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Enhanced Oil Recovery

A study of ethane adsorption, desorption and transport in Bakken core using NMR measurements and numerical modelling

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Enhanced Oil Recovery

Presentation Overview

- Study Objectives
- Background
- Equilibrium Experiment
- Degassing Experiment
- Numerical Modelling
- Discussion

Study Objectives

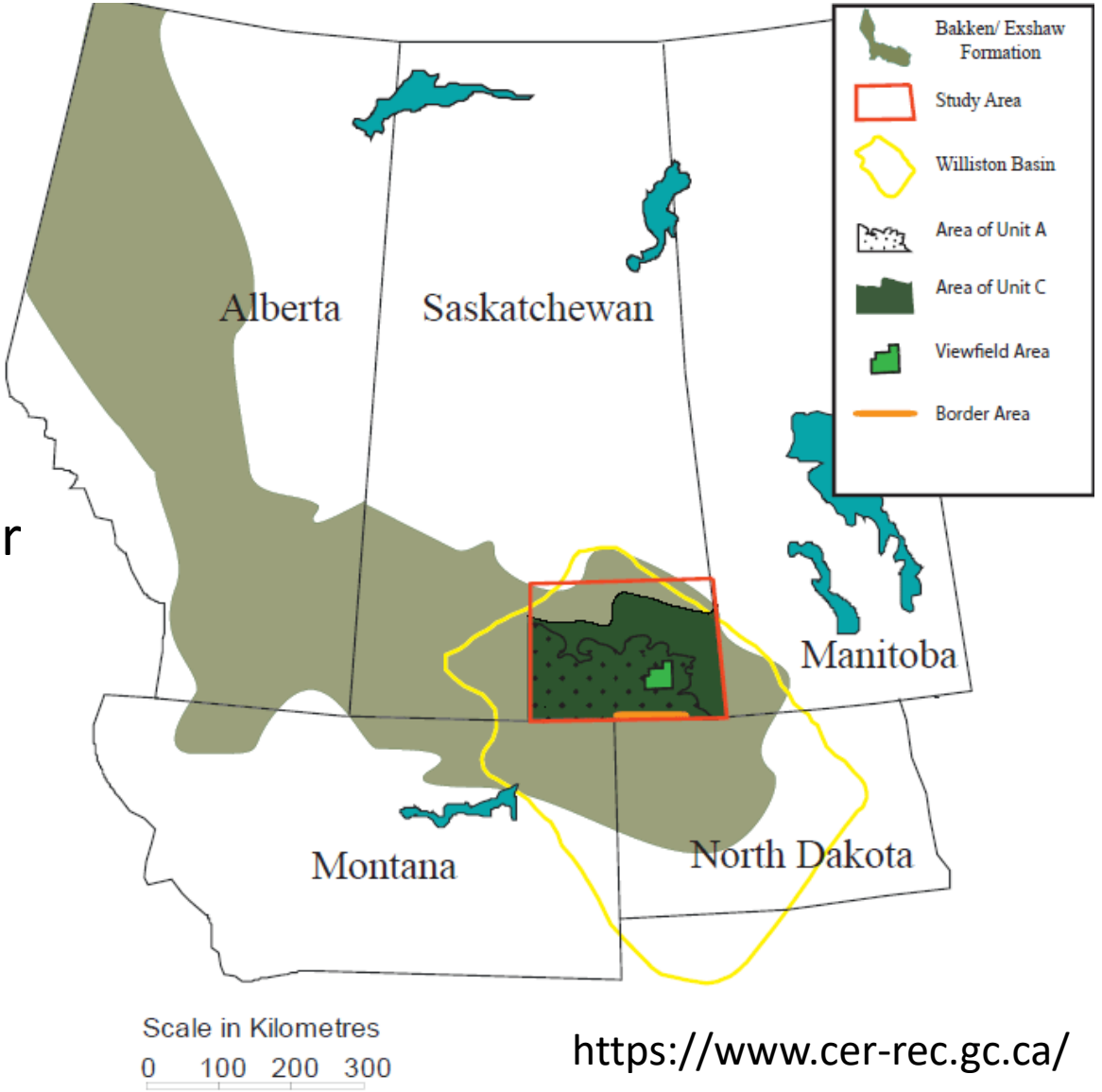
- Build upon a non-destructive, NMR-based adsorption technique, developed for coal bed methane and natural gas reservoirs.
- Objective was to quantify the processes affecting gas movement in tight rock, including advection, diffusion and sorption.

Bakken System

- Deposited in the Upper Devonian.
- Upper and Lower Members are organic-rich shales that are source and cap rocks.
- In Canada, 81.2 billion m^3 (2.9 trillion ft^3) of marketable natural gas.
- Core sample is from Viewfield Area, Upper Member shale.

Core Sample Data

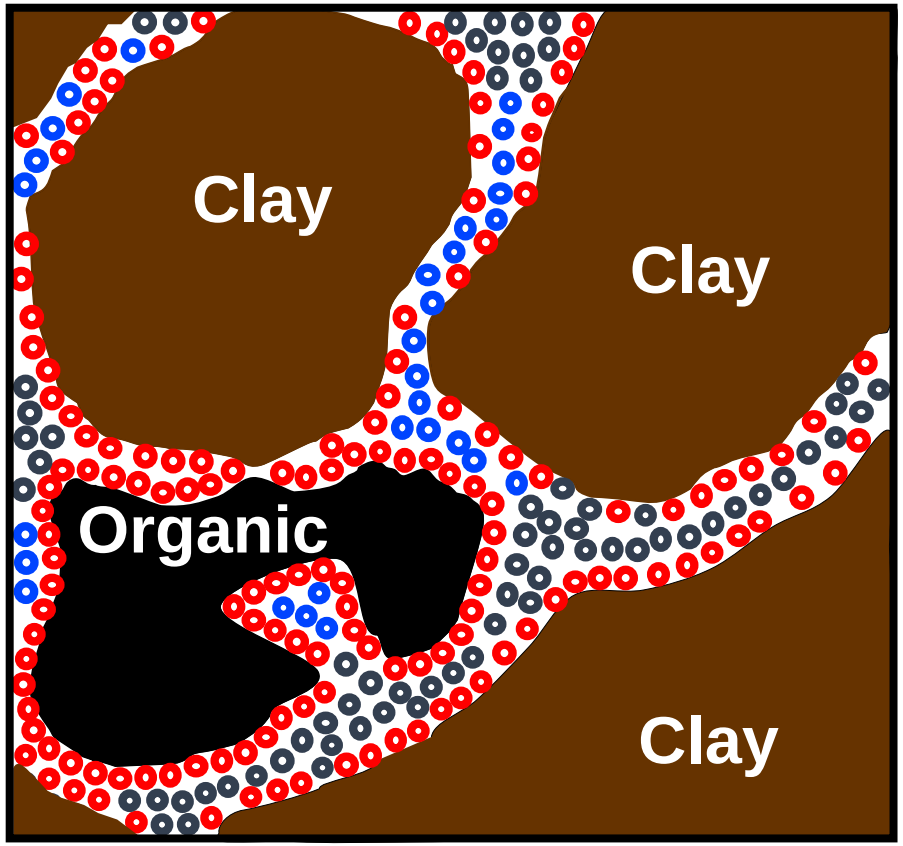
Parameter (unit)	Value
Core Diameter (cm)	2.49
Core Length (cm)	1.59
Porosity – water (unitless)	0.023



