UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
COLORADO SCHOOL OF MINES

Sensitivities of Fractured Horizontal Wells in Shale Gas Plays to Technical and Economic Parameters

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Outline

- Background
- Trilinear flow model
- Productivity Index
- Rate of Change of Productivity
- Sensitivity Discussion
  - Technical approach
  - Economic approach
- Results
- Conclusions

Background

Understanding of parameters that affect recovery from shale-gas plays.

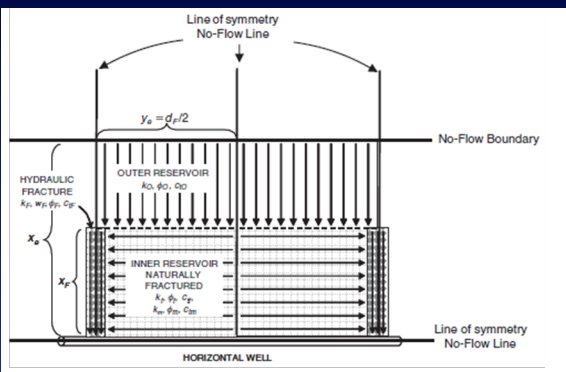
- Horizontal well
  - Well length
- Hydraulic fracture
  - Hydraulic fracture permeability, distance between and fracture half length
- Naturally fractured Reservoir
  - Matrix permeability, natural fracture permeability and natural fracture density

Understanding of parameters that affect economic performance

- Net present value
- Internal rate of return
- Break-even prices

Trilinear Flow Model

Physical Definition and the Assumptions of the Trilinear-Flow Model



Trilinear-Flow Model Schematic (Brown et al., 2009)

Productivity Index

$$J = \begin{cases} \dfrac{q_t}{\overline{p} - p_{wf}} & \text{for oil} \\ \dfrac{q_t}{m\left(\overline{p}\right) - m\left(p_{wf}\right)} & \text{for gas} \end{cases}$$

$$J = \frac{q_t}{\overline{P} - P_{wf}} = \frac{q_t}{\left(P_i - P_{wf}\right) - \left(P_i - \overline{P}\right)} = \frac{q_t}{L^{-1}\left\{\overline{\Delta p}_{wf}\left(s\right)\right\} - \Delta\overline{P}}$$

$$P_i - \overline{P} = \frac{0.234 q_t B}{Ah\left(\phi_f c_f h_{ft}\right)\left(1+\omega\right)} t$$

Rate of Change of Productivity Index

Derivative of the productivity index with respect to well, reservoir, or fracture property, ξ , developed by

$$\frac{\partial J}{\partial \xi} = \frac{\partial}{\partial \xi}\left\{\frac{q_t}{L^{-1}\left\{\overline{\Delta p}_{wf}\left(s\right)\right\} - \Delta\overline{p}}\right\}$$

$$= -\frac{q_t}{\left[L^{-1}\left\{\overline{\Delta p}_{wf}\left(s\right)\right\} - \Delta\overline{p}\right]^2}\frac{\partial}{\partial \xi}\left[L^{-1}\left\{\overline{\Delta p}_{wf}\left(s\right)\right\} - \Delta\overline{p}\right]$$

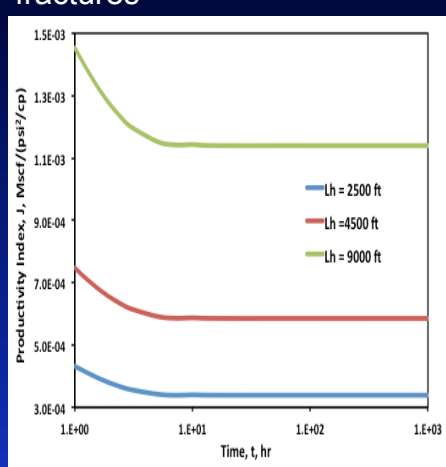
$$\frac{\partial J}{\partial \xi} = -\frac{1}{q_t}J^2\left[L^{-1}\left\{\frac{\partial}{\partial \xi}\overline{\Delta p}_{wf}\left(s\right)\right\} - \frac{\partial}{\partial \xi}\Delta\overline{p}\right]$$

