PSThe Impact of Stress on Gas Production from the Shale*

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Abstract

The prediction of the hydraulic fracture properties in shale gas reservoirs is difficult because of the complex nature of hydraulic fracture growth, lack of good quality reservoir information, and the very low permeability of the matrix in shale gas reservoir. Furthermore, the propagating fracture causes a stress change, commonly known as a stress shadow, which influence the hydraulic fracture properties in the subsequent fracture stages. Additionally, shale is more sensitive to stress changes, which accompanies the gas production. In this study, the available information from a Marcellus Shale horizontal well in West Virginia was utilized in conjunction with a commercially available software to predict the hydraulic fracture properties accounting for the stress shadow impact. A reservoir simulation model was then developed based on the Marcellus Shale properties and the predicted hydraulic fracture properties. The production model incorporated the geomechanical factors associated with stress increase during the production. The inclusion of the stress shadow and the geomechanical factors provided more realistic prediction of the Marcellus Shale horizontal well production performance. Finally, parametric studies were performed to investigate the impact of stress changes and stress shadow on production performance and gas recovery.

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The Impact of Stress on Gas Production from Shale

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Introduction

Geotechnical Factors

As the Gas Is Produced from the Reservoir, the Net Stress Increases Because The Pore (Gas) Pressure Decreases while the Overburden Pressure Remains Constant. This Leads to the Matrix and the Fissure Permeability Reduction, as well as the Hydraulic Fracture Conductivity Impairment due to Proppant Embedment.

Stress Shadowing

When a Hydraulic Fracture Is Created, the Local Stress Is Changed. The Stress Increases Can Result in either the Deviation of Nearby Fractures or Limited the Propagation of the Fractures. This Is Referred to as *Stress Shadowing*.

Objectives & Methodology

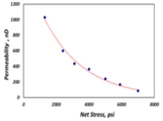
The Objective of This Study Was to Investigate the Impact of the Stress Shadowing and Geomechanical Factors on the Gas Production from the Horizontal Wells With Multiple Hydraulic Fractures Completed In Marcellus Shale.

Methodology

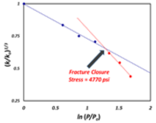
- Data Collection & Analysis
  1. Core Data
  2. Well Log Data
  3. Adsorption Characteristic
  4. Hydraulic Fracture Conductivity (Stress-dependency)
  5. Completion Records
  6. Production History
- Prediction of the Hydraulic Fracture Properties (GOFHER Software)
- Incorporating Geomechanical Factors into the Reservoir Model (CMG Software)
- Parametric Studies.

Data Collection & Analysis

1. CORE ANALYSIS



Impact of Net Stress on the Absolute Permeability of the Marcellus Shale (Elsaig 2016)



Estimation of the Fracture Closure Pressure for Marcellus Shale (Elsaig 2016)

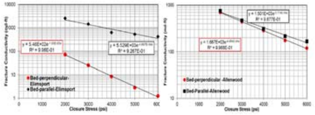
2. WELL LOG DATA

Gamma Ray, Density, Resistivity, Sonic, and Neutron Logs, available from a nearby well (3H), were utilized to estimate the Minimum Horizontal Stress (σ_H).

3. ADSORPTION CHARACTERISTICS

The Langmuir Pressure and Volume for Marcellus Shale obtained from core plug measurements (Zamirian et al. 2015).

4. STRESS-DEPENDENCY OF THE PROPPED FRACTURE CONDUCTIVITY(PUBLISHED DATA)



Conductivity of the Propped Hydraulic Fractures in Marcellus Shale (McGinley et al. 2015)

5. COMPLETION RECORDS

Well 6H Was Stimulated in 8 Stages over A Lateral Length of 2,380 Ft.

6. PRODUCTION HISTORY

Production data for Well 6H (12/2011 to 12/2015, 1473 days).

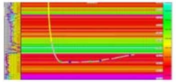
Prediction of the Hydraulic Fracture Properties

INPUT Parameters for GOFHER Software:

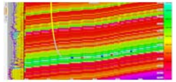
1. Parameters Estimated from the Well Log Data
   - Rock Properties (Young's Modulus, Poisson's Ratio, and Biot's Coefficient)
   - Overburden Pressure
   - Minimum Horizontal Stress (σ_H)
   - Pore Pressure Gradient
2. Fracture Treatment Design:
   Injection Rate, Proppant Size/Concentration, Fluid Type, Etc.

3. GEOSTEERING

The Log Data from the Vertical Section of Well 3h Were Converted to Fit Horizontal Section of the Well 6h by Geosteering. Geosteering Is Performed Based on the Similarities in the GR Signatures in Both Wells to Assure That the Horizontal Section Is in the Correct Zone.