https://www.cer-rec.gc.ca/

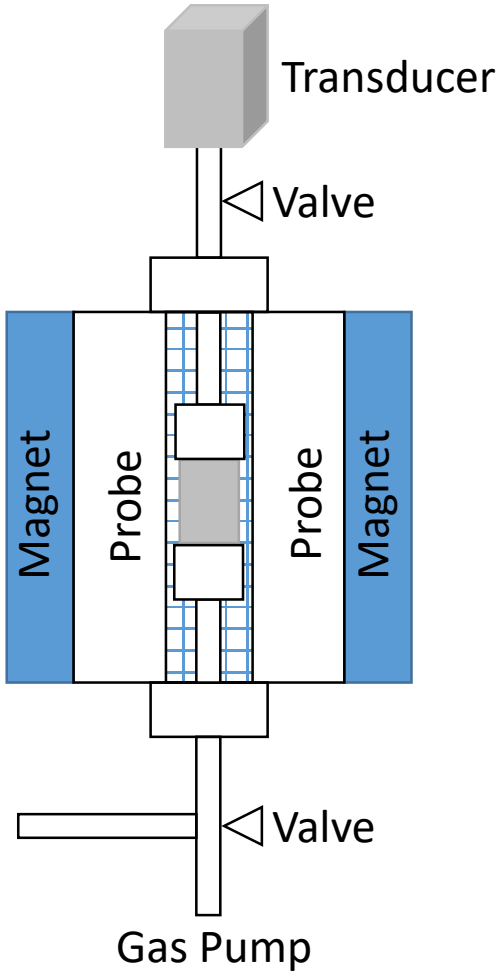
Processes Affecting Ethane Movement

- Advection – ethane gas that moves under a pressure gradient.
- Diffusion – gas that moves under a chemical gradient.
- Adsorption and desorption – physical process where gas is loosely attached to the rock with van der waal forces.



NMR Background

- Permanent magnets tip hydrogen nuclei in fluids and the NMR probe send RF pulses to excite the nuclei.
- Nuclei release the energy as RF waves that are read by the NMR probe.
- This process is called “relaxation” and happens over time based on the nuclei colliding.
- Relaxation occurs due to two processes:

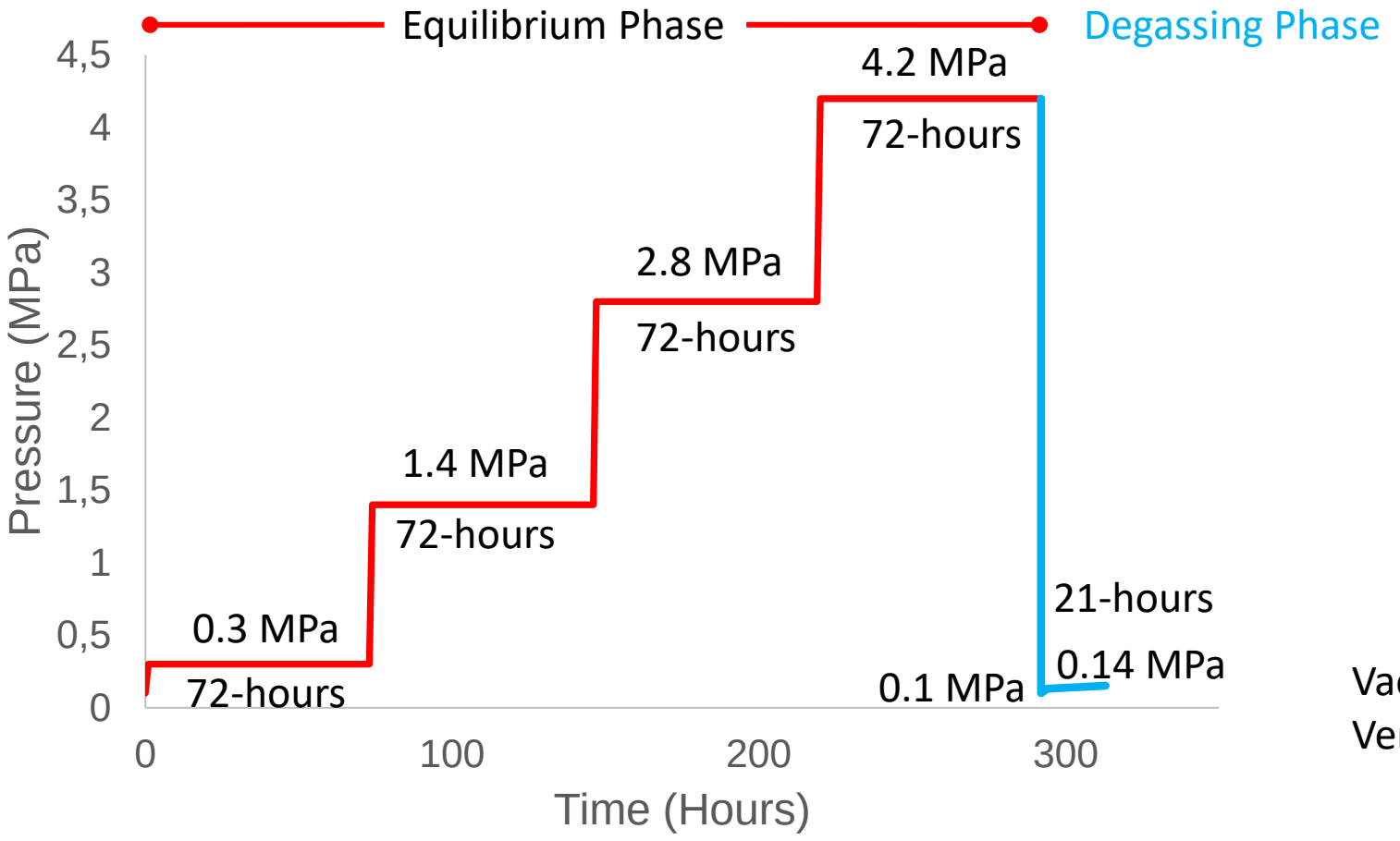


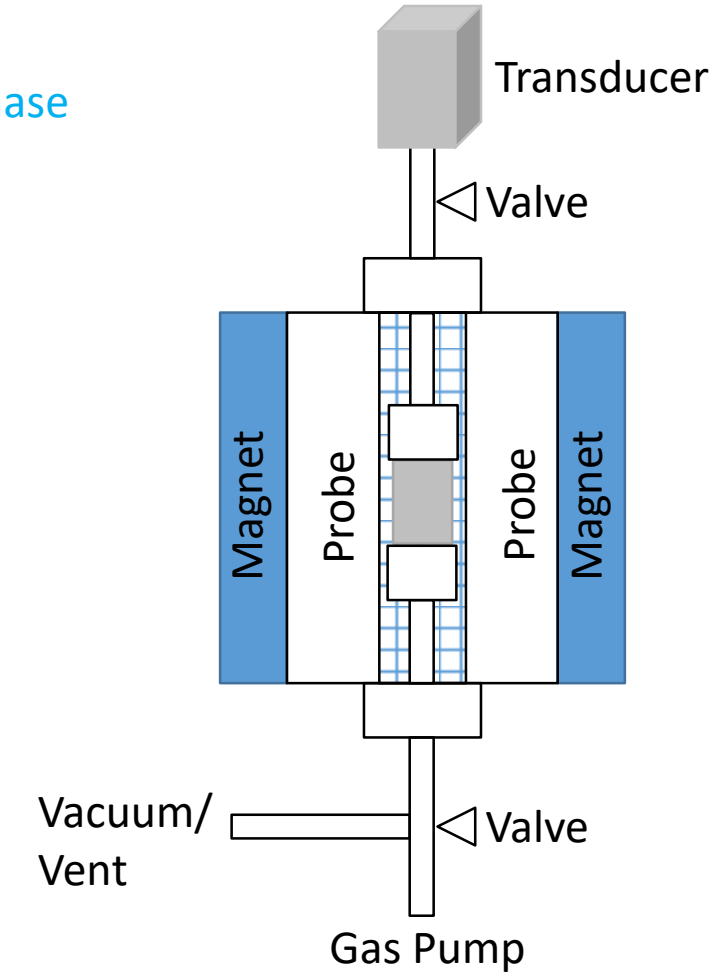
$$\frac{1}{T_2} = P\frac{S}{V} + \frac{1}{T_{2,bulk}}$$

Collisions of adsorbed ethane with rock
Collisions of pore gas ethane with pore walls

