

Modeling Hydraulic Fracture Entering Stress Barrier: Theory and Practical Recommendations

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Abstract

Numerical modeling of hydraulic fracturing is complicated when a fracture reaches a stress barrier. For high barriers, it may require changing of a computational scheme. Despite there are examples of modeling propagation through barriers, there is no general theory clarifying when and why conventional schemes may become inefficient, and how to overcome computational difficulties. The paper presents the theory and practical recommendations following from it.

We start from the definition of the barrier intensity, which exposes that the barrier strength may change from zero for contrast-free propagation to infinity for channelized propagation. The analysis reveals two types of computational difficulties caused by *spatial discretization*: (i) *general* arising for fine grids and aggravated by a barrier; and (ii) *specific*, caused entirely by a strong barrier.

The *asymptotic approach* which avoids spatial discretization is suggested. It is illustrated by solving *bench-mark* problems for barriers of arbitrary intensity. The analysis distinguishes three typical stages of the fracture penetration into a barrier, and provides theoretical values of the Nolte-Smith slope parameter and arrest time as functions of the barrier intensity.

Special analysis establishes the accuracy and bounds of the asymptotic approach. It appears that the approach provides physically significant and accurate results for fracture penetration into high, intermediate and even weak stress barriers.

On this basis, simple practical recommendations are given for modeling hydraulic fractures in rocks with stress barriers. The recommendations may be promptly implemented in any program using spatial discretization to model fracture propagation.

Keywords Hydraulic fracture; Stress barrier; Barrier intensity; Numerical modeling

1 Introduction

Since early studies of hydraulic fracturing (HF) (e.g., Perkins and Kern 1961; Nordgren 1972), the impact of stress inhomogeneity on the fracture propagation has been taken into account. Specifically, channelized propagation along a pay-layer between impenetrable neighbors was simulated by the classical Perkins-Kern-Nordgren (PKN) model. However, with increasing pumping pressure, a fracture extends also into neighbor layers, what affects final footprints and openings, and so, the efficiency of a HF treatment. This stimulated effort to account for the fracture growth beyond a pay-layer, which resulted in successive development of pseudo-three dimensional (P3D) models (Settari and Cleary 1982, 1986; Palmer and Carroll 1982, 1983; Palmer and Craig 1984; Meyer 1986; Morales 1989; Warpinski and Smith 1989; Mack and Warpinski 2000; Adachi et al. 2007; Rahman and Rahman 2010; Dontsov and Peirce 2015; Linkov and Markov 2020). They complemented the PKN model by equations for out-of-layer growth.

All these models presume that the variation of in-situ stresses, caused by the difference in elastic modules of rock layers, impacts the fracture growth much more significantly than the difference in the modules itself. Then rock mass may be assumed homogeneous, while the assigned initial stresses change. Numerical results, obtained by solving problems for a crack, intersecting layers with different elastic modules and different assigned stresses (Erdogan and Biricikoglu 1973; Peirce and Siebrits 2001a), support the suggestion on the predominant impact of stress-contrasts. Other solutions for 3D layered structures with

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Practical Guide To Hydraulic Fracture

Usman Ahmed,D. Nathan Meehan



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Hydraulic fracture geometry characterization based on distributed fiber optic strain measurements Kan Wu, Yongzan Liu, Ge Jin, Aishwarya Srinivasan, 2024-06-05 Fiber optic based measurements are innovative tools for the oil and gas industry to utilize in monitoring wells in a variety of applications including geothermal activity Monitoring unconventional reservoirs is still challenging due to complex subsurface conditions and current research focuses on qualitative interpretation of field data Hydraulic Fracture Geometry Characterization from Fiber Optic Based Strain Measurements delivers a critical reference for reservoir and completion engineers to better quantify the propagation process and evolution of fracture geometry with a forward model and novel inversion model The reference reviews different fiber optic based temperature acoustic and strain measurements for monitoring fracture behaviors and includes advantages and limitations of each measurement giving engineers a better understanding of measurements applied in all types of subsurface formations Stress strain rate responses on rock deformation are given a holistic approach including guidelines and an automatic algorithm for identification of fracture hits Last a novel inversion model is introduced to show how fracture geometry can be used for optimization on well placement decisions Supported by case studies Hydraulic Fracture Geometry Characterization from Fiber Optic Based Strain Measurements gives today's engineers better understanding of all complex subsurface measurements through fiber optic technology Examine the basics of distributed fiber optic strain measurements Conduct a detailed analysis of strain responses observed in both horizontal and vertical monitoring wells Present a systematic approach for interpreting strain data measured in the field Highlight the significant insights and values that can be derived from the field measured strain dataset Support monitoring and modeling for subsurface energy extraction and safe storage

Shale Oil and Gas Production Processes James G. Speight, 2019-11-18 Shale Oil and Gas Production Processes delivers the basics on current production technologies and the processing and refining of shale oil Starting with the potential of formations and then proceeding to production and completion this foundational resource also dives into the chemical and physical nature of the precursor of oil shale kerogen to help users understand and optimize its properties in shale Rounding out with reporting in situ retorting refining and environmental aspects this book gives engineers and managers a strong starting point on how to manage the challenges and processes necessary for the further development of these complex resources Helps readers grasp current research on production from shale formations including properties and composition Fill in the gaps between research and practical application including discussions of existing literature Includes a glossary to help readers fully understand key concepts

