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Storing Carbon Dioxide in Coalbeds

Tony Kavscek
Petroleum Engineering Department

**in collaboration with T. Chaturvedi, K. Jessen, W. Lin,
F. M. Orr Jr., G.-Q. Tang,**



Overview

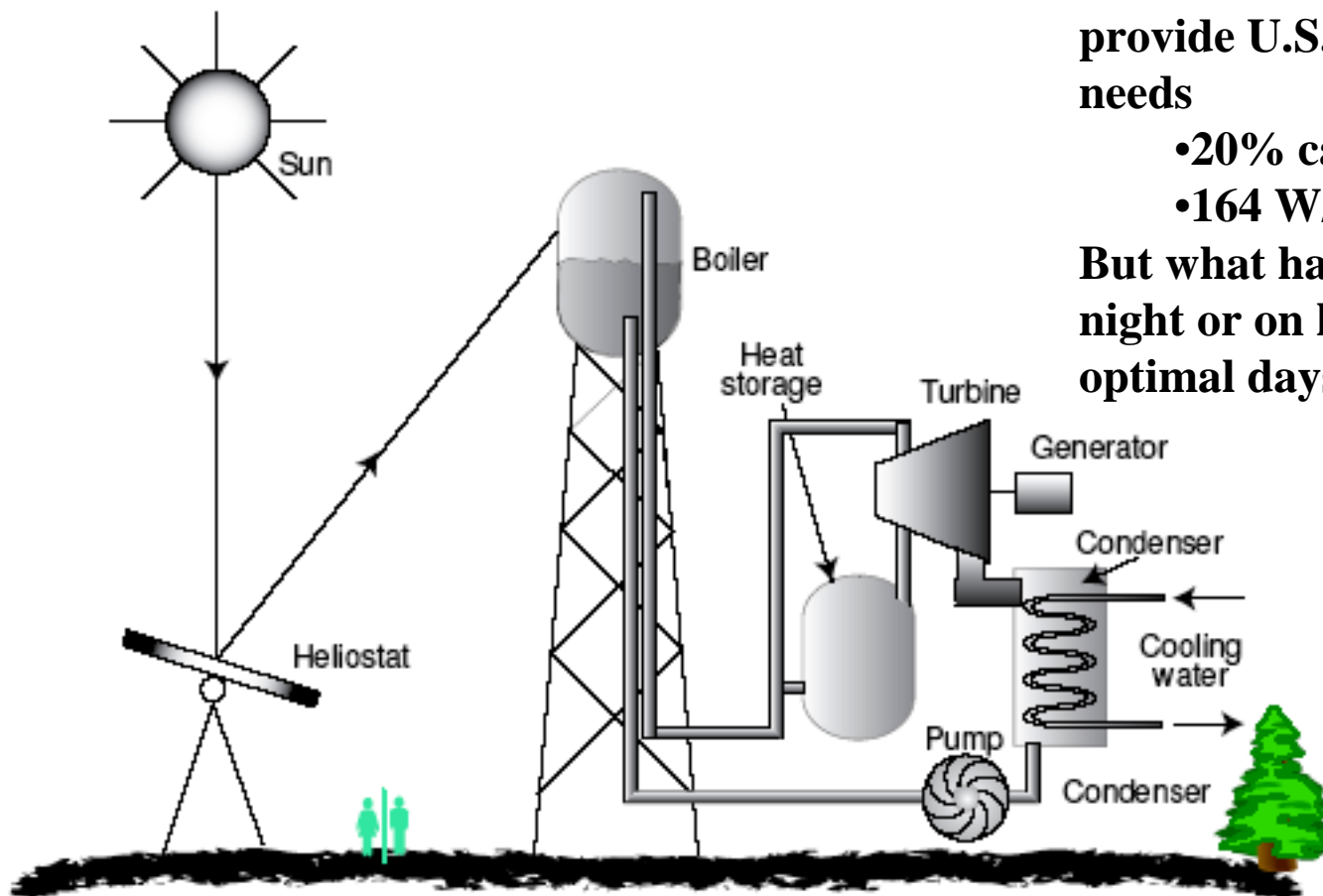


- Integration of enhanced coalbed methane (ECBM) and renewable energy
- Challenges for modeling ECBM processes with streamlines
- Conceptual/numerical model development
 - experimental program
 - permeability reduction
 - ECBM and CO₂ storage
- Looking forward
- Conclusions



Integration

Solar I Power Plant



1% of land area could provide U.S. energy needs

- 20% capture
- 164 W/m²

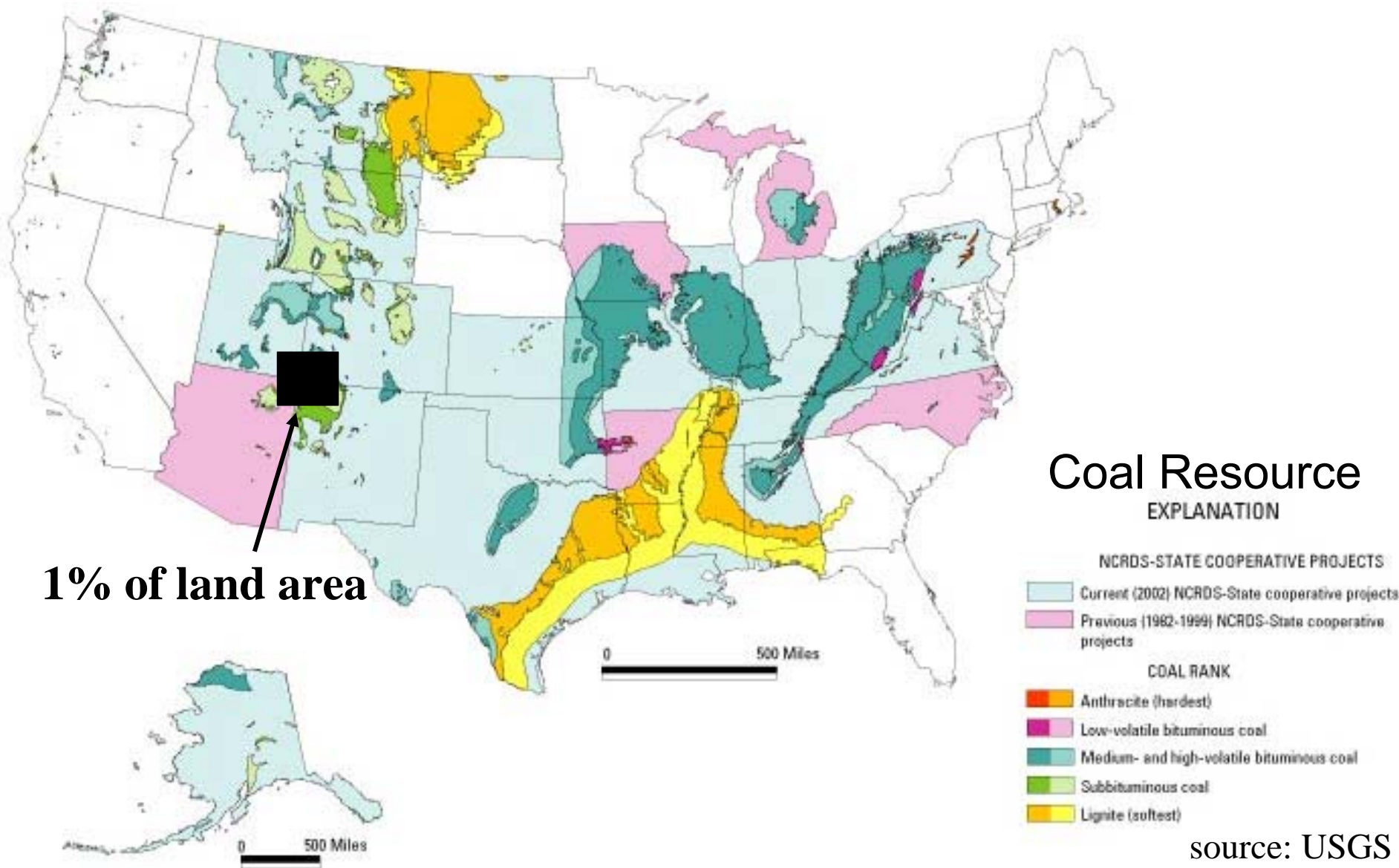
But what happens at night or on less than optimal days?

from A. DaRosa, Fundamentals of Energy Processes



Integration

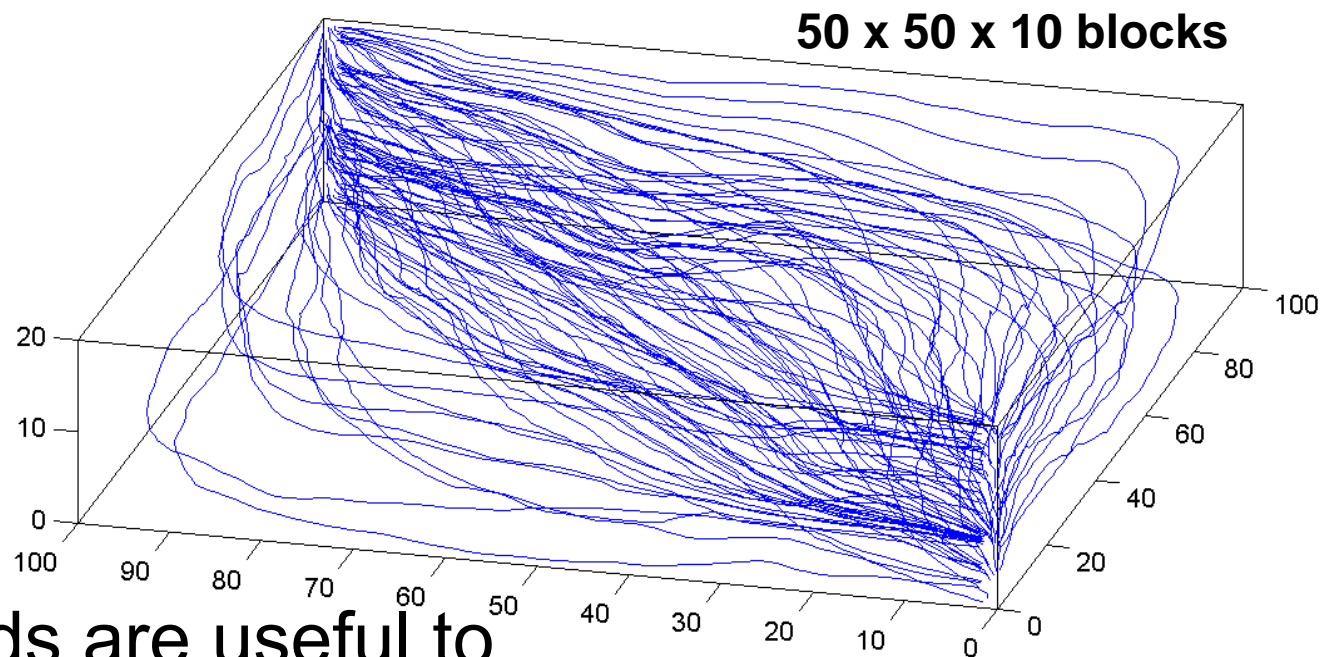
Renewables, enhanced CBM, sequestration



source: USGS



ECBM Prediction via Streamlines



- Such methods are useful to
 - predict where CO₂ is likely to flow
 - interpret the volume and space contacted
 - optimize injection and recovery operations
- What is the process model for ECBM with CO₂ storage?



