Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic–Coal Seams (2)

Laboratory Investigation of Coalbed Methane Recovery by Gas Injection; Paper 179

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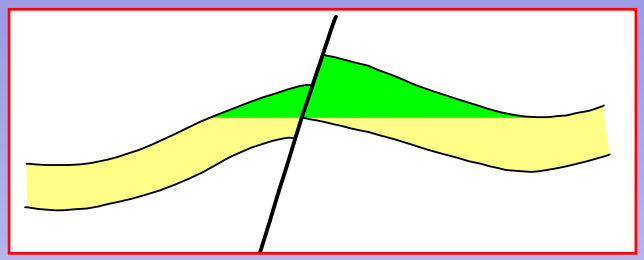
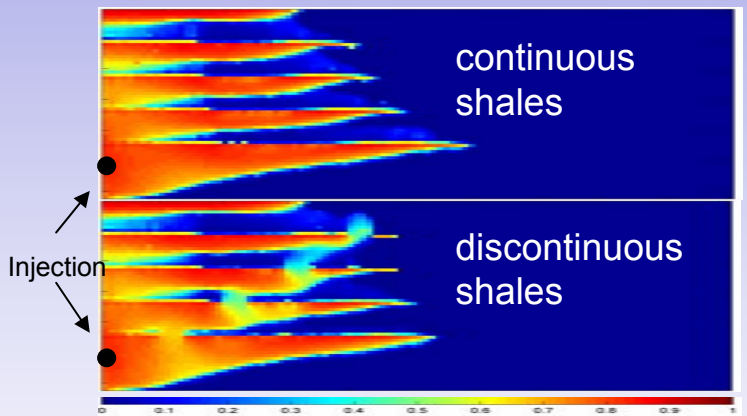
Geologic Storage of CO_2

GCEP: Global Climate and Energy Project

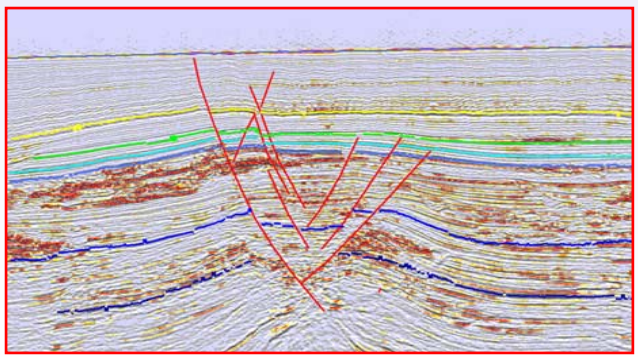
Project Components:

- **Site selection and evaluation: effective methods to assess the integrity of geologic seals that limit CO_2 migration.**
- **Fluid migration: efficient methods for predicting the flow paths and long-term fate of injected CO_2.**
- **Monitoring: appropriate tools for monitoring the state of injection projects at each stage.**

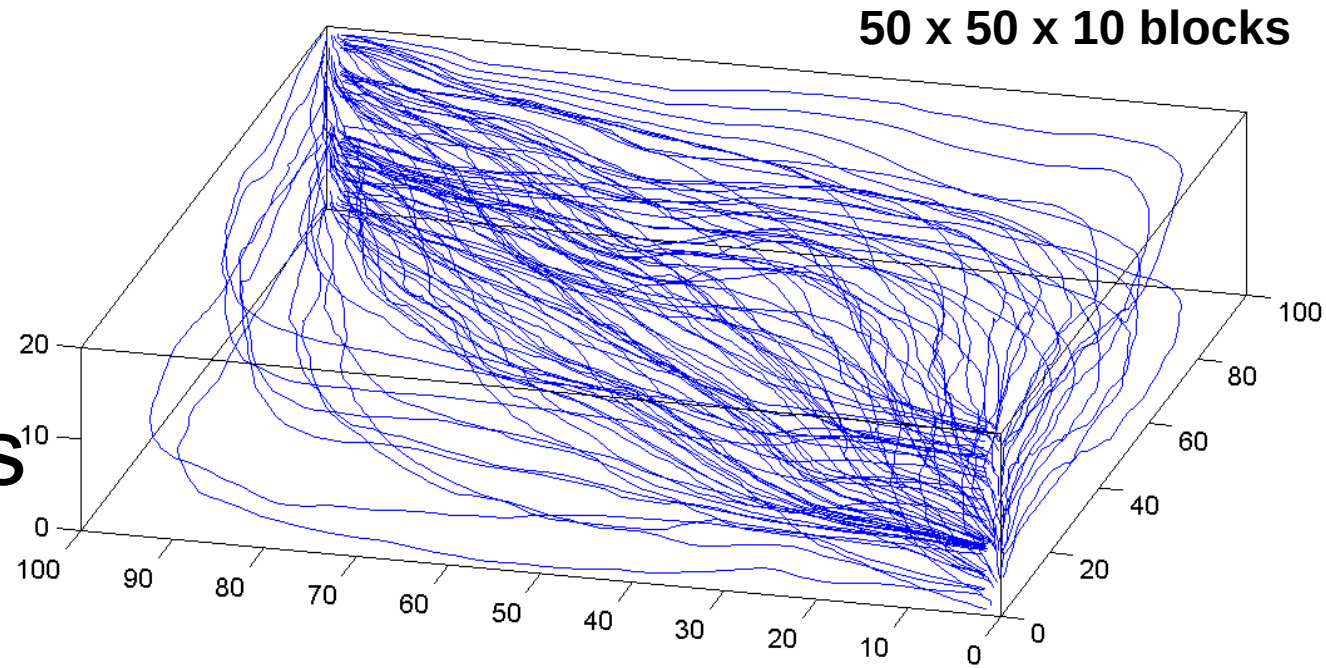




Saturation of CO_2



Efficient Prediction Using Streamlines



- Why?
  - ultra-fast – address uncertainty
- Such methods are useful to
  - predict where CO_2 is likely to flow
  - interpret the volume and space contacted
  - optimize injection and recovery operations
- What is the process model for ECBM?

Experimental Objective

- **Establish a feasible $CO_2/CH_4/N_2$ adsorption/desorption model and displacement mechanism that is implementable within a streamline framework so that CBM production and CO_2 storage on field scale is predicted.**
- **Probe:**
  - **recovery efficiency**
  - **mixed gases (CO_2 & N_2)**
  - **permeability wrt gas composition**

Relevant Coalpack Data

(Powder River Basin, WY)