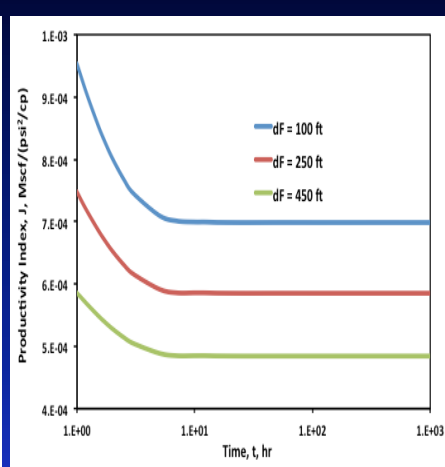
Results Discussion-Cases

Parameter	Low	Base	High
Formation thickness, h, ft	Base	250	Base
Wellbore radius, r_w, ft	Base	0.25	Base
Horizontal well length, L_h, ft	**2500**	**4500**	**9000**
Viscosity, μ, cp	Base	0.0184	Base
Matrix Permeability, k_m, md	**1.00E-08**	**1.00E-06**	**1.00E-04**
Matrix Porosity, $\emptyset_m$	Base	0.05	Base
Matrix Total Compressibility, c_{tm}, psi-1	Base	1.00E-05	Base
Natural fracture Permeability, k_f, md	**1.00E+03**	**5.00E+03**	**1.00E+04**
Natural fracture Porosity, $\emptyset_f$	Base	4.50E-01	Base
Natural fracture Total Compressibility, c_{tf}, psi-1	Base	1.00E-05	1.00E-05
Natural fracture thickness, h_f, ft	Base	1.00E-03	1.00E-03
Natural fracture density, ρ_f, number of fractures/ft	**0.2**	**0.8**	**1.2**
Distance between hydraulic fractures, dF, ft	**100**	**250**	**450**
Hydraulic fracture porosity, $\emptyset_F$	Base	0.38	0.38
Hydraulic fracture permeability, k_F, md	**1.00E+04**	**5.00E+04**	**1.00E+05**
Hydraulic fracture Total Compressibility, c_{tf}, psi-1	Base	1.00E-05	1.00E-05
Hydraulic fracture half-length, x_F, ft	**150**	**250**	**350**
Hydraulic fracture width, w_F, ft	Base	0.01	Base
Initial Reservoir Pressure, p_i, psi	Base	4500	Base
Constant flow rate, q, MSCF/d	Base	1500	Base
Reservoir Temperature T, ˚F	Base	150	Base
Dimensionless wellbore storage coeff, C_D	Base	0	Base
Mechanical skin, s_c	Base	0	Base

Productivity Index as a function of time

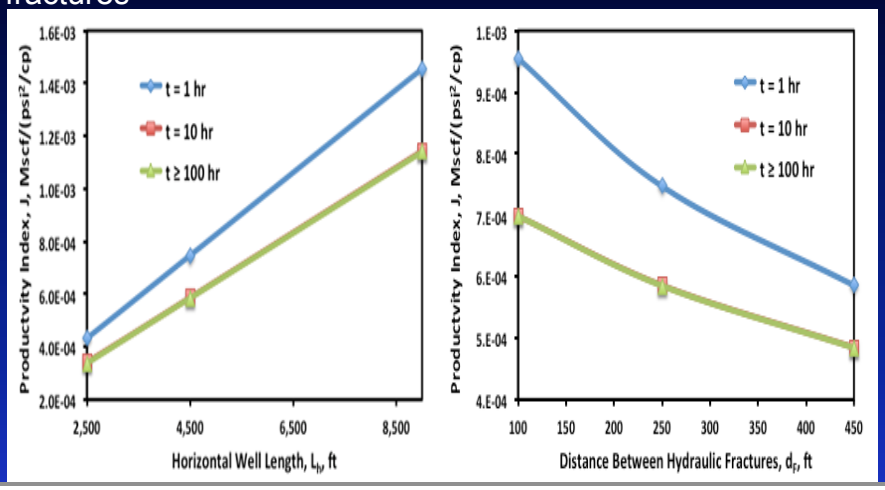
Horizontal Well Length and Distance between hydraulic fractures





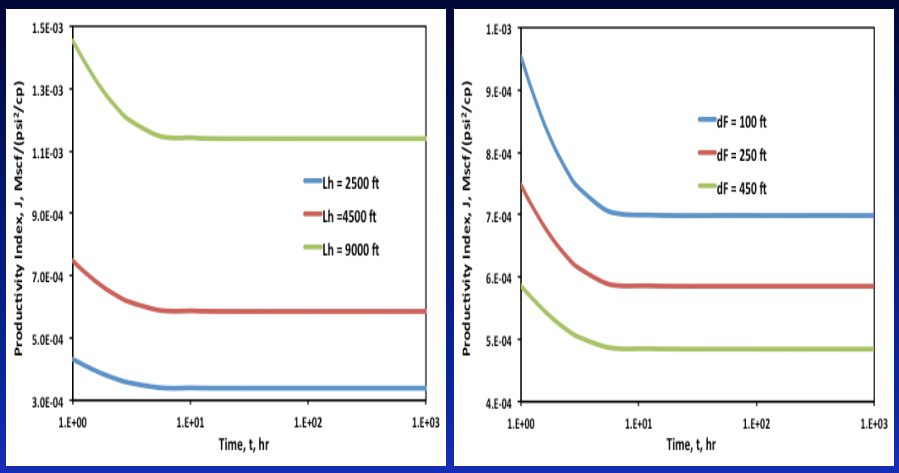
Productivity Index as a function of time

Horizontal Well Length and Distance between hydraulic fractures



Productivity Index as a function of time

Natural Fracture Density and Hydraulic Fracture half-length



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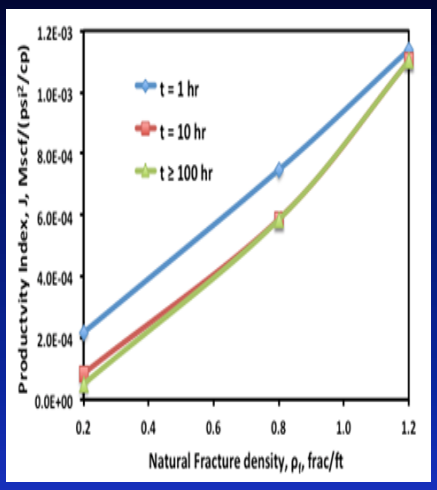
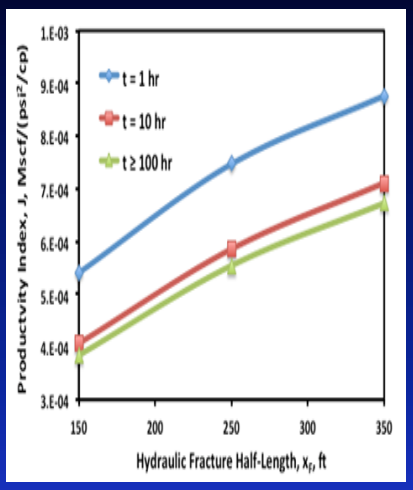
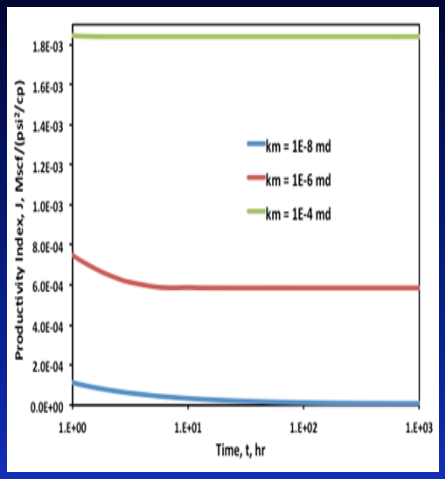
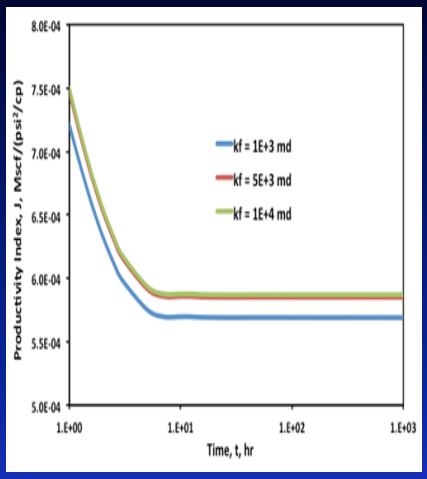




Productivity Index as a function of time

Matrix and Natural Fracture Permeability





Productivity Index as a function of time

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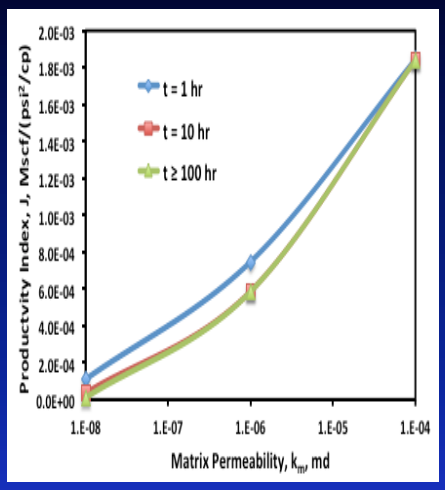
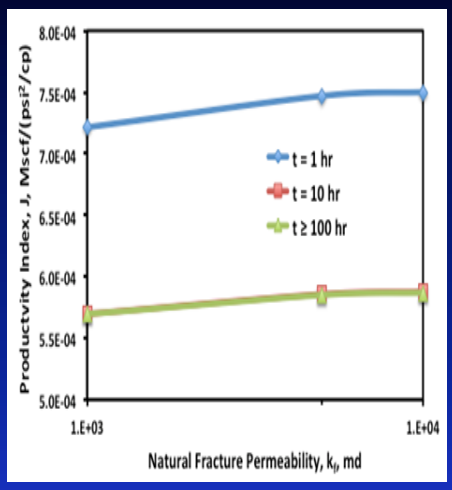
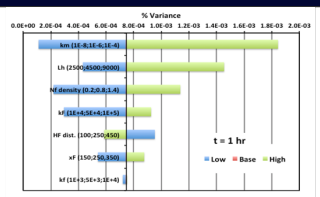