Experimental Objective



- Establish a feasible $\text{CO}_2/\text{CH}_4/\text{N}_2$ 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:
 - adsorption/desorption behavior
 - permeability with respect to gas composition
 - recovery efficiency and CO_2 storage



Relevant Coalpack Data (Powder River Basin, WY)



As received



After grinding



| Coalpack | #1 | #2 | #3 |
|--------------------------------|-------|-------|-------|
| Size of coal particles, meshes | <60 | <60 | <60 |
| Length of the coalpack, cm | 25.0 | 25.0 | 25.0 |
| Diameter of the coalpack, cm | 4.25 | 4.25 | 4.25 |
| Porosity, % | 44 | 37 | 34 |
| Permeability, md | 144.0 | 43.0 | 26.3 |
| Weight of coal, g | 218.0 | 231.0 | 239.4 |
| S_{wi} , % | 0 | 0 | 8-10 |

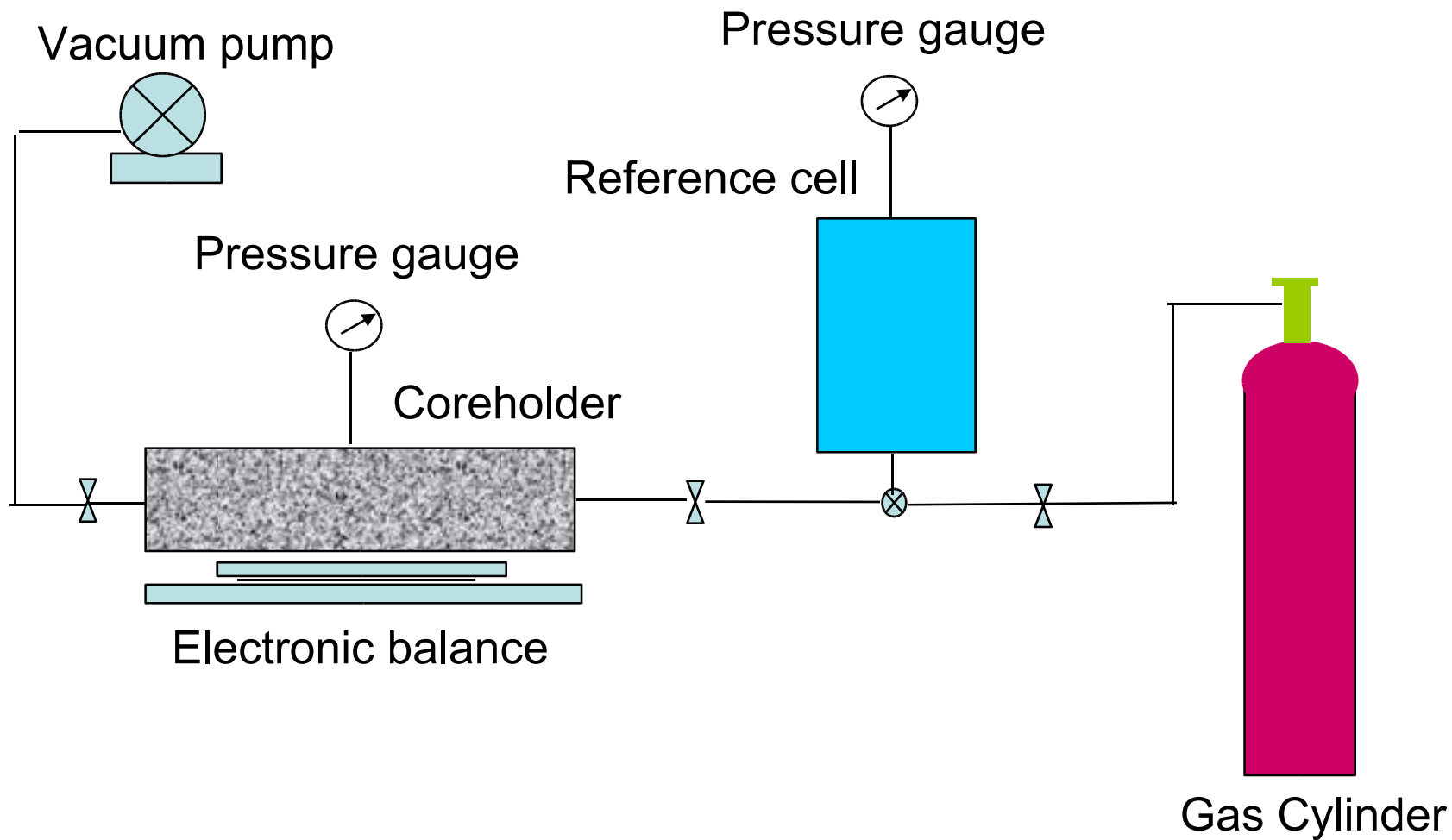


Adsorption/Desorption Phenomena



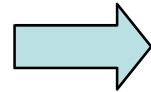
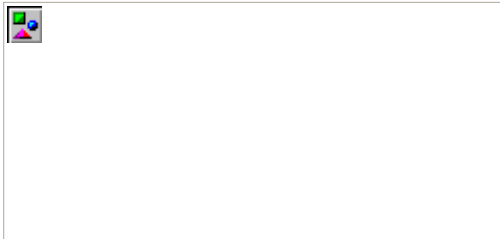
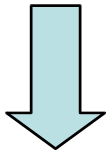
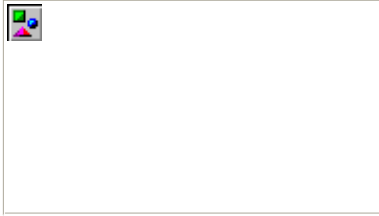
Experimental Setup

Adsorption/Desorption $\text{CO}_2/\text{N}_2/\text{CH}_4$

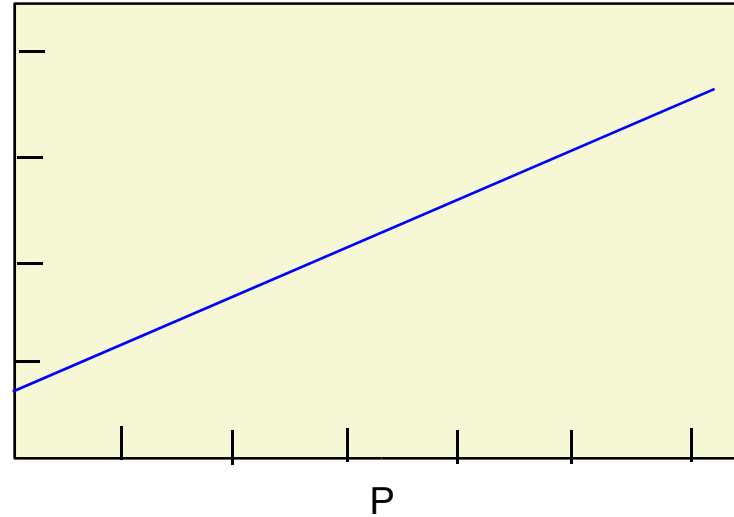




Langmuir Adsorption Isotherm: Pure Gas



P/V



V = gas adsorption

P = pressure

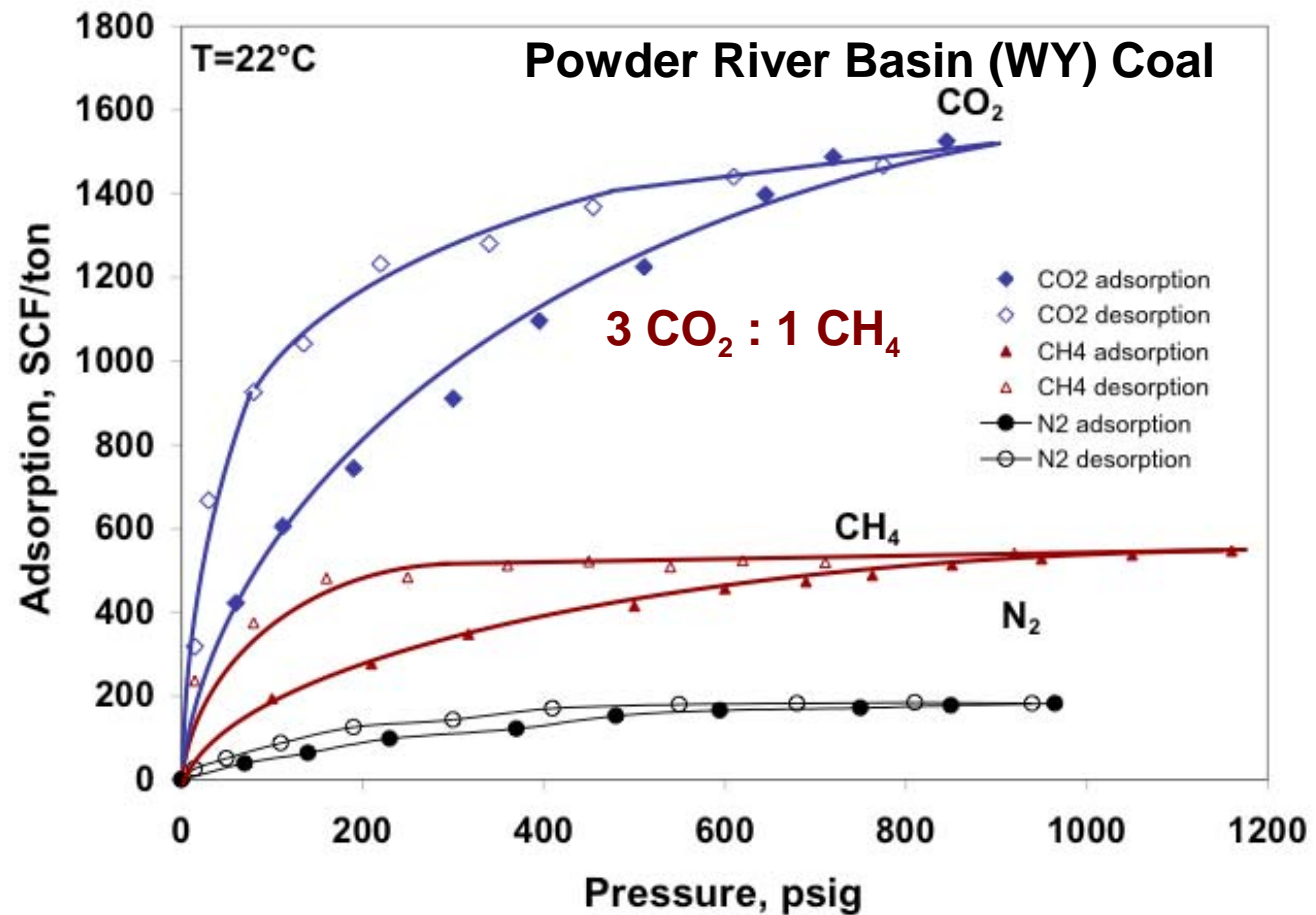
V_m = saturation adsorption constant

b = constant



Adsorption/Desorption

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

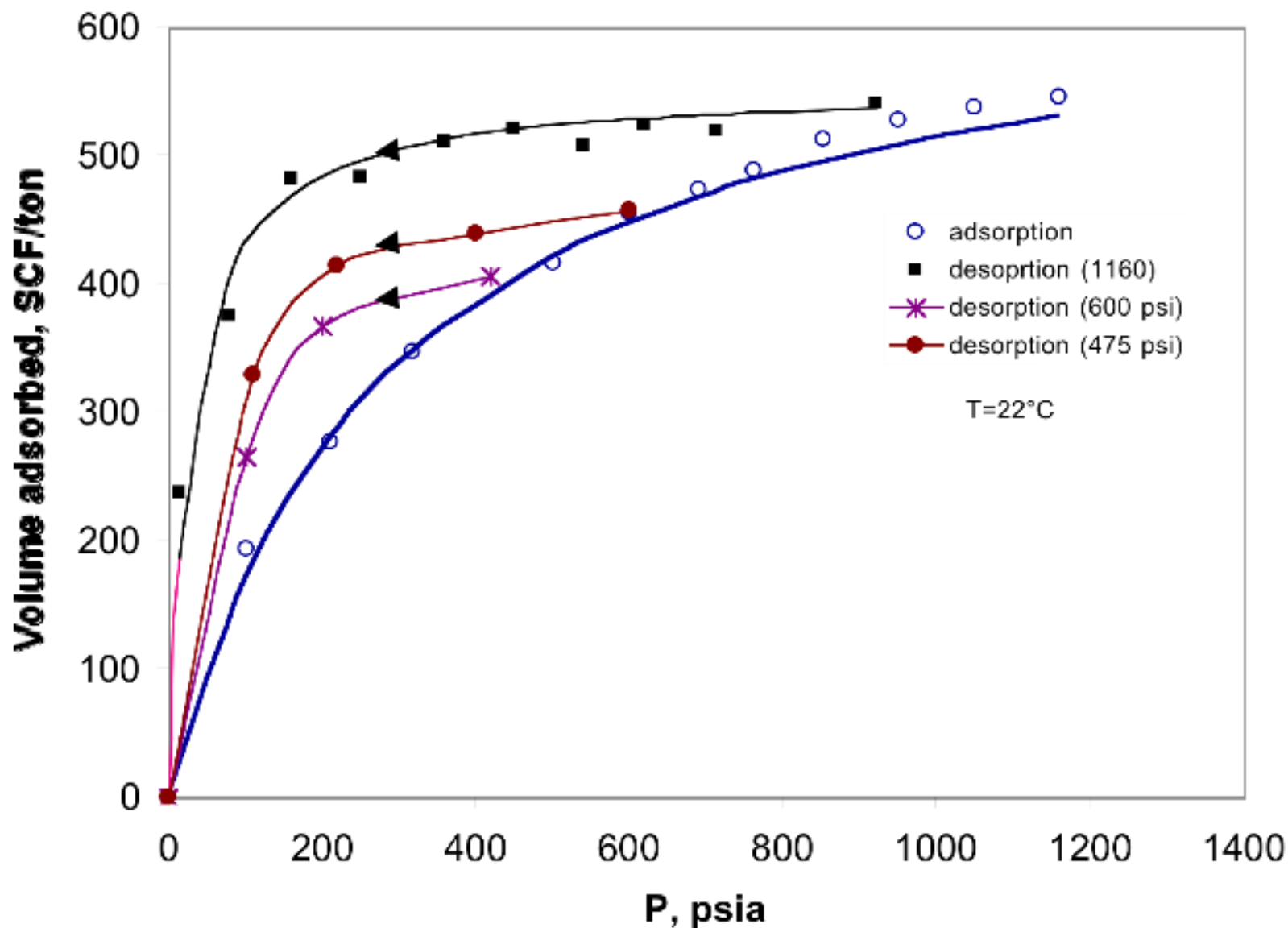




CH₄ Scanning Loops



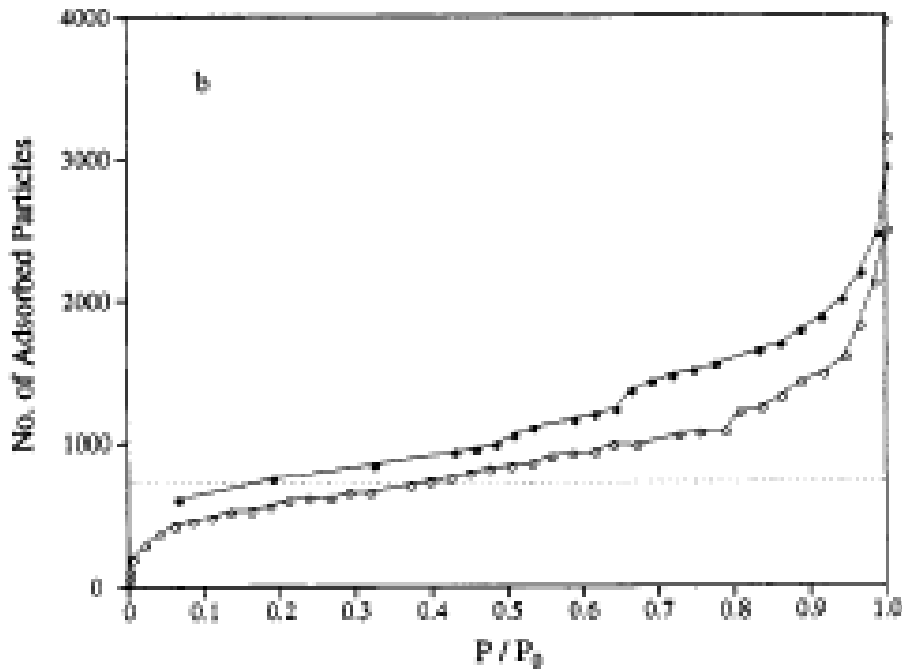
Initial pressure influences desorption hysteresis



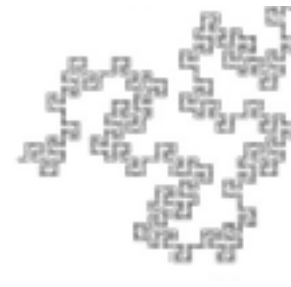


Why is there hysteresis?

Surface geometry heterogeneity—Seri-Levy and Avnir (1993) 




- Monte Carlo simulation
- rough surfaces

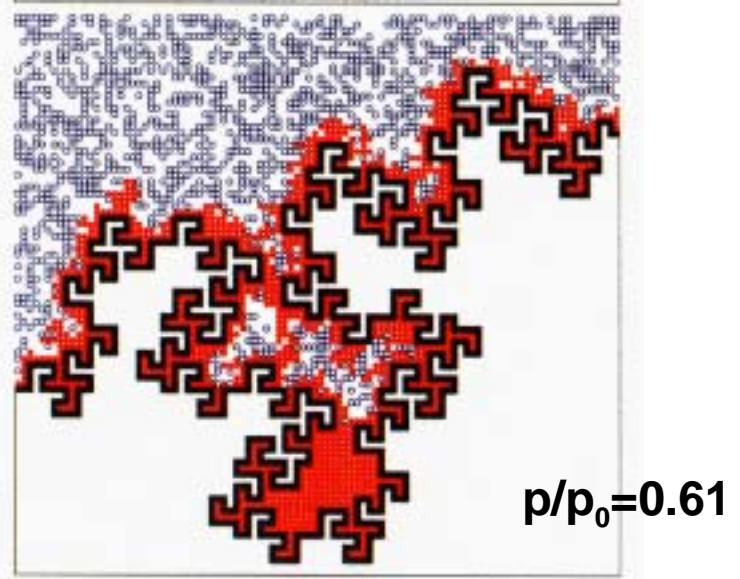
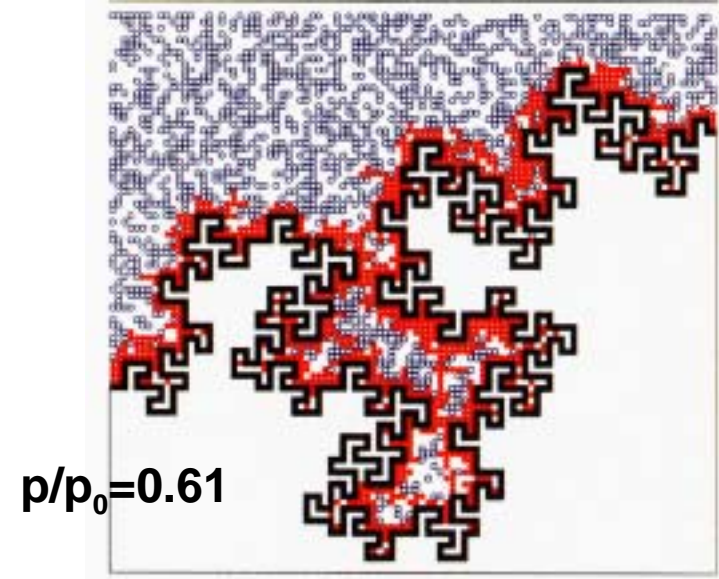
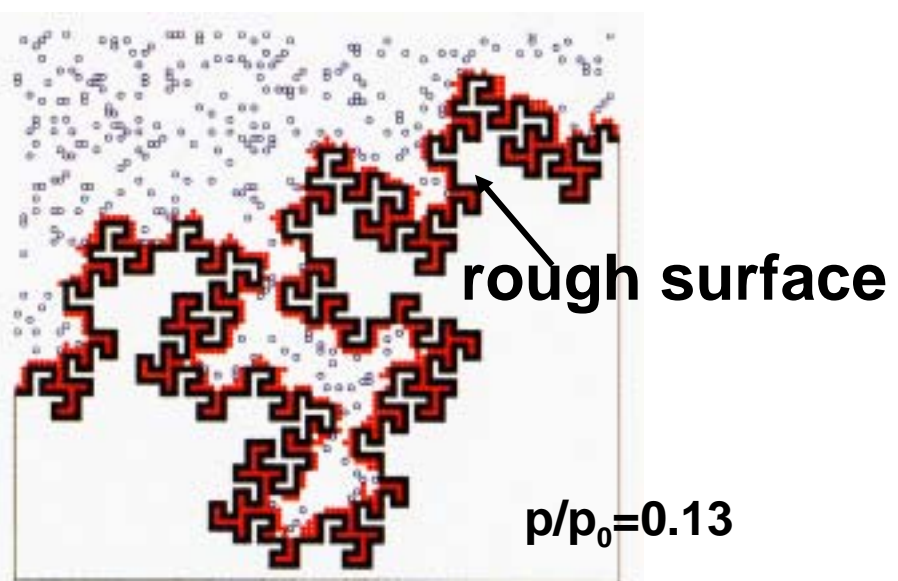
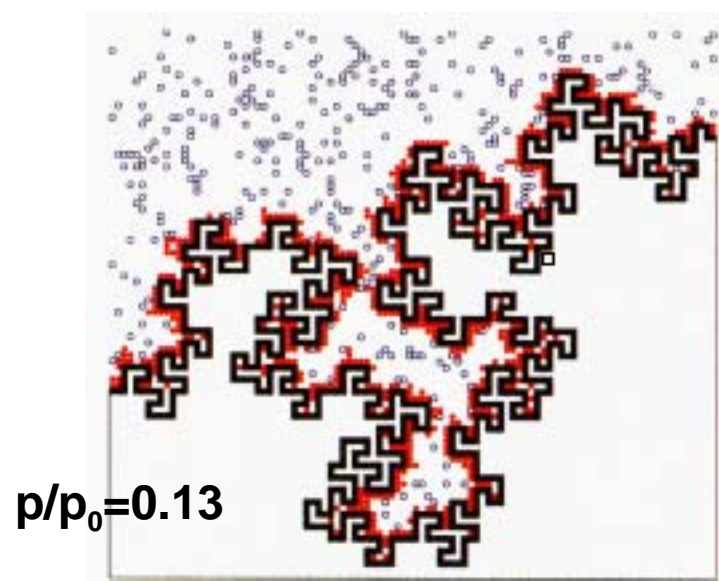


- various hysteresis curves obtained by modifying surface geometry



Why is there hysteresis?