Microseismic Imaging of Hydraulic Fracturing Shawn Mawell, Society of Exploration Geophysicists, 2014-01-01 Microseismic Imaging of Hydraulic Fracturing Improved Engineering of Unconventional Shale Reservoirs SEG Distinguished Instructor Series No 17 covers the use of microseismic data to enhance engineering design of hydraulic fracturing and well completion The book which accompanies the 2014 SEG

Distinguished Instructor Short Course describes the design acquisition processing and interpretation of an effective microseismic project The text includes a tutorial of the basics of hydraulic fracturing including the geologic and geomechanical factors that control fracture growth In addition to practical issues associated with collecting and interpreting microseismic data potential pitfalls and quality control steps are discussed Actual case studies are used to demonstrate engineering benefits and improved production through the use of microseismic monitoring Providing a practical user guide for survey design quality control interpretation and application of microseismic hydraulic fracture monitoring this book will be of interest to geoscientists and engineers involved in development of unconventional reservoirs **Fracture Mechanics**

Lucas Alves,2016-10-19 This book is a collection of 13 chapters divided into seven sections Section I General Foundations of the Stress Field and Toughness with one chapter Section II Fractography and Impact Analysis with two chapters Section III Toughness Fracture with three chapters Section IV Fracture Behavior with two chapters Section V Natural and Hydraulic Fractures with two chapters section VI Fatigue with one chapter and Section VII Fracture Biomaterials and compatible with two chapters This book covers a wide range of application of fracture mechanics in materials science engineering rock prospecting dentistry and medicine The book is aimed towards materials scientists metallurgists mechanical and civil engineers doctors and dentists and can also be well used in education research and industry Deep Shale Oil and Gas

James G. Speight,2016-09-10 Natural gas and crude oil production from hydrocarbon rich deep shale formations is one of the most quickly expanding trends in domestic oil and gas exploration Vast new natural gas and oil resources are being discovered every year across North America and one of those new resources comes from the development of deep shale formations typically located many thousands of feet below the surface of the Earth in tight low permeability formations Deep Shale Oil and Gas provides an introduction to shale gas resources as well as offer a basic understanding of the geomechanical properties of shale the need for hydraulic fracturing and an indication of shale gas processing The book also examines the issues regarding the nature of shale gas development the potential environmental impacts and the ability of the current regulatory structure to deal with these issues Deep Shale Oil and Gas delivers a useful reference that today s petroleum and natural gas engineer can use to make informed decisions about meeting and managing the challenges they may face in the development of these resources Clarifies all the basic information needed to quickly understand today s deeper shale oil and gas industry horizontal drilling fracture fluids chemicals needed and completions Addresses critical coverage on water treatment in shale and important and evolving technology Practical handbook with real world case shale plays discussed especially the up and coming deeper areas of shale development *Unconventional Oil and Gas Resources Handbook* Y Zee Ma,Stephen Holditch,2015-10-06 Unconventional Oil and Gas Resources Handbook Evaluation and Development is a must have helpful handbook that brings a wealth of information to engineers and geoscientists Bridging between subsurface and production the handbook provides engineers and geoscientists with effective methodology to better

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Innovations in Enhanced and Improved Oil Recovery - New Advances Mansoor Zoveidavianpoor, 2024-04-24 This book navigates the evolving landscape of Enhanced Oil Recovery EOR and Improved Oil Recovery IOR covering diverse topics such as lithological dynamics in CO2 EOR the impact of asphaltene precipitation in WAG implementation progress in CO2 EOR and storage technology in situ foam generation for unconventional fractured reservoirs electromagnetic radiation effects on heavy oil upgrading advancements in hydraulic fracturing in situ synthesis of nanoparticles and operational insights in the Bakken Shale This comprehensive volume serves as an indispensable resource for professionals and researchers in the ever changing field of enhanced and improved oil recovery

Unconventional Oil and Gas Resources Usman Ahmed, D. Nathan Meehan, 2016-04-05 As the shale revolution continues in North America unconventional resource markets are emerging on every continent In the next eight to ten years more than 100 000 wells and

one to two million hydraulic fracturing stages could be executed resulting in close to one trillion dollars in industry spending. This growth has prompted professionals to explore the *Characterization, Prediction and Modelling of the Crustal Present-Day In-Situ Stresses*. R. Goteti, T. Finkbeiner, M. O. Ziegler, C. Massiot, 2024-08-01. Geomechanics has a marked impact on the safe and sustainable use of the subsurface. Along with an ongoing demand for hydrocarbon resources, there is also a growing emphasis on sustainable subsurface exploitation and development, storage of carbon hydrogen energy and radioactive waste, as well as sustainable geothermal resource utilization. Such activities are accompanied by an ever-increasing need for higher resolution fit-for-purpose solutions, workflows and approaches to constrain present-day subsurface stresses and minimize associated uncertainties. Building high-fidelity geomechanical numerical models provides critical input and understanding for diverse engineering designs and construction, as well as geoscience applications. Such models greatly contribute towards uncertainty reduction, risk management and risk mitigation during the operational life of a given subsurface development and associated infrastructures, both on and below the surface. This Special Publication contains contributions detailing the latest efforts and perspectives in present-day in-situ stress characterization, prediction and modelling from the borehole to plate tectonic scale. There is particular emphasis on the uncertainties that are often associated with data and models.

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