Before Geosteering



After Geosteering

Incorporating Geomechanical Factors into the Reservoir Model

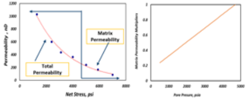
INPUT Parameters for CMG Software:

Base Model Parameters

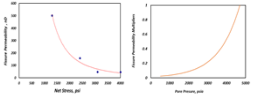
Reservoir Parameters	Values	Units
Model Dimensions (L×W×H)	4000×1000×90	ft.
Initial Reservoir Pressure	4700	psia.
Fissure Porosity	0.0001	Fraction
Matrix Porosity	0.045	Fraction
Fissure Permeability i, j, k	0.001,0.001,0.0001	md
Matrix Permeability i, j, k	0.0004,0.0004,0.00004	md
Water Saturation	0.15	Fraction
Rock Density	120	lb/ft^3
Langmuir Pressure	500	psi
Langmuir Volume	0.12	gmol/lb

Geomechanical Factors

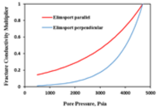
Matrix Permeability Multiplier



Fissure Permeability Multiplie



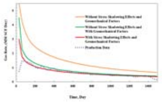
Propped Fracture Conductivity Multiplier



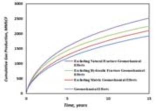
Predicted Fracture Properties

Stages	Average Fracture Width		Fracture Height		Fracture Half-Length		Fracture Conductivity	
	Without Stress Shadowing Effects	With Stress Shadowing Effects	Without Stress Shadowing Effects	With Stress Shadowing Effects	Without Stress Shadowing Effects	With Stress Shadowing Effects	Without Stress Shadowing Effects	With Stress Shadowing Effects
	in	in	ft.	ft.	ft.	ft.	md-ft	md-ft
1	0.46	0.46	120	120	300	300	12	12
2	0.46	0.38	120	100	300	280	18	10
3	0.46	0.29	120	90	300	280	16	4
4	0.44	0.40	120	100	300	280	13	8
5	0.43	0.32	130	120	320	280	14	9
6	0.43	0.31	140	130	320	300	17	9
7	0.46	0.29	140	130	300	220	17	7
8	0.44	0.23	140	70	300	180	15	3

Predicted Production Performance



Impact of Geomechanical Factors and Stress Shadowing on Gas Production on Predicted Production Rate Well 6h



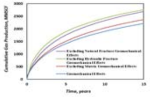
Impact of Different Geomechanical Factors on Well 6H Production (Base Case)

Parametric studies

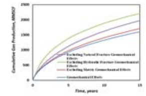
The Parametric Studies, Using Well 6H Model, Were Conducted To Investigate The Impact Of Fracture Half-length, Fracture Conductivity, Initial Fissure Permeability And Fracture Spacing (FS) On Production Performance.

Parameter		Base Case	Range	Units
Fracture Half-Length		**300**	350-450	ft.
Stage Spacing	Same number of Stages	**340**	100-260	ft.
	Increasing the number of Stages		100(24),180(14),260(10)	ft.
Initial Fracture Conductivity		**25**	5-20	md-ft.
Initial Fissure Permeability		**0.001**	0.002-0.006	md

Parametric Studies-Fracture Properties

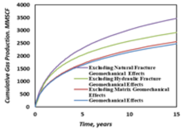


Impact of Different Geomechanical Factors on Well 6H Production (Fracture Half-Length 450 ft.)



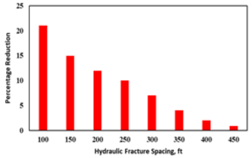
Impact of Different Geomechanical Factors on Well 6H Production (Initial Fracture Conductivity 5 md-ft.)

Parametric Studies-Fissure Permeability

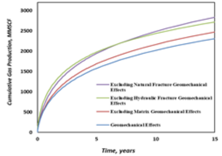


Cumulative Gas Production for Initial Fissure Permeability of 0.006 md.

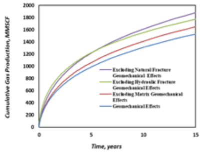
Parametric Studies-Fracture Spacing



Reduction in Gas Recovery Due to the Stress Shadowing

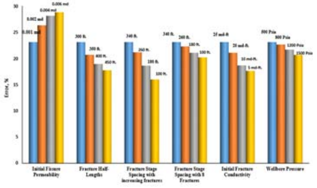


Impact of Different Geomechanical Factors on Production for Fracture Stage Spacing 180 ft. with 14 Stages



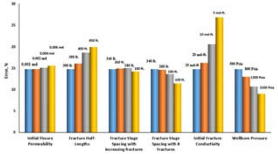
Impact of Different Geomechanical Factors on Production for Fracture Stage Spacing 180 ft. with 8 Stages

Parametric Studies- Fissure Permeability Geomechanical Factor



Impact of the Fissure Permeability Geomechanical Factor on Gas Recovery

Parametric Studies- Fracture Conductivity Geomechanical Factor



Impact of the Fracture Conductivity Geomechanical Factor on Gas Recovery

Conclusions

- Accounting for stress caused by stress shadowing and geomechanical factors provided in a more realistic estimate of hydraulic fracture properties and improved the production prediction.
- The impact of the geomechanical factors on gas production could be significant particularly at the early stages of the production (1-5 years).
- The fissure permeability and propped fracture conductivity geomechanical factors have major impact on the production while the matrix permeability geomechanical factor has only a minor impact on production
- The impact of the fissure permeability geomechanical factor decreases as the fracture half-length and conductivity increase.
- The impact of the fissure permeability geomechanical factor increases as the fracture spacing increases.
- Stress shadowing increases as the fracture spacing decreases and reduces fracture length, height, and conductivity.
- The predicted fracture in Marcellus Shale grows vertically, if the stress shadowing effects are ignored.
- The higher is the fracture height, the greater is the impact of the stress shadowing on Marcellus Shale.
- Ignoring stress shadowing leads to over-estimation of the gas recovery.
- The impact of the stress shadowing on gas production is more significant at the early stages of the production (1-5 years).

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