Surface geometry heterogeneity—Seri-Levy and Avnir (1993) 





Extended Langmuir Isotherm: Binary Gas



J

V : adsorption

P =partial pressure

V_m =saturation adsorption constant

b =constant

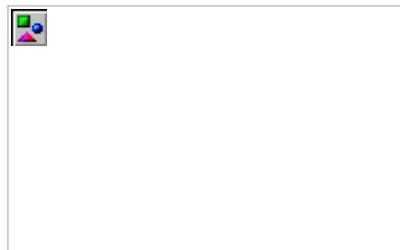
y =free gas mole fraction

α =selectivity ratio

x =sorbed gas mole fraction

i, j =gas components

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





Summary of Langmuir Constants



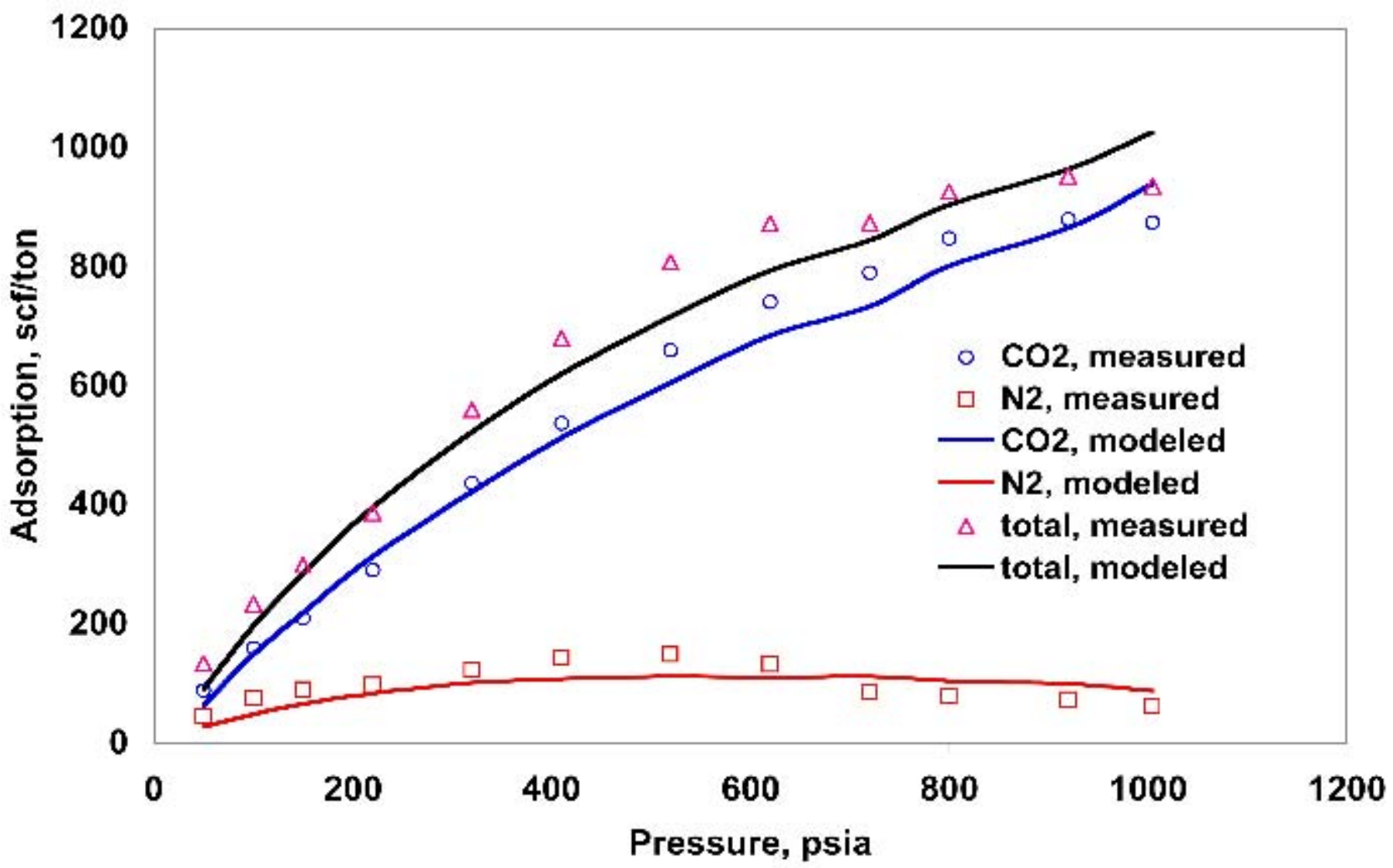
| Constants | V_m | b | α |
|----------------------------------|--------|--------|----------|
| CH ₄ | 714.8 | 0.0029 | |
| CO ₂ | 1666.7 | 0.0062 | |
| N ₂ | 263.2 | 0.0025 | |
| CH ₄ +CO ₂ | | | 0.2006 |
| CH ₄ +N ₂ | | | 3.1503 |
| CO ₂ +N ₂ | | | 15.705 |



CO₂+N₂ Mixture Adsorption



Extended Langmuir Appears to be Acceptable

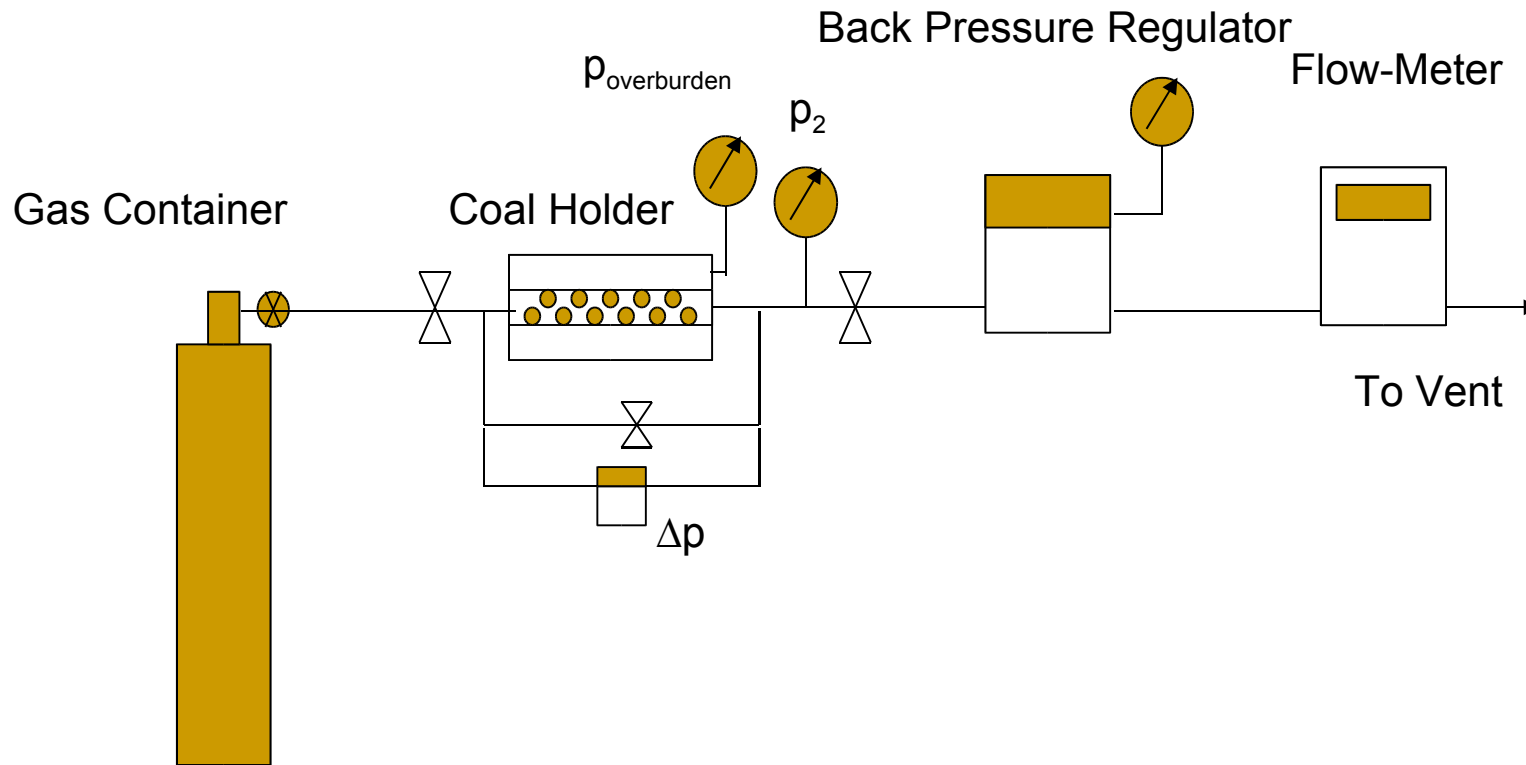




Permeability Versus Gas Composition (CH₄, N₂, CO₂)



