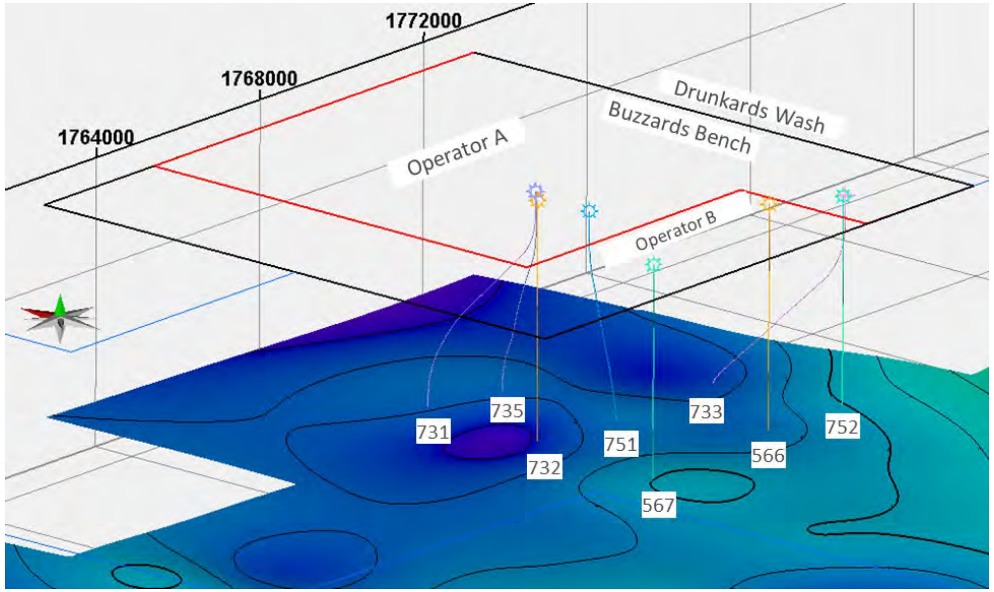
- Positive adsorption of CO_2
- Permeability of the coal doesn’t collapse (Compared to pure CO_2)
- Evaluate the fluid stratification and flow paths of N_2 and CO_2

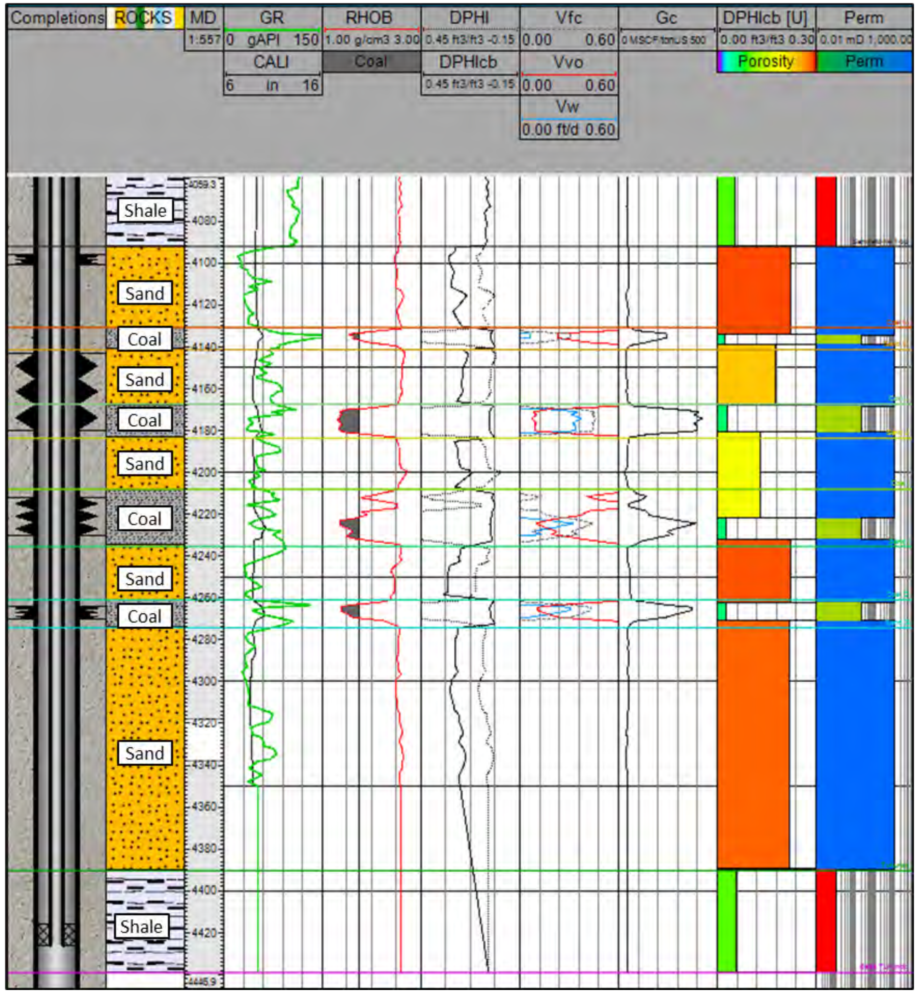
Background: CBM Reservoir, Buzzard Bench Field, Utah



- Buzzard bench field operating since 1970's
- CBM operations ongoing
  - Depth: 3500 ft
  - Temp: 38 C
- Feasibility for CO_2 storage
- Project sponsored by Rocky Mountain Power

Background: CBM Reservoir, Buzzard Bench Field, Utah



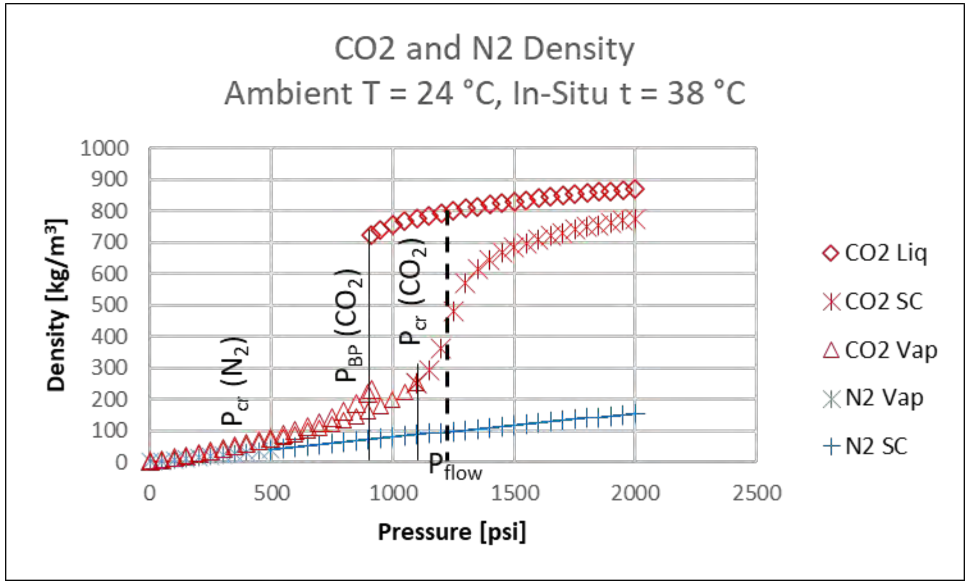


- 4 Coal seams considered in this project

- Density and GR logs used for characterization

- Proximity and Ultimate adsorption test quantifying the adsorbed CO_2.

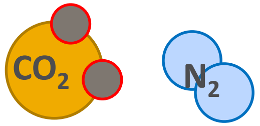
Thermodynamics: CO_2 Density and Fluid Stratification



Vega-Ortiz (2022).

At atmospheric conditions P = 14 psi, T = 24 °C

CO_2 and N_2 have similar DENSITY



Buoyant Forces = Viscous Forces

At Reservoir Conditions: P = 1200 psi, T = 38 °C

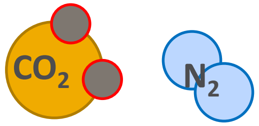
CO_2 ~ 800 km/m^3

N_2 ~ 100 kg/m^3

Density difference is considerable large

Buoyant Forces >> Viscous Forces

:

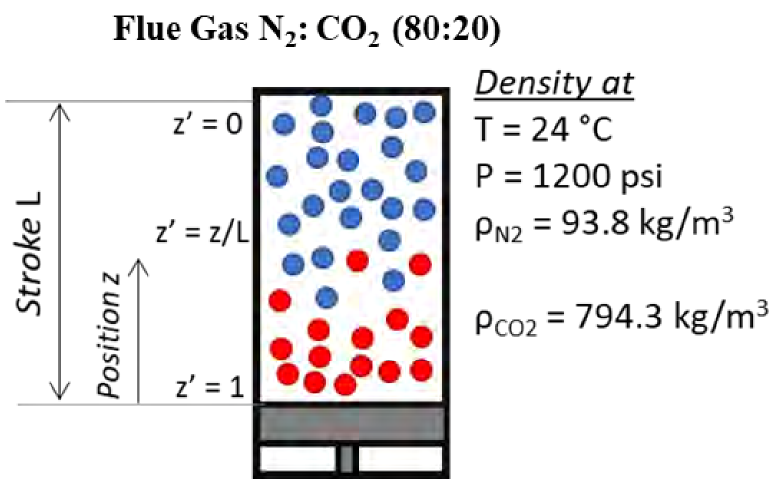


Flue Gas: CO_2-N_2 composition and Fluid Stratification

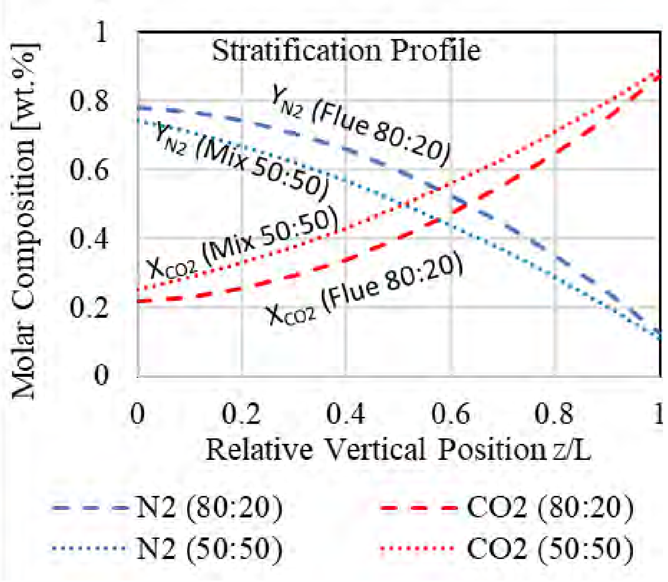
Typical composition of flue gas

N_2:	85%
CO_2:	14%
NOx:	~ ppm
SOx:	~ ppm
H_2S:	~ ppm

*Post-combustion of coal-powered turbine

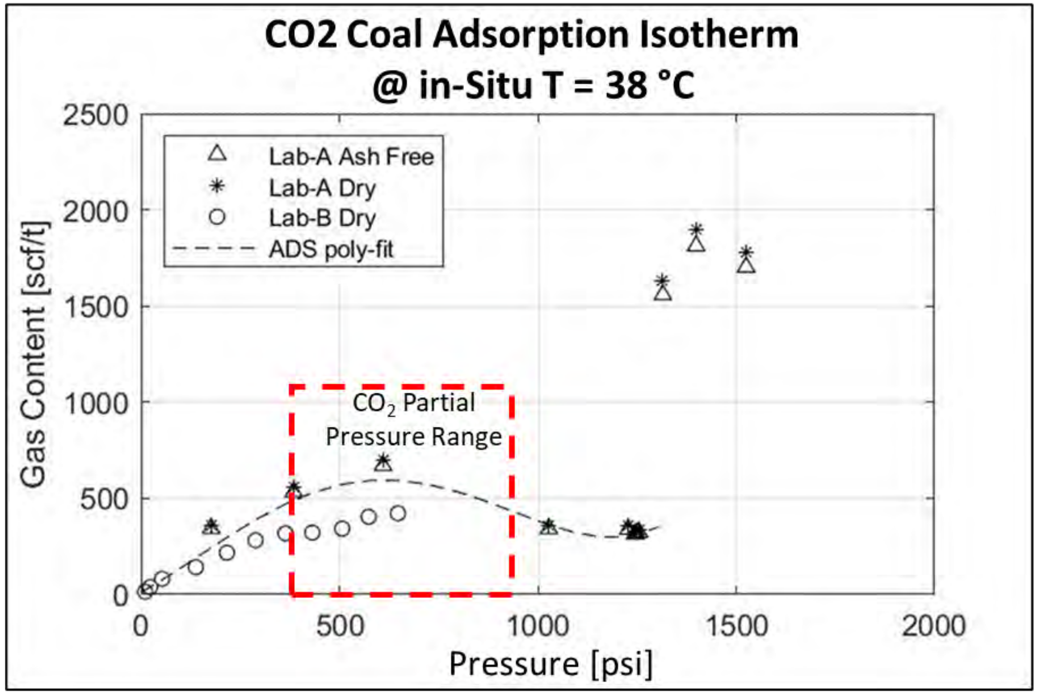


Stratification Profile



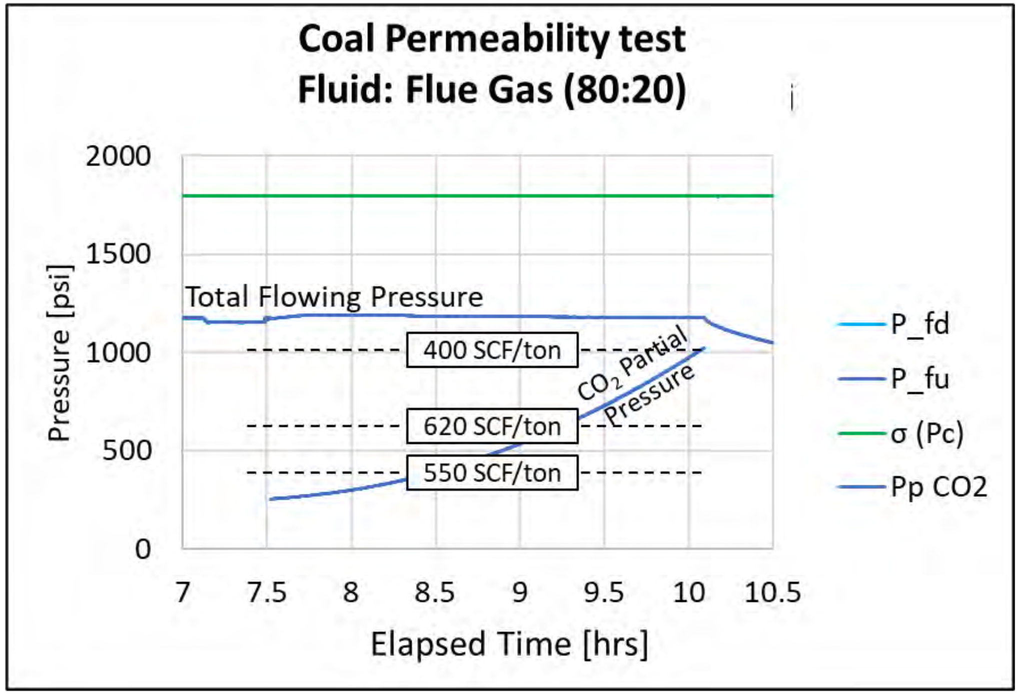
Adsorption of CO_2 in Coal

Buzzard Bench Adsorption Isotherm



Partial pressure for stratified flow

Flowing stratified flow in coal sample



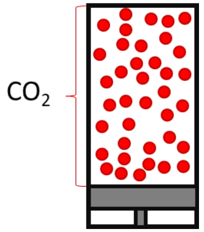