Collisions of bulk ethane with each other

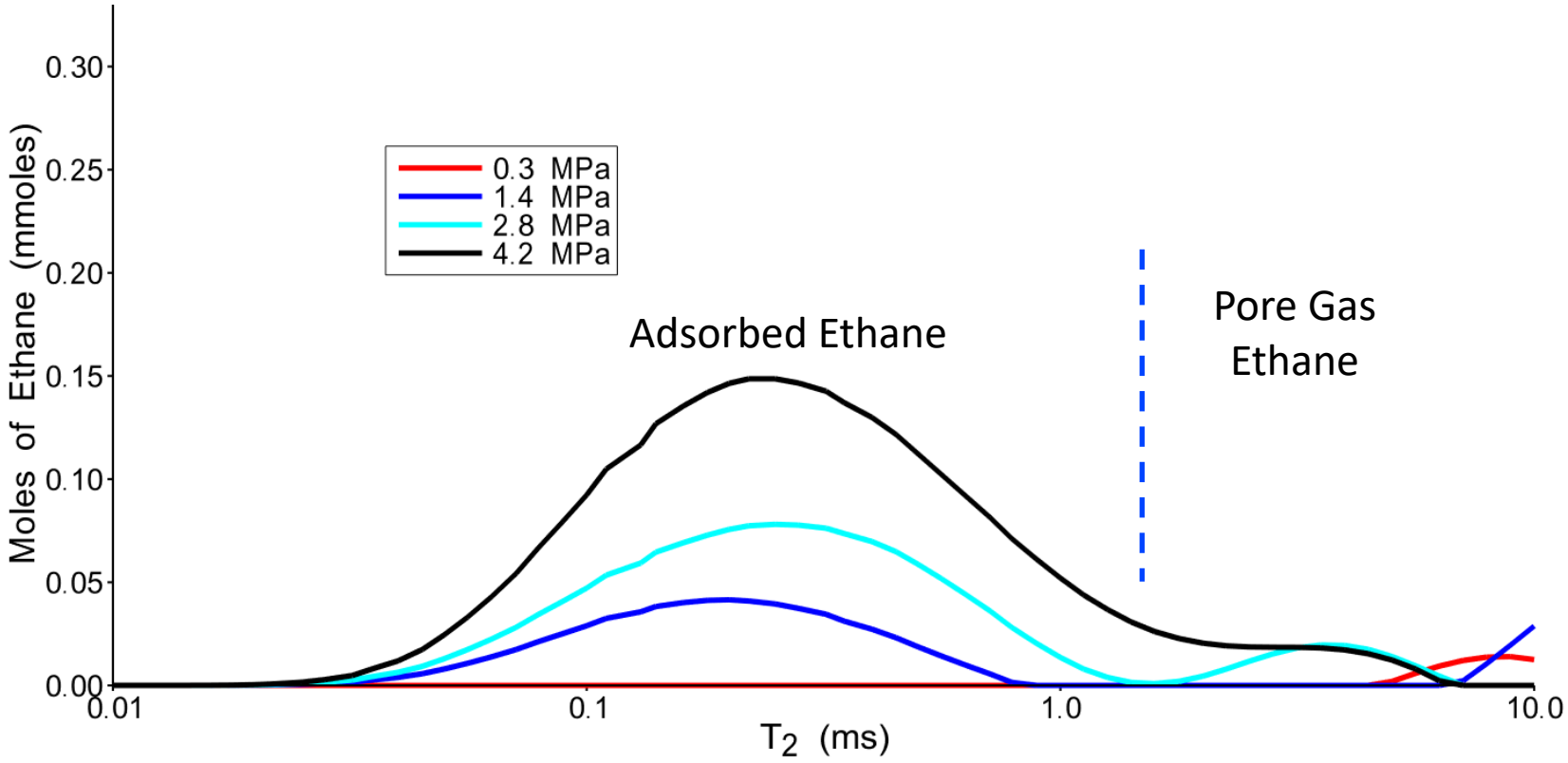
Experimental Overview





Ethane Equilibration Results

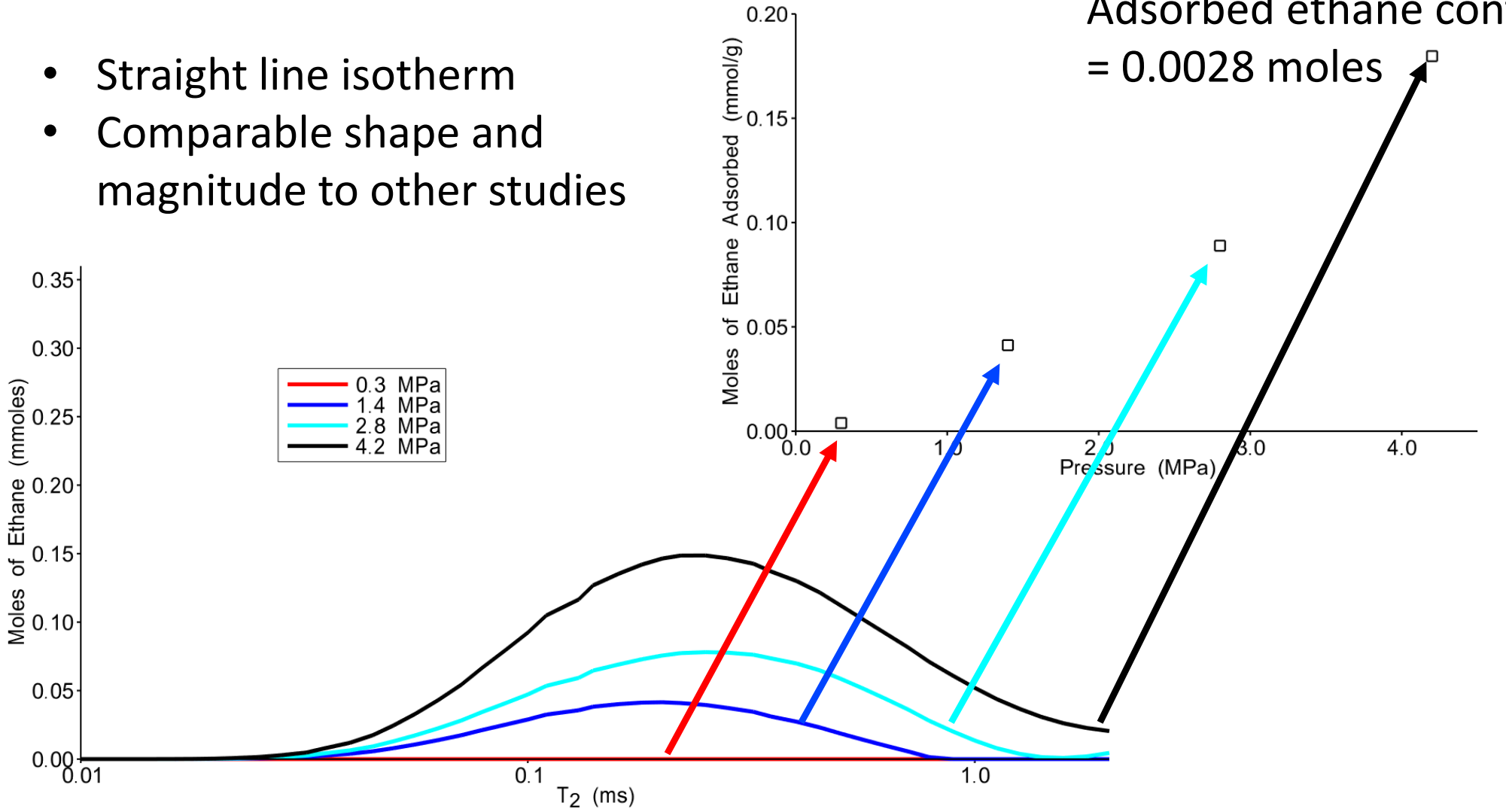
- First Peak is adsorbed ethane
- Adsorbed signal increases with each pressure
- The area under each curve is the mass of ethane adsorbed at each pressure



Ethane Equilibration Results - Isotherm

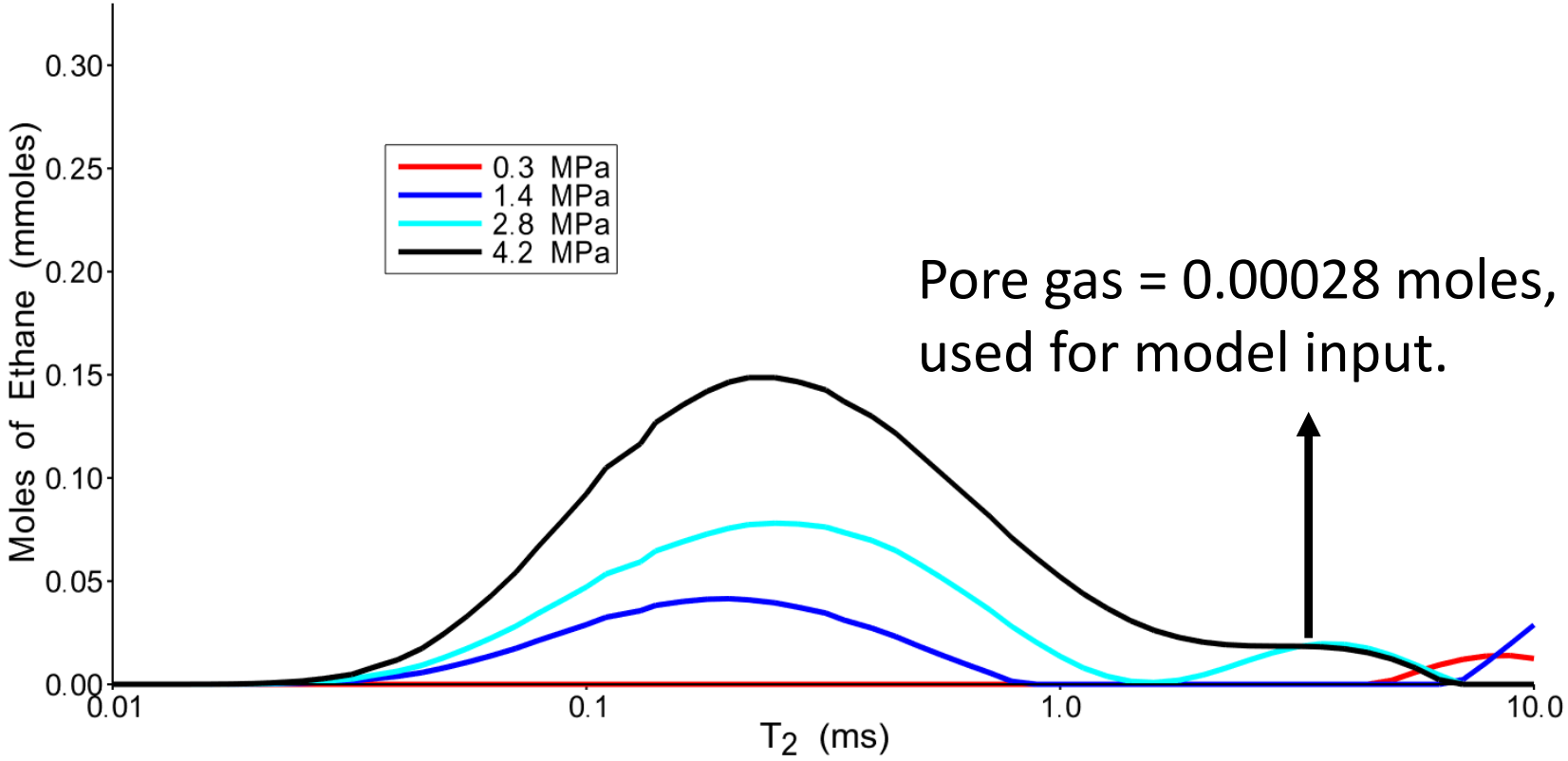
- Straight line isotherm
- Comparable shape and magnitude to other studies