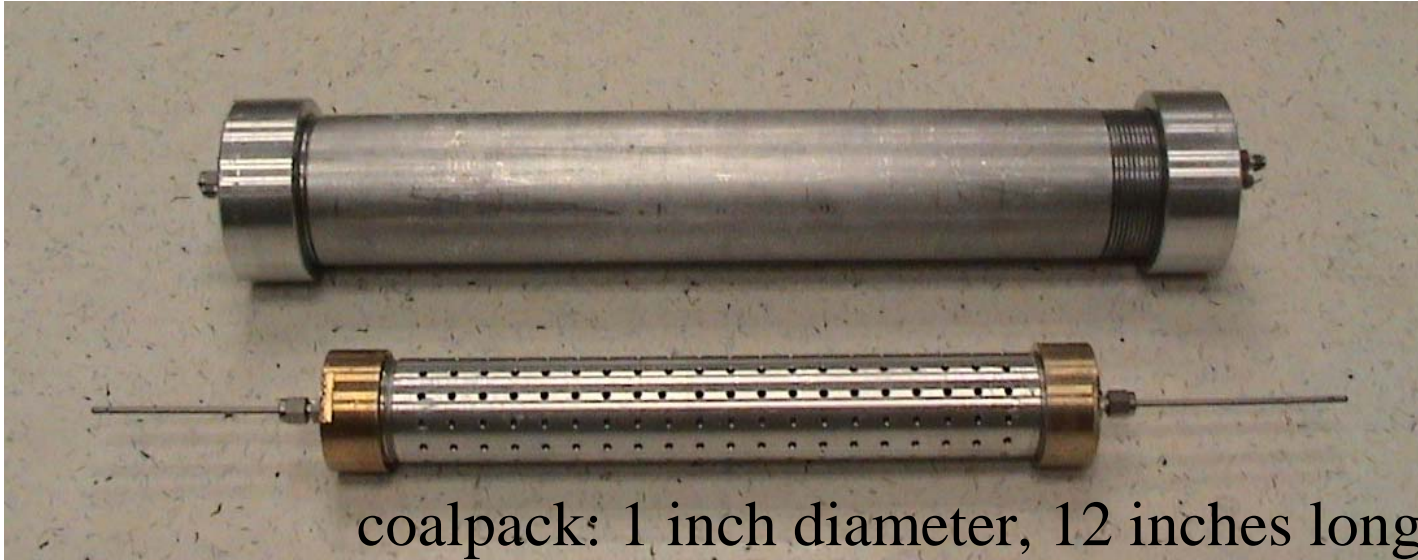
Flow Through Apparatus



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



Core Holder

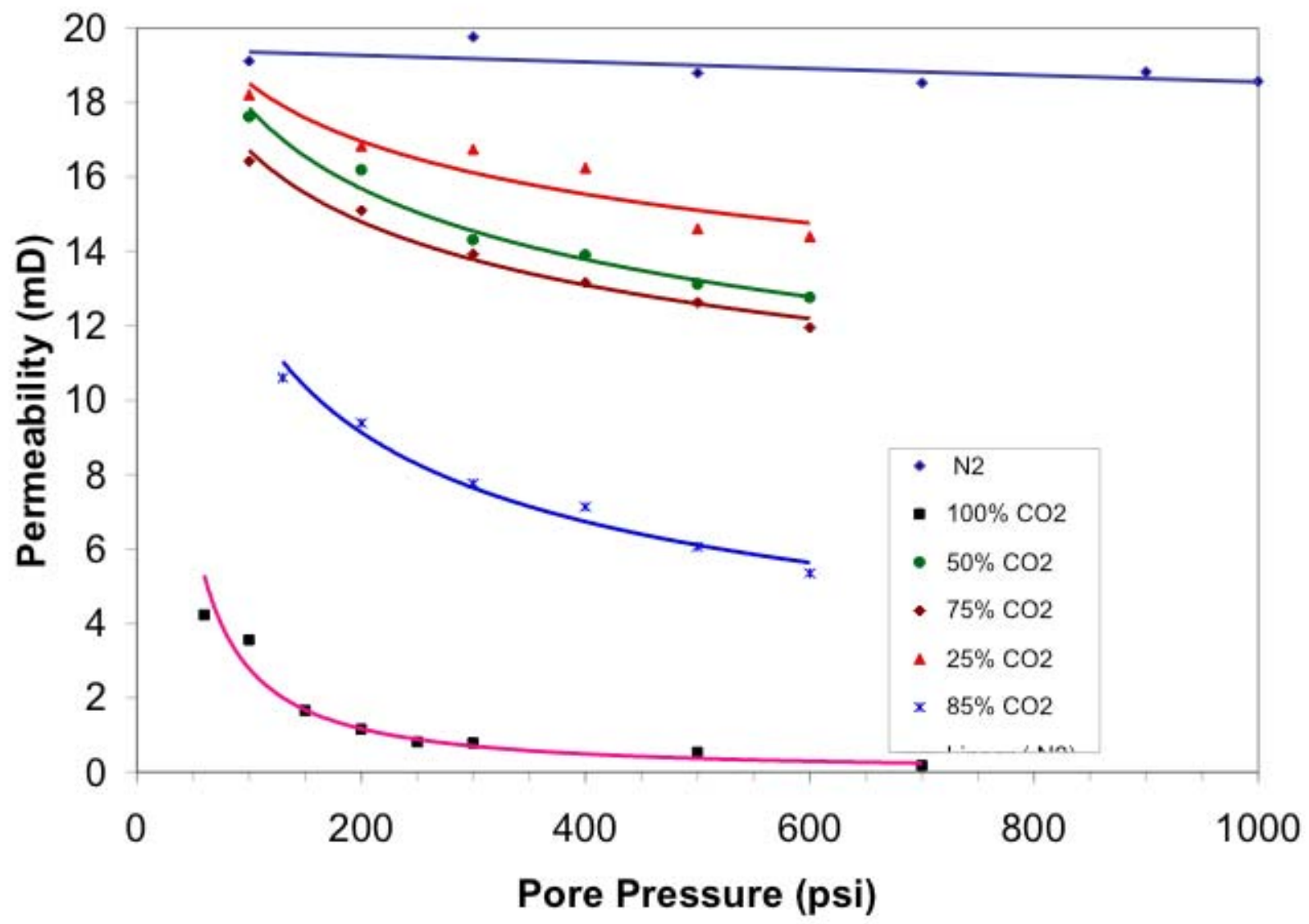




Steady State Permeability

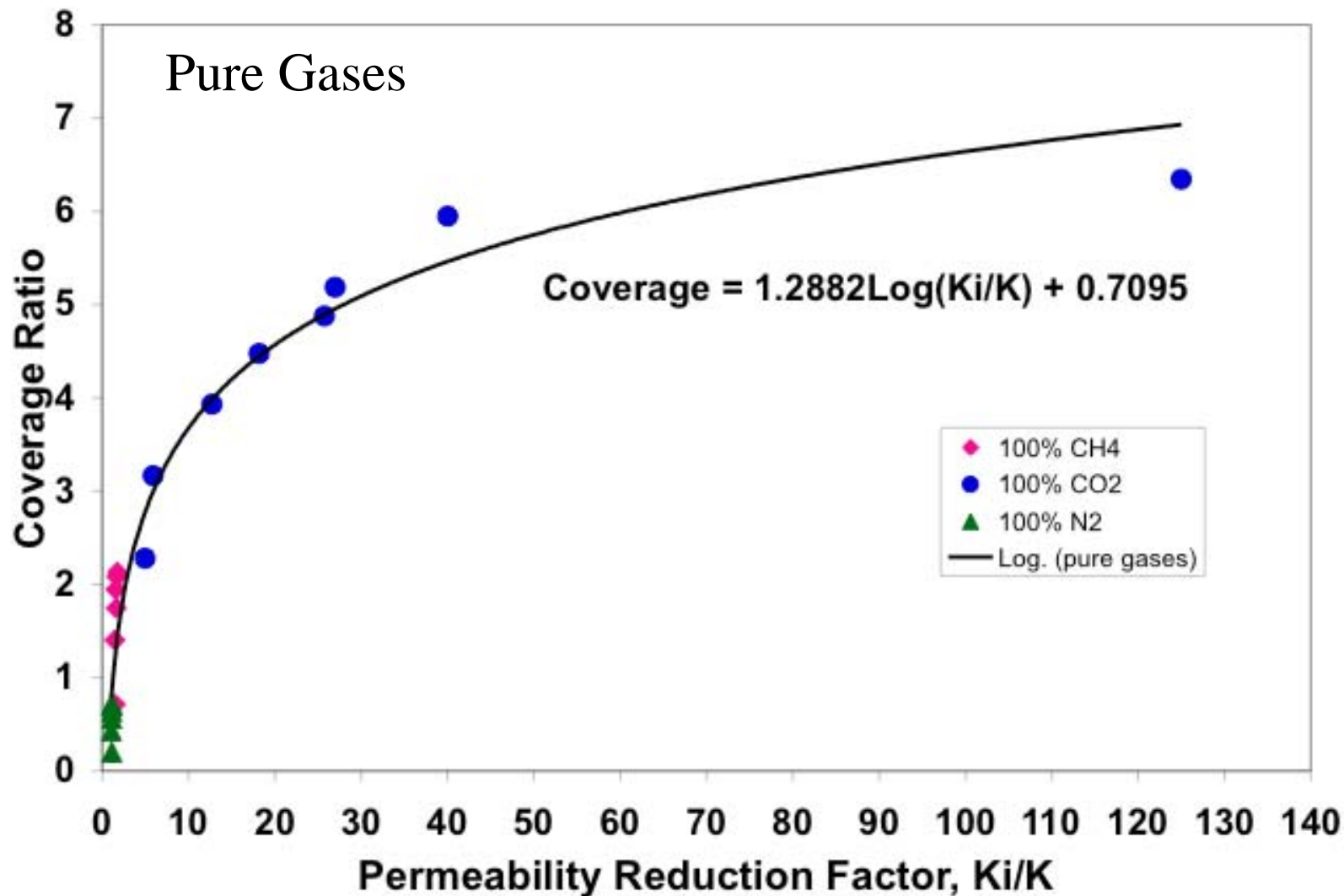


$$P_{\text{confining}} - P_{\text{pore}} = 400 \text{ psi}$$



