

PS A Parametric Analysis of Carbon Dioxide Sequestration Potential in Depleted Marcellus Shale Gas Reservoirs*

Burak Kulga¹ and Turgay Ertekin¹

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¹The Pennsylvania State University, State College, PA, United States (burak.kulga@alumni.psu.edu)

Abstract

An investigation involving three different project design parameters that are stimulated reservoir volume (SRV) fracture permeability, SRV fracture porosity, and SRV fracture spacing were carried out using in-house PSU-SHALECOMP model, which is a compositional dual porosity, dual-permeability, multiphase reservoir simulator. The simulator treats the shale gas formation as a dual-porosity, dual-permeability system with micropore and macropore structures representing the shale matrix and natural fracture network, respectively. Furthermore, the model is capable of investigating the effects of water present in the micropore structure as well as the effects of matrix shrinkage and swelling as a consequence of the carbon dioxide injection and production operations. In the numerical experiments considered, primarily rock and fluid properties and reservoir conditions representative of a Marcellus shale scenario were utilized as the basis to examine potential production rates of methane and cumulative methane production capacities. Horizontal well configurations together with the implementation of a computationally inexpensive SRV model with the ability to generate similar behavior to that of an equivalent discrete fracture network model have been instrumental in the analysis. It is observed that it is essential to obtain higher fracture permeabilities within the SRV zone to be able to effectively produce methane during the depletion period and to inject carbon dioxide. In the investigation of the SRV fracture porosity, it is shown that SRV fracture porosity values have a pronounced effect on bottomhole pressure, which may lead to longer injection periods.

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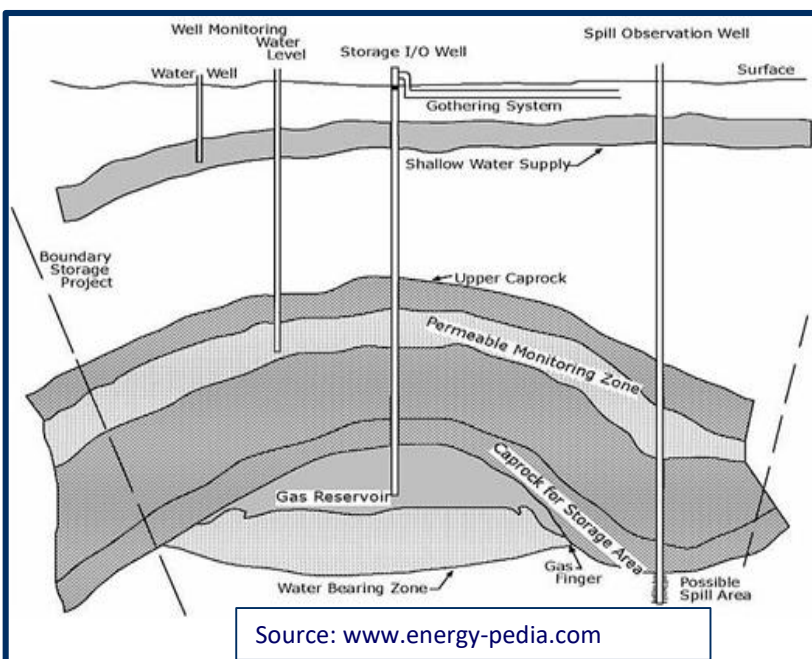
Abstract

An investigation involving three different project design parameters that are stimulated reservoir volume (SRV) fracture permeability, SRV fracture porosity, and SRV fracture spacing were carried out using in-house PSU-SHALECOMP model, which is a compositional dual porosity, dual-permeability, multiphase reservoir simulator. The simulator treats the shale gas formation as a dual-porosity, dual-permeability system with micropore and macropore structures representing the shale matrix and natural fracture network, respectively. Furthermore, the model is capable of investigating the effects of water present in the micropore structure as well as the effects of matrix shrinkage and swelling as a consequence of the carbon dioxide injection and production operations. In the numerical experiments considered, primarily rock and fluid properties and reservoir conditions representative of a Marcellus shale scenario were utilized as the basis to examine potential production rates of methane and cumulative methane production capacities. Horizontal well configurations together with the implementation of a computationally inexpensive SRV model with the ability to generate similar behavior to that of an equivalent discrete fracture network model have been instrumental in the analysis. It is observed that it is essential to obtain higher fracture permeabilities within the SRV zone to be able to effectively produce methane during the depletion period and to inject carbon dioxide. In the investigation of the SRV fracture porosity, it is shown that SRV fracture porosity values have a pronounced effect on bottomhole pressure, which may lead to longer injection periods.

Introduction

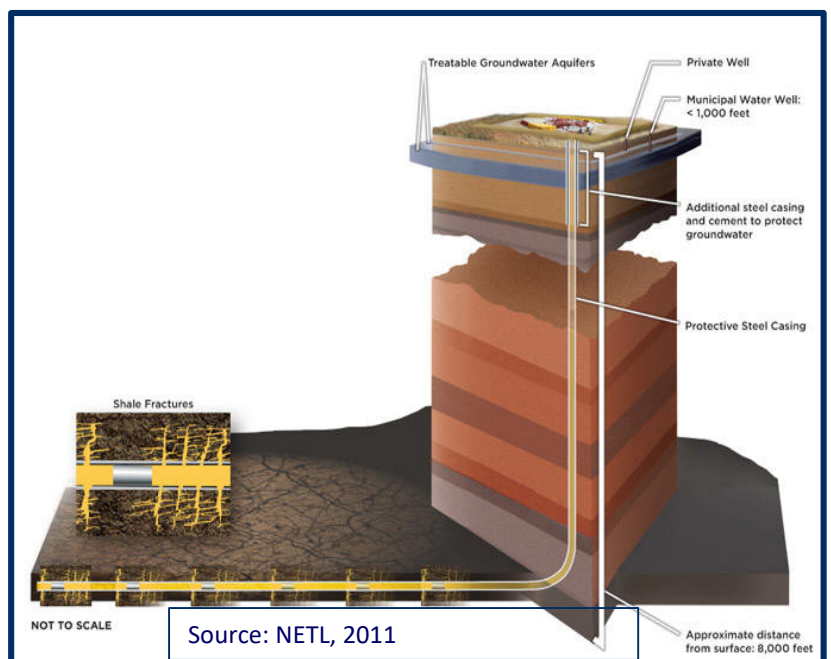
Conventional Sequestration

CO₂ is trapped and becomes immobile in a conventional reservoir, underneath a thick seal



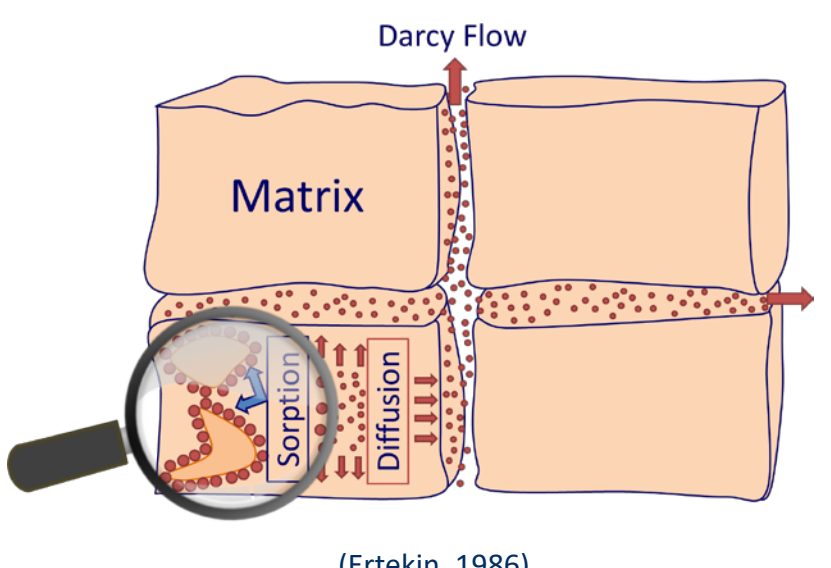
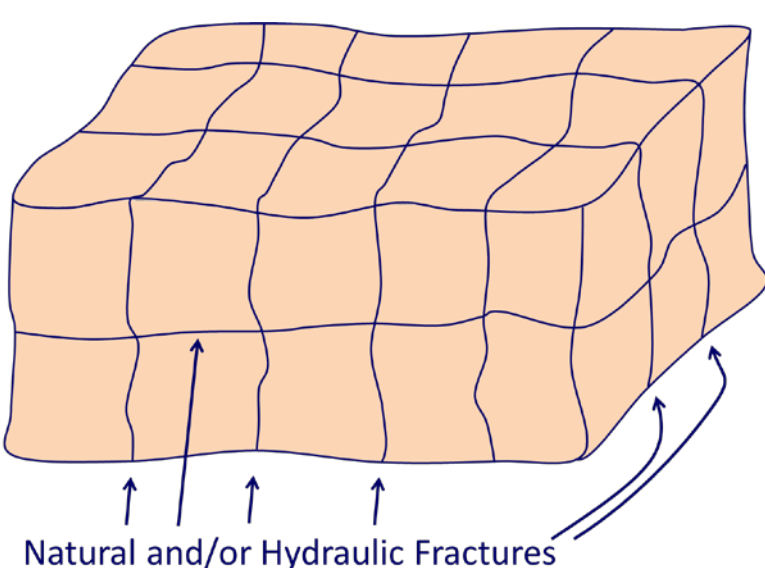
Unconventional Sequestration

CO₂ can be stored in an unconventional reservoir with horizontal wellbore drilling and hydraulic fracturing technologies



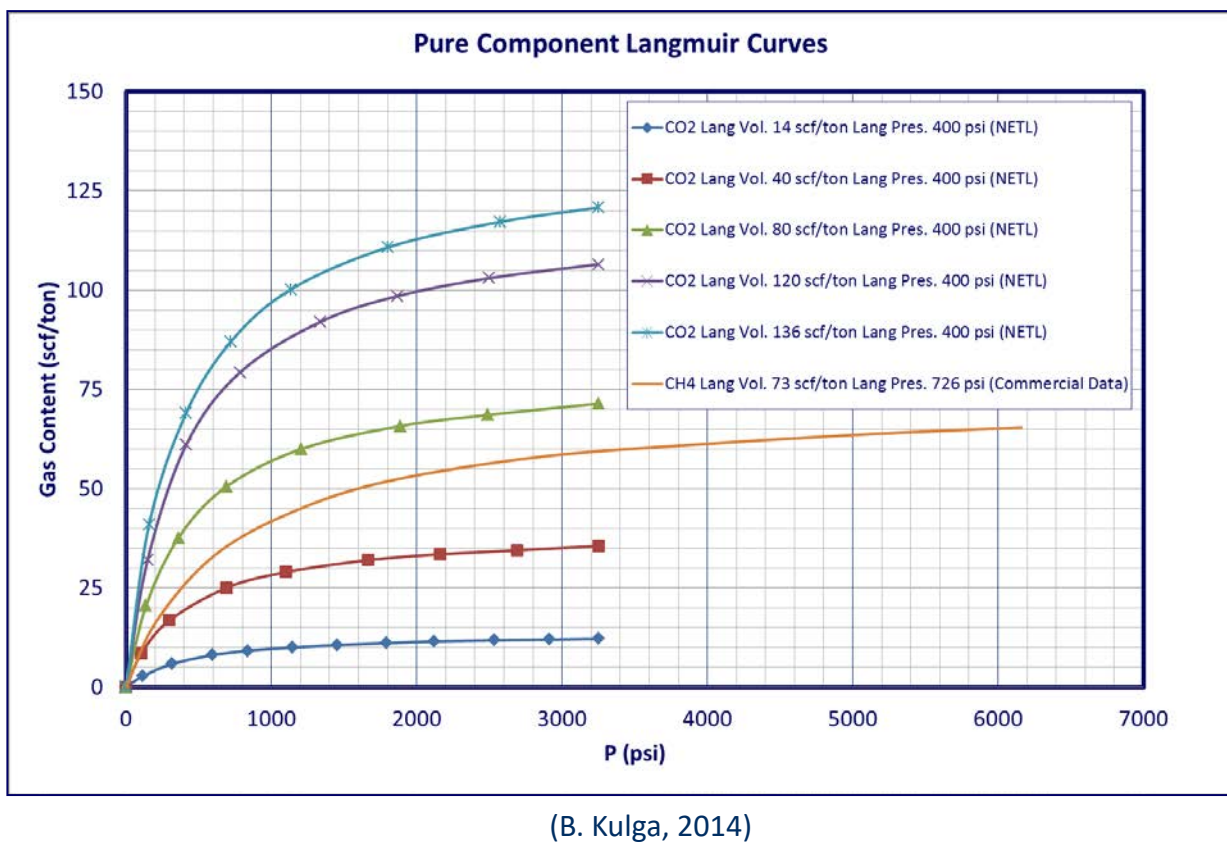
Shale Rock Properties

- Natural and/or hydraulic fractures
- Some portion of the gas fractures is in fractures, some in rock, some adsorbed



Adsorption Capacity of Shale Rocks

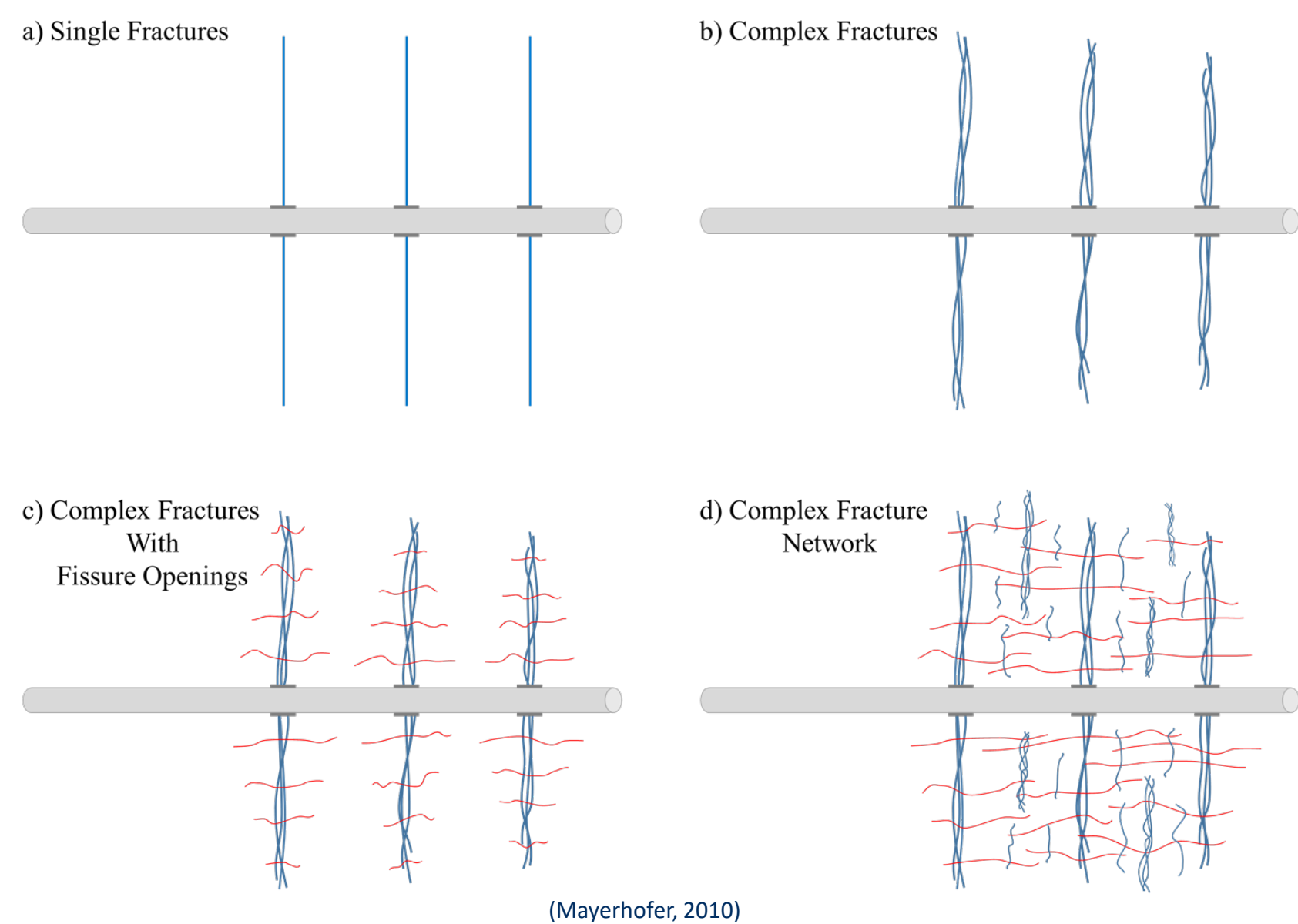
Langmuir isotherms for CO₂ are from black shales of Kentucky. CO₂ adsorption exceeds CH₄ adsorption by a factor of 5 (Nuttall, 2004), which is an advantage in sequestration of CO₂.



(B. Kulga, 2014)

Types of Fracture Growth

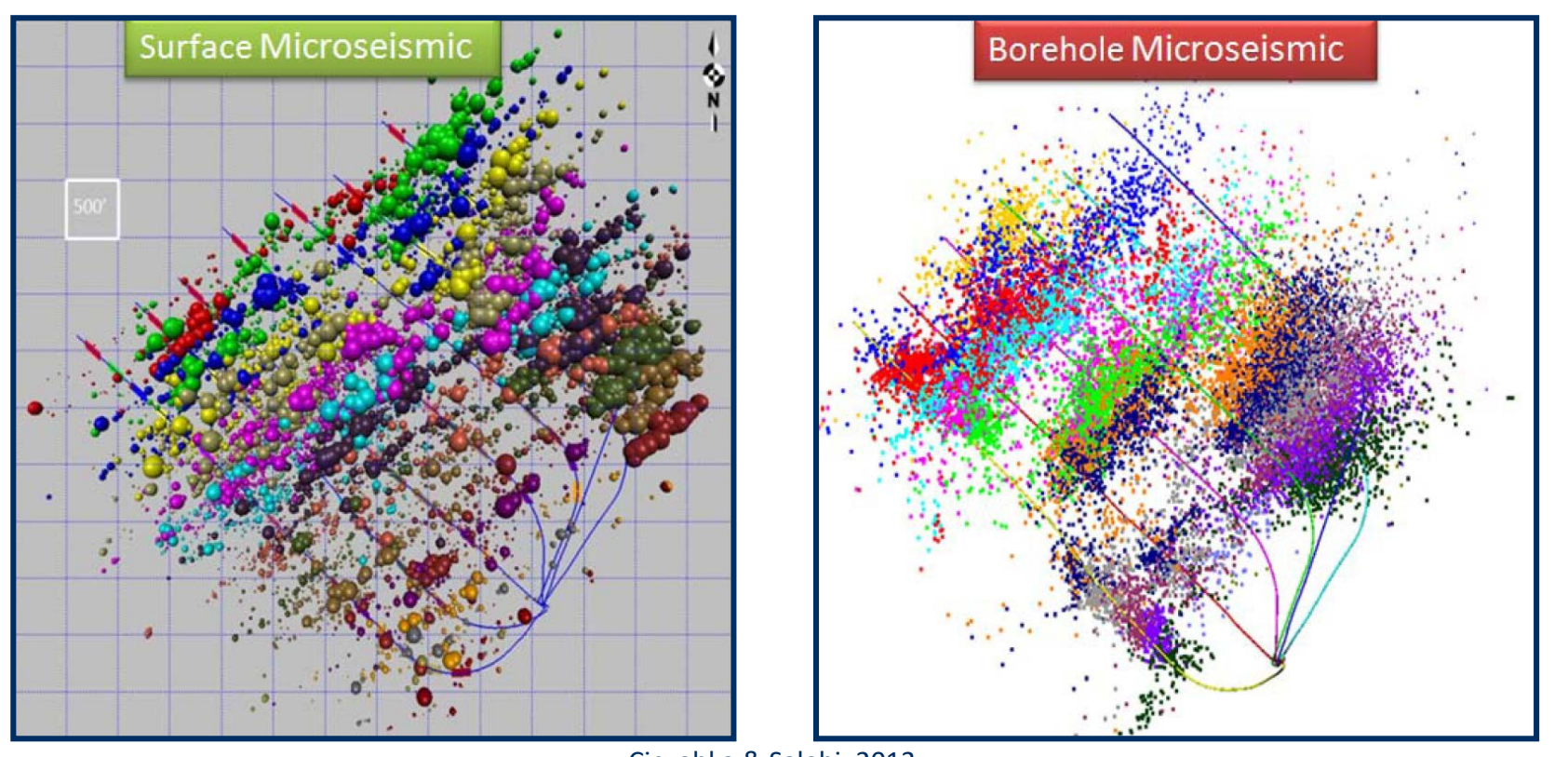
In shale reservoirs, the type of fracture growth forms in a complex fracture network form.



(Mayerhofer, 2010)

Microseismic Studies in Shale Reservoirs

- Significant numbers of seismic activities observed between each of the fracture stages which are created by both brittleness of the formation and hydraulic fracturing operations.
- Fracture connectivities between lateral wells. These microseismic surveys show that instead of having planar or discrete fractures it is more likely to have "crushed" zone or SRV zone in shale gas fields.



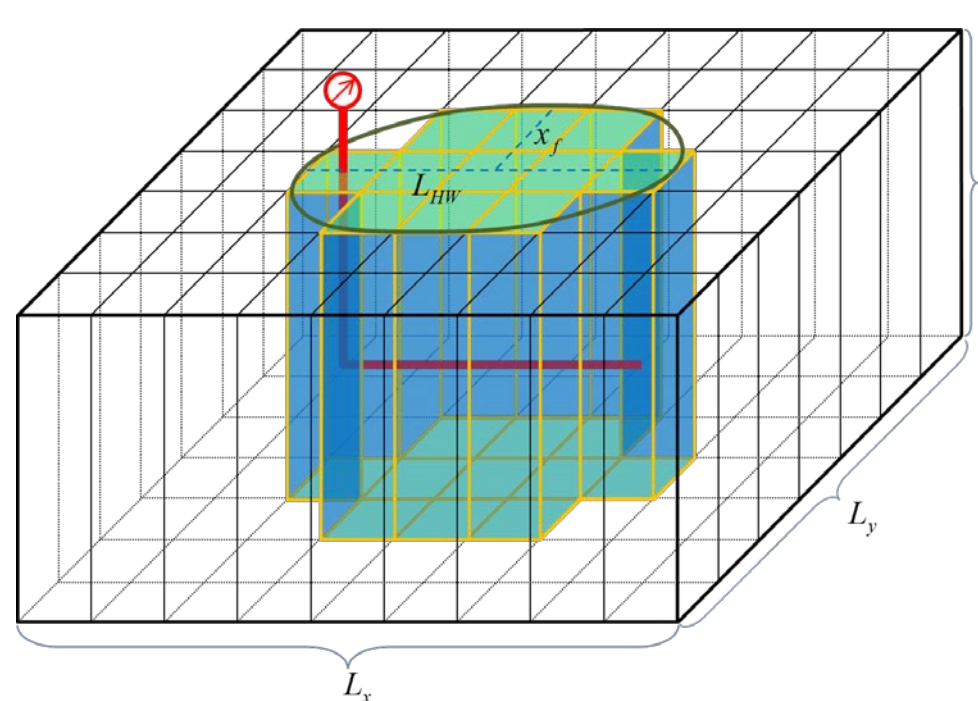
Ciezobka & Salehi, 2013

Methodology

PSU-SHALECOMP Simulator Capabilities

- Compositional
- Multiphase
- Dual porosity and dual permeability
- Multi-mechanistic flow
- Shrinkage and swelling effect (Kulga, 2014)