Partial pressure for stratified flow

The total CO_2 adsorption is determined by the PARTIAL PRESSURE. $P_{xi} = x_i.P$

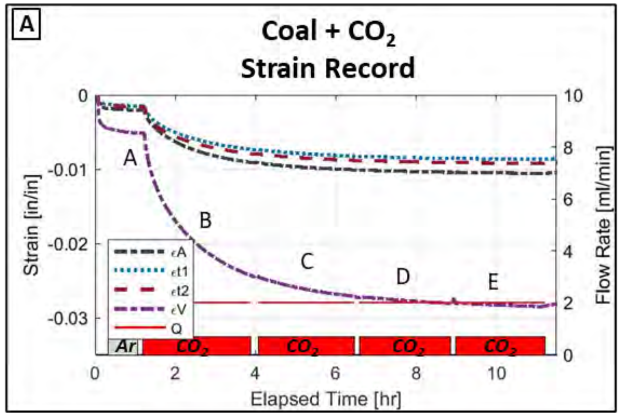
Bench scale Experiments: Flow of pressurized flue gas in coal

Flowing pure CO_2

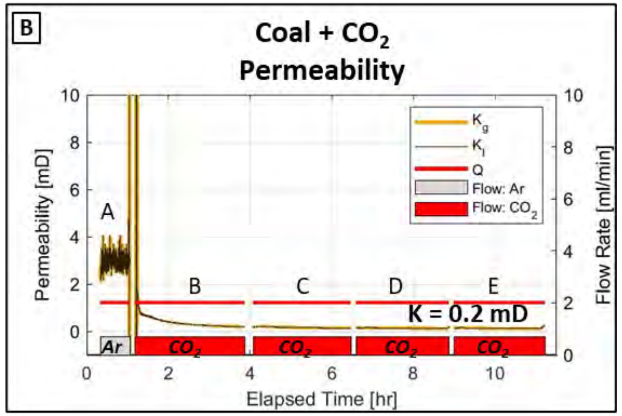
Test 1
CO_2



Pure CO_2



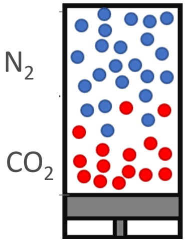
Flue gas mixture CO_2:N_2 20:80

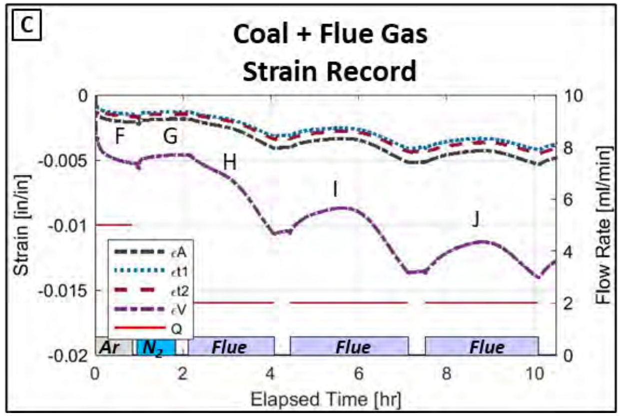


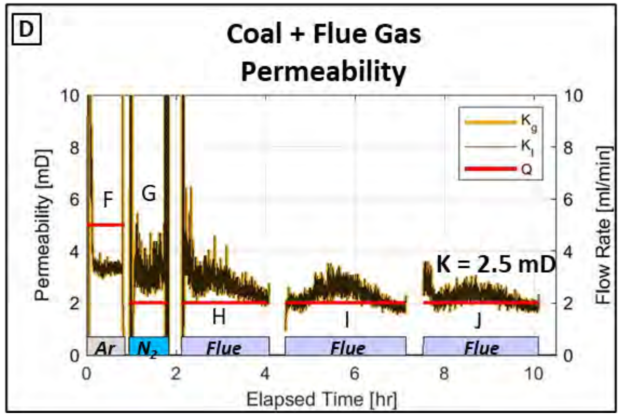
OBSERVATIONS

- Coal swelling upon contact of CO_2
- Cleats and conductive channels closed
- Loss of permeability

