PS Numerical Validation of Stimulated Reservoir Volume Approach in Shale Reservoirs by Using a Compositional, Dual-porosity, Dual-permeability, Multiphase Reservoir Simulator*

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Search and Discovery Article #70329 (2018)**
Posted April 2, 2018

*Adapted from poster presentation given at AAPG Eastern Section 46th Annual Meeting, Morgantown, West Virginia, September 24-27, 2017

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Abstract

Most existing unconventional gas reservoir simulators often treat shale gas reservoirs as dual-porosity, single-permeability flow systems with no water saturation and with no permeability in the micropore (matrix) structure. The PSU-SHALECOMP, is a compositional dual-porosity, dual-permeability, multi-phase reservoir simulator, which also incorporates the effects of water presence in the micropore structure and those of matrix shrinkage and swelling. In PSU-SHALECOMP, shale gas reservoir is treated as a dual-porosity, dual-permeability system consisting of shale matrix and fracture network allowing realistic natural fracture spacing characteristics. In the simulator, computations on the partial adsorption capacity of gas components are based on the thermodynamic equilibrium between gas components in the free and adsorbed phases following the ideal adsorbed solution model using an analogy to vapor-liquid-equilibria calculations. Apart from the aforementioned capabilities of PSU-SHALECOMP, the concept of stimulated reservoir volume (SRV) approach is introduced to the numerical models. The SRV is approximated by modifying the values of fracture spacing, fracture permeability and fracture porosity where the hydraulic fractures exist. In the validation phase of the simulator, rock and fluid properties and reservoir conditions of Marcellus Shale gas reservoir were used with the implementation of a computationally inexpensive SRV model, which has the ability to generate similar behavior in terms of production performances to that of an equivalent discrete fracture network model. The results were also compared with a series of normalized field production data that is obtained from existing Marcellus Shale wells, and it is shown that the PSU-SHALECOMP simulator with the implementation of SRV model is capable of matching the historical data very efficiently and rapidly.

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(The work presented was funded by the US - Department of Energy – NETL)

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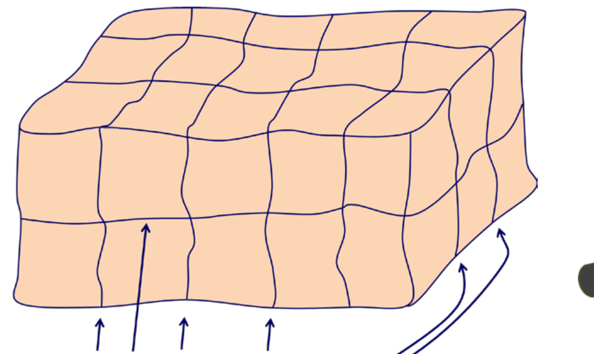
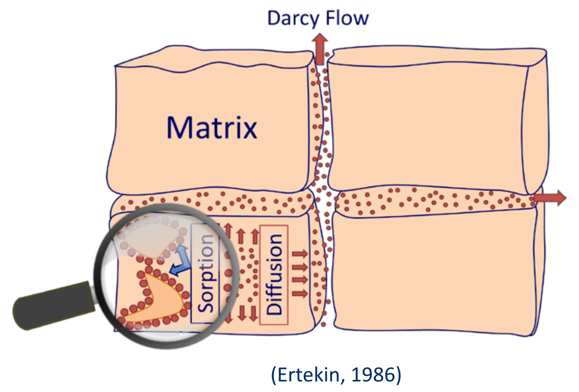
Introduction

Shale Rock Properties

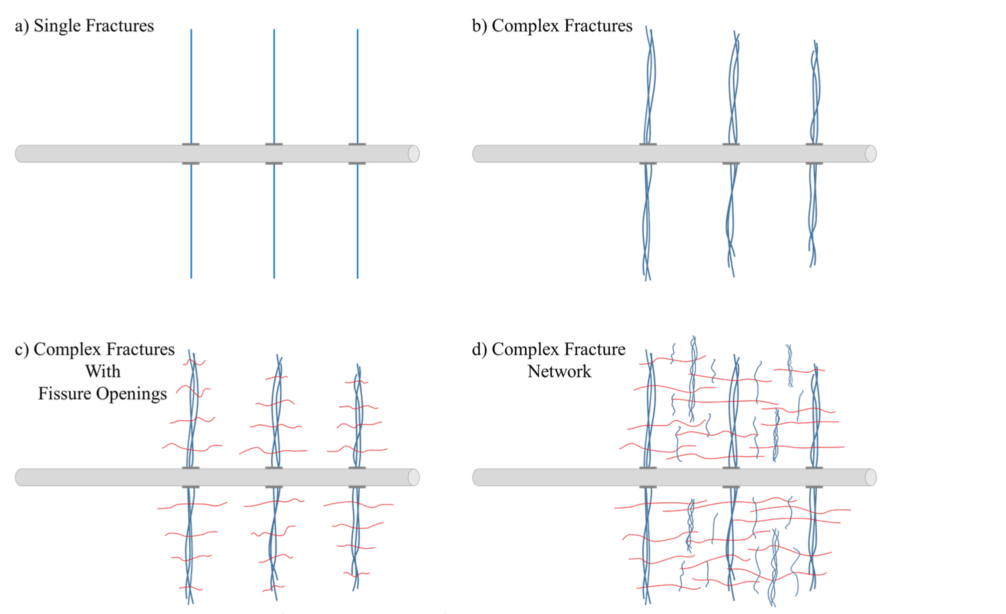
- Natural and/or hydraulic fractures.
- Some portion of the gas fractures is in the fractures, some in rock matrix, and some in adsorbed state.


Natural and/or Hydraulic Fractures



(Ertekin, 1986)

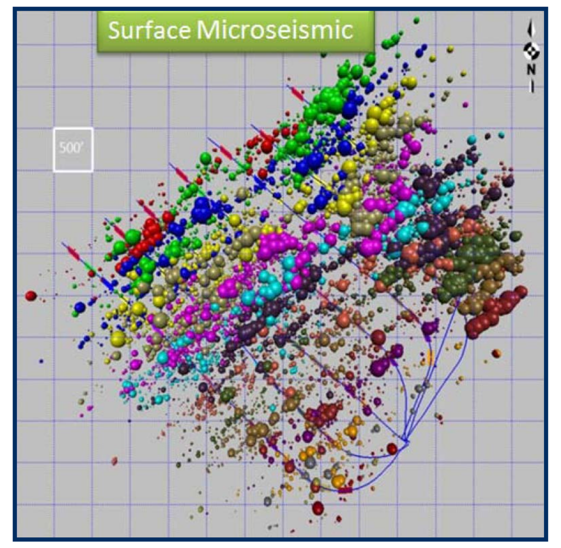
Types of Fracture Growth

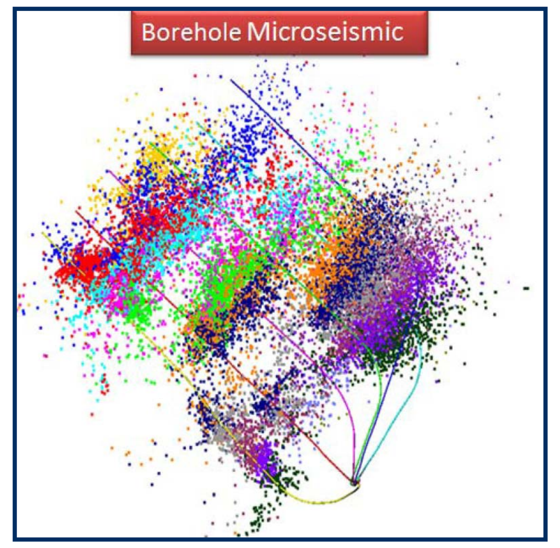


(Mayerhofer, 2010)

Microseismic Studies in Shale Reservoirs

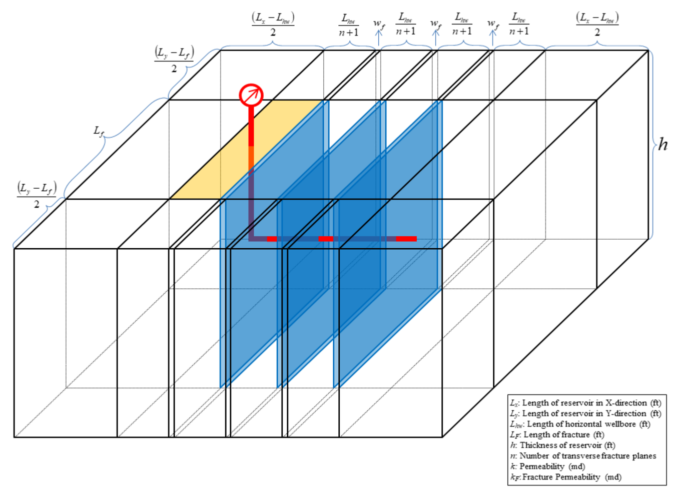
- Significant numbers of seismic activities observed between each of the fracture stages which are created by both brittleness of the formation and hydraulic fracturing operations.
- Fracture connectivities between lateral wells. These microseismic surveys show that instead of having planar or discrete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





Ciezobka & Salehi, 2013

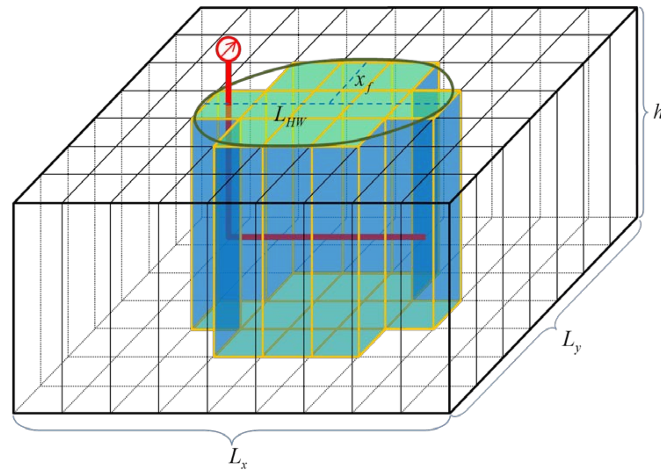
Discrete Fracture Network (DFN)


Kulga, Artun, & Ertekin, 2017

Discrete fracture network (DFM) modelling is the most widely applied approach to model shale-gas reservoirs where the entire reservoir is discretely created, including the network fractures, hydraulic fracture, matrix blocks, and unstimulated areas. However, DFM modelling increases computational time, creates potential convergence and stability issues, and building a grid design with local grid refinements is laborious and can be time-consuming.

Stimulated Reservoir Volume Approach

Shale reservoirs inherently have complex network structure. The concepts of single-plane-fractures and conductivity are insufficient to describe stimulation performance as in conventional reservoirs. It is hypothesized that the concept of using SRV defines the production performance better in shale gas systems. In our study, we employed a dual-porosity/dual-permeability, compositional simulator (PSU-SHALECOMP) by implementing stimulated reservoir volume (SRV) approach.



The size of the complex network structures in shale gas reservoirs can be represented as the 3D volume of the microseismic fracture mapping in numerical simulators. Modified Parameters in the SRV are:

- Fracture permeability,
- Fracture porosity,
- Fracture spacing

(Siripatrachai, 2012)

- The elliptical area that represents the top view of the SRV zone.
- The minor axis of the ellipse is considered as the half-length of hydraulic fracture (x_f)
- The major axis is the length of the horizontal wellbore (L_{hw}).
- The thickness (h) of the reservoir is also considered as SRV zone's thickness.

