Boundary Value Effects on Migration Patterns in Hydraulically Fractured Shale Formations

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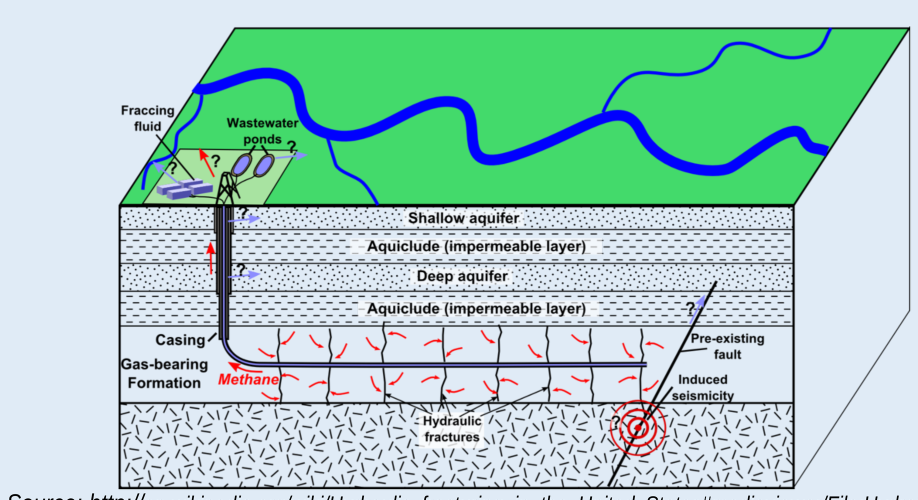
Introduction

Re-activation of sealed faults that extend beyond the reservoir boundaries sometimes occur during the hydraulic fracturing of shale reservoirs.

This study seeks to investigate the effect of changes in the conceptualization of reservoir boundaries on fluid flow in fractured shale formations.



Source: http://en.wikipedia.org/wiki/Hydraulic_fracturing_in_the_United_States#mediaviewer/File:HydroFrac.png

Figure. 1 - Schematic depiction of hydraulic fracturing for shale gas, showing potential environmental effects

Computational Model

Flow in the reservoir domain is governed by Darcy's Law and the mass conservation equations. A simplified representation of these governing equations is presented below:

$$v = -\frac{k}{\mu}\nabla p \qquad (1)$$

$$\frac{\partial}{\partial t}\left(M_p \right) = -\nabla.(\rho v) \qquad (2)$$

Semi-explicit representations of the pre-existing fault, horizontal bedding planes and hydraulic fractures are generated as shown in Figure 2.

Flow in the fractures are modeled using COMSOL's Fracture Flow Interface which reduces the dimensionality of the fracture domain and solves for equation (1) using tangential derivatives to the pressure gradient

$$q_f = -\frac{k_f}{\mu} d_f(\nabla_T p) \qquad (3)$$

Simulations are carried out using two test cases:

- The formation with natural bedding planes and a pre-existing fault (Pre-frac)
- Hydraulically fractured formation with natural bedding planes and pre-existing fault (Post-frac).

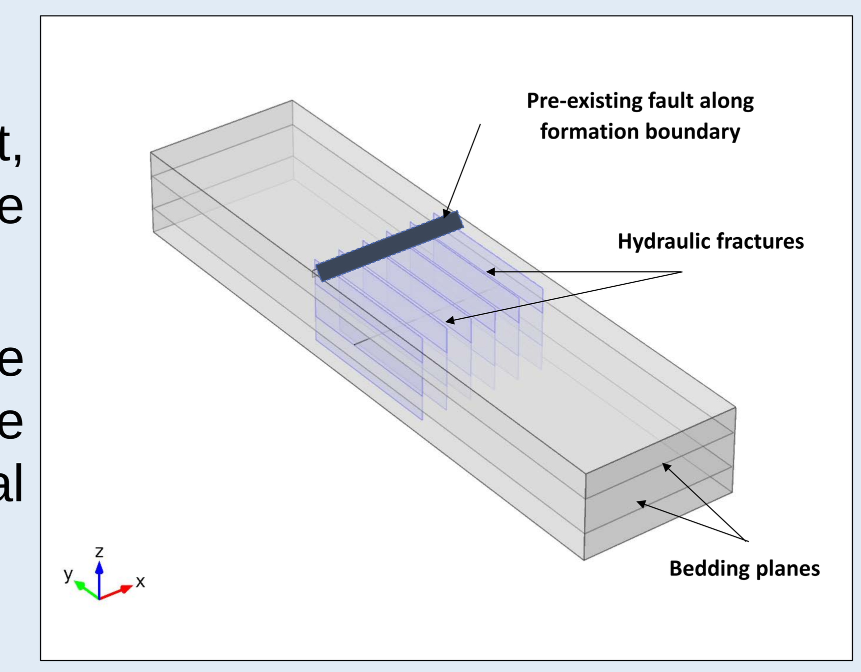


Figure. 2 - Reservoir geometry showing Post-fracturing state and a fault along the top boundary