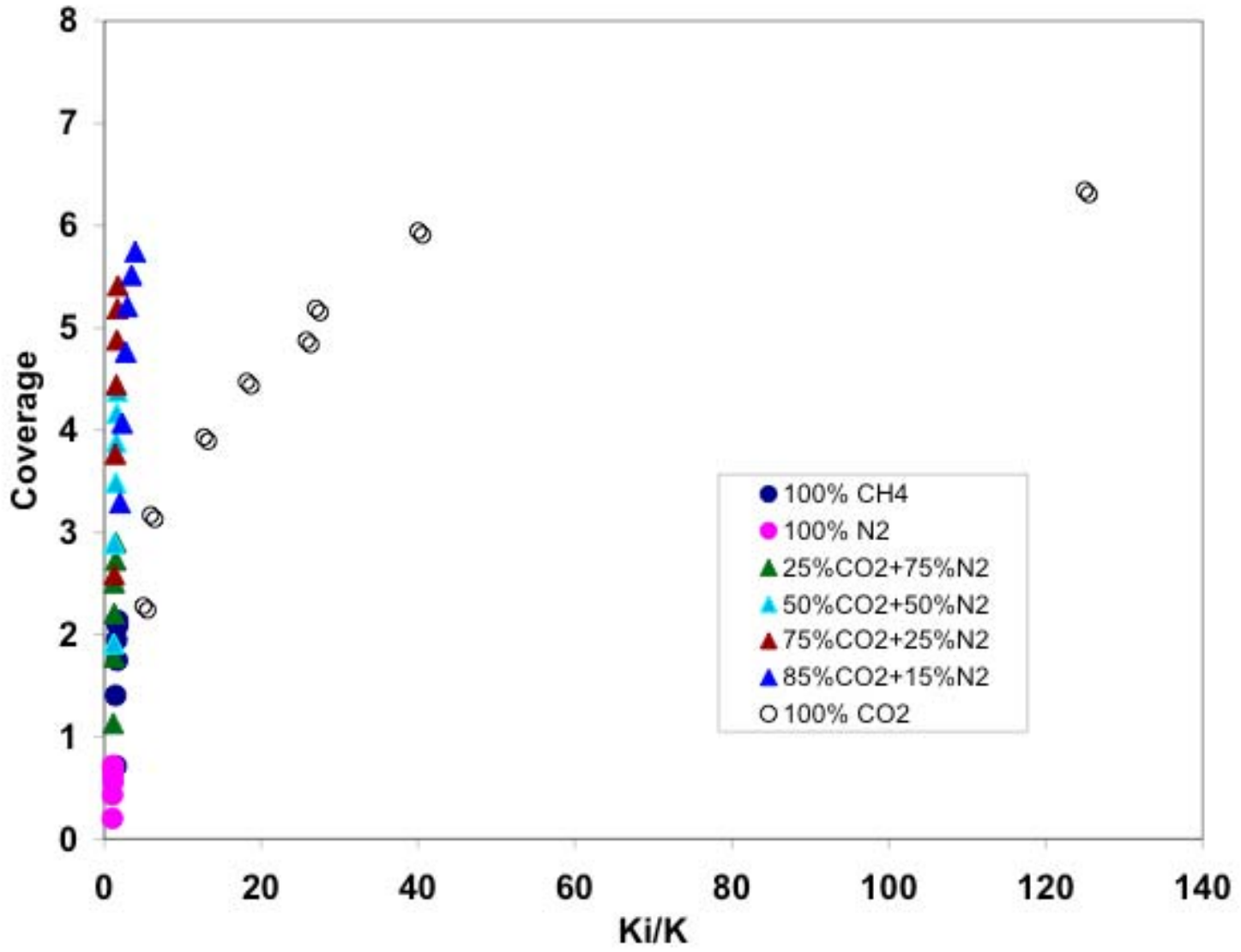


Permeability Reduction Correlates With Surface Coverage





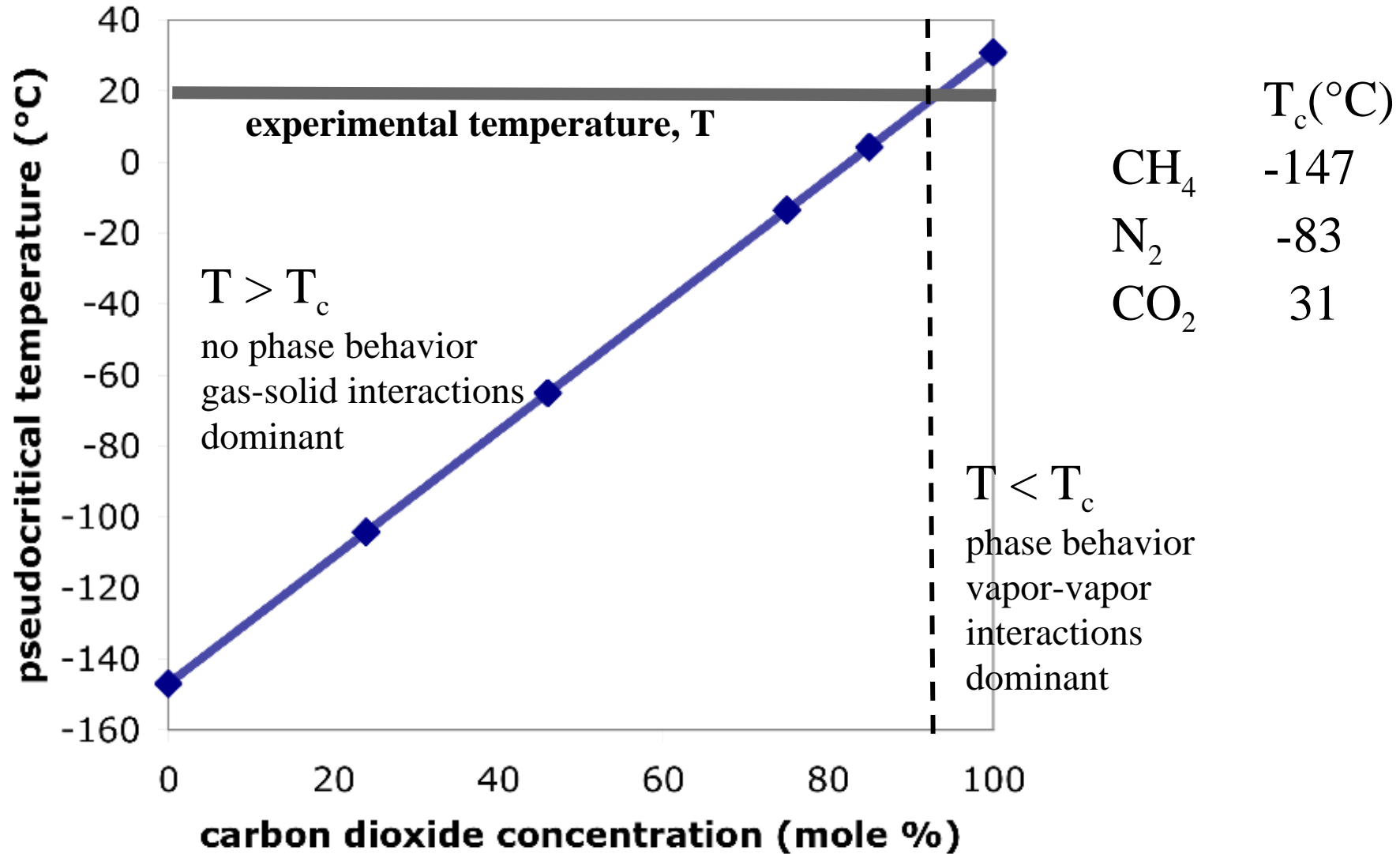
Coverage vs Permeability Reduction Pure and Mixed Gases





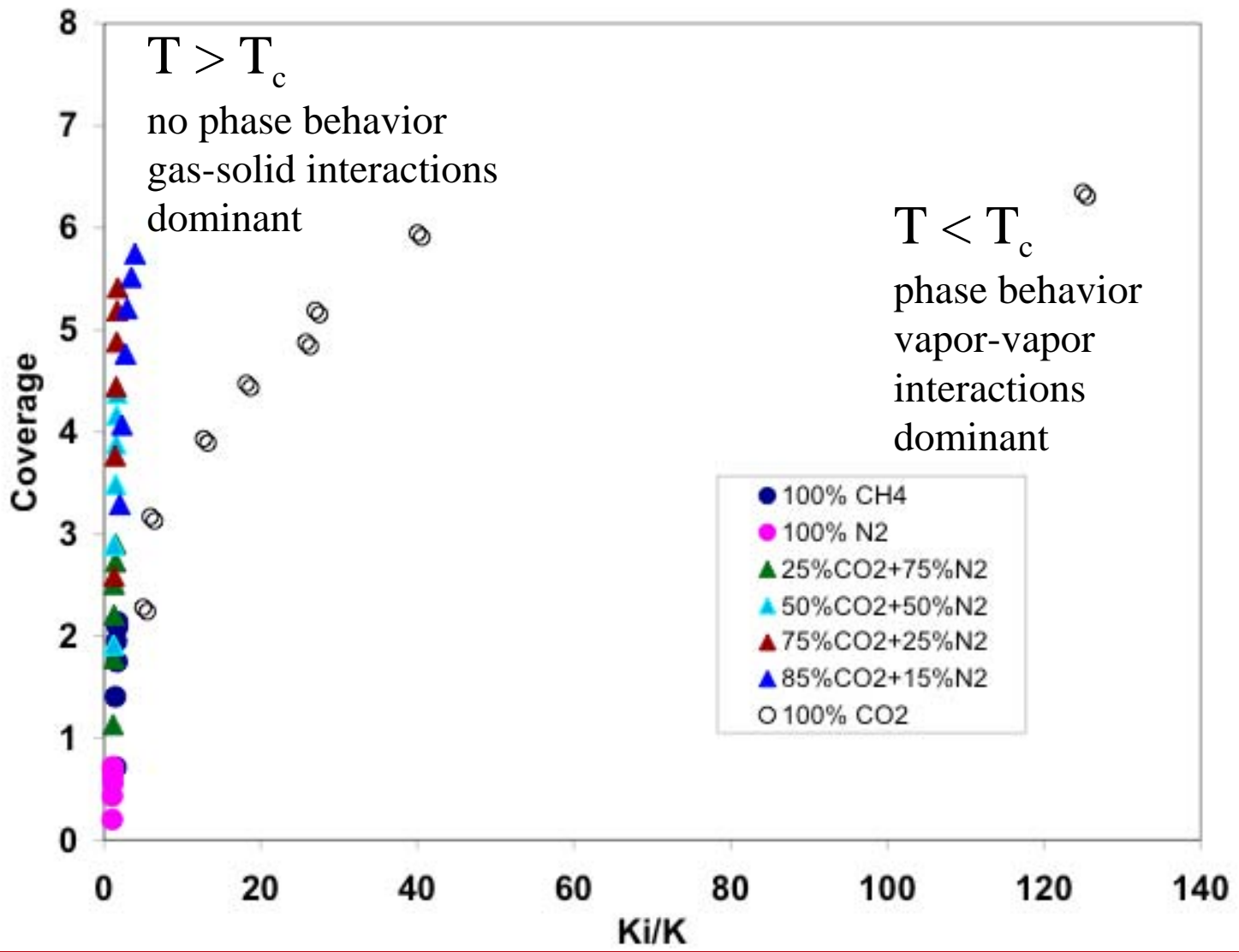
Permeability Reduction

Phase Behavior (CO₂/N₂)