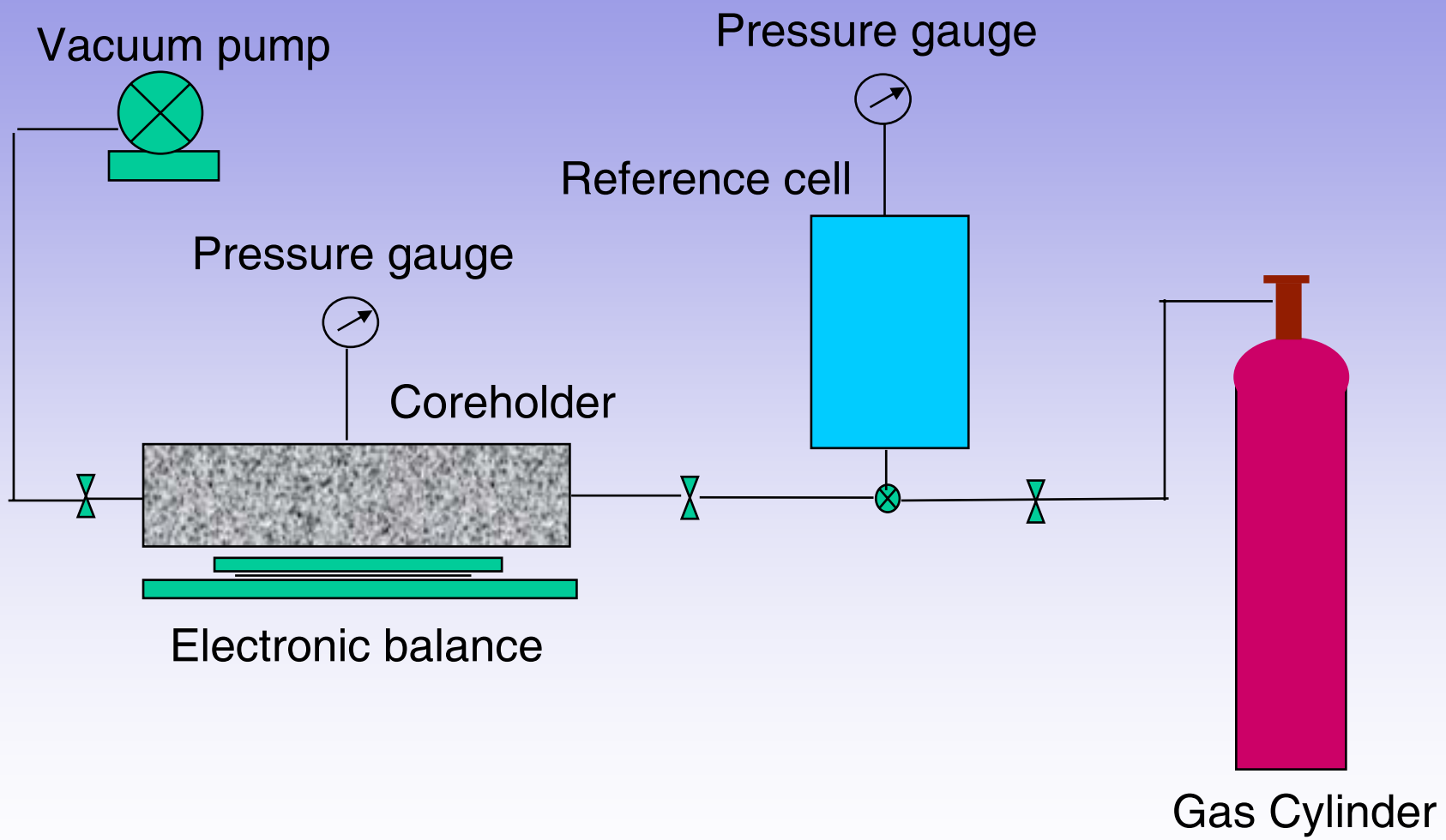
As received

After grinding

Length, cm	25.0
Diameter, cm	3.75
Permeability, md	145
Porosity, %	42
Total coal, g	227
Coal size, mesh	60
S_{wi}, %	0-8%

Experimental Setup

Adsorption/Desorption $CO_2/N_2/CH_4$



Langmuir Adsorption Isotherm: Pure Gas

$$V = \frac{V_m bP}{1 + bP}$$

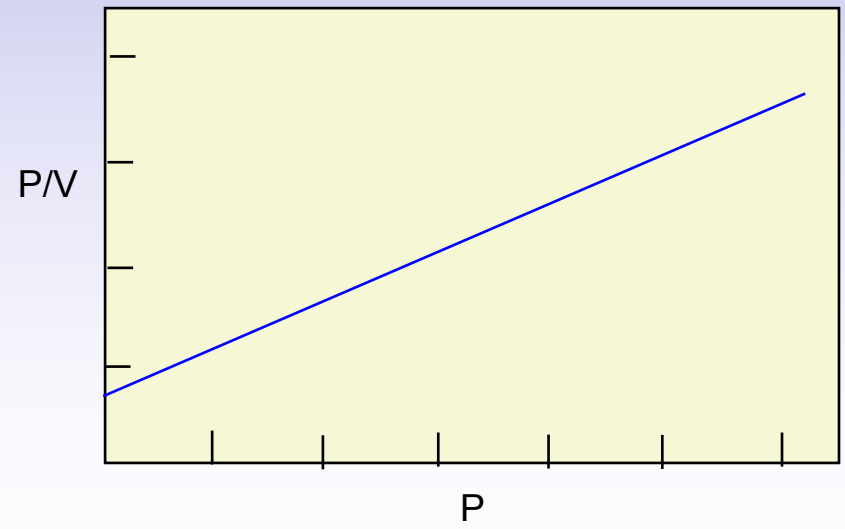
V= gas adsorption

P=pressure

V_m=saturation adsorption constant

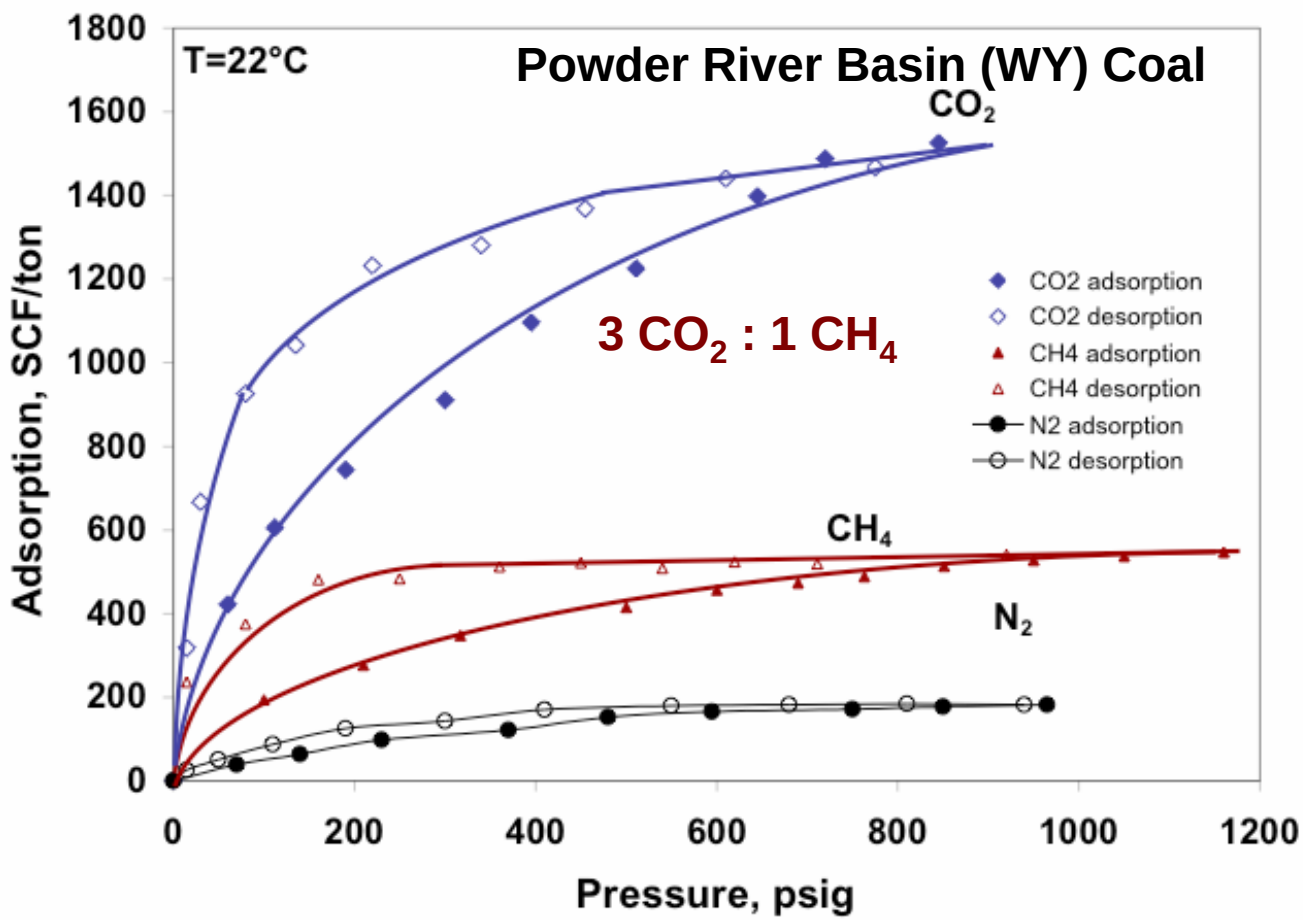
b=constant

$$\frac{P}{V} = \frac{P}{V_m} + \frac{1}{bV_m}$$



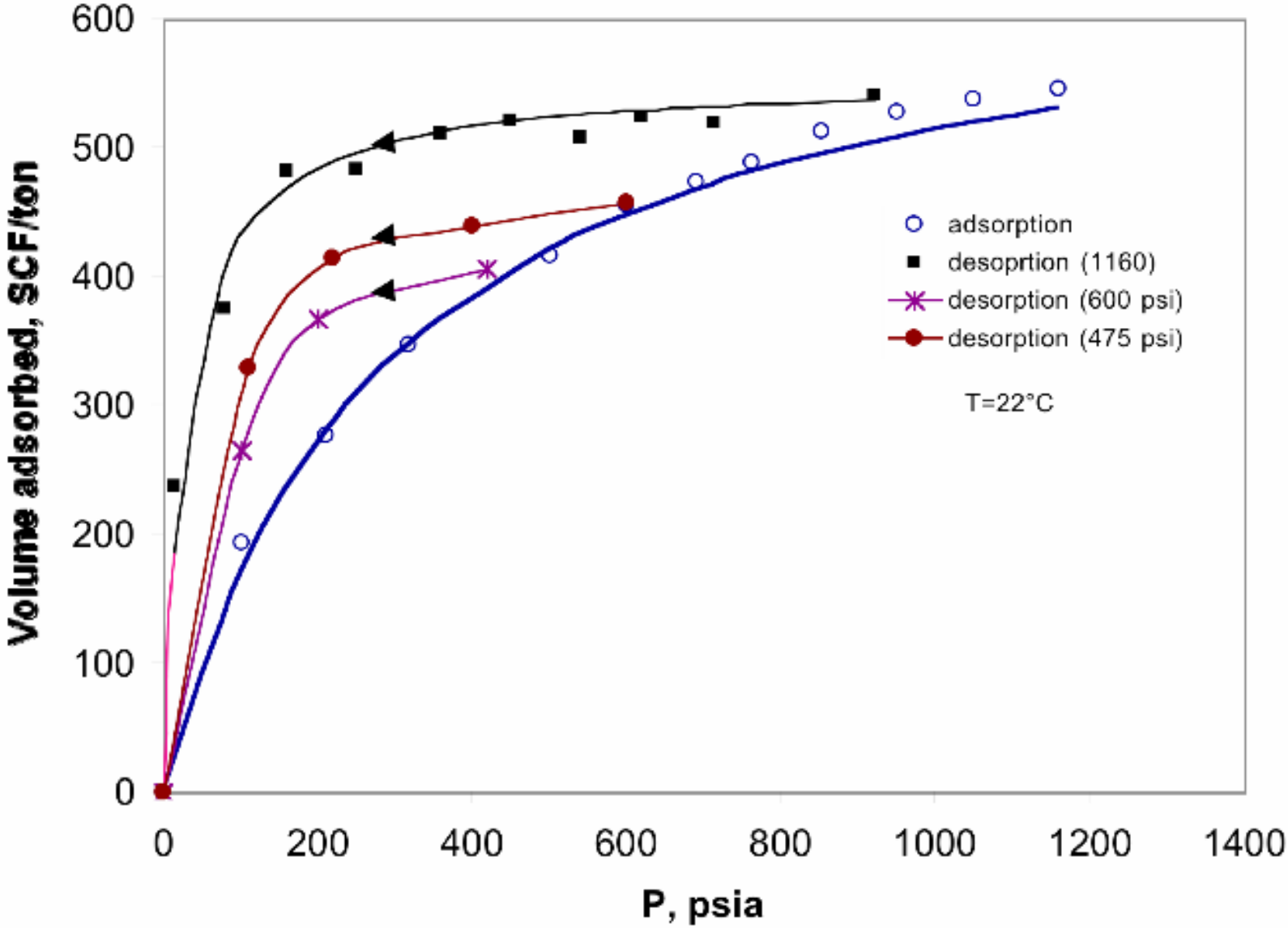
CO_2, CH_4, N_2 Adsorption/Desorption

- All adsorption data is well fit by Langmuir isotherm
- CO_2 adsorbs preferentially
- adsorption hysteresis for all gases
- scanning loops are evident



CH_4 Adsorption/Desorption Scanning Loops

Initial pressure influences desorption hysteresis



Extended Langmuir Isotherm: Binary Gas

$$V_i = \frac{V_{mi} b_i P_i}{1 + \sum_j b_j P_j}$$

$$P_i = P y_i$$

$$\alpha = \frac{(x/y)_i}{(x/y)_j}$$

$$\alpha = \frac{(V_m b)_i}{(V_m b)_j}$$

V: adsorption

P=partial pressure

V_m=saturation adsorption constant

b=constant

y=free gas mole fraction

α=selectivity ratio

x=sorbed gas mole fraction

i, j=gas components

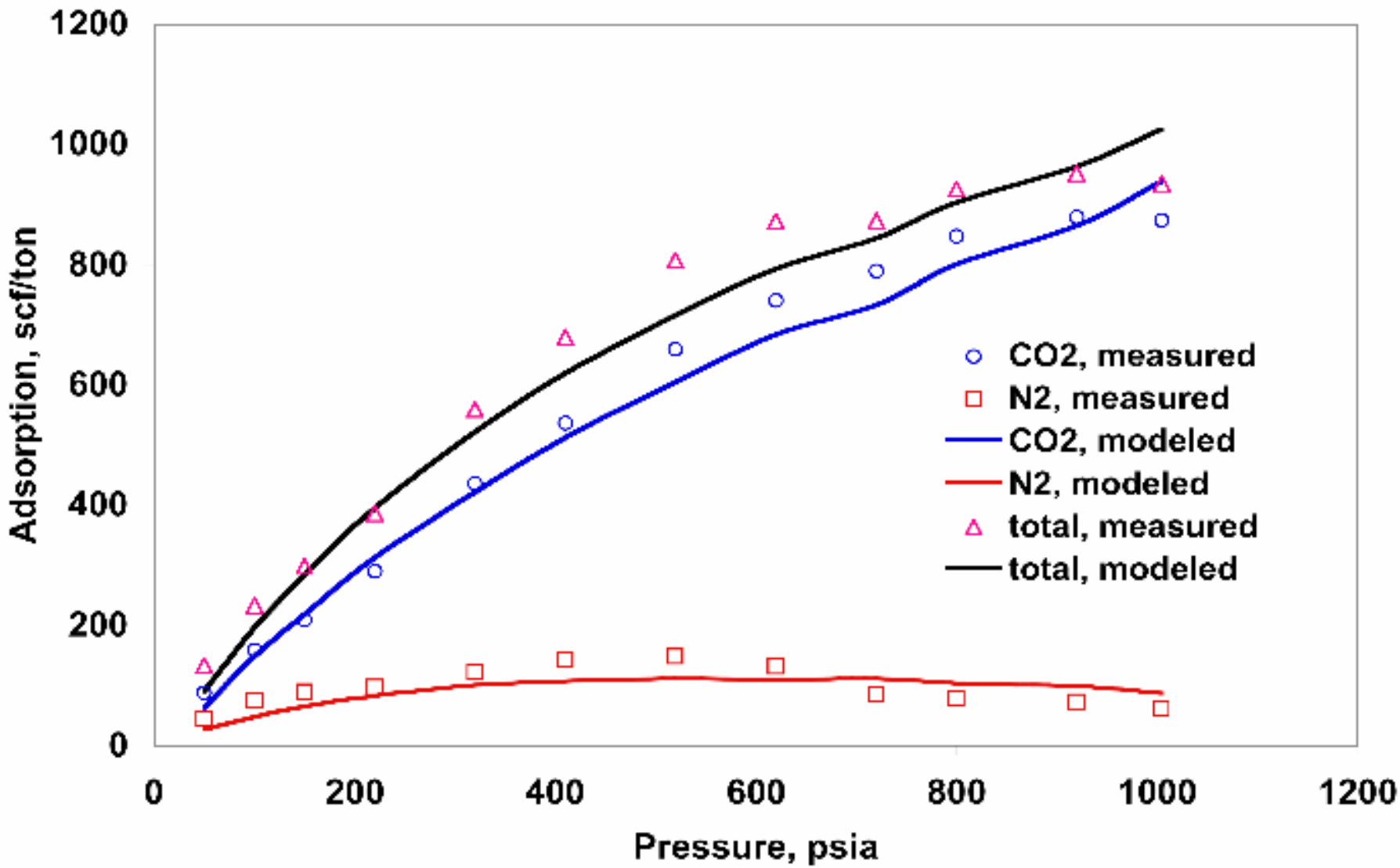
(cf, SPE 24363, Arri, et al, 1992)