Stimulated Reservoir Volume (SRV) 3D View

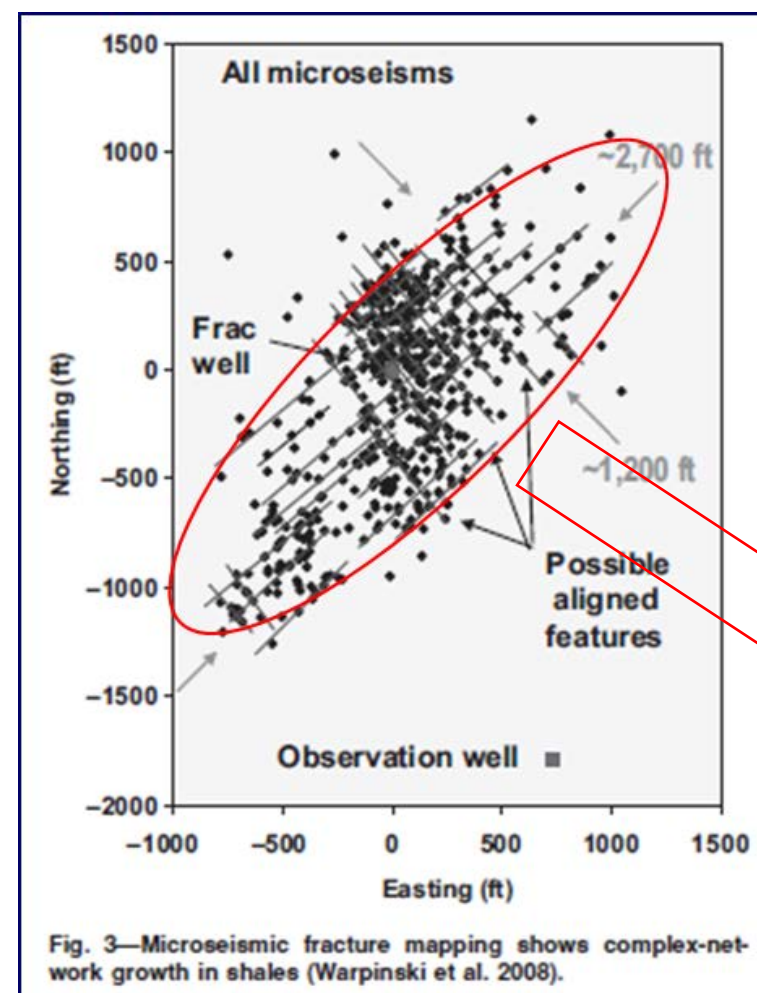


Modified Parameters within the blue zone:

- SRV permeability,
- SRV porosity,
- SRV fracture spacing (Siripatrachai, 2012)

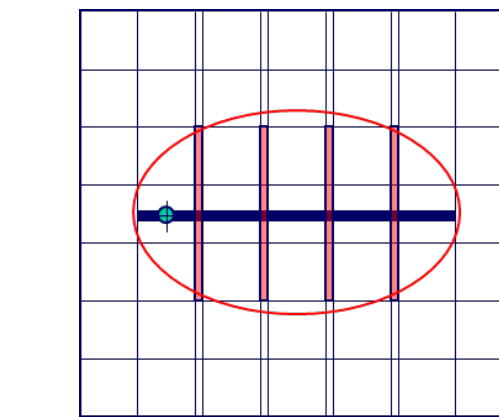
SRV Top View

In the construction of the models with hydraulically fractured reservoirs, discrete fracture networking or stimulated reservoir volume (SRV) approach can be used. In this study, we implemented SRV approach in our models.

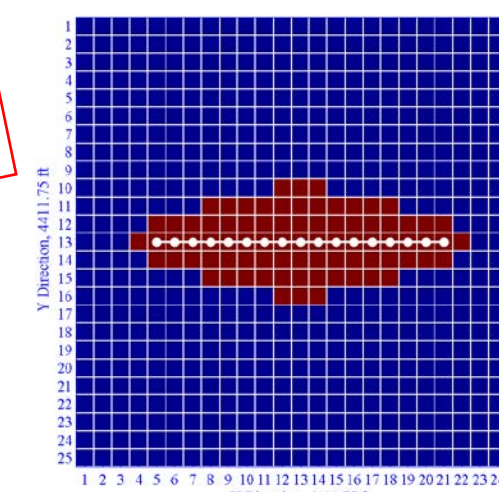


(Mayerhofer, 2010)

Discrete Fracture Network

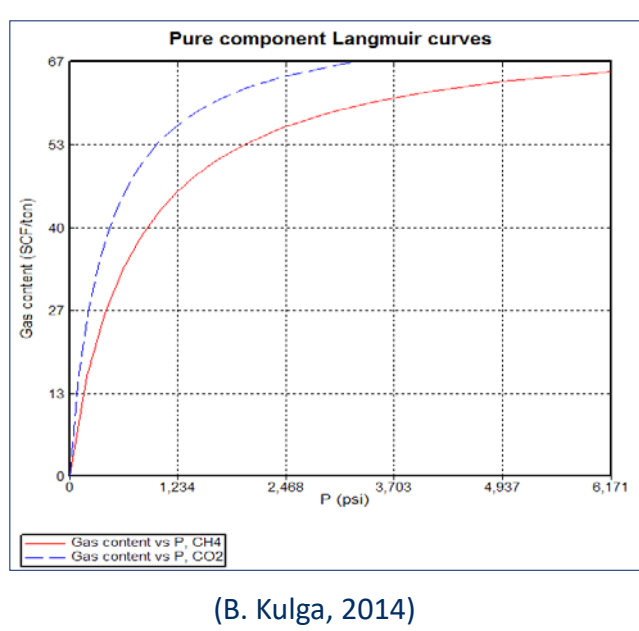


OR Stimulated Reservoir Volume



Rock and Fluid Properties

Model Parameters					
Grid System	25 x 25	Matrix Permeability (md)	0.0006		
X Dimension (ft)	4,411	Fracture Permeability (md)	0.00185		
Y Dimension (ft)	4,411	Fracture Spacing (ft)	2.1		
Drainage Area (acres)	447	Lang. Vol. of CH ₄ (scf/ton)	73		
Thickness (ft)	271	Lang. Pres. of CH ₄ (psi)	726		
Depth (ft)	6,500	Lang. Vol. of CO ₂ (scf/ton)	75		
Res. Pressure (psi)	3,940	Lang. Pres. of CO ₂ (psi)	400		
Res. Temperature (F)	142	Hor. Wellbore Length (ft)	3,000		
Sw in Matrix (%)	10	Production Constraint (psi)	14.7		
Sw in Fracture (%)	0.1	CO ₂ inj. rate (MMSCFD)	1.5		
Matrix Porosity (%)	8.5	SRV Fracture Spacing (ft)	0.2		
Matrix Permeability (%)	1.05	SRV Fracture Porosity (%)	4		
Sw	Krw	Pcow	Sg	Krg	Pcog
0	0	0	1	1	0
1	0	0			