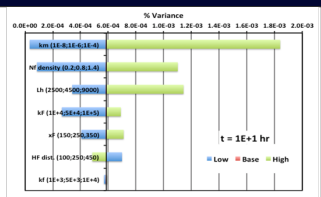


Productivity Sensitivity

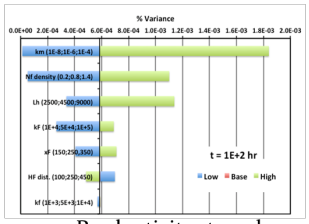
Tornado Charts



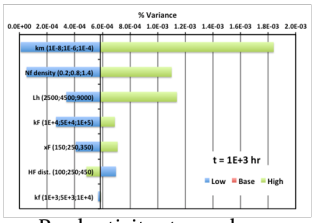
Productivity at 1 hr



Productivity at 10 hrs.



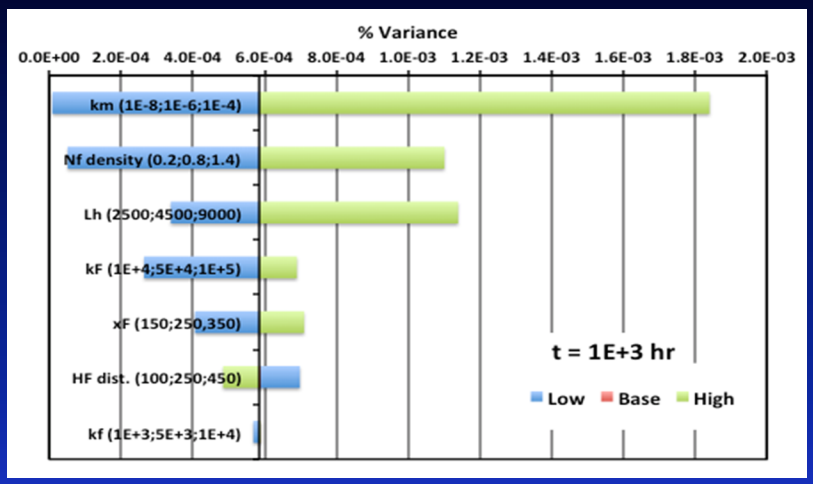
Productivity at 100 hrs.



Productivity at 1000 hrs.

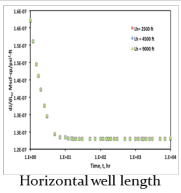
Productivity Sensitivity

Sensitivity of productivity for t=1000 hr.

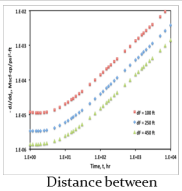


Productivity Sensitivity

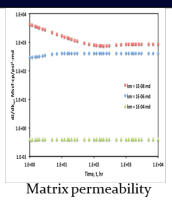
Rate of Change of Productivity



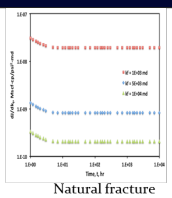
Horizontal well length



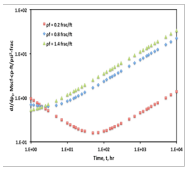
Distance between hydraulic fractures



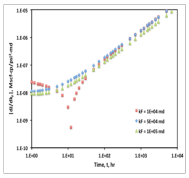
Matrix permeability



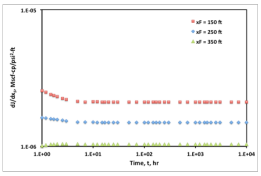
Natural fracture permeability



Density of natural fractures



Hydraulic fracture. permeability



Hydraulic fracture half length

Conclusions

- Technical analysis indicates that the productivity of fractured horizontal wells in shale gas plays is most sensitive to matrix permeability and least sensitive to natural-fracture permeability.
- Sensitivity to natural fracture density is high
- Among well and hydraulic fracture properties, well length has the highest effect, hydraulic fracture permeability moderate effect and distance between fractures as well as hydraulic fracture half length an insignificant effect.
- Economic analysis indicates that NPV and IRR are flexible by improving economics on well construction and stimulation.
- Favorable reservoir properties appear to be necessary for a sucessful economic
- That said, reservoir properties are not enough and do not ensure economic success without well construction and stimulation optimization.