Summary of Langmuir Constants

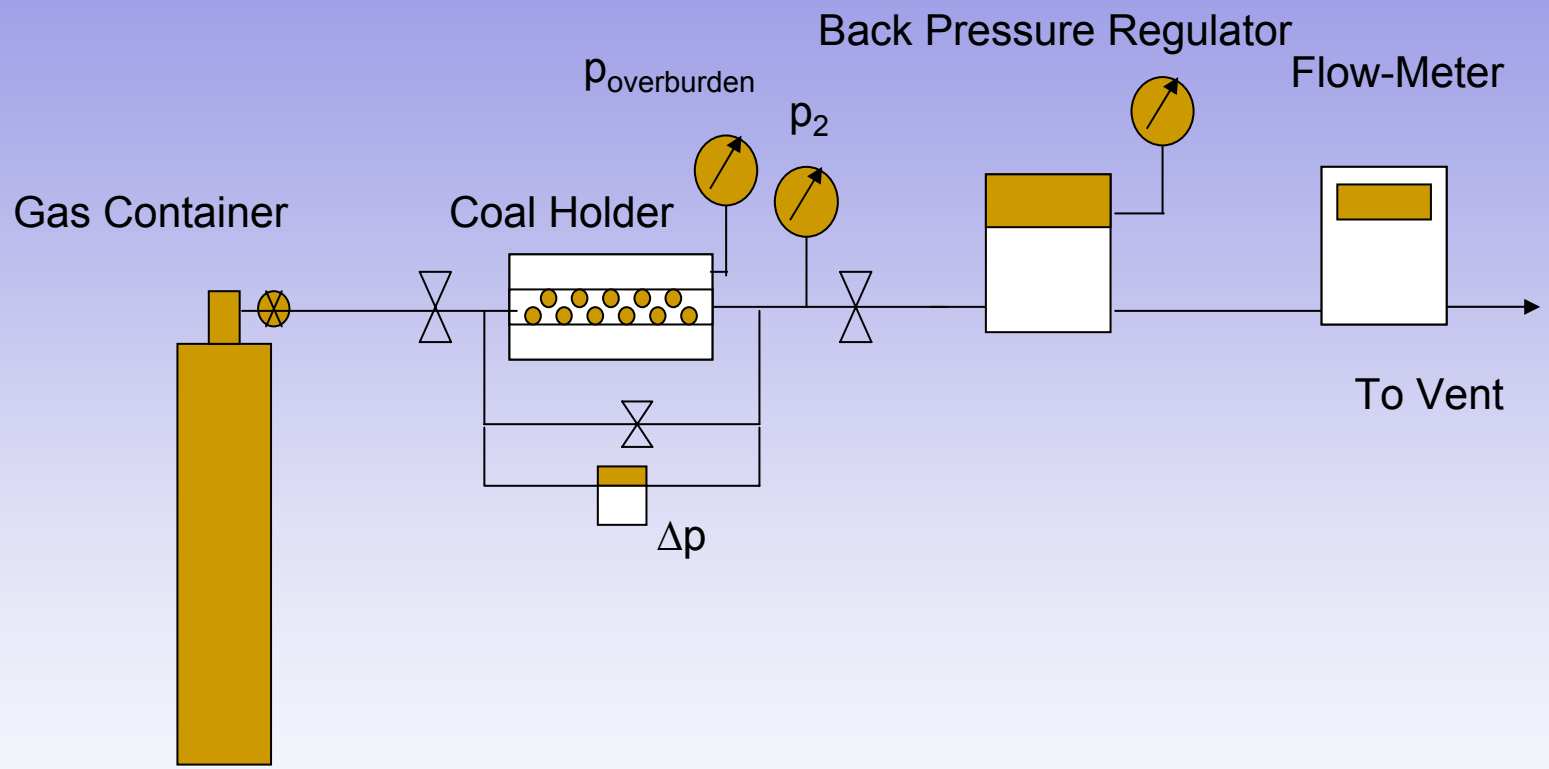
Constants	V_m	b	α
CH_4	714.8	0.0029	
CO_2	1666.7	0.0062	
N_2	263.2	0.0025	
CH_4+CO_2			0.2006
CH_4+N_2			3.1503
CO_2+N_2			15.705

CO_2+N_2 Mixture Adsorption

Extended Langmuir Appears to be Acceptable

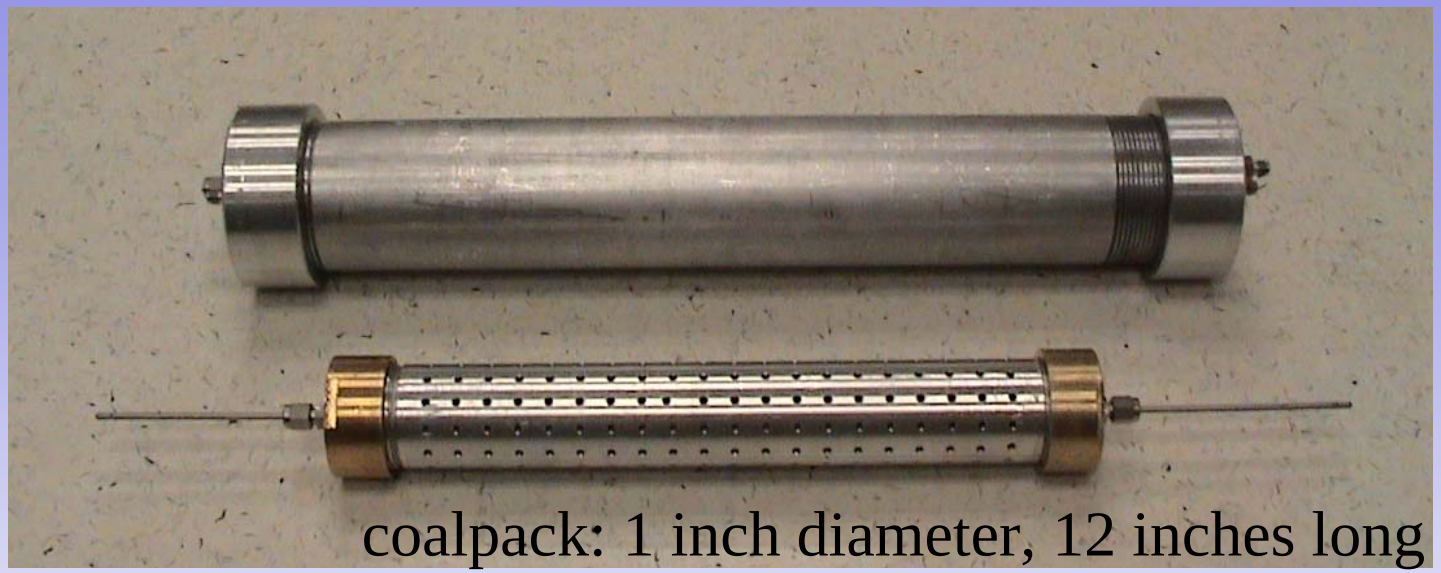


Flow Through Apparatus



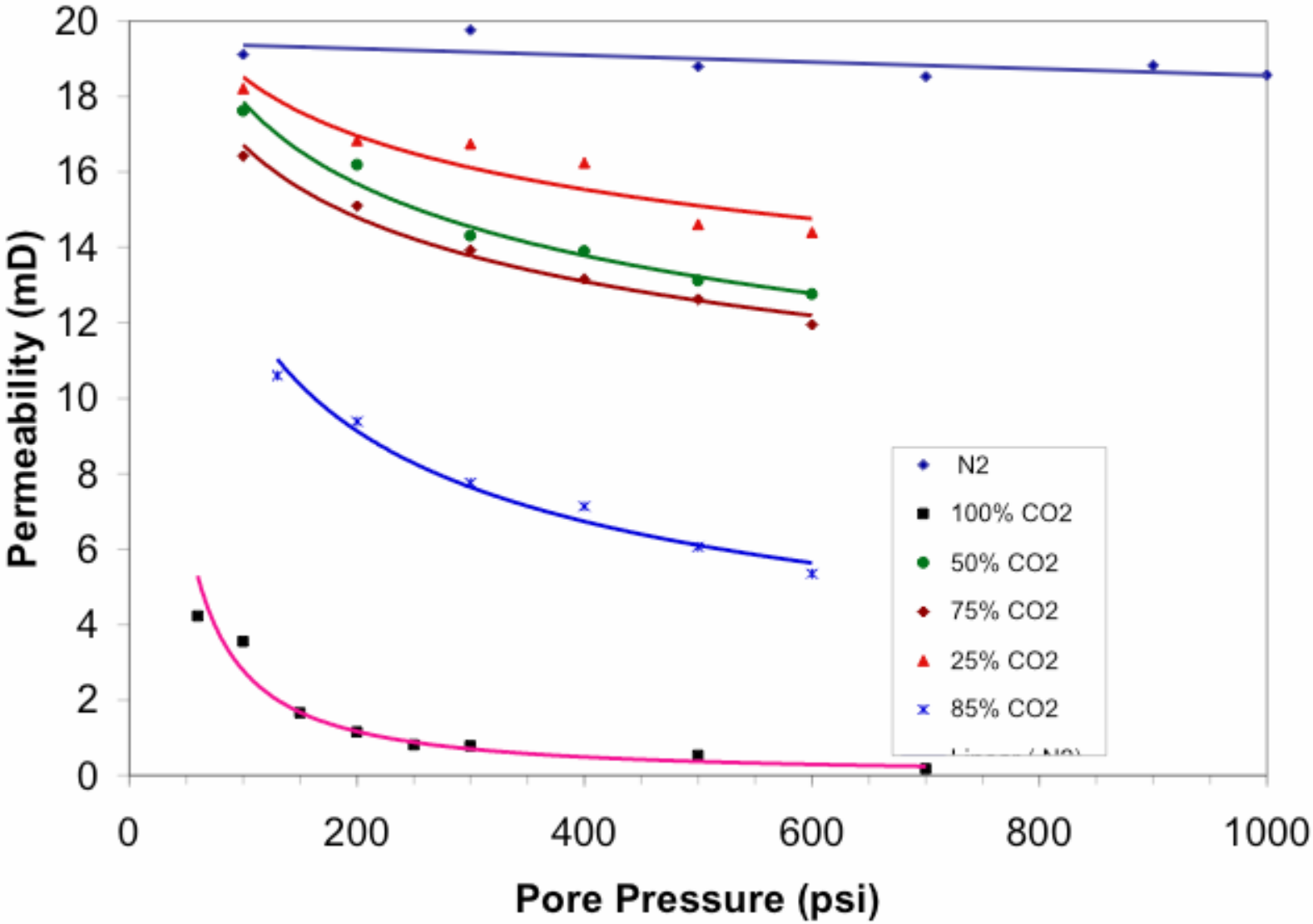
- Net overburden pressure=400 psi, Pore pressure: 60~1100 psi
- Gas mixtures made in the lab by weight