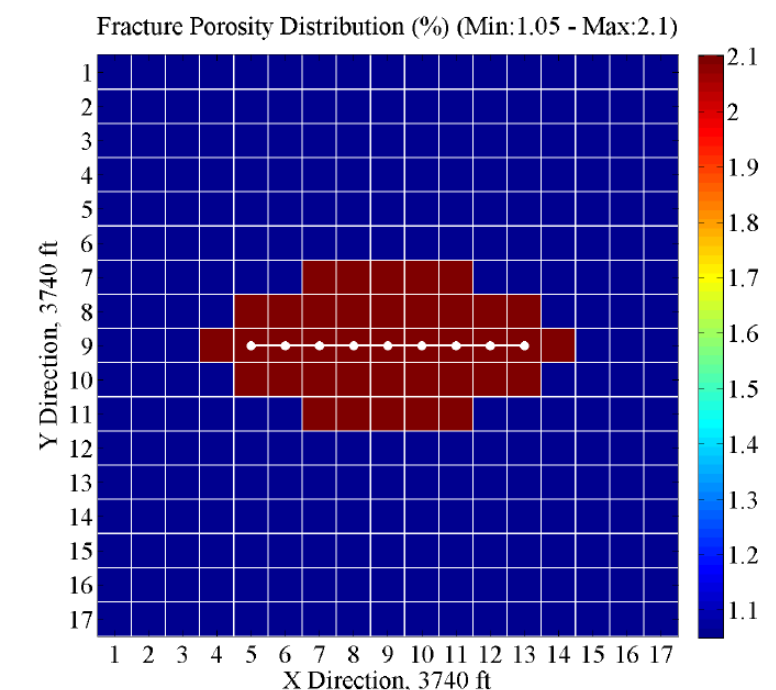
(B. Kulga, 2014)

Results

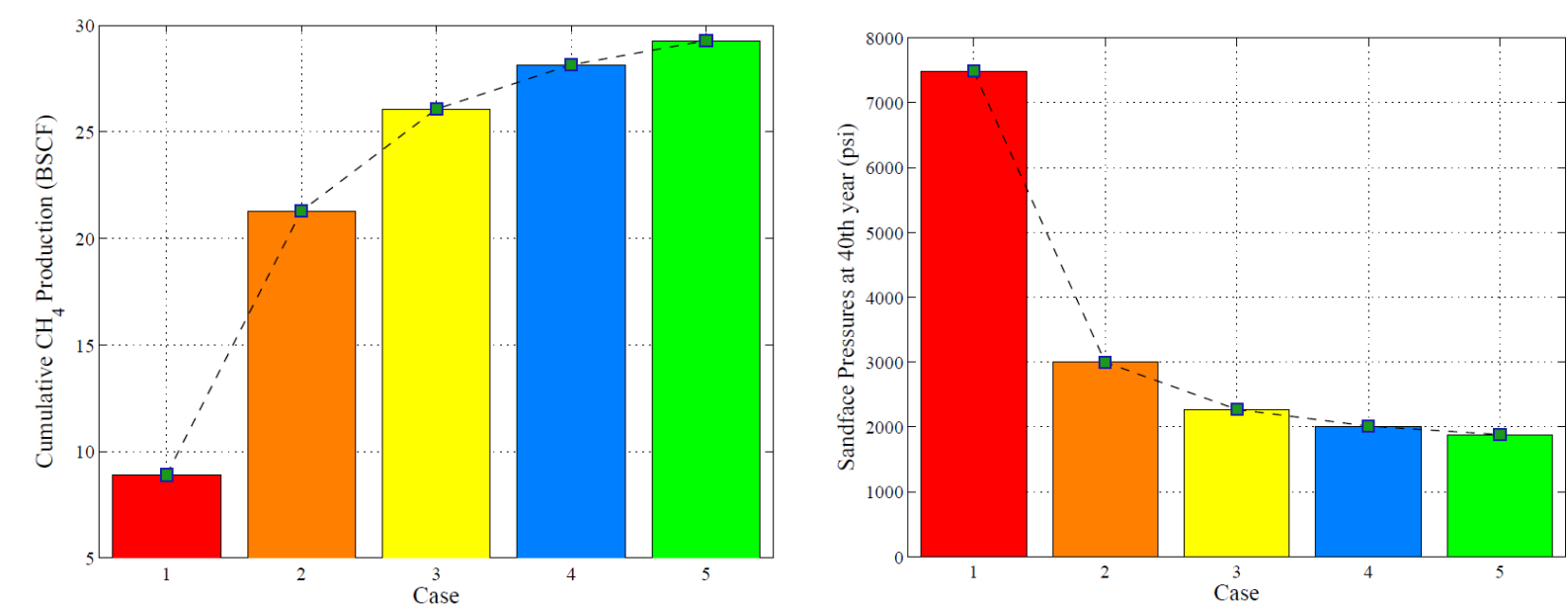
SRV Permeability

In this study, production time is taken as 30 years. Injection constraint is specified flowrate, which is 1.5 MMSCFD; bottomhole pressures are compared after 10 years of injection. It is observed that it is essential to obtain higher fracture permeabilities within the SRV zone to be able to effectively produce CH₄ and inject CO₂.