Results

Table 1—Model Input Parameters

Parameter	*Value*	*Units*
Matrix permeability	1.0×10^{-4}	mD
Porosity of the matrix	5	%
Initial Reservoir pressure	3800	psi
Reservoir volume(x*y*z)	500 * 2000 *250	ft^3
Reservoir width	2000	ft
Reservoir length	500	ft
Number of hydraulic fractures	6	
Number of bedding planes	2	
Hydraulic fracture porosity	50	%
Hyd. fracture permeability	1.0×10^{5}	mD
Hydraulic fracture aperture	0.02	ft
Hydraulic fracture length	500	ft
Hydraulic fracture height	250	ft
Boundary fault permeability	2.0×10^{3}	mD
Boundary fault porosity	50	%
Boundary fault length	495	ft
Boundary fault aperture	0.02	ft
Boundary fault depth	20	ft
Fluid Viscosity	0.0184	cP
Fluid Density	0.66	kg/m^3
Fluid compressibility	2.5×10^{-4}	psi^{-1}
Boundary Conditions		
All faces	No-Flux	
Fault Boundary Edge	Changing pressure	
Well-bore pressure	500	psi

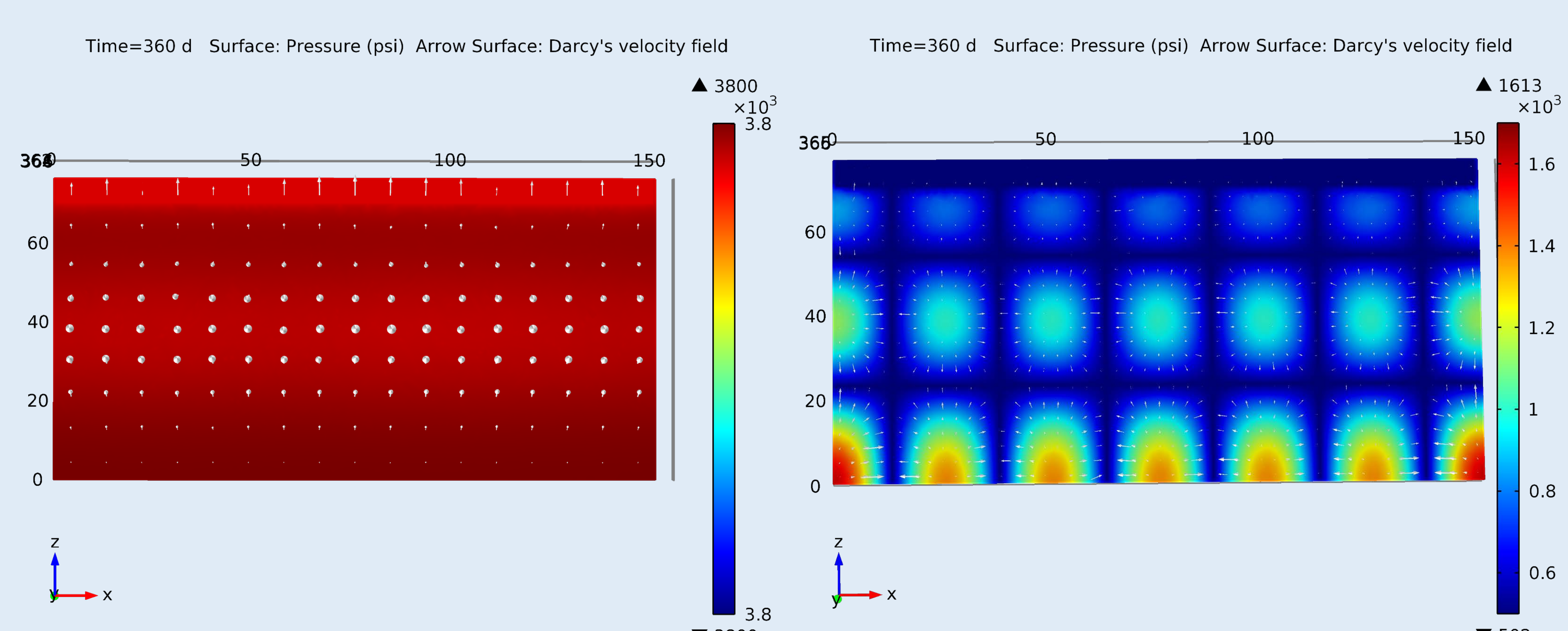
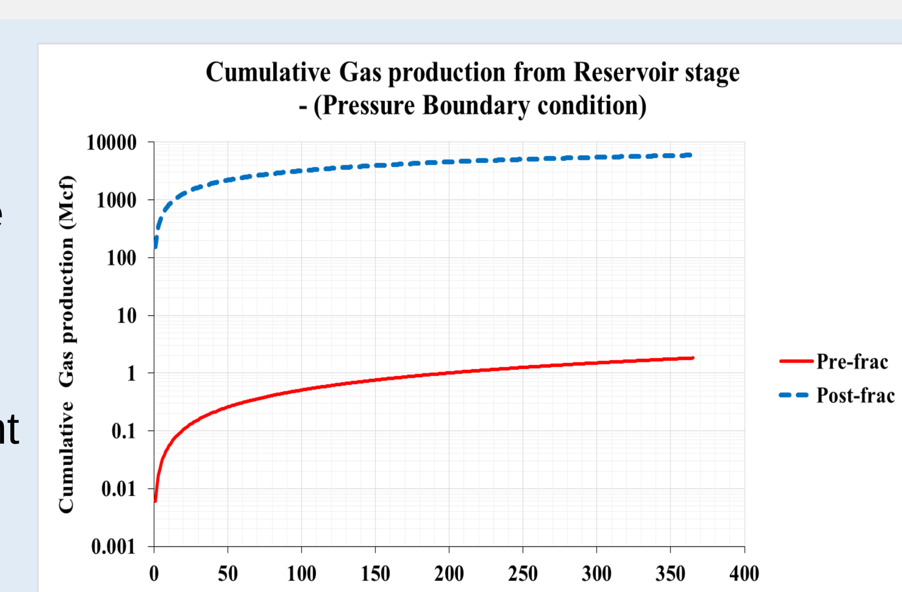