Core Holder

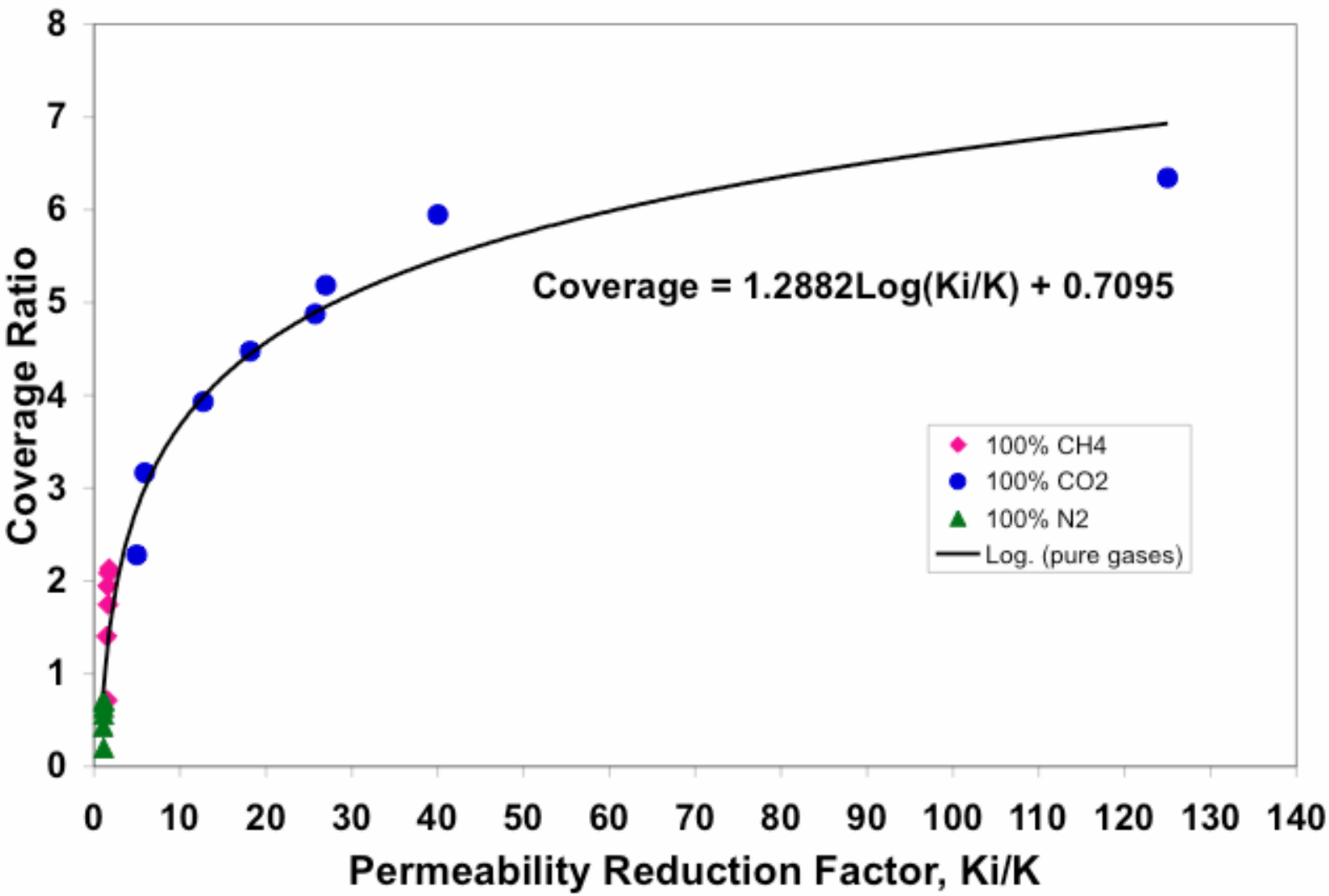


Steady State Permeability

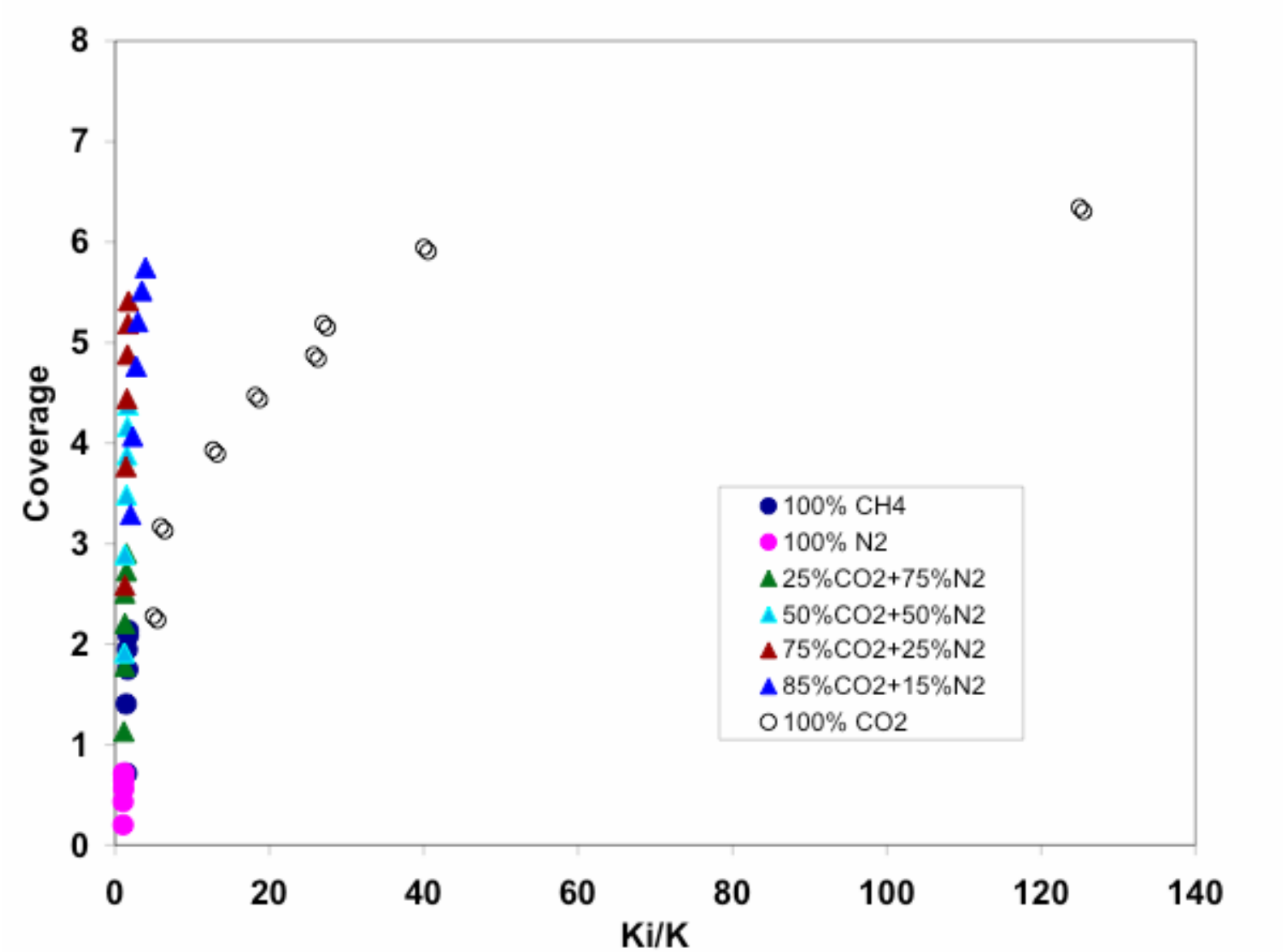
$P_{confining}$-P_{pore} = 400 psi



Permeability Reduction of Pure Gases Correlates With Surface Coverage

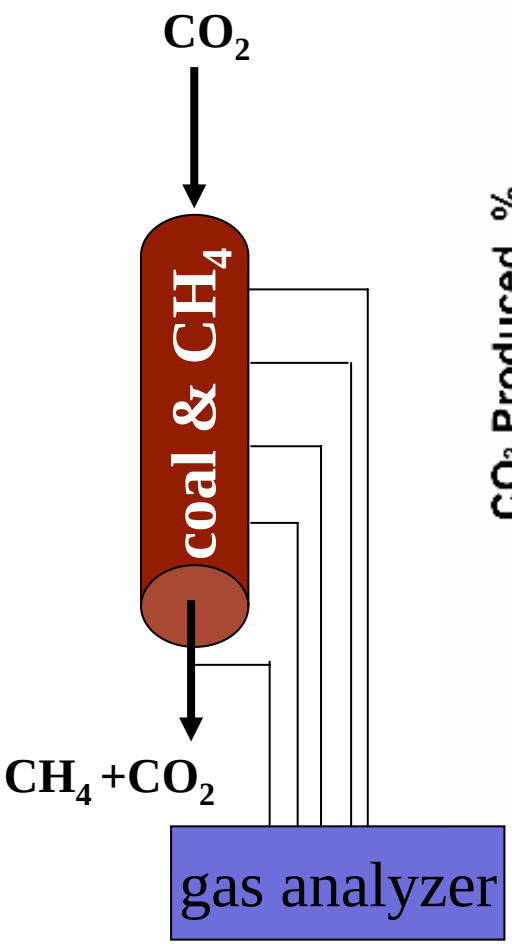


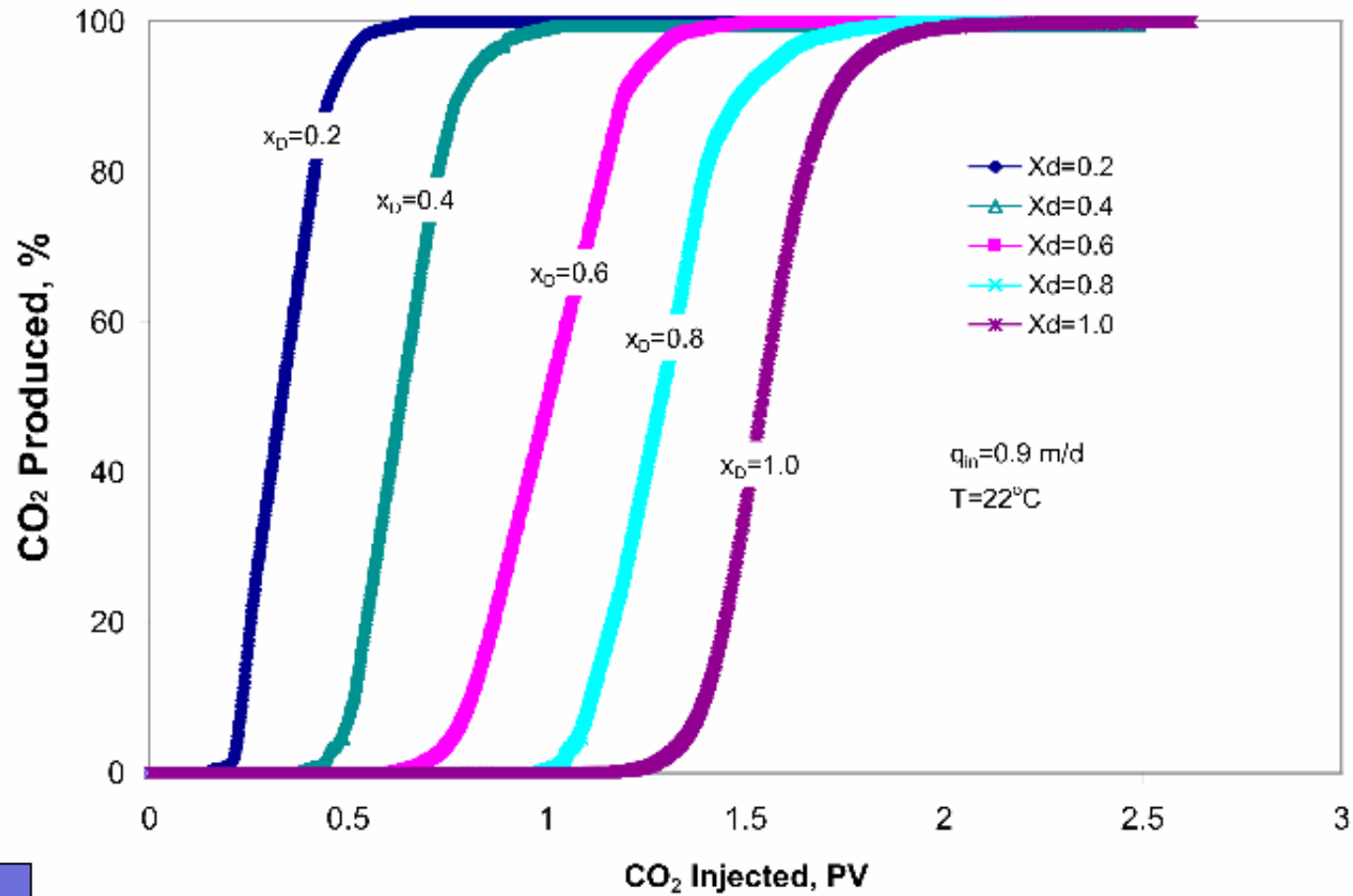
Coverage vs Permeability Reduction Pure and Mixed Gases



CO_2 Displacing CH_4

Piston like advance of CO_2





Mixed Gas Injection Data

Temperature: 72°F

Pressure: 600 psia

Initial Water Saturation: 0

Gas Injection Rate: 0.5 cc/min

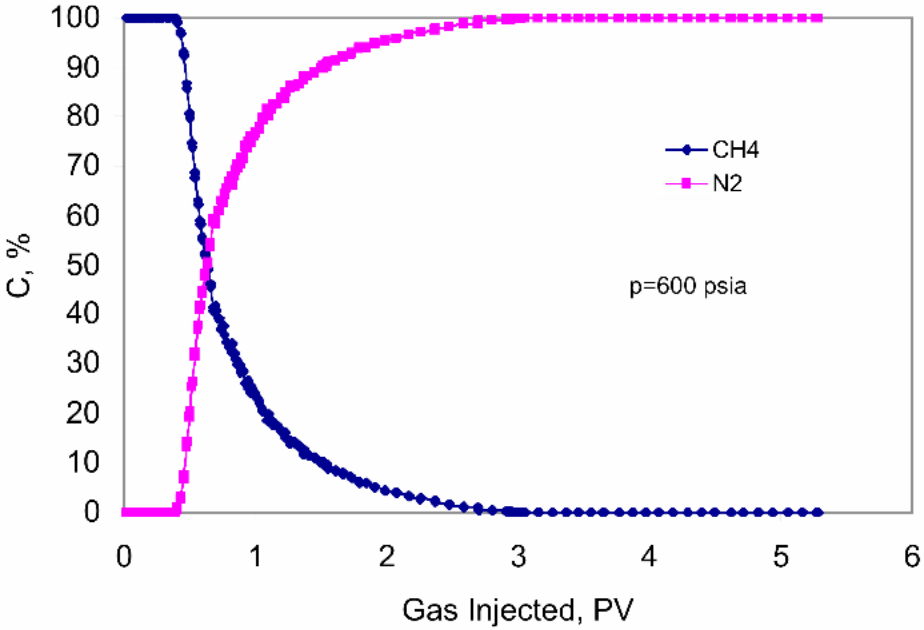
Injection-gas composition:

- **-100% CO_2, 0% N_2 (c100n0)**
- **-85% CO_2, 15% N_2 (c85n15)**
- **-46% CO_2, 54% N_2 (c46n54)**
- **-24% CO_2, 76% N_2 (c24n76)**
- **-0% CO_2, 100% N_2 (c0n100)**

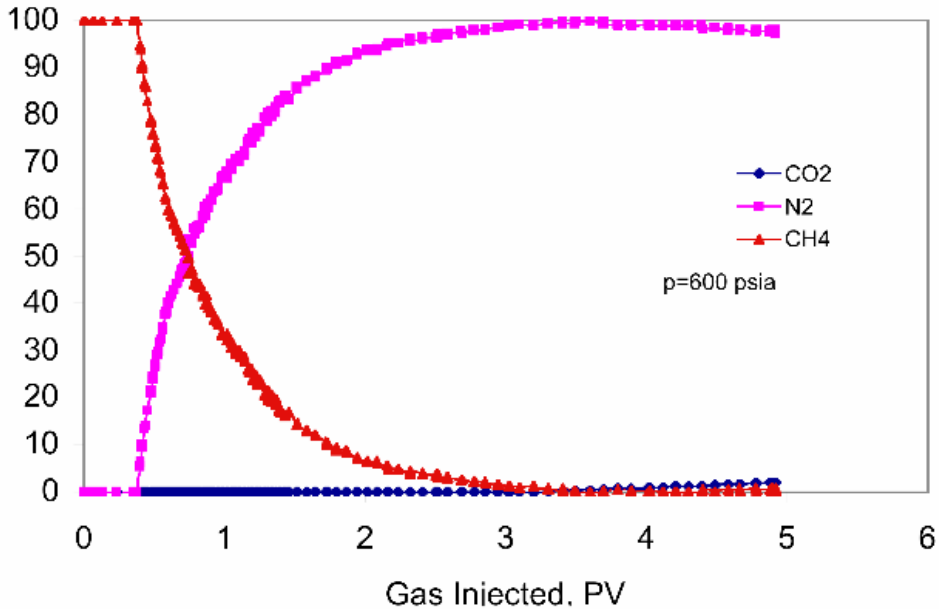
Mixed Gas (CO_2 and N_2)

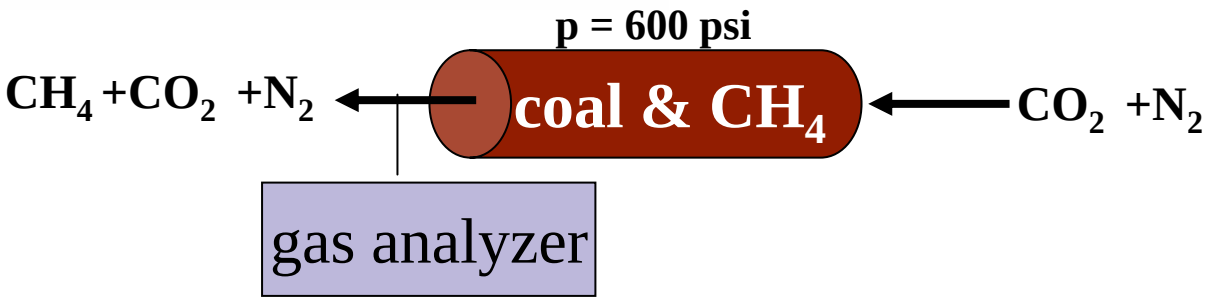
Chromatographic Separation of CO_2 and N_2

0% CO_2



24% CO_2 76% N_2

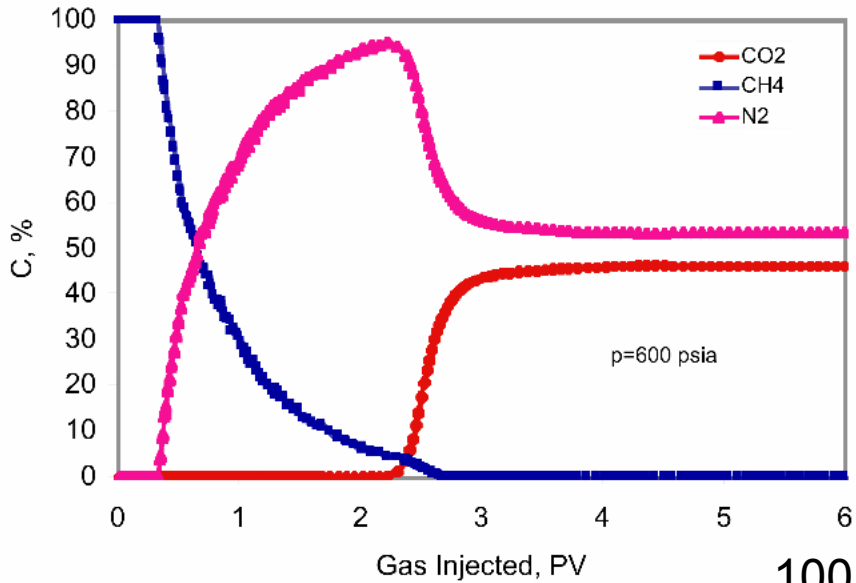




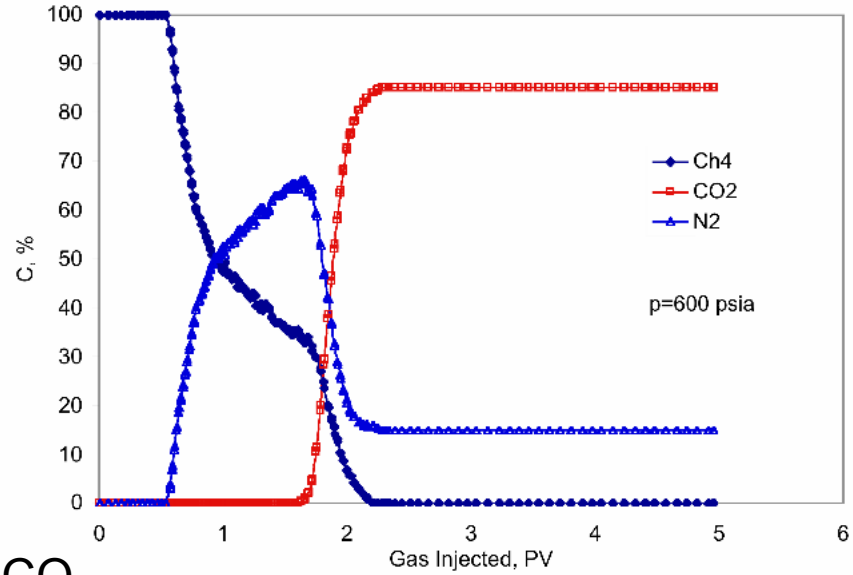
Mixed Gas (CO_2 and N_2)

Chromatographic Separation of CO_2 and N_2

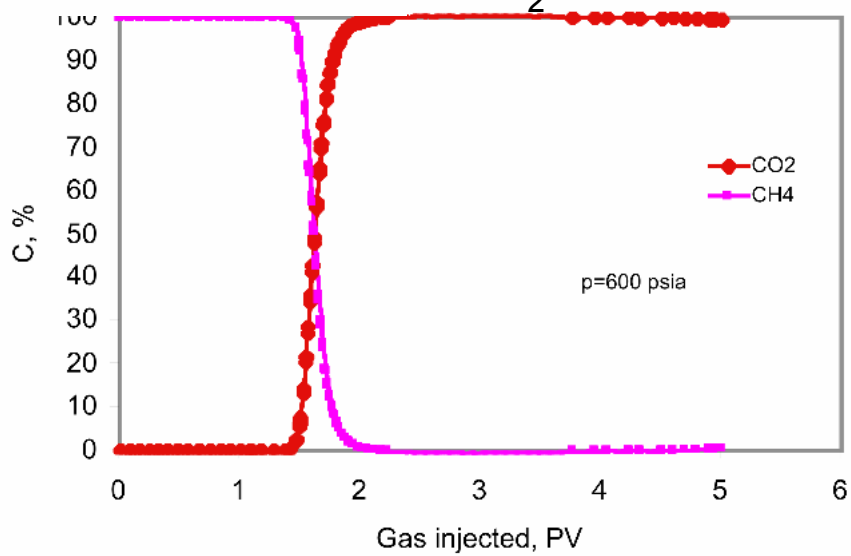
46% CO_2 54% N_2



85% CO_2 15% N_2

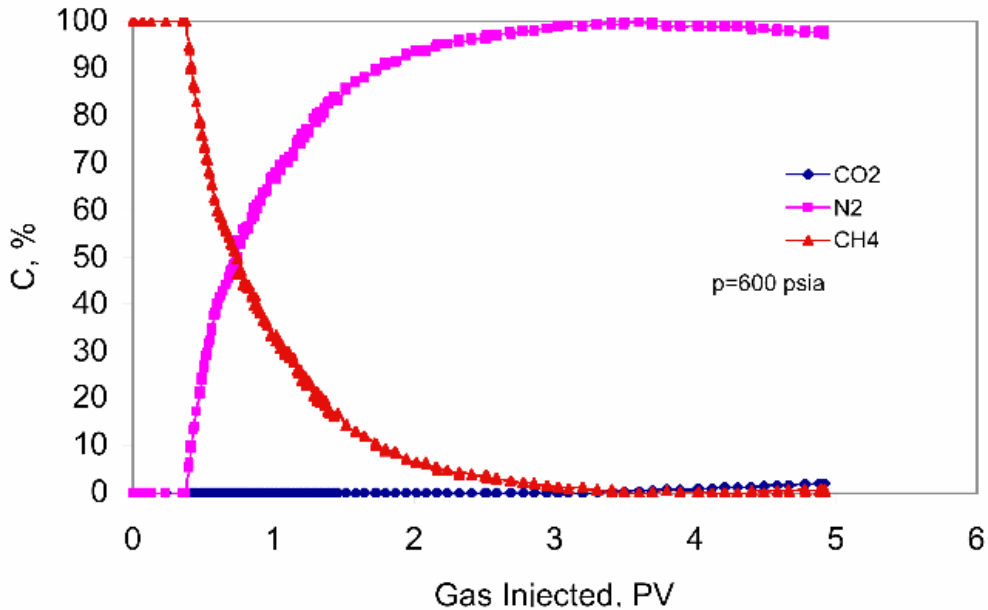


100 % CO_2

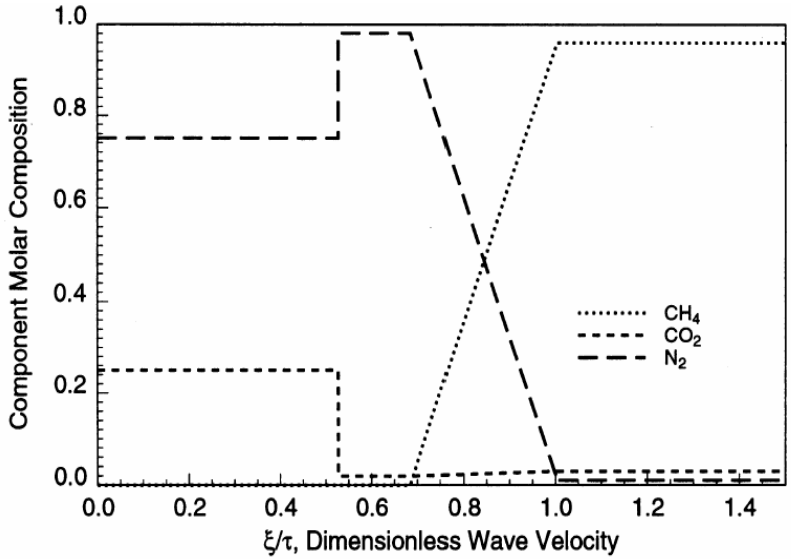


Comparison: CH_4 by 76% N_2+24% CO_2

Experimental

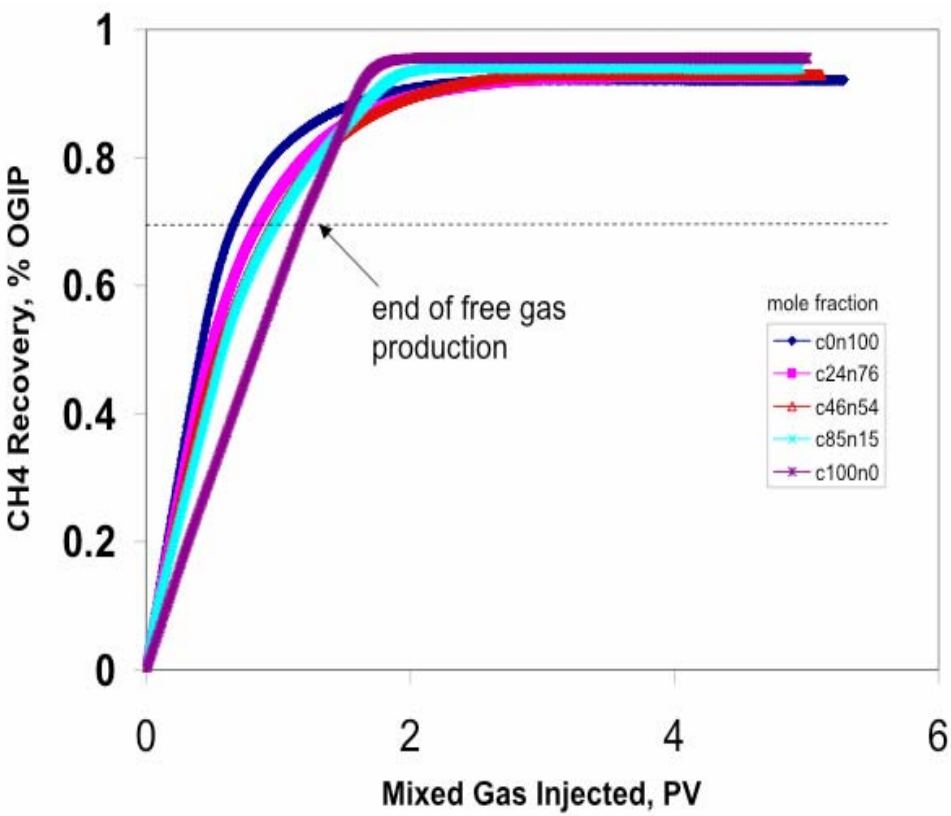


Analytical model by Zhu et al



CH_4 Recovery
%OGIP Recovered > 92% All Cases

Experimental



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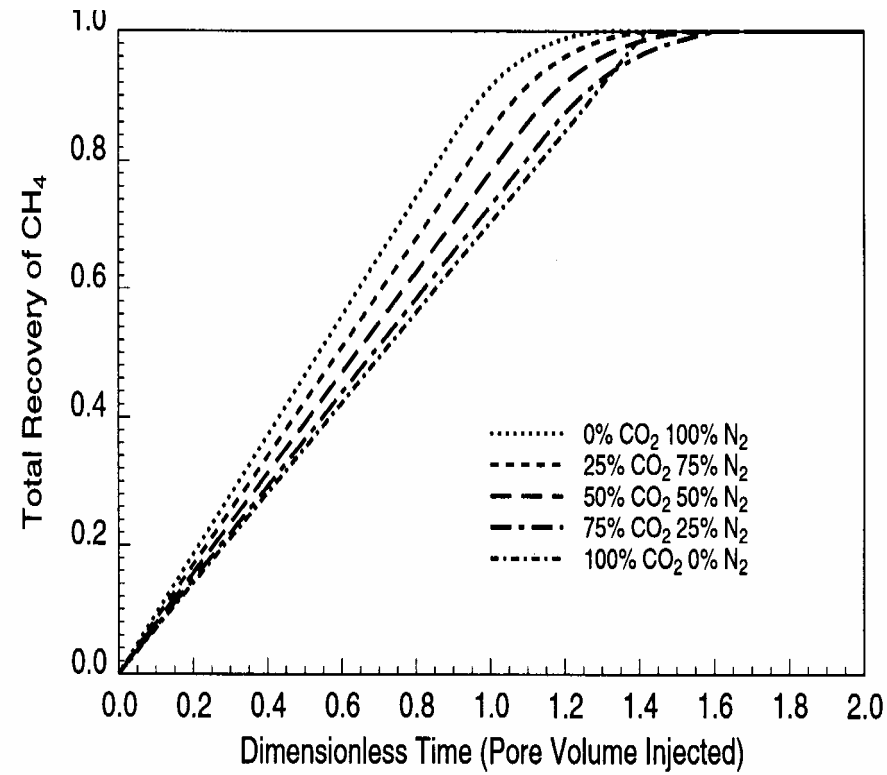

Conclusions

- **Pure and mixture CH_4, CO_2, N_2 adsorption on Wyoming PBR coal is well by the Langmuir Isotherm.**
  - **CO_2: CH_4 is about 3:1**
  - **CO_2: N_2 is about 8:1**
- **Significant hysteresis measured. It is a function of maximum adsorption pressure (scanning loops).**
- **Permeability decreases as pore space fills with immobile adsorbed gas**
  - **reduction in porosity available for flow**
  - **not necessarily swelling**
  - **some N_2 appears to preserve permeability**
- **CO_2 displacement displays piston-like behavior, but N_2 is more dispersed.**

Acknowledgement

- **This work was supported by Stanford University Global Climate and Energy Project (GCEP). Funding is acknowledged gratefully.**