SRV-k _f	
Case 1	0.00185
Case 2	0.00925
Case 3	0.01850
Case 4	0.02775
Case 5	0.03700

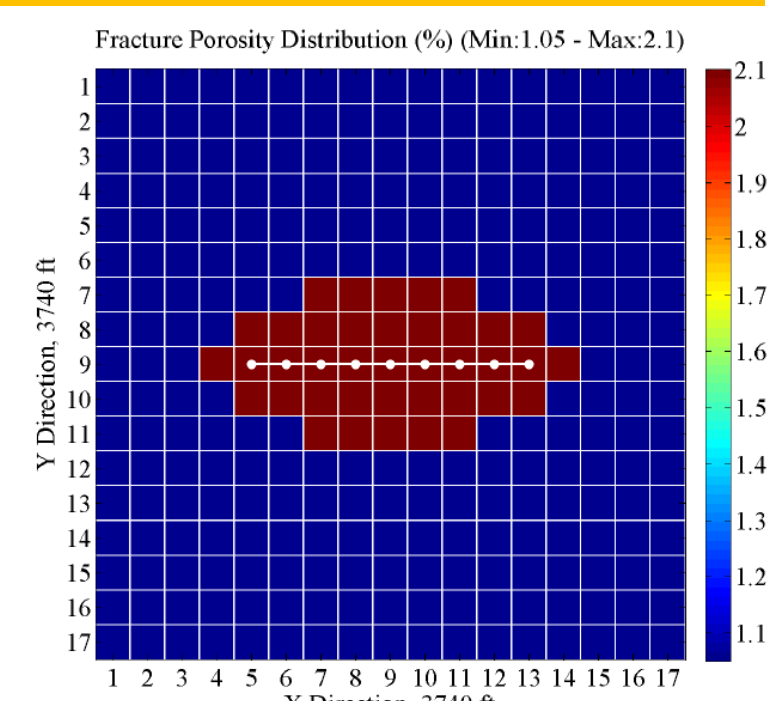


If fracture permeability values can be increased by the magnitude of 5, about 3 times larger production values can be obtained in 30 years. Sandface pressure after 10 years of injection in Case 1 is more than 2 times larger than Case 2 for the same amount of injected CO₂. Again, acquiring larger SRV-k_f values is very important on the performances of CO₂ sequestration operations.

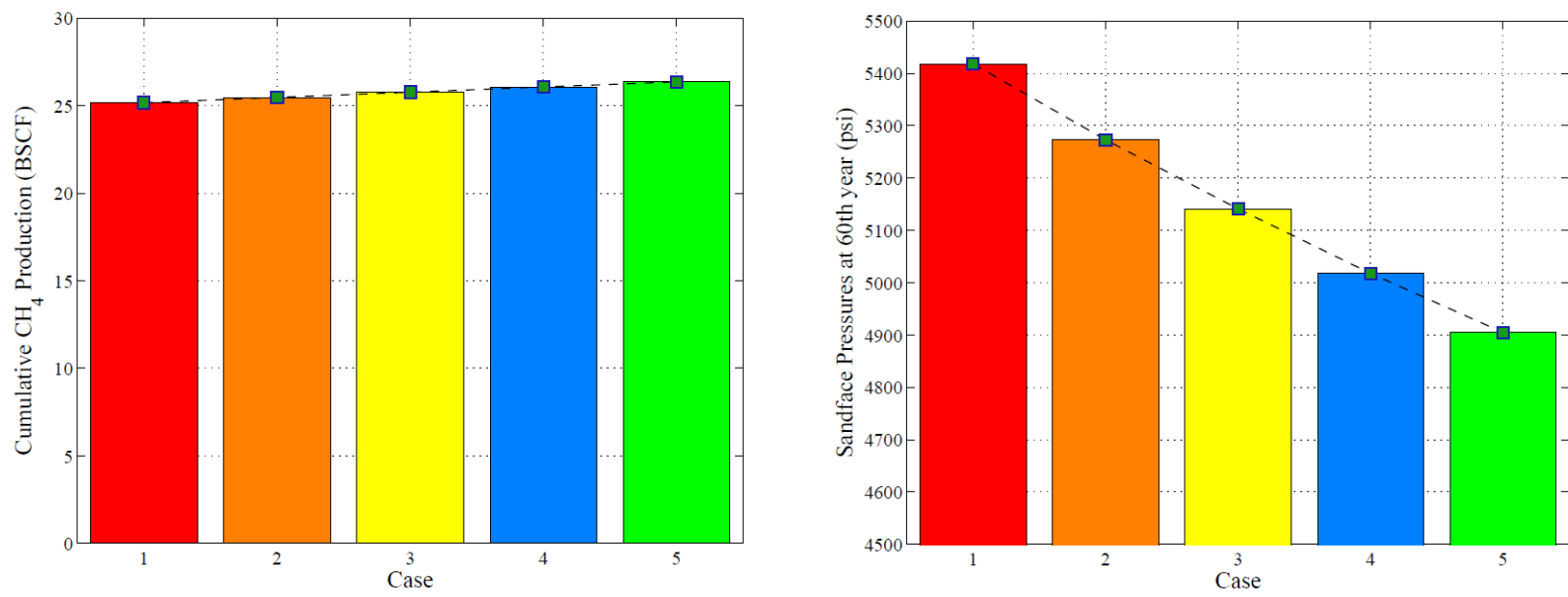


SRV Porosity

SRV-φ _f (%)	
Case 1	1.2
Case 2	1.5
Case 3	1.8
Case 4	2.1
Case 5	2.4

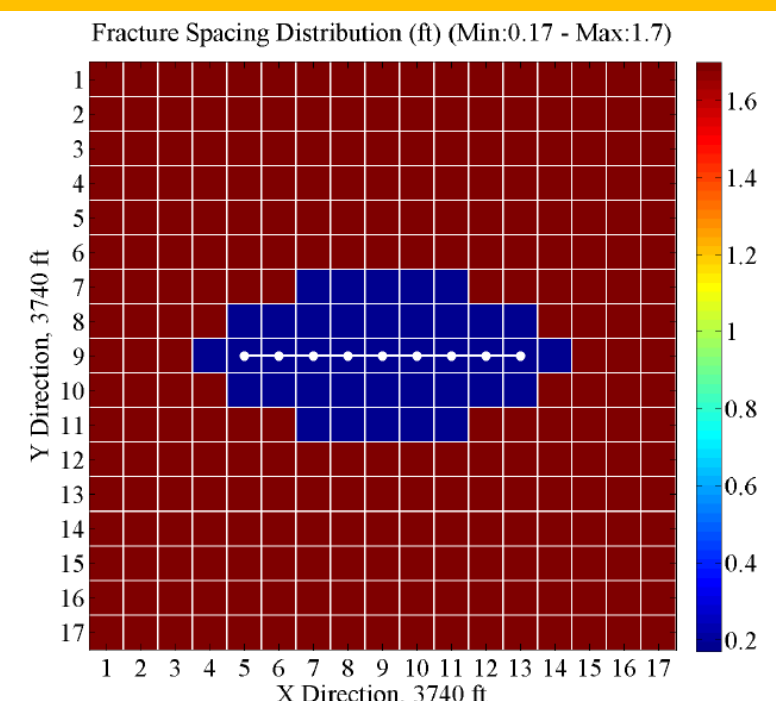


Fracture porosity has a relatively small, almost negligible impact on cumulative production. Larger SRV fracture porosity values have significantly lower bottomhole pressure values, which in turn, increases the duration of the CO₂ injection period, which leads to larger injection values of CO₂.

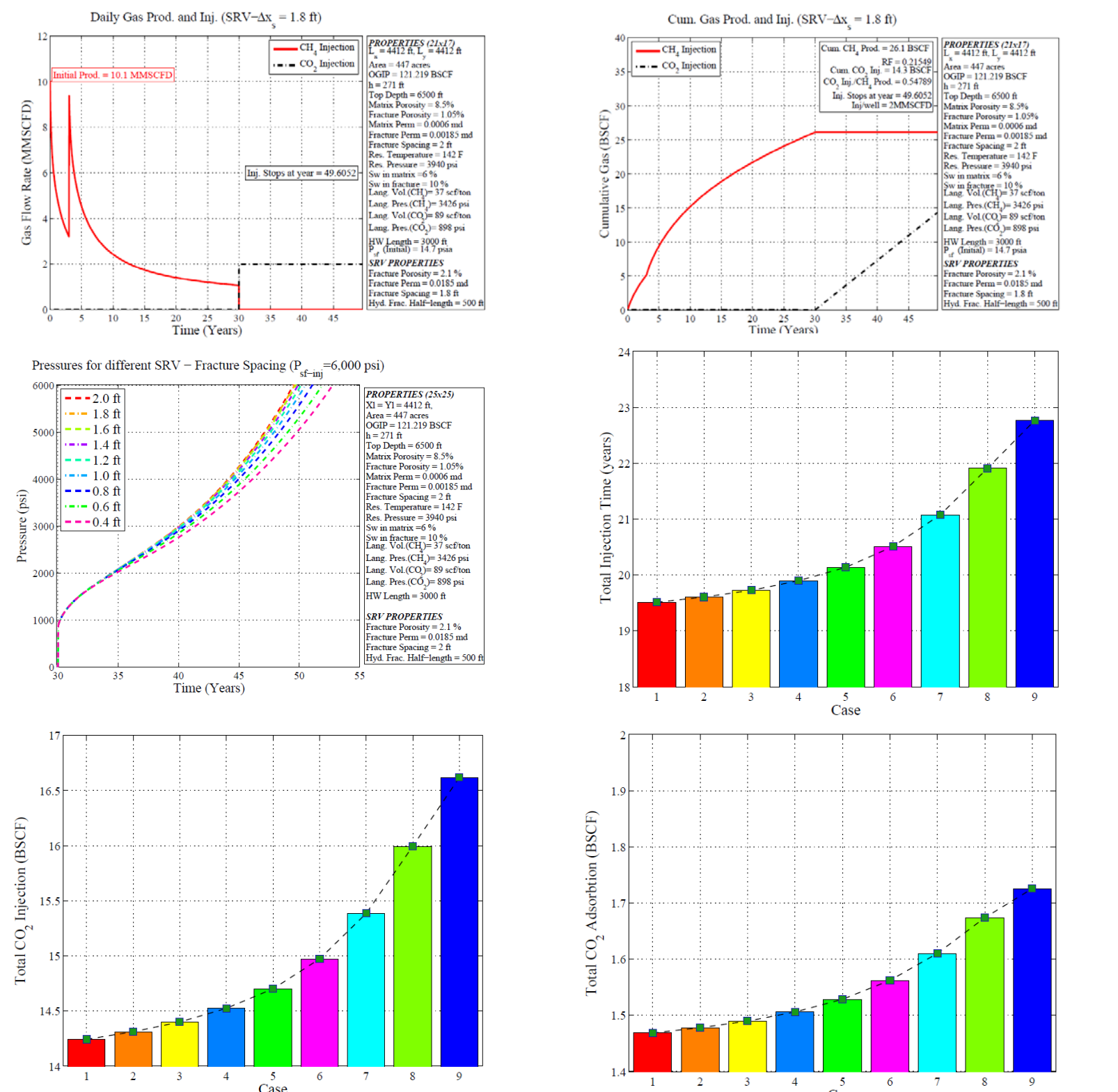


SRV Fracture Spacing

SRV-Δx _f (ft)	
Case 1	2.0
Case 2	1.8
Case 3	1.6
Case 4	1.4
Case 5	1.2
Case 6	1.0
Case 7	0.8
Case 8	0.6
Case 9	0.4



In this case, fracturing pressure is taken as 6,000 psi. Therefore, once the bottomhole pressure during an injection cycle reaches 6,000 psi, the simulation shuts-in the injection. About 26 BSCF of methane is produced from the reservoir in 30 years of time in Case 2. Approximately 19.2 years of injection is achieved in Case 2 with a rate of 2 MMSCFD of CO₂.



There is more than 2 BSCF of total CO₂ difference between Case 1 and Case 9. As the SRV-Δx_f values get smaller, more CO₂ can be adsorbed by the shale matrix, since the surface area of the stimulated reservoir volume zone gets increased because of hydraulic fracturing operations. Also, the total CO₂ adsorbed by the reservoir, mostly in the SRV zone. More the 250 MMSCF of CO₂ is adsorbed by the shale formation.

Summary

- It is uniformly observed that fracture permeability plays more dominant role in increasing the project life for carbon dioxide injection.
- It is also essential to obtain higher fracture porosities and lower fracture spacing values within the SRV zone by hydraulic fracturing operations.
- Significantly large percentage of the produced gas originates from the fractured zone so as significantly large percentage of the injected gas will end up occupying the pore spaces in the fractured zone.
- Injection of carbon dioxide into undepleted or unsuccessfully fractured shale gas reservoirs is not promising because of its ultra-tight permeability characteristics.