Methodology

PSU-SHALECOMP Simulator

- **3D**: The simulator is capable of modeling a reservoir in a three-dimensional design.
- **Compositional**: Reservoir fluid phase behavior or the compositional changes associated with depth, temperature and pressure are taken into account by using an equation of state.
- **Multiphase**: It is two-phase, which is single component for water and multi-component for a gas mixture, which can also model CO_2 and air injections scenarios.
- **Dual porosity and dual permeability**: The flow both in the matrix and fractures are taken into consideration in the formulations and in the simulator.
- **Multi-mechanistic flow**: The gas follows two driving mechanisms, including flow through the pressure field (Darcian flow) and, flow through the concentration field (Fickian flow).
- **Multi-component sorption**: Thermodynamically consistent multi-component gas sorption equilibria where the partial adsorption capacity of gas components is determined and calculated by the partial pressures of gas components in the free gas mixture successfully. (B. Kulga, 2014)

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. Having microseismic data would help to obtain better numerical models.

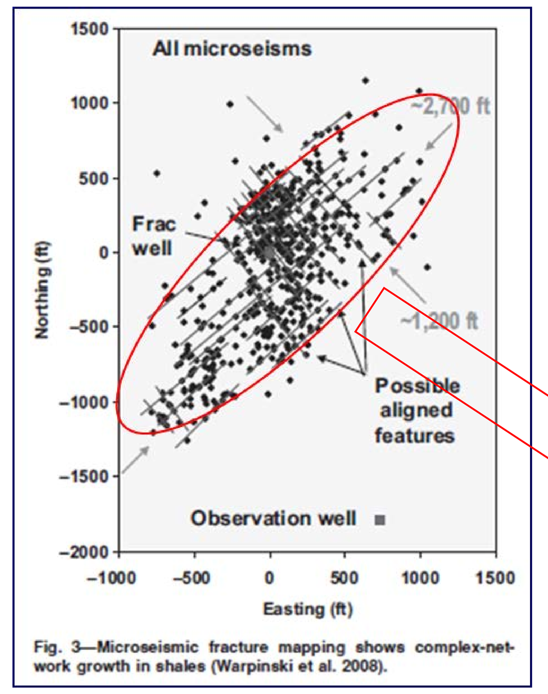
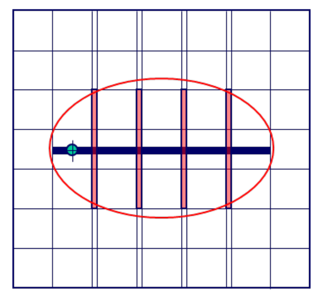


Fig. 3—Microseismic fracture mapping shows complex-network growth in shales (Warpinski et al. 2008).

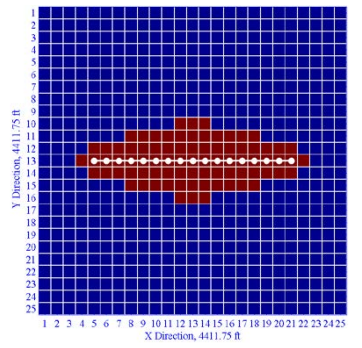
(Mayerhofer, 2010)