Coverage vs Permeability Reduction Pure and Mixed Gases





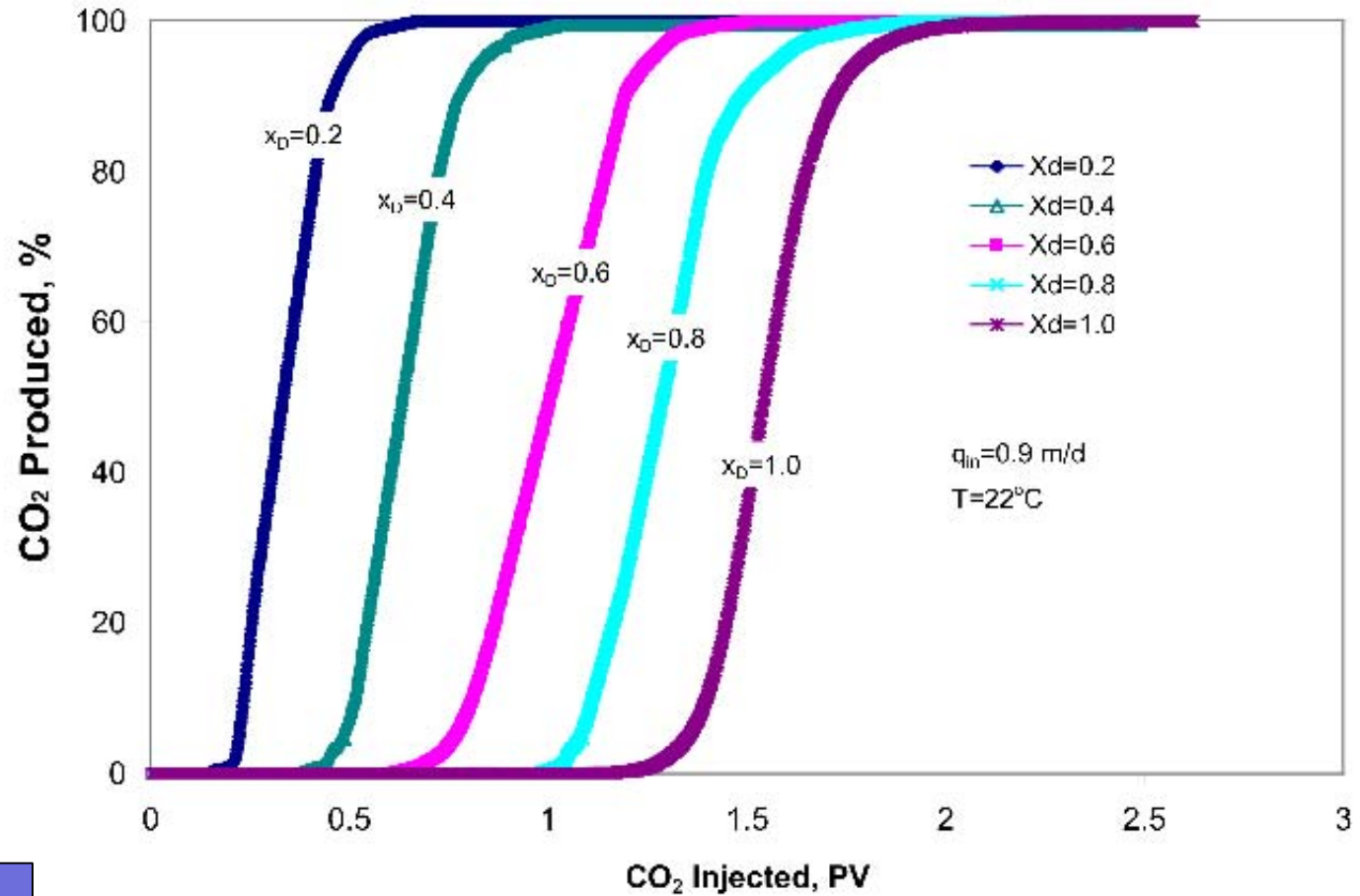
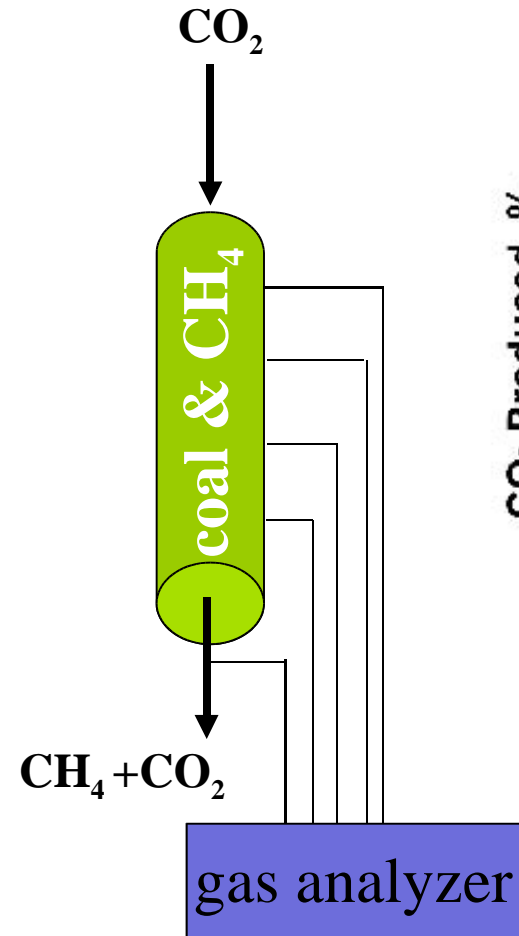
ECBM and CO₂ Storage



CO₂ Displacing CH₄



Piston like advance of CO₂





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% CO₂, 0% N₂ (c100n0)

-85% CO₂, 15% N₂ (c85n15)

-46% CO₂, 54% N₂ (c46n54)

-24% CO₂, 76% N₂ (c24n76)

-0% CO₂, 100% N₂ (c0n100)



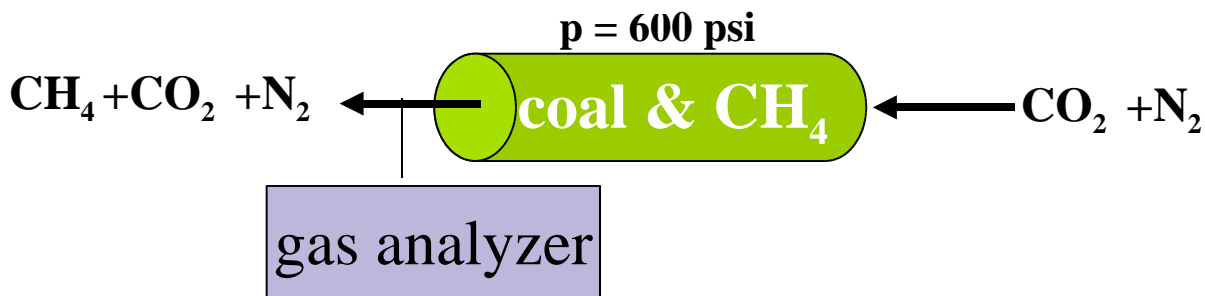
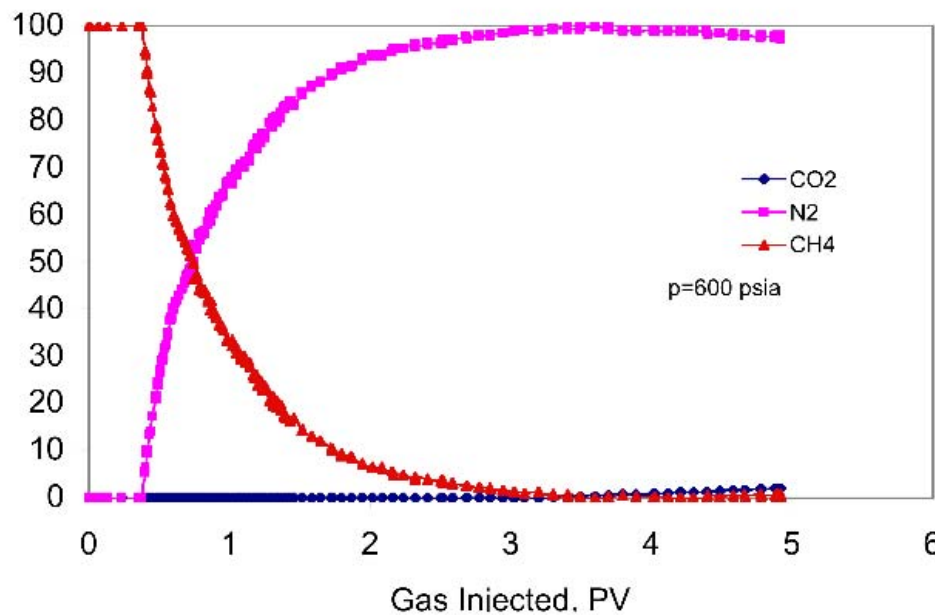
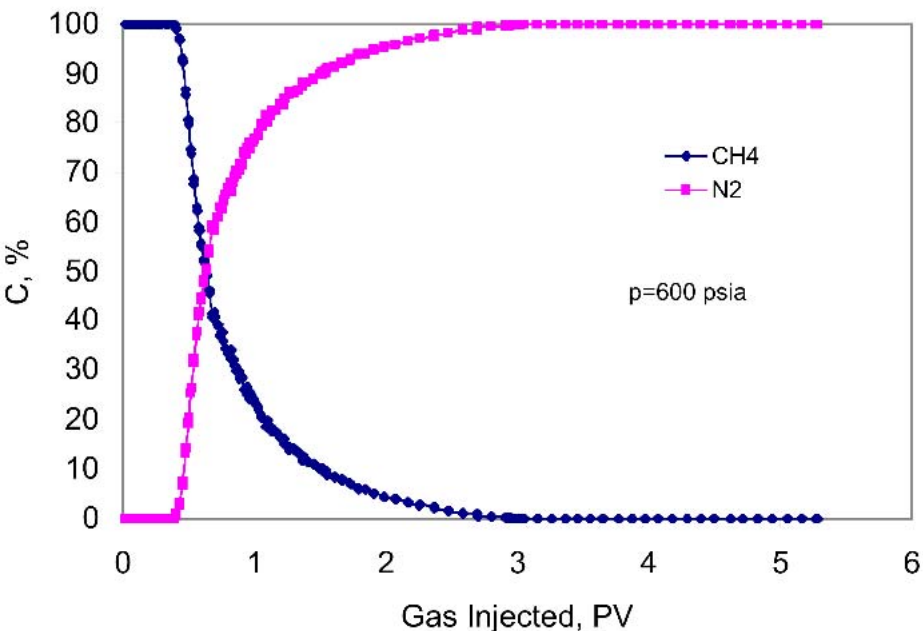
Mixed Gas (CO₂ and N₂)



Chromatographic Separation of CO₂ and N₂

0% CO₂

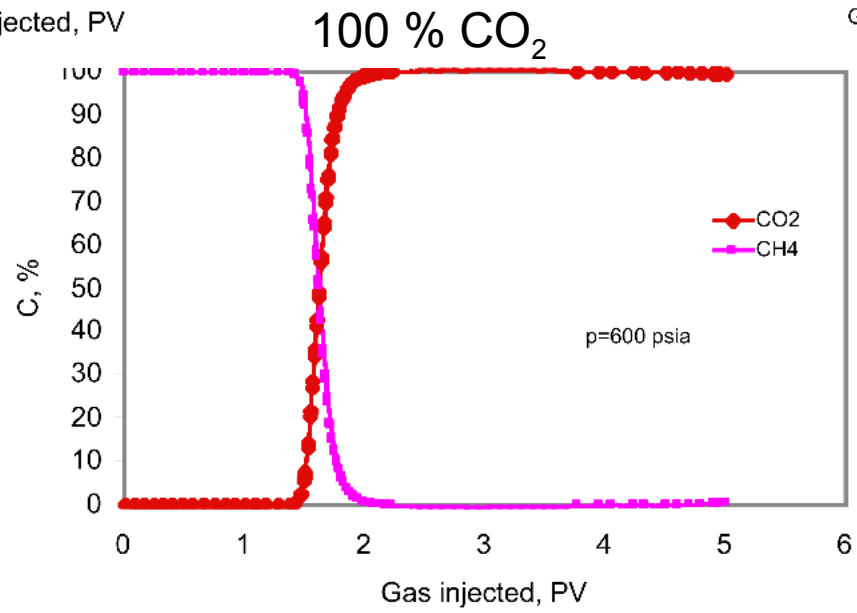
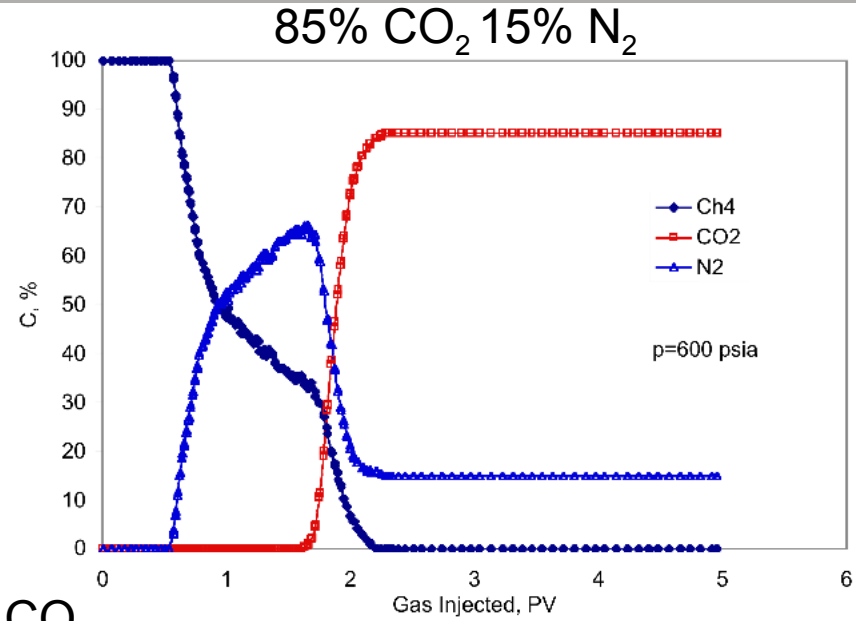
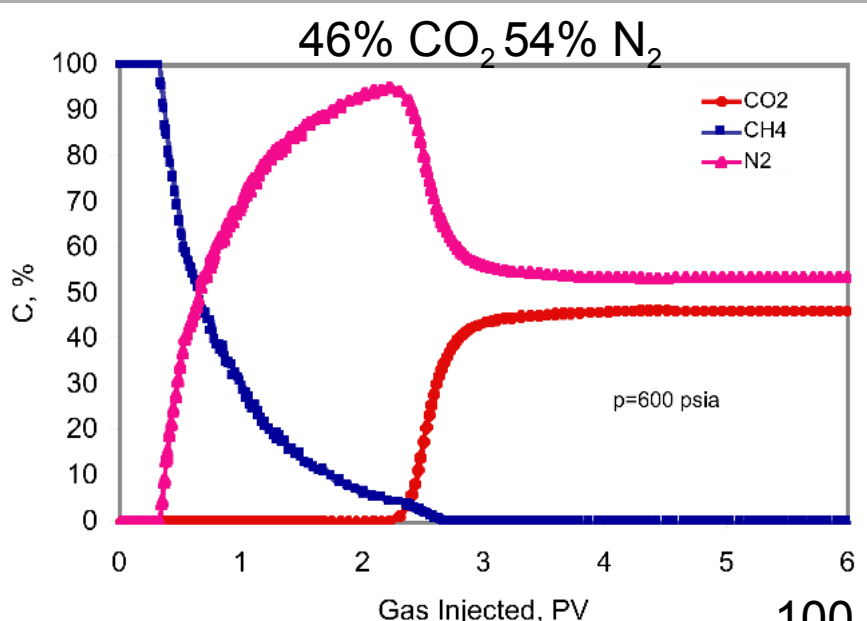
24% CO₂ 76% N₂