Adsorbed ethane content = 0.0028 moles

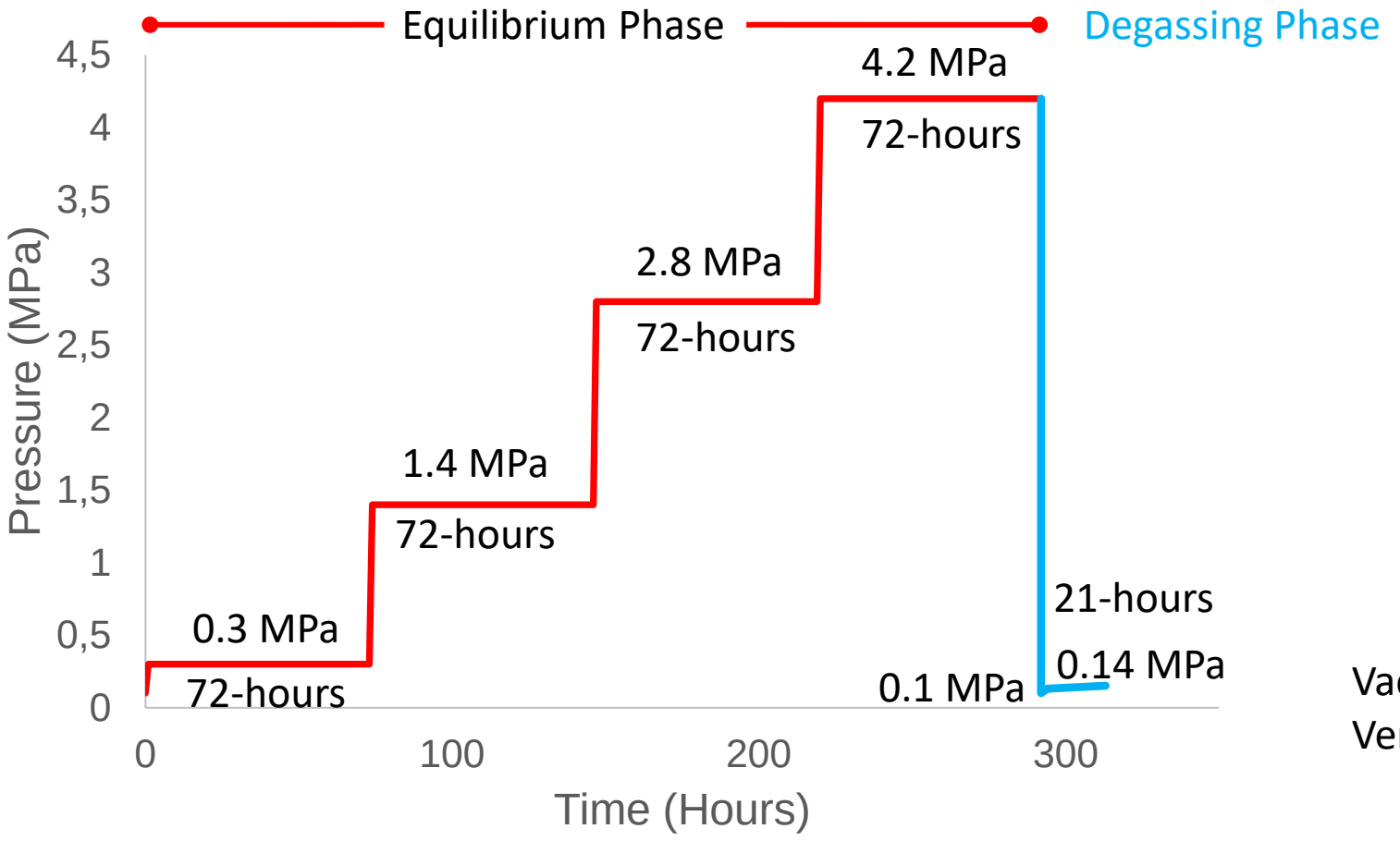


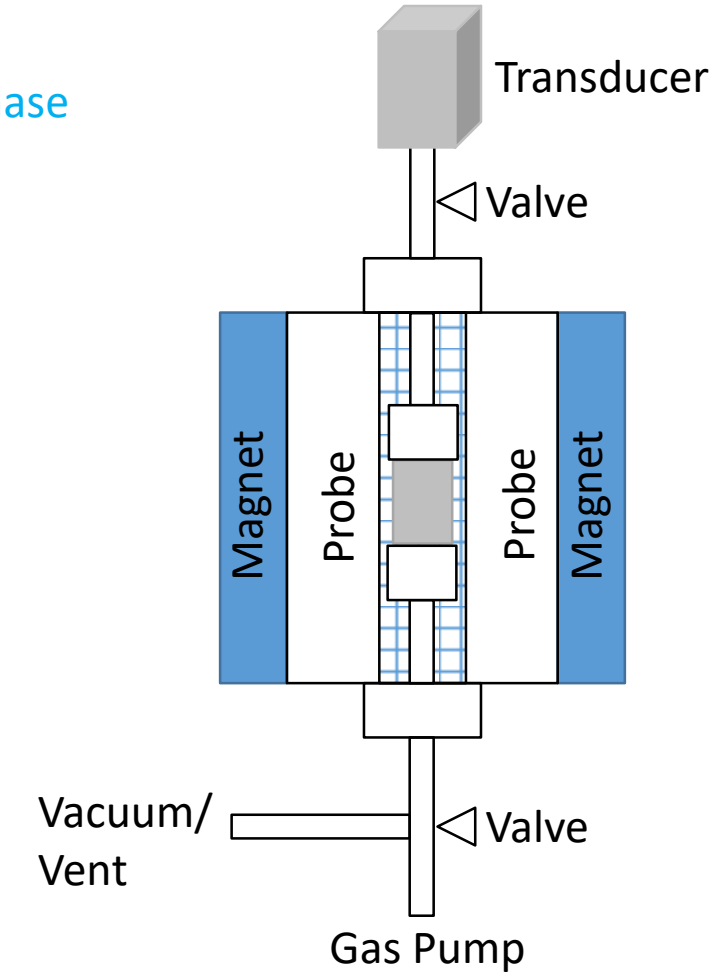
Ethane Equilibration Results – Pore Gas

- Second Peak is pore gas.
- Only 2.8 and 4.2 MPa signals appear.
- Low porosity limits hydrogen mass in pores, NMR signal.
- Calculated pore gas is 0.00052 moles assuming all pore space available.



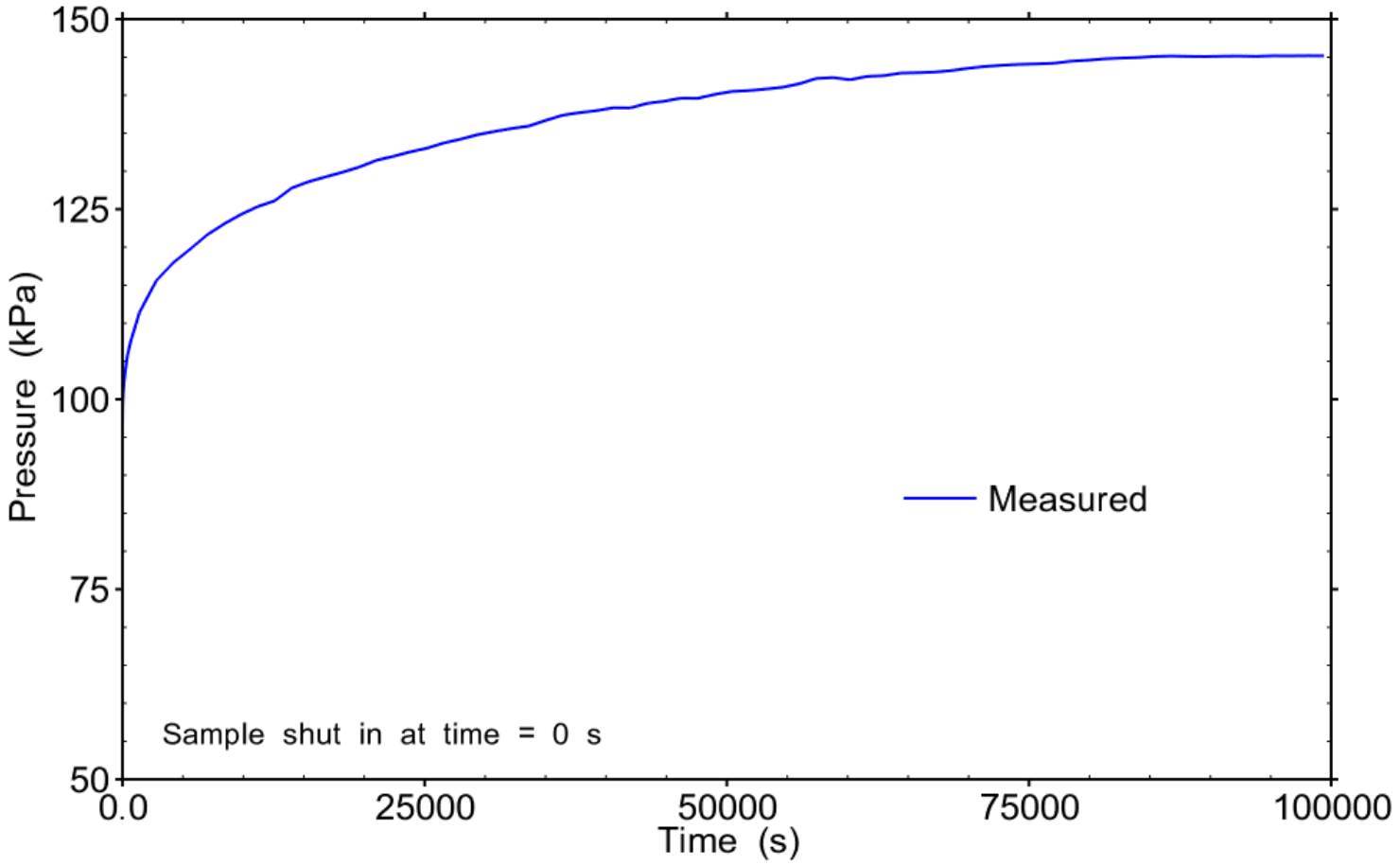
Experimental Overview





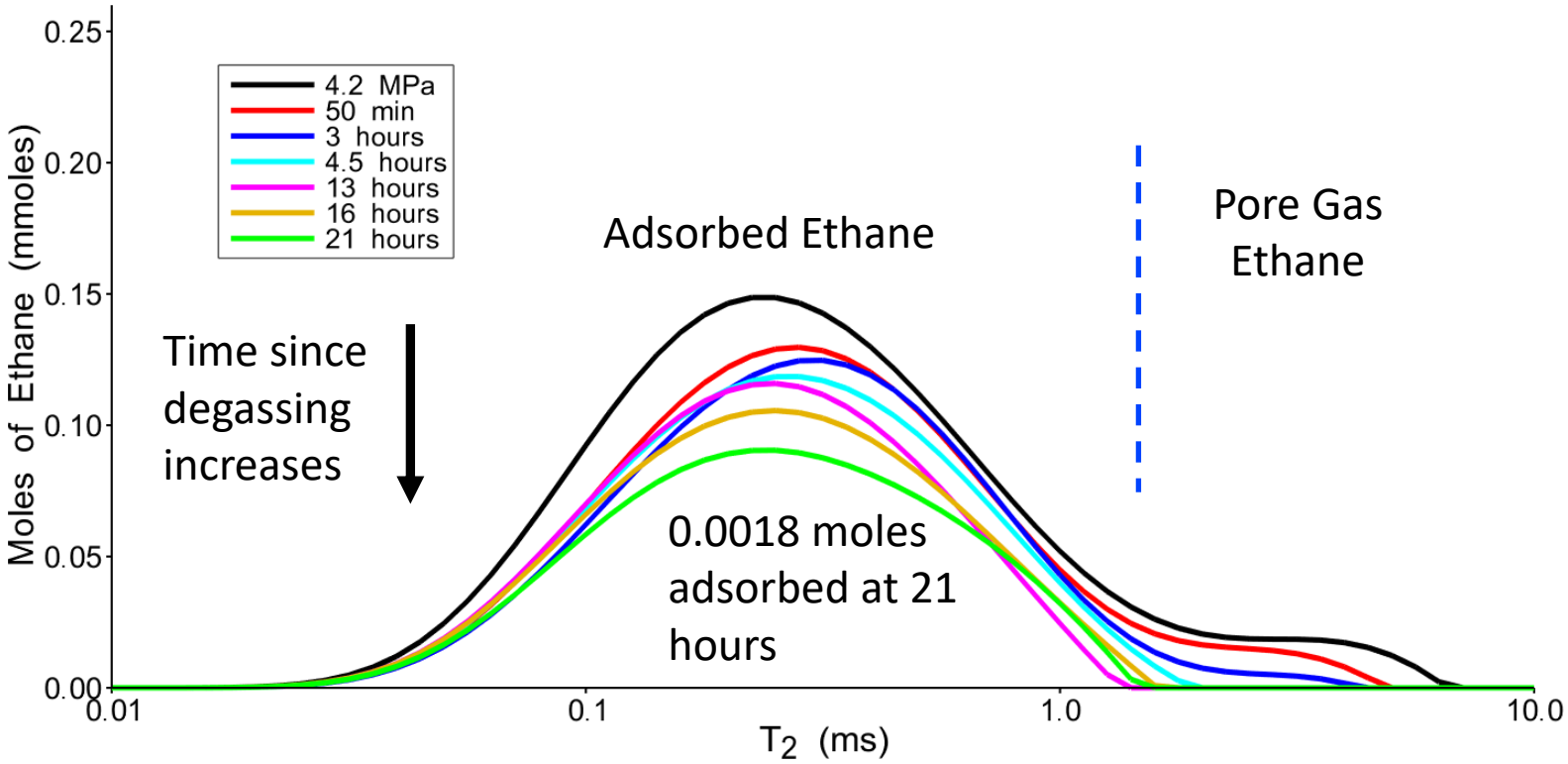
Degassing – Measured Pressure

- NMR probe degassed over a few minutes.
- Pressure increased from 0.1 to 0.14 MPa.
- Pressure change over final 3 hours was <0.0002 MPa.