Discrete Fracture Network



OR

Stimulated Reservoir Volume



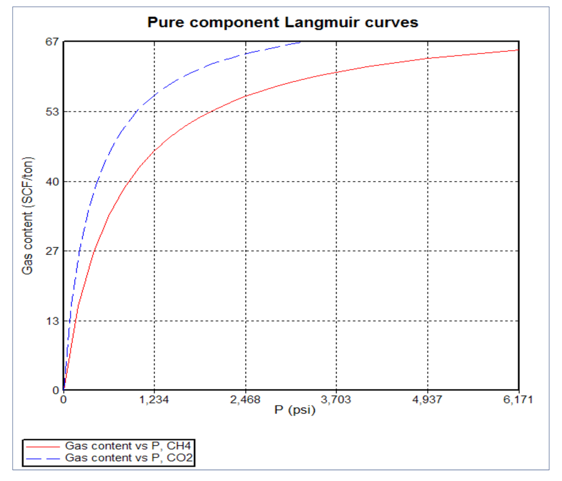
Rock and Fluid Properties

Source: National Energy Technology Laboratory - US Department of Energy

Parameter	low rate	mid rate	high rate	Unit
Initial Flow Rates (q_{i-prod})	1	10	20	MMscfd
Grid Size on X direction (L_x)	100	215	270	ft
Grid Size on Y direction (L_y)	80	215	270	ft
Area (A)	53	307	484	acres
Thickness (h)	264	271	276	ft
Depth (D)	6,500	6,500	6,500	ft
Matrix Porosity (ϕ_m)	6	8.5	11	%
Fracture Porosity (ϕ_f)	0.6	1.05	1.5	%
Matrix Permeability (k_m)	0.0003	0.0006	0.0009	md
Fracture Permeability (k_f)	0.0007	0.00185	0.003	md
Fracture Spacing (Δx_s)	2.5	1.7	0.9	ft
Reservoir Temperature (T_i)	142	142	142	F
Reservoir Pressure (P_i)	3,940	3,940	3,940	psi
Water Saturation in Matrix ($S_{w,m}$)	10	10	10	%
Water Saturation in Fracture ($S_{w,f}$)	0.1	0.1	0.1	%
Langmuir Volume of CH_4 (V_{L-CH_4})	73	73	73	scf/ton
Langmuir Pressure of CH_4 (P_{L-CH_4})	726	726	726	psi
Langmuir Volume of CO_2 (V_{L-CO_2})	75	75	75	scf/ton
Langmuir Pressure of CO_2 (P_{L-CO_2})	400	400	400	psi
Horizontal Wellbore Length (L_{hw})	500	1,935	2,970	ft
Hydraulic Fracture Half-length (x_f)	120	537.5	675	ft
Production Psf ($P_{sf-prod}$)	568	495	1,110	psi
SRV Fracture Porosity (*SRV*-ϕ_f)	1.2	2.1	3	%
SRV Fracture Permeability (*SRV*-k_f)	0.007	0.0185	0.03	md
SRV Fracture Spacing (*SRV*-Δx_s)	0.25	0.17	0.1	ft

Sw	Krw	Pcow
0	0	0
1	0	0

Sg	Krg	Pcog
0	0	0
1	1	0

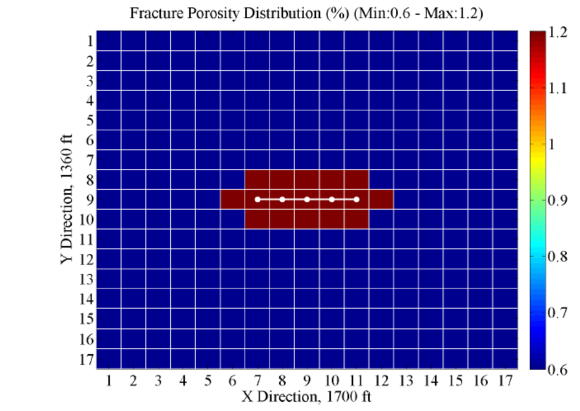
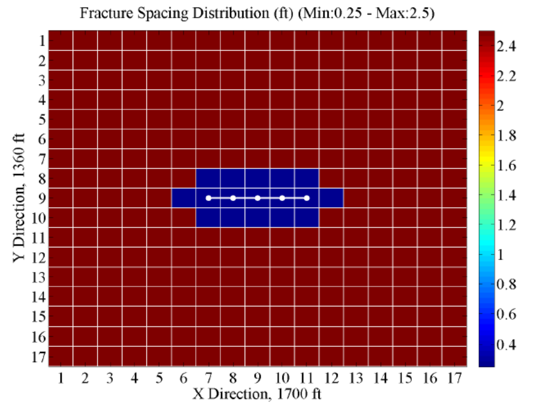


(B. Kulga, 2014)

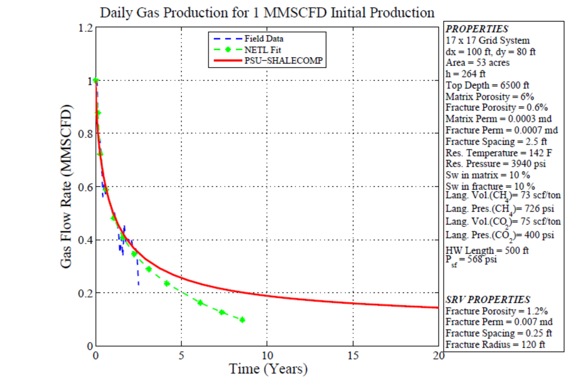
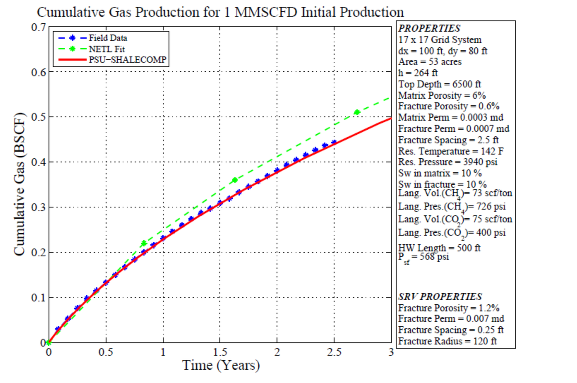
Results

Low-rate Case

- Initial production is selected as 1 MMSCFD
- SRV porosity is doubled from 0.6% to 1.2%
- SRV-kf is increased by magnitude of 10 from 0.0007 to 0.007 md
- SRV fracture spacing is decreased by magnitude of 10 from 2.5 ft to 0.25 ft

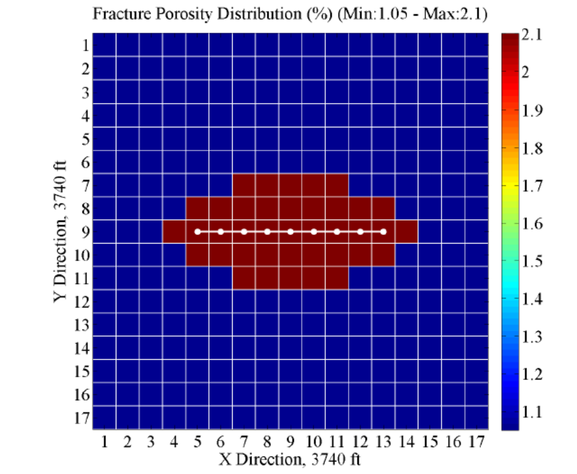
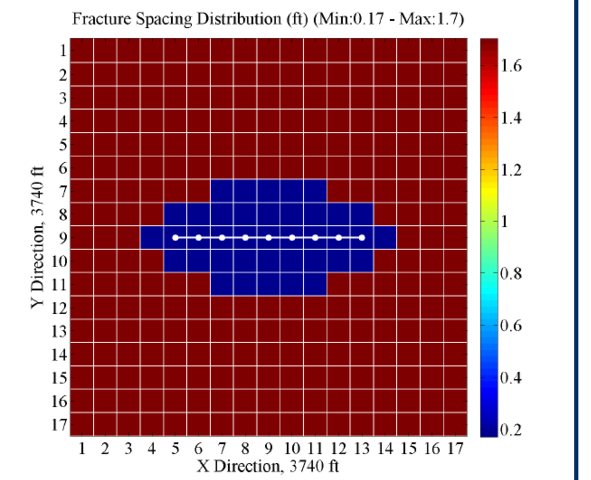



In this history match, reservoir area is kept relatively small as well as the horizontal wellbore length and hydraulic fracture dimensions to match the proposed initial flow rate, which is 1 MMSCFD. It is calculated that the daily production average error of field data versus PSU-SHALECOMP is 7.8% and the average error values for cumulative volume is 1.2%.

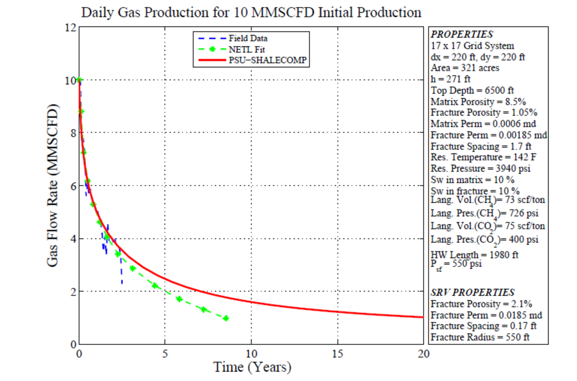
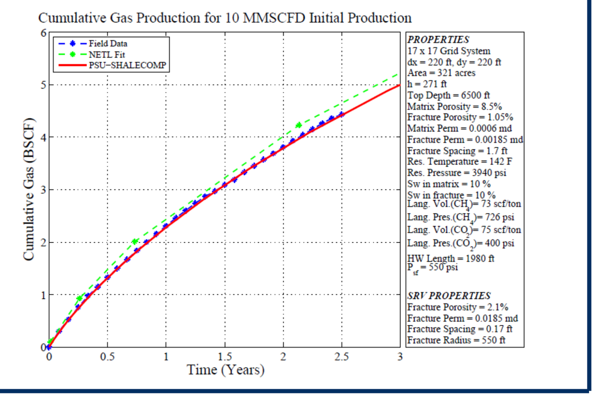



Mid-rate Case

- Initial production is selected as 10 MMSCFD
- SRV porosity is doubled from 1.05% to 2.1%
- SRV-kf is increased by magnitude of 10 from 0.00185 to 0.0185 md
- SRV fracture spacing is decreased by the magnitude of 10 from 1.7 ft to 0.17 ft

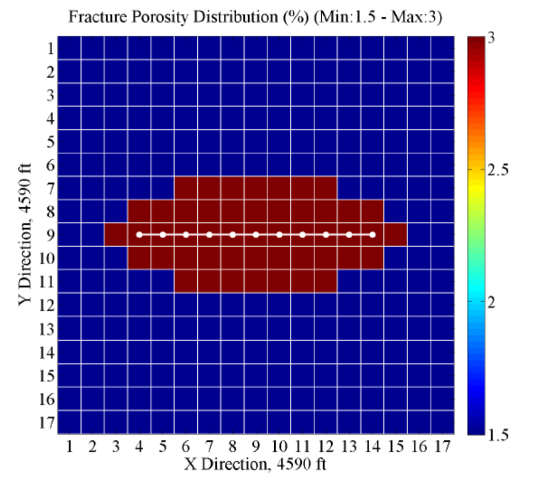
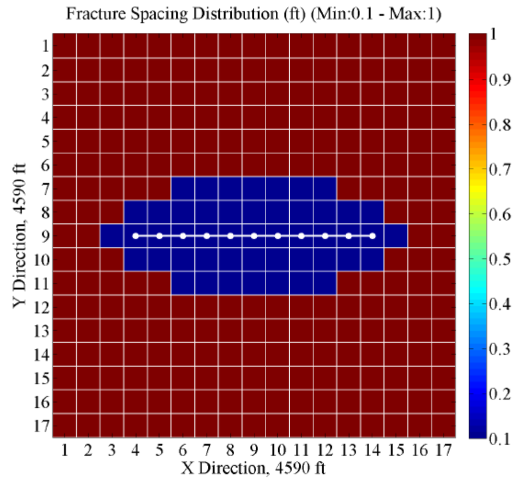



PSU-SHALECOMP is capable of matching the historical data very effectively with the combination of SRV approach. It is calculated that the daily production average error of field data versus PSU-SHALECOMP is 5.9% and the average error values for cumulative volume is 0.7%.