Flowing surrogate FLUE GAS CO_2 :N_2





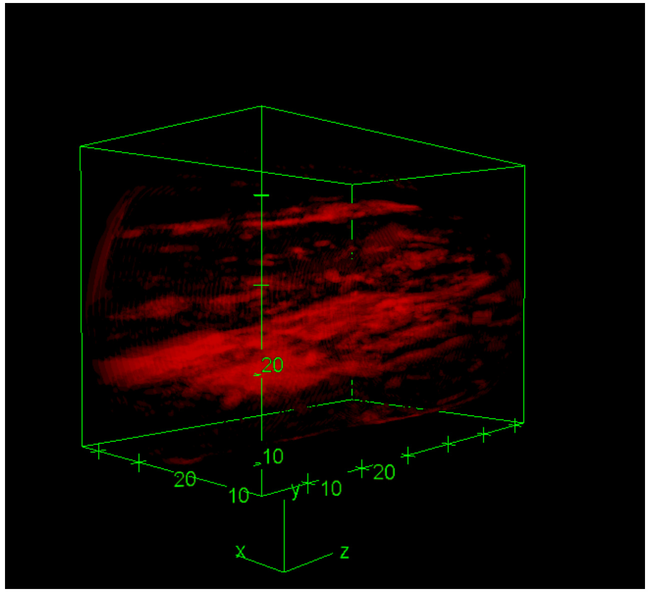


OBSERVATIONS

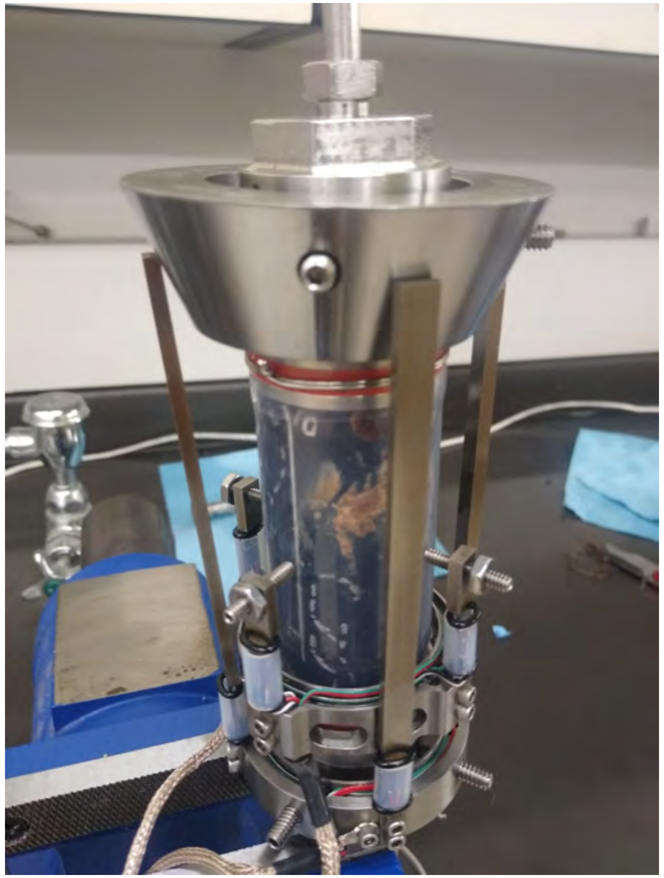
- Coal swelling in cyclic pattern
- Cleats and conductive channels opening and closing
- Permeability PRESERVED

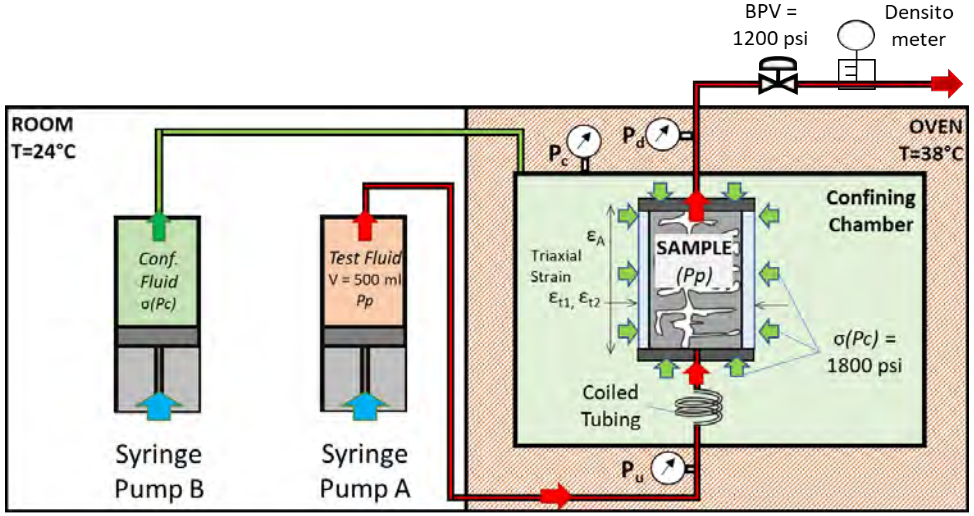
Bench scale Experiments: Characterization

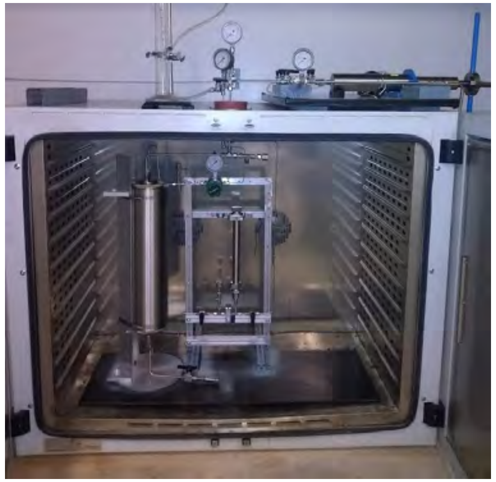
Flow test and poroelatic analysis at in-situ conditions



Coal Cleat Distribution
CT Scanning







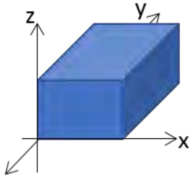
Numerical Simulation

Material Balance Equation

$$-\frac{\partial}{\partial x}(\rho u_x A_x)\Delta_x - \frac{\partial}{\partial y}(\rho u_y A_y)\Delta_y + \frac{m_s(ads)}{\alpha_c} = \frac{V_b}{\alpha_c}\frac{\partial}{\partial x}(\phi(P)\rho)$$

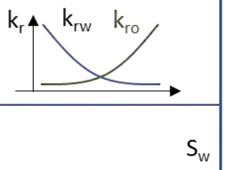
Grid Size

Δx *[ft] - Penetration*
Δy *[ft] - Width*
Δz *[ft] – Vertical Depth*
A_x *[ft²] – Area (YZ)*
A_y *[ft²] – Area (XZ)*
A_z *[ft²] – Area (XY)*
V_b *[ft³] – Block Volume (XYZ)*
Number of Grid Blocks
nx, ny, nz



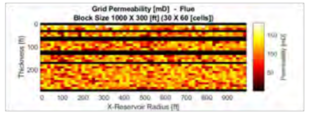
Fluid Properties

μ_o *[cp]* – Oil Viscosity
μ_w *[cp]* – Water Viscosity
Bo [n/a] – Oil Formation Factor
Bw [n/a] – Water Formation Factor
Relative Permeabilities
k_{rw} *[mD]* – Rel Perm Water
k_{ro} *[mD]* – Rel Perm OIl

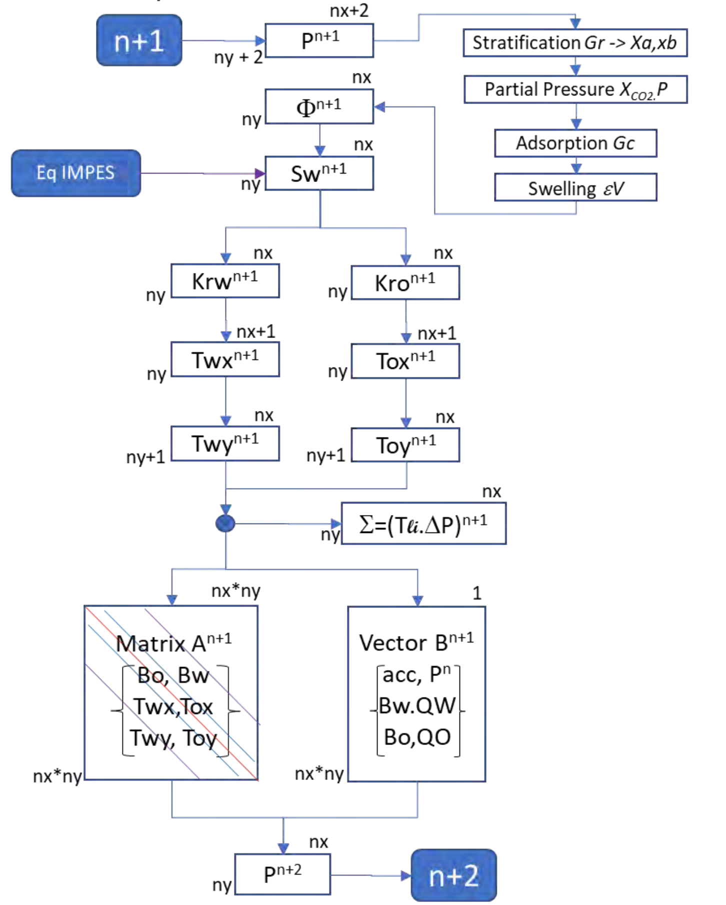


Formation Properties

ϕ_i *[%]* – Porosity
S_w *[%]* – Water Saturation
c_f *[1/psi]* – Rock Compressibility
P_i *[psi]* – Formation Pressure
K [mD] – Permeability (GRID)

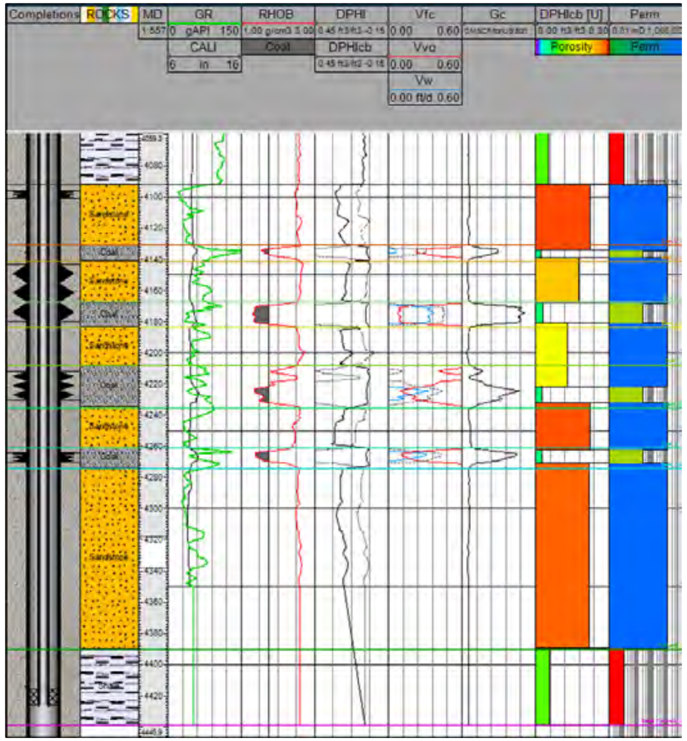


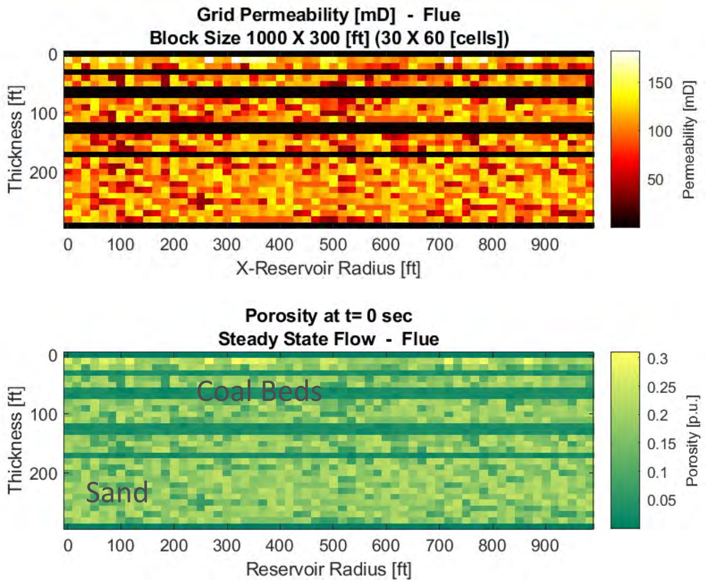
Finite Differential Method
Newton Raphson - IMPES