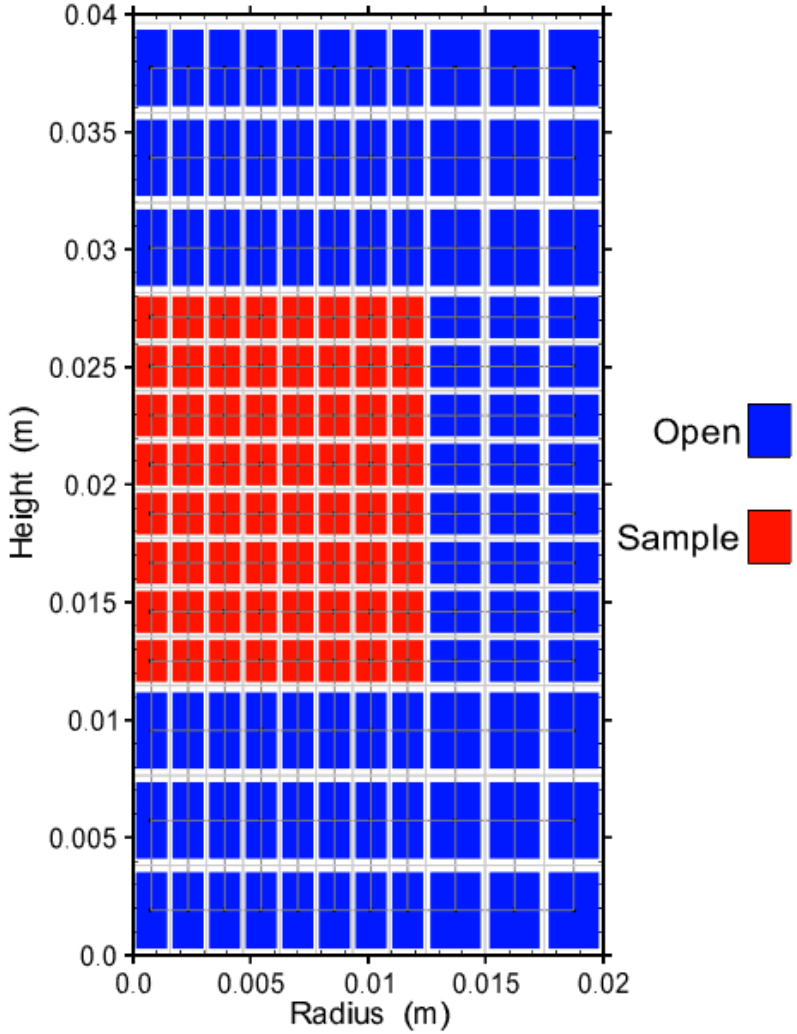
Degassing – Results

- Adsorbed ethane hysteresis.
- Only a third of the ethane desorbed at 0.14 MPa.
- Pore gas not evident 4.5-hours after degassing.
- Pressure increase in pressure observed with decrease in adsorbed and pore gas ethane.



Numerical Modelling

- TOUGH2 - Transport Of Unsaturated Groundwater and Heat, EOS7C Module.
- EOS7C includes adsorption for Enhanced Coal Bed Methane (ECBM) projects.
- Updated model for ethane gas.
- 2-D radially symmetrical model with 154 nodes, with 64 nodes representing the sample, and 90 nodes representing the air-filled void space .



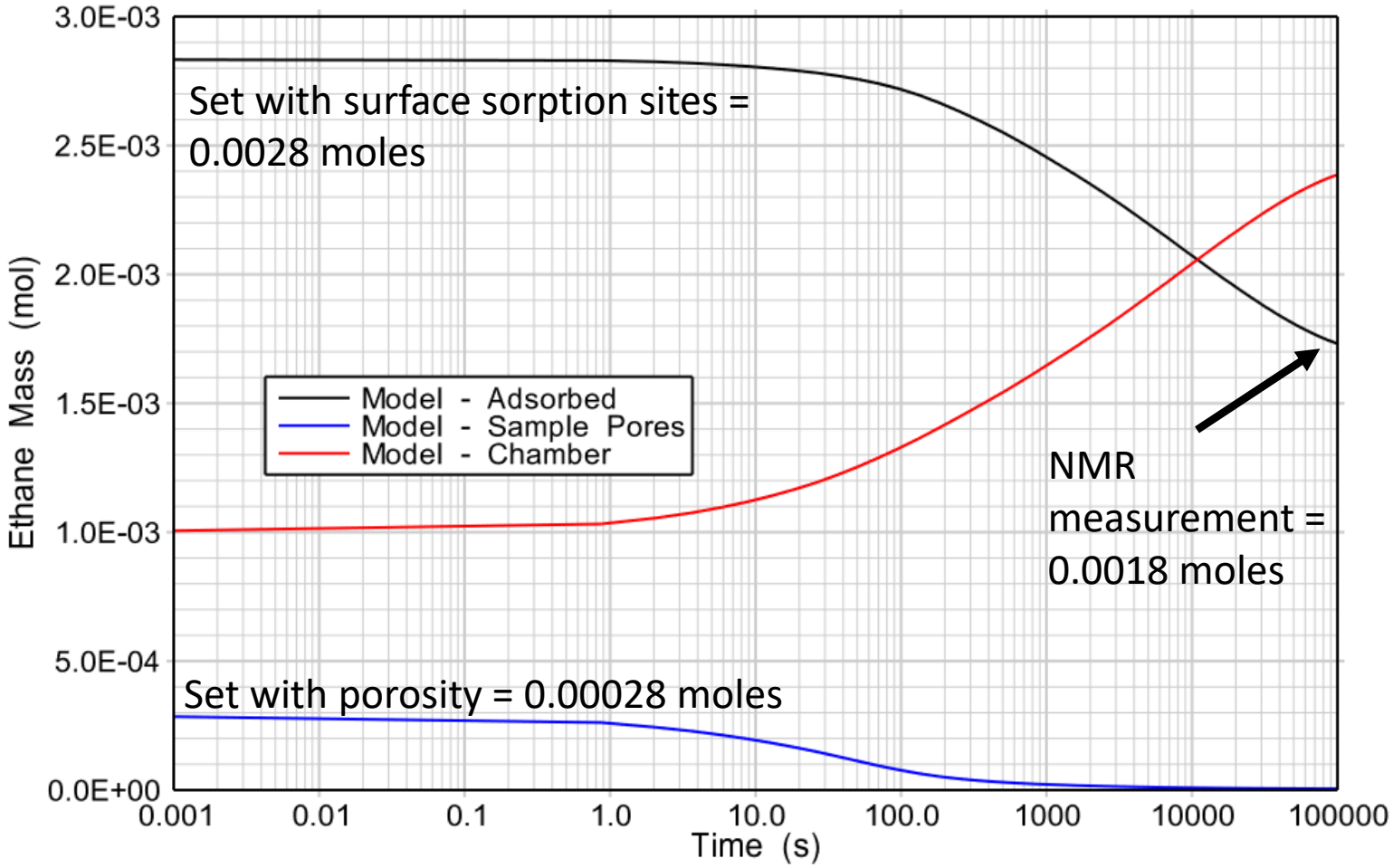
Numerical Modelling

- Pore pressure was final equilibrium pressure.
- Langmuir capacity and porosity adjusted to fit NMR peaks.
- Low porosity suggests inaccessible pores.
- Remaining parameters optimized using the simplex method.

Parameter	Value	Unit	Fitting Method
Pressure	4.2	MPa	Equil. Pressure
Langmuir Storage Capacity	0.0178	sm^3/kg	First peak NMR
Porosity	0.0129	Unitless	Second peak NMR
Permeability	2.67×10^{-20}	m^2	Optimized
Diffusion Coefficient	8.19×10^{-14}	m^2/s	Optimized
Langmuir Pressure	0.11	MPa	Optimized

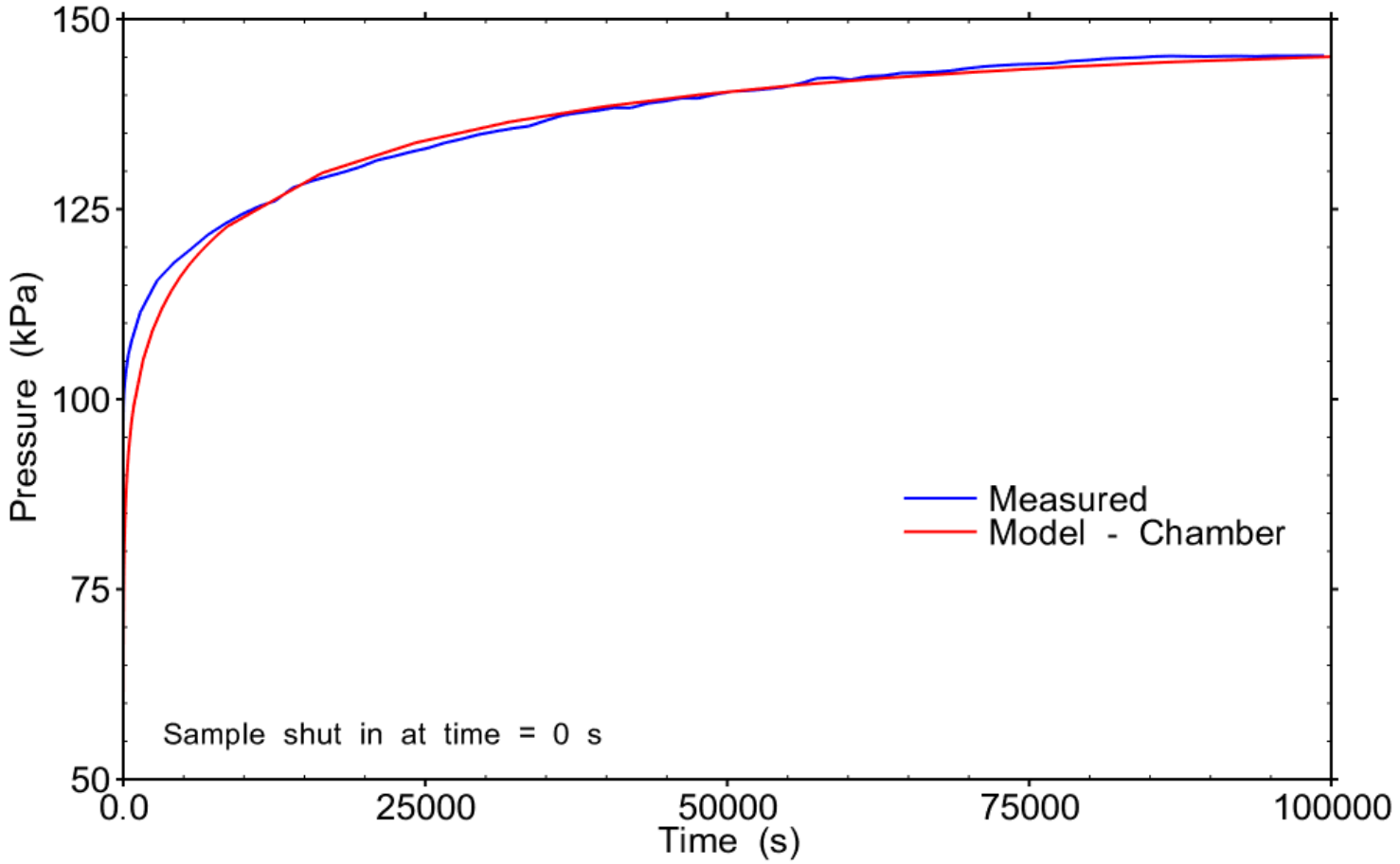
Numerical Modelling – Mass Results

- Good mass balance results.
- Modeled final adsorbed mass within 0.0001 moles of NMR measurement.
- Modeled pore gas within 0.00005 moles of NMR measurement at 3 hours.



Pressure Results

- Mass fit and pressure fit indicate critical physical processes are included in the model.
- Under-estimate early time pressure.
  - Non-Darcian flow?
  - Skin?
- Low k and D indicate no micro-fracturing of the rock due to pressure drop



Parameter	Value	Unit	Fitting Method
Permeability	2.67×10^{-20}	m^2	Optimized
Diffusion Coefficient	8.19×10^{-14}	m^2/s	Optimized

Discussion

Adsorption/Desorption

- Ten times more ethane adsorbed compared to in the pores.
- One third of the ethane desorbed, two thirds remained adsorbed.
- Competitive sorption/desorption schemes required to improve ethane recovery.

Porosity

- Modeled porosity was lower than measured porosity.
- Suggests ethane could not access each pore.
- Ethane may not be able to be removed from each pore.

Diffusion

- Small impact on model results.
- Small coefficient indicative of small pores, perhaps due to adsorbed ethane.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