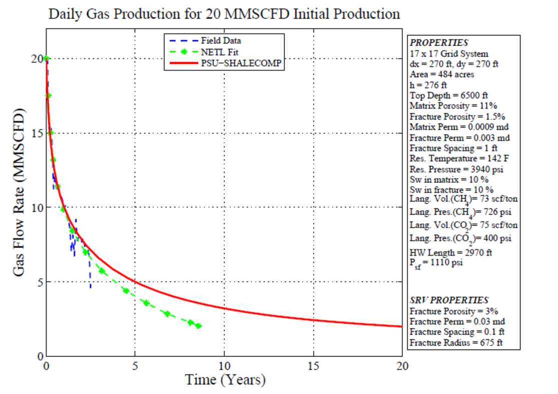
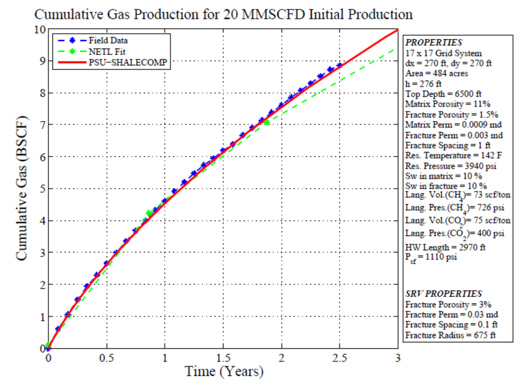



High-rate Case

- Initial production is selected as 20 MMSCFD
- SRV porosity is doubled from 1.5% to 3.0%
- SRV-kf is increased by magnitude of 10 from 0.003 to 0.03 md
- SRV fracture spacing is decreased by magnitude of 10 from 1.0 ft to 0.1 ft

Again, PSU-SHALECOMPs results had a near-perfect match against the normalized field data using the SRV concept. This model is rather large in terms of area. It can be seen that the well will produce nearly 2 MMSCFD at the end of the 20th year, making it highly economical. It is calculated that the daily production average error of field data versus PSU-SHALECOMP is 7.2% and the average error values for cumulative volume is 1.1%.

Conclusion

- With the implementation of SRV, convergence and instability issues are minimized that are caused by discrete fracture network modelling. The simulation times are also reduced significantly.
- PSU-SHALECOMP's results had very good matches against the normalized field data using the SRV concept. It is considered that this approach not only produces effectively accurate results but also time savings especially in terms of grid design and the fact that no local grid refinements are made around discrete fracture networks.
- It is calculated that the daily production average error of field data versus PSU-SHALECOMP is 7.8%, 5.9%, and 7.2% for low-rate, mid-rate and high-rate cases, respectively. The average error values for cumulative volumes produced are 1.2%, 0.7%, and 1.1%, respectively.
- With the addition of multi-mechanistic and desorption capability to shale gas numerical models, more hydrocarbon production is added from the rock matrix. Therefore, boundary effects in the production performances are seen in the later phases of production. More realistic results for shale gas performances are obtained.
- It is re-proved that implementation of the horizontal borehole technology and hydraulic fracturing are the two most important factors that will increase the efficacy of methane production.
- Although the PSU-SHALECOMP simulator matched the normalized field data effectively, the low-rate case should not be considered as a practical scenario for production of methane in shale reservoirs because the drainage area (53 acres), horizontal wellbore length (500 feet) and SRV values were required to be unrealistically small to be able to history-match the commercial field data.