Discrete Fracture Model For Coupled Flow And Geomechanics

Constitutive modelling is the mathematical description of how materials respond to various loadings. This is the most intensely researched field within solid mechanics because of its complexity and the importance of accurate constitutive models for practical engineering problems. Topics covered include: Elasticity - Plasticity theory - Creep theory - The nonlinear finite element method - Solution of nonlinear equilibrium equations - Integration of elastoplastic constitutive equations - The thermodynamic framework for constitutive modelling – Thermoplasticity - Uniqueness and discontinuous bifurcations • More comprehensive in scope than competitive titles, with detailed discussion of thermodynamics and numerical methods. • Offers appropriate strategies for numerical solution, illustrated by discussion of specific models. • Demonstrates each topic in a complete and self-contained framework, with extensive referencing. This book describes the theoretical and computational aspects of the mimetic finite difference method for a wide class of multidimensional elliptic problems, which includes diffusion, advection-diffusion, Stokes, elasticity, magnetostatics and plate bending problems. The modern mimetic discretization technology developed in part by the Authors allows one to solve these equations on unstructured polygonal, polyhedral and generalized polyhedral meshes. The book provides a practical guide for those scientists and engineers that are interested in the computational properties of the mimetic finite difference method such as the accuracy, stability, robustness, and efficiency. Many examples are provided to help the reader to understand and implement this method. This monograph also provides the essential background material and describes basic mathematical tools required to develop further the mimetic discretization technology and to extend it to various applications.

Applied mathematical modeling is concerned with solving unsteady problems. Splitting schemes are attributed to the transition from a complex problem to a chain of simpler problems. This book shows how to construct additive difference schemes (splitting schemes) to solve approximately unsteady multi-dimensional problems for PDEs. Two classes of schemes are highlighted: methods of splitting with respect to spatial variables (alternating direction methods) and schemes of splitting into physical processes. Also regionally additive schemes (domain decomposition methods) and unconditionally stable additive schemes of multi-component splitting are considered for evolutionary equations of first and second order as well as for systems of equations. The book is written for specialists in computational mathematics and mathematical modeling. All topics are presented in a clear and accessible manner.

This dissertation intends to advance fundamental understanding of two areas of interest in the petroleum industry: complex stimulated fracture network during hydraulic fracturing treatments and induced seismicity during wastewater disposal operations.

Successful completion of hydraulic fractures in unconventional formations has been the primary source of increased oil and gas production in the US. However, field observations suggest that the hydraulic fracture networks are much more complex and different from the classical description of bi-wing planar fractures. Thus, the attempts to optimize this stimulation technique are hindered by the uncertainties in predicting the complex fracture network. A by-product of massive improvement in oil and gas production is a significant amount of water being co-produced from these formations. The common practice in the industry is to recycle wastewater for hydraulic fracturing purposes or reinject it into the reservoir through disposal wells. In certain regions of the US, this wastewater injection has led to historically high seismicity rates and earthquakes of Magnitude 5 and above which caused the public to be concerned. To maintain the social license to continue such operations, these concerns need to be addressed, and the physics behind such induced events need to be understood. Two novel hydraulic fracturing and induced seismicity simulators are developed that implicitly couple fluid flow with the stresses induced by fracture deformation in large, complex, three-dimensional discrete fracture networks. The simulators can describe the propagation of hydraulic fractures and opening and shear stimulation of natural fractures. Fracture elements can open or slide, depending on their stress state, fluid pressure, and mechanical properties. Fracture sliding occurs in the direction of maximum resolved shear stress. Nonlinear empirical relations are used to relate normal stress, fracture opening, and fracture sliding to fracture aperture and transmissivity. Field-scale hydraulic fracturing simulations were performed in a dense naturally fractured formation. Height containment of propagating hydraulic fractures between bedding layers is modeled with a vertically heterogeneous stress field or by explicitly imposing hydraulic fracture height containment as a model assumption. The propagating hydraulic fractures can cross natural fractures or terminate against them depending on the natural fracture orientation and stress anisotropy. The simulations demonstrate how interaction with natural fractures in the formation can help explain the high net pressures, relatively short hydraulic fracture lengths, and broad regions of microseismicity that are often observed in the field during stimulation in low permeability formations, some of which were not predicted by classical hydraulic fracturing models. Depending on input parameters, our simulations predicted a variety of stimulation behaviors, from long hydraulic fractures with minimal leakoff into surrounding fractures to broad regions of dense fracturing with a branching network of many natural and newly formed fractures. Induced seismicity simulator was developed to investigate the effects of multiple operational, hydraulic, and geophysical parameters on the magnitude of induced earthquakes. The rate-and-state framework is implemented to include the effect of fault nonlinear friction evolution and to model unstable earthquake rupture. The Embedded Discrete Fracture Model (EDFM) technique is used to model the fluid flow between the matrix and fractures efficiently. The results show that high-rate injections are more likely to induce a more significant earthquake, confirming the statistical correlation attributing induced events to high-rate injection wells. To understand the seismic occurrence outside of the injection zone, the effect of fault permeability structure on seismicity is studied by assigning non-uniform permeabilities as an input parameter. The model shows that the fault rupture is dