GEO-SEQ Project

Numerical Model Comparison Study for Greenhouse Gas Sequestration in Coalbeds – History Match Results

David H.-S. Law and W. D. (Bill) Gunter

Alberta Research Council (ARC) Inc.

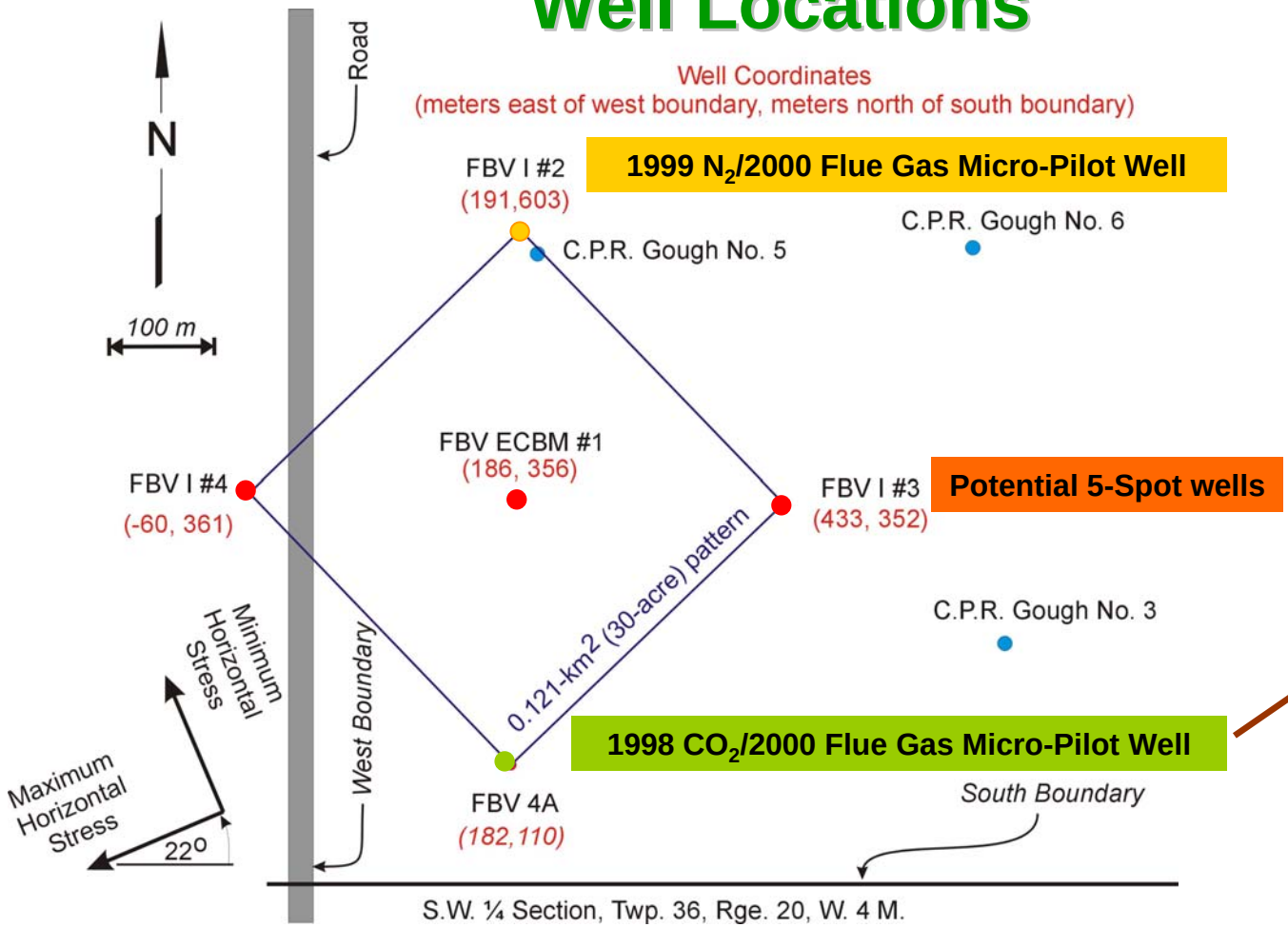
Edmonton, Alberta Canada

Test Problems

Model Attributes Tested	Part I CO_2 (Single Well & 5-Spot)	Part II Flue Gas (Single Well & 5–Spot)	Part IIIA CO_2 (5–Spot)	Part IIIB CO_2 (5–Spot)	Part IV CO_2 & Flue Gas (Field Tests)
Multiple Gas Components	2	✔	2	2	✔
Dual Porosity Approach	✘	✘	✔	✘	✔
Mixed Gas Diffusion (Different Diffusion Rates)	✘	✘	✔	✘	✔
Mixed Gas Sorption (Extended Langmuir Model)	✔	✔	✔	✔	✔
Stress Dependent Permeability & Porosity	✘	✘	✘	✔	✔
Coal Shrinkage (Primary Process)	✘	✘	✘	✔	✔
Coal Shrinkage/Swelling (ECBM Processes)	✘	✘	✘	✘	✔

Part IV: Field Tests
History Match Field Data

Well Locations



- CMG
- TNO
- ARI
- BP
- Imperial College
- Shell

Two micro-pilot tests data released

Field Test Data
Provided

- Coalbed Characteristics
  - Coal thickness, permeability, porosity, coal & water properties
  - Pure gas adsorption isotherms
  - Recommended gas-water relative permeability curves (Gash, 1991)
- Initial Conditions
  - Temperature, pressure, gas & water saturations, gas composition
- Gas Injection Rate & Composition
- Well Bottom-hole Pressure
- Gas Production Rate & Composition
- Water Production Rate

History Match Methodology

- **Injection/Pressure Falloff Stages**

Input Parameter:
- Gas Injection Rates

→

Matching Parameter:
- Bottom-hole Pressures

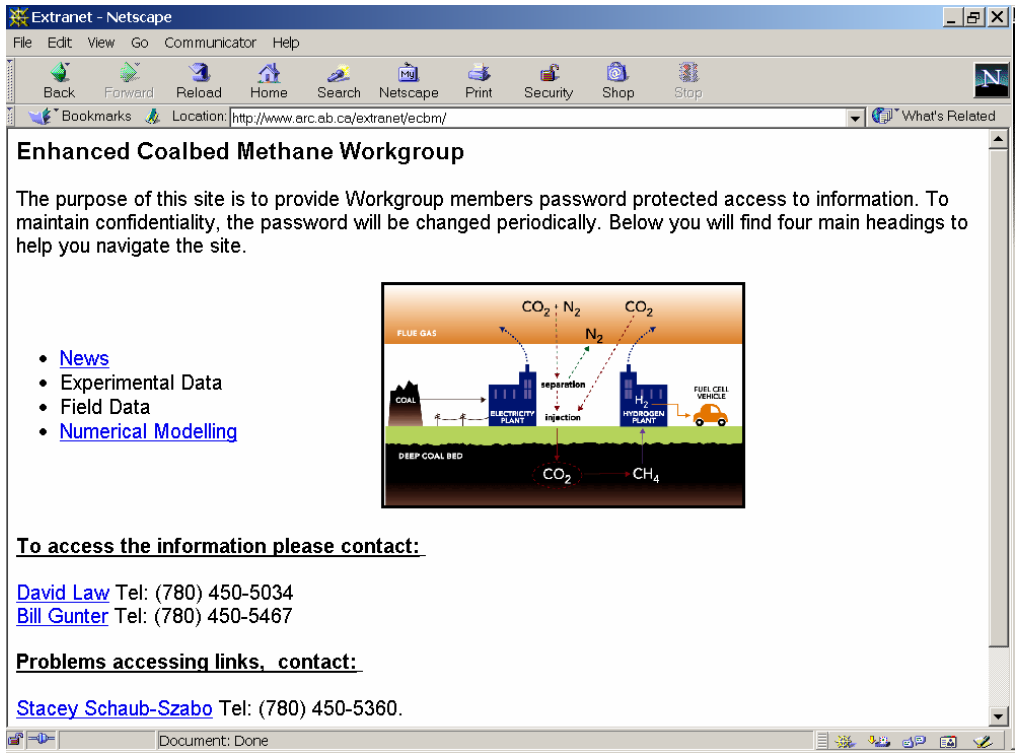
- **Production/Pressure Build-up Stages**

Input Parameter:
- Gas Production Rates

→

Matching Parameter:
- Bottom-hole Pressures
- Production Gas Composition

Final Results



Final comparison results posted in ARC password protected website:

http://www.arc.ab.ca/extranet/ecbm/

History Match ARC's Field Data Using GEM

Numerical Grid System
Used as Recommended

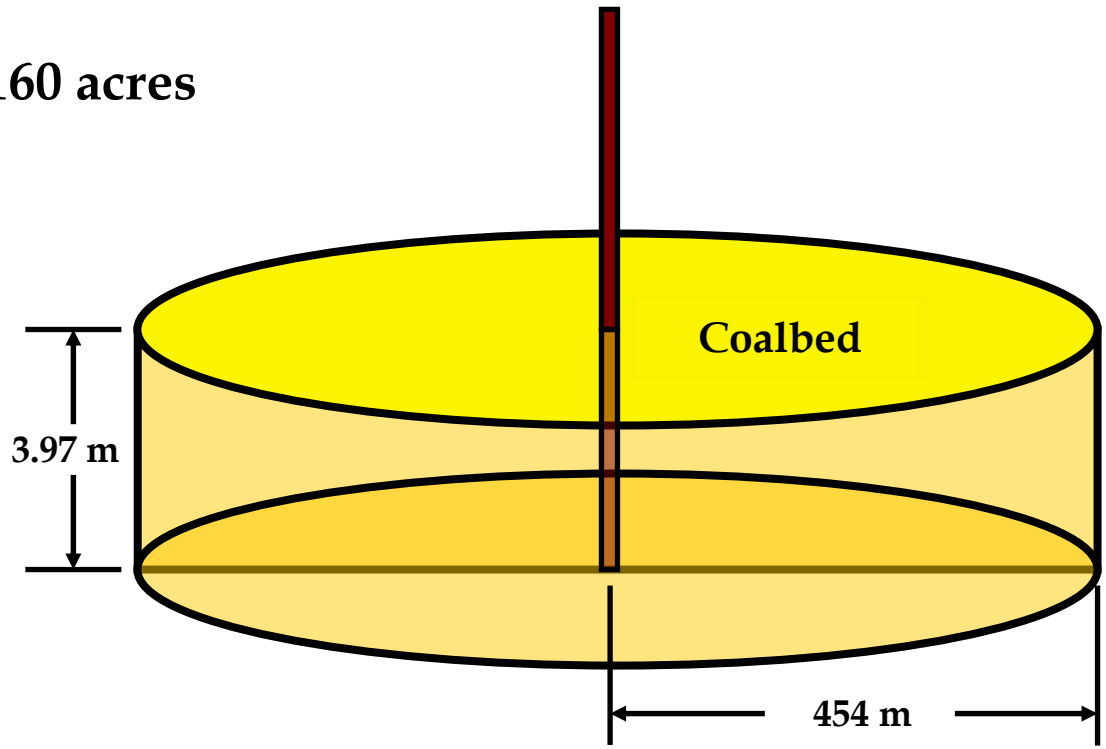
Region of Investigation:

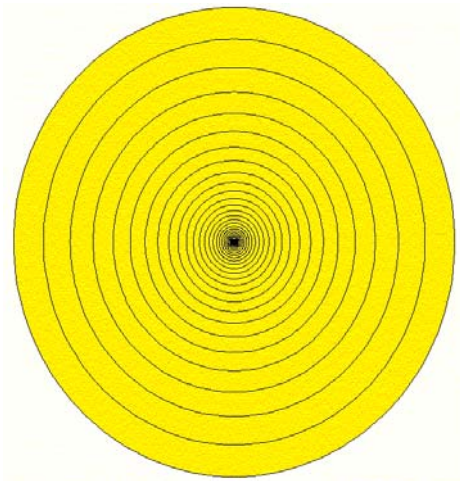
160 acres

Grid Blocks Numbers:

Radial Direction = 29

Axial Direction = 1



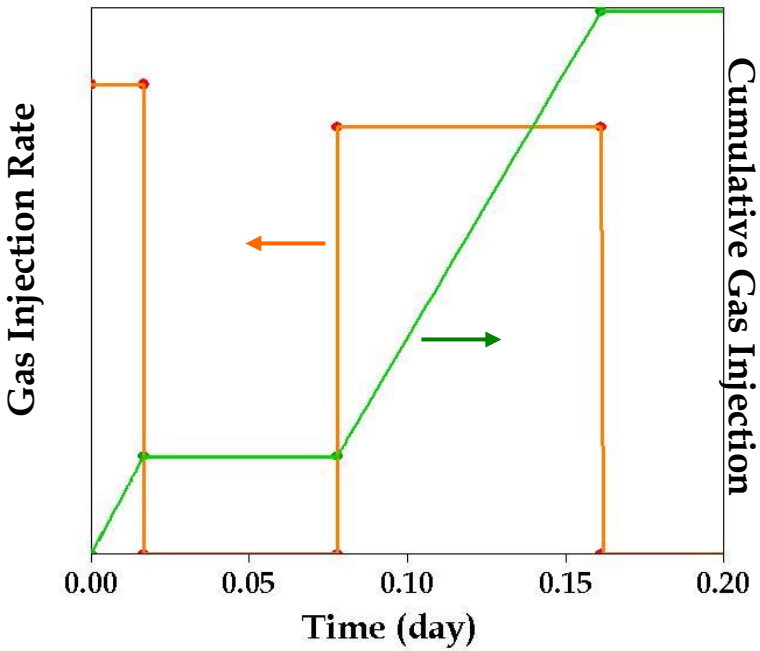


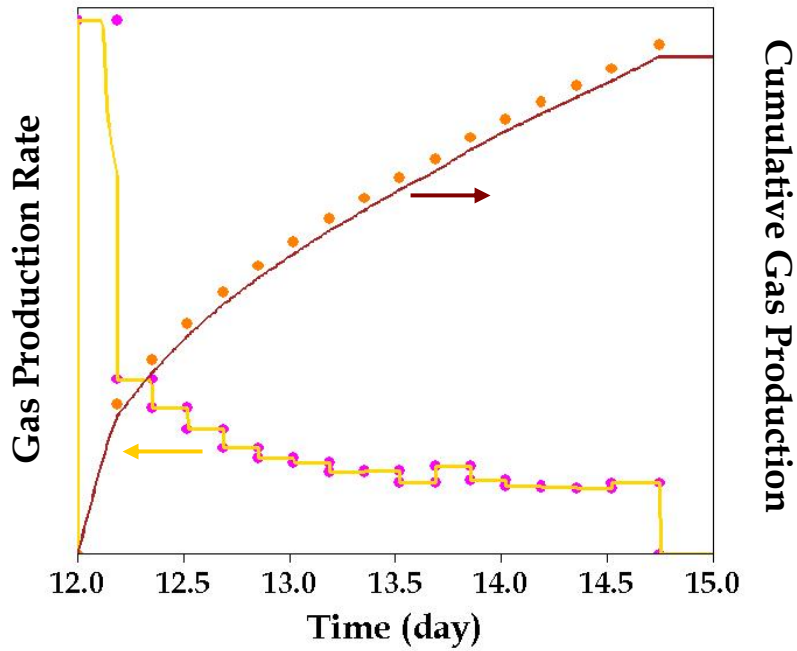
ARC CO_2 Micro-Pilot

- **Six stages:**
  - **First pure CO_2 injection**
  - **First shut-in and pressure fall-off**
  - **Second pure CO_2 injection**
  - **Second shut-in and pressure fall-off**
  - **Post-injection production**
  - **Shut-in and pressure build-up**

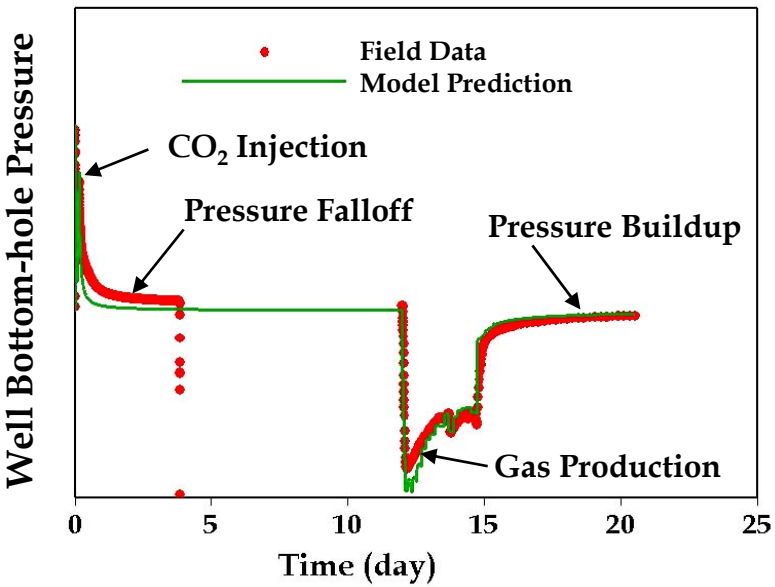
ARC CO_2 Micro-Pilot

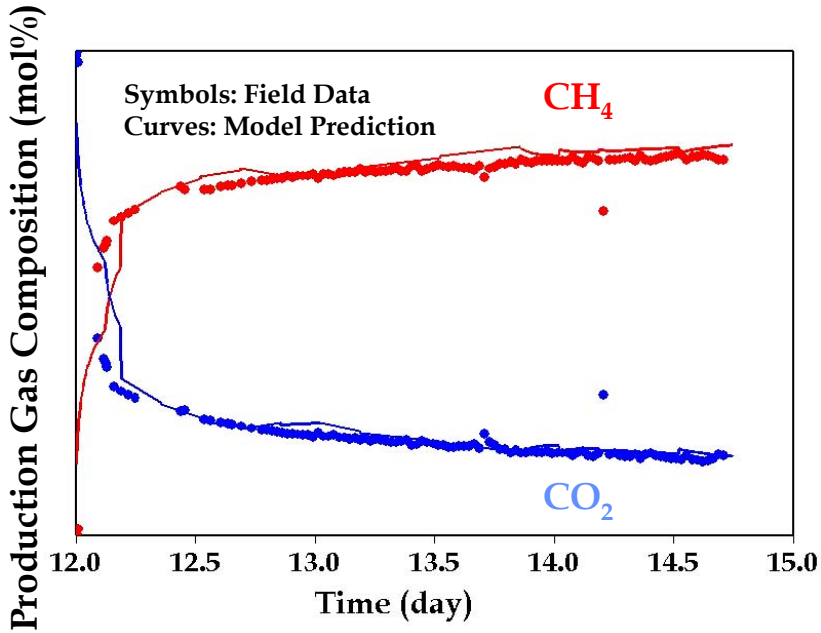
Injectivity & Productivity (CMG's GEM)





ARC CO_2 Micro-Pilot
History Match (CMG's GEM)





- **Numerical Features:**
  - Dual porosity approach
  - Mixed gas diffusion
  - Mixed gas sorption
  - Permeability multipliers

ARC CO_2 Micro-Pilot
Based on History Match (CMG's GEM)

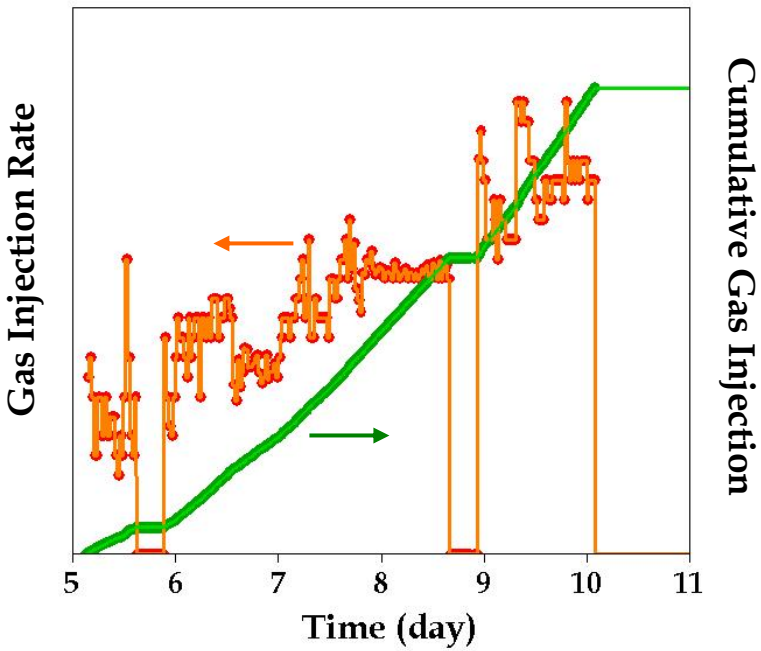
	Permeability Ratio (k/k_i)	Free Gas Composition in Natural Fracture System (mol. fr.) near Well		
		CO_2	N_2	CH_4
Initial Stage	1.00	0.0212	0.0346	0.9442
1st CO_2 Inj.	2.72	0.9880	0.0000	0.0120
1st Shut-in	0.08	0.6269	0.0000	0.3731
2nd CO_2 Inj.	1.50	0.9963	0.0000	0.0037
2nd Shut-in	0.30	0.7939	0.0000	0.2061
Production 1	1.15	0.4299	0.0145	0.5556
Production 2	0.50	0.1644	0.0282	0.8074
Final Stage	0.27	0.0998	0.0314	0.8688

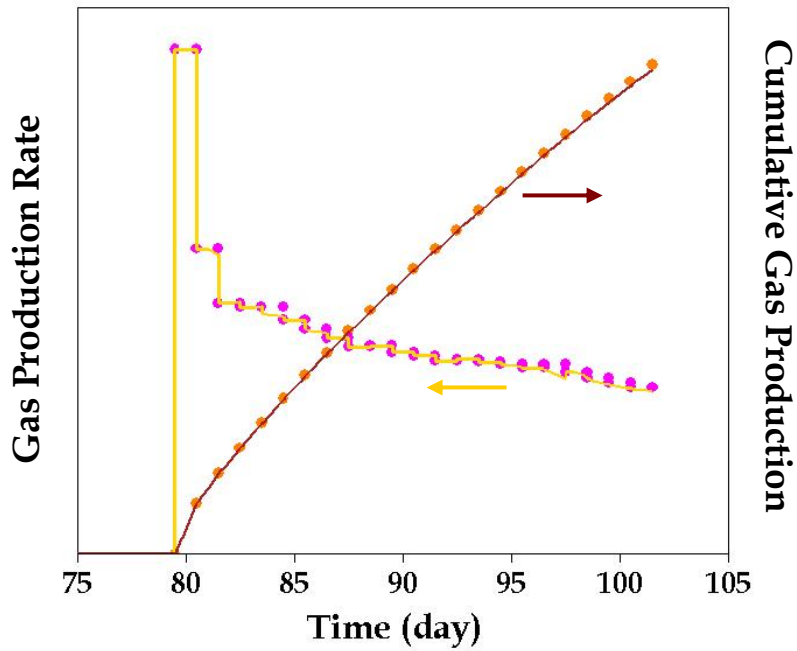
ARC Flue Gas Micro-Pilot

- **Three stages:**
  - **Flue gas (~13% CO_2 & 87% N_2) injection**
  - **Shut-in and pressure fall-off**
  - **Post-injection production**

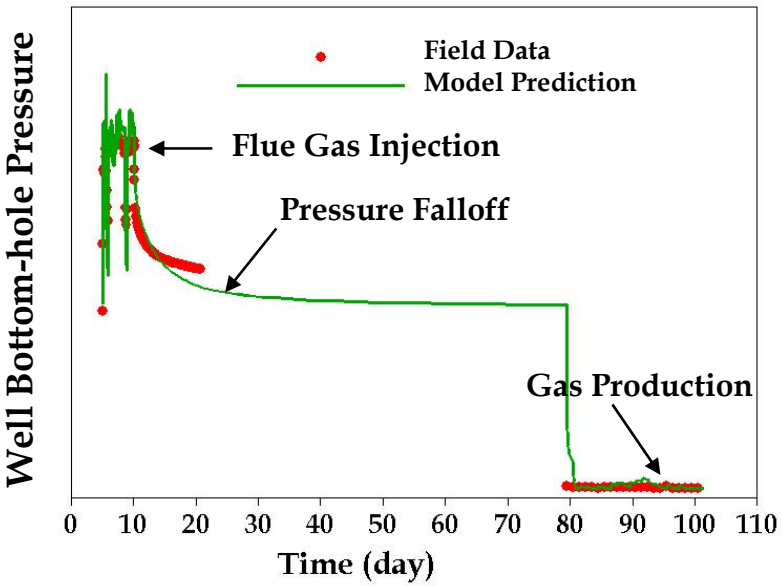
ARC Flue Gas Micro-Pilot

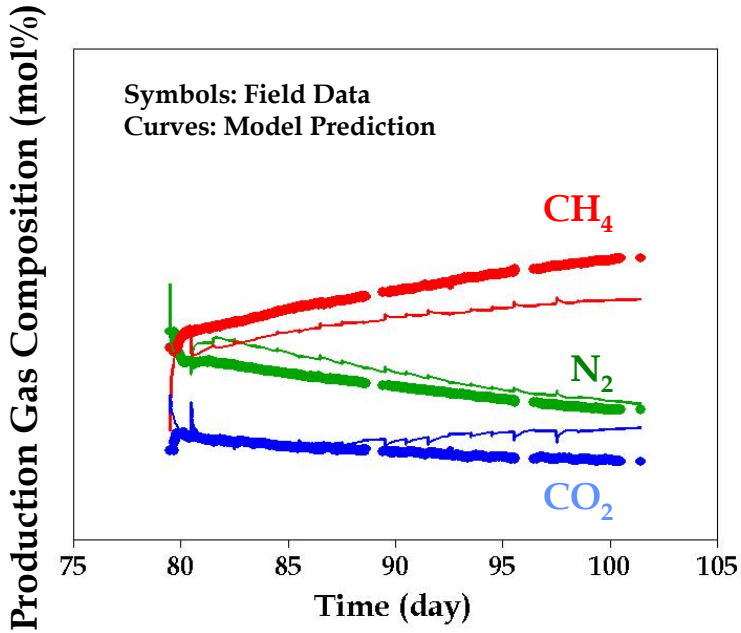
Injectivity & Productivity (CMG's GEM)





ARC Flue Gas Micro-Pilot
History Match (CMG's GEM)





- **Additional Numerical Features:**
  - Dual porosity approach
  - Mixed gas diffusion
  - Mixed gas sorption
  - Permeability multipliers

ARC Flue Gas Micro-Pilot

Based on History Match (CMG's GEM)

	Permeability Ratio (k/k_i)	Free Gas Composition in Natural Fracture System (mol. fr.) near Well		
		CO_2	N_2	CH_4
Initial Stage	1.00	0.2981	0.0318	0.6701
Flue Gas Inj.	5.00	0.1279	0.8389	0.0332
Shut-in	0.0006	0.1704	0.6044	0.2252
Production	0.041	0.1953	0.3957	0.4090
Final Stage	0.042	0.1601	0.2655	0.5744

ARC Micro-Pilots

Matching Parameters (CMG's GEM)

	Permeability Ratio (k/k_i)	Gas Desorption Time Constant (Days)		
		CH_4	N_2	CO_2
CO_2 Injection	0.08 – 2.72	5.0	10.0	0.004
Flue Gas Inj.	0.0006 - 5.00	5.0	10.0	0.004

Refined History Match ARC's Field Data Using CMG's GEM

CMG's GEM
ARC's Permeability Theory

- **Based on analysis of ARC's micro-pilot test data**
- **Stress and multi-component gas adsorbed content dependent**
- **Incorporated into CMG's GEM**

$$\frac{\phi}{\phi_i} = 1 + \frac{p - p_i}{\phi_i M} + \frac{\varepsilon_L}{\phi_i}\left(1 - \frac{K}{M}\right)$$

Based on Volumetric Strain – Pressure Correlation for Mixed Gas

ARC/CMG Confidential Agreement

ARC CO_2/Flue Gas Micro-Pilots

Matching Parameters (CMG's GEM)

Currently, attempt to use ARC's Permeability Theory to refine history match

History Match of Micro-Pilots

Conclusions

- GEM is capable to history match field data
- Better understanding of process mechanisms based on history match
  - —Significant permeability variation
  - —Diffusion limited adsorption/desorption
- Incorporation of ARC's Permeability Theory into GEM allows it to become a useful predictive tool
  - —Further investigation of hysteresis effect is necessary
  - —Model development/testing is ongoing