Initial Conditions

Boundary and Initial Conditions upscaled from numerical model





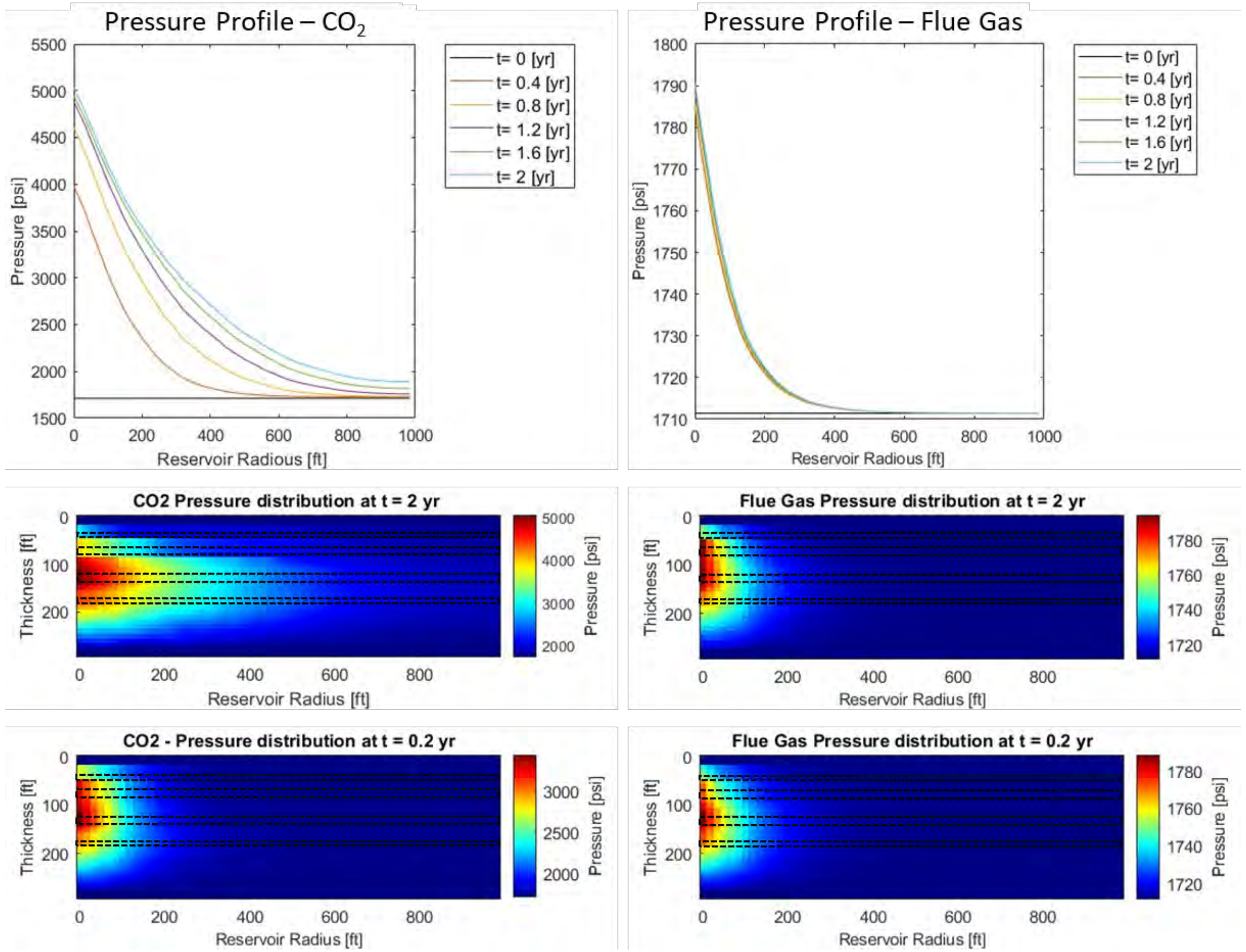
Permeability

Porosity

Simulation Results

Pure CO2 results in a large formation pressure developed after 2 years.

Cleat closure being a limiting factor



FLUE gas results indicate an steady flowing pressure after 2 years.

Cleat closure is inhibited by the presence of N2 (reduces the CO_2 partial pressure)

CO_2 storage is effective

Conclusions

- Flue gas can be injected in Coal (CBM) fields
- Stratified FLUE gas CO_2:N_2 is a mechanism to preserve the PERMEABILITY
- Capture Facilities CAPEX and OPEX are reduced
- Field-scale experiments are due
- Model to be implemented in commercial numerical simulations to handle dynamic phenomenon:
  - Fluid stratification
  - Adsorption
  - Poro-elastic stresses
- Patent application submitted.

Thanks for attending

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Fluid Stratification

5.2 Fluid Properties

Stratification of N_2-CO_2 Mixture: Grashof Number

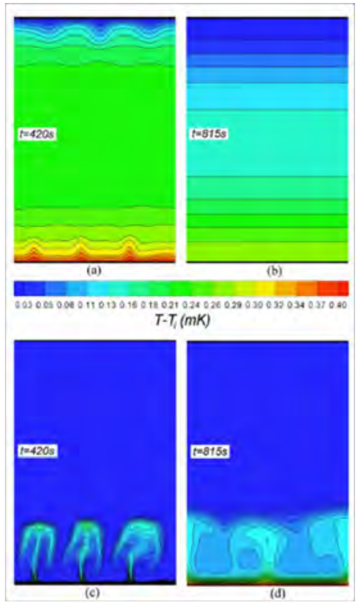
Natural convection
- Driving Force: Density Gradient
- Defines "turbulent" flow after $Gr > 10^7$

$$Gr = \frac{g L_c^2 \rho \Delta \rho}{\mu^2}$$

Ratio between Buoyant to Viscous Forces

Lighter Fluid UP

Denser Fluid DOWN



Example of turbulent flow under density differential from thermal gradient (Accary, et al, 2007)