Figure. 3— Pressure distribution and Arrow surface plots for cut-plane sections through plane containing boundary fault for (a) Pre-frac and (b) Post-frac conceptual models

- There is observable pressure dissipation towards the fault and the wellbore as a result of interconnected fractures induced by the hydraulic fracturing process.
- At the end of a 1 year simulation period, fluid movement is towards the pre-existing fault (top 20 ft. of domain) in the Pre-frac case, while the major fluid migration direction is towards the fracture network in the Post-frac case as shown by the arrow surface plots.

- Introduction of hydraulic fractures into the formation leads to a noticeable difference in the wellbore gas production values - Figure 4(a).
- The presence of the fault at the model boundary reduces the amount of gas recovered at the wellbore (compared to a no-flux boundary case).



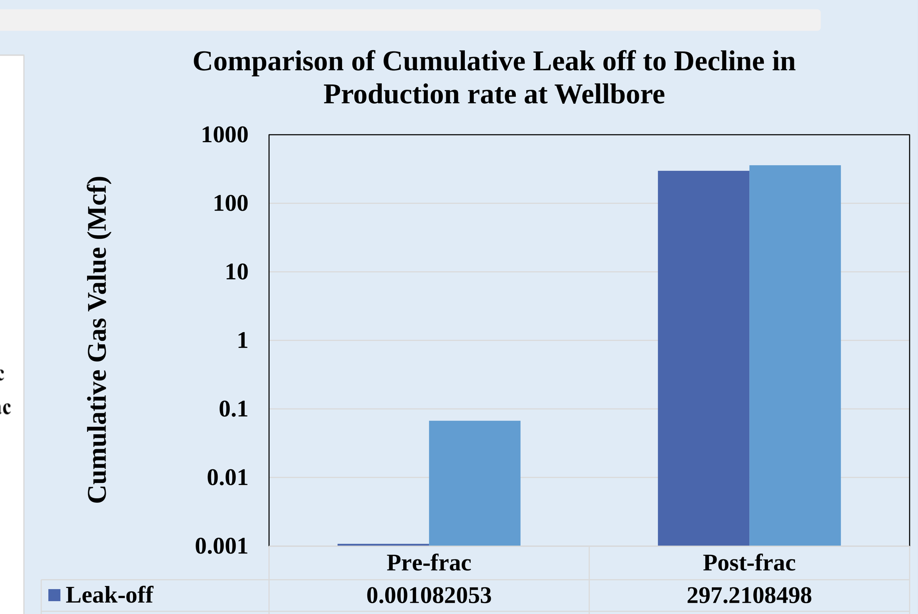


Figure. 4—Comparison of (a) Cumulative gas production from the reservoir and (b) Cumulative leak off rates to decline in Wellbore production, after a 1 year period for the Pre-frac and Post-frac modeling scenarios.

Conclusions

- The assumption of a no-flux boundary condition in the presence of a fault along the boundary of a reservoir formation leads to an improper accounting of the leak-off values associated with the fault boundaries.
- A sensitivity analysis of the fault parameters as well as the properties of the overlying formations needs to be conducted in order to ascertain that this leak-off stream does not travel into overlying formations and contaminate adjacent aquifers in gas production areas.

Acknowledgements

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References:

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