Mixed Gas (CO₂ and N₂)

Chromatographic Separation of CO₂ and N₂

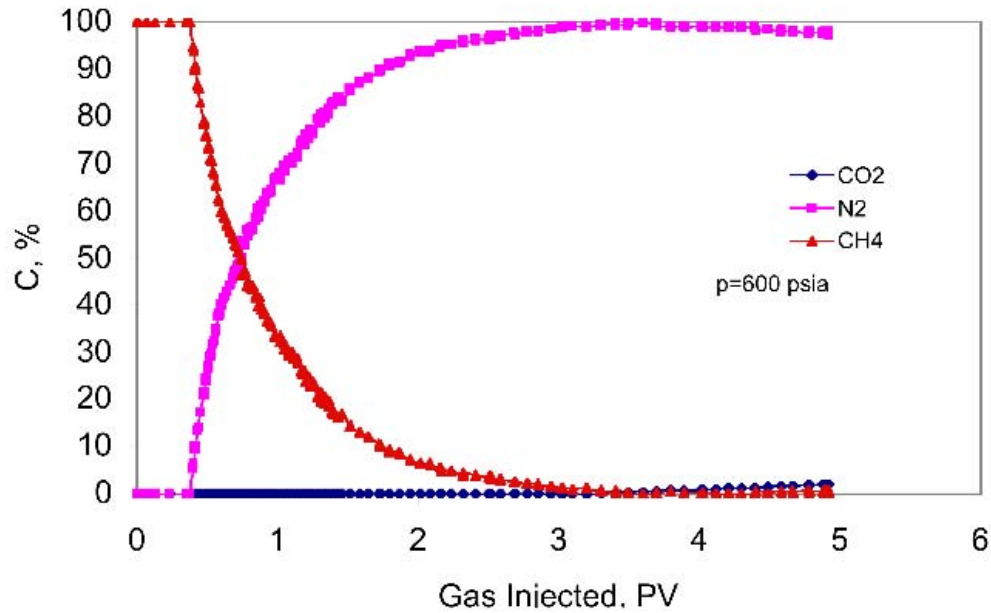




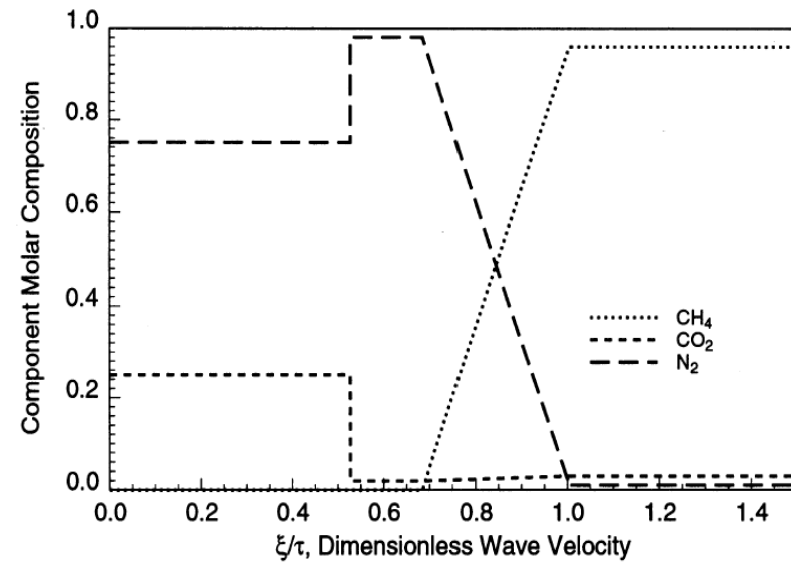
Comparison: 76% N₂+24% CO₂



Experimental



Analytical model by Zhu et al



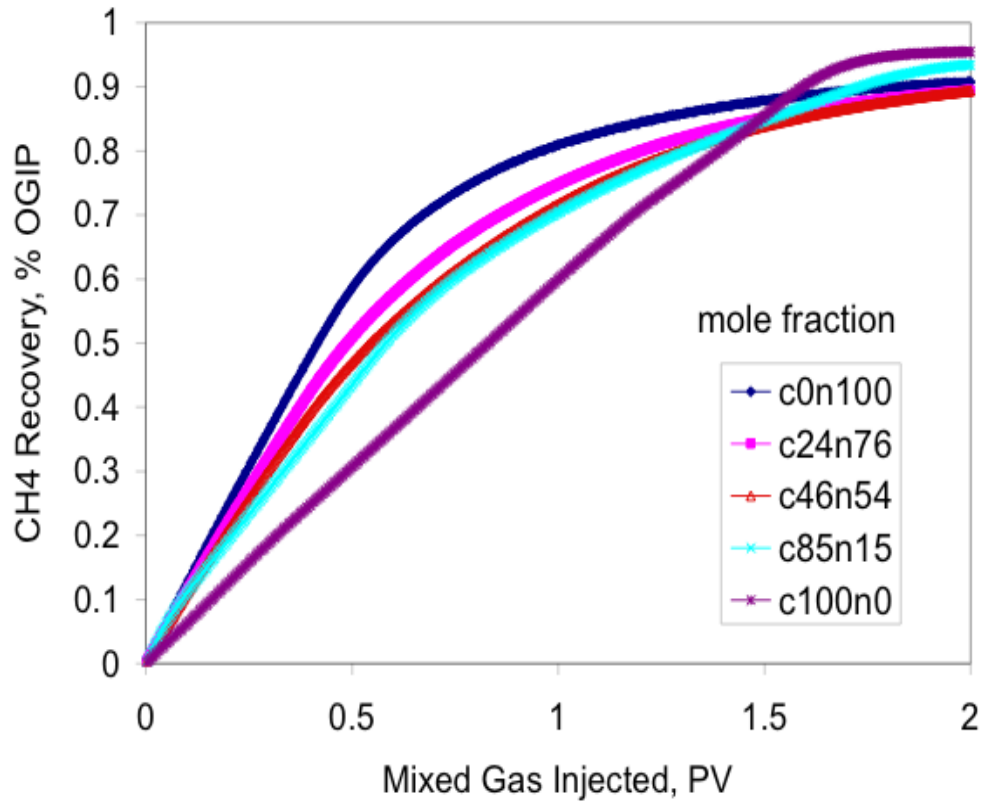


CH₄ Recovery

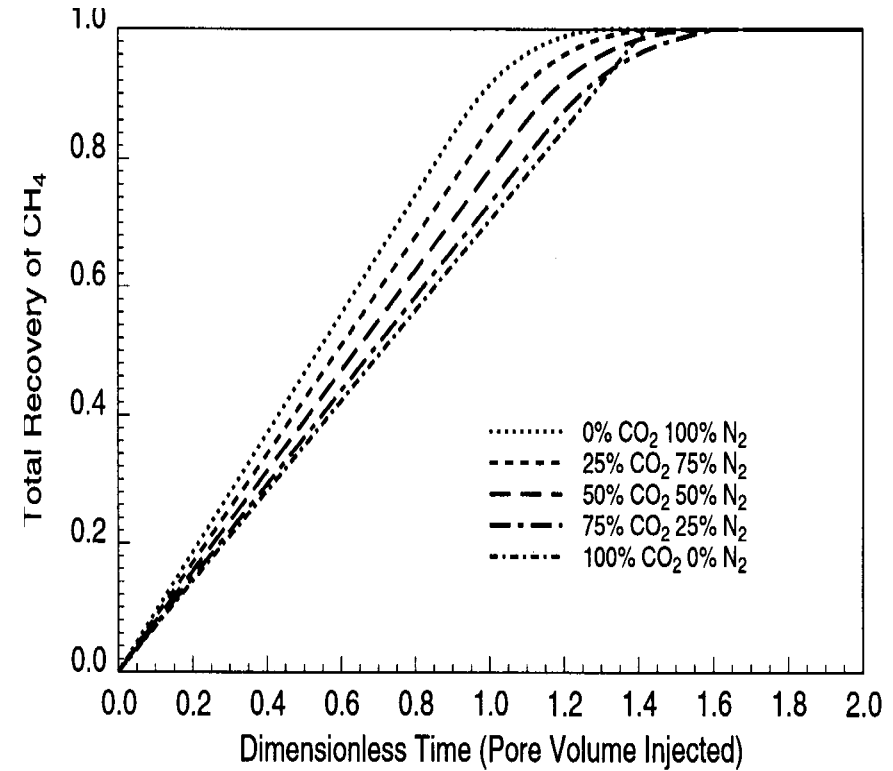


%OGIP Recovered > 92% All Cases

Experimental



Analytical model by Zhu et al





Looking Forward



- Permeability of coal to supercritical CO₂ ($T > T_c$)
- N₂ permeability preservation wrt to geological setting (T and P)
- Effect of moisture
 - wettability as pH approaches 3.5
- Permeability versus gas composition under triaxial stress
- Verification of analytical and numerical models
 - dry coal: ternary systems
 - wet coal: quaternary systems



Conclusions



- Pure and mixture CH_4 , CO_2 , N_2 adsorption on Wyoming PBR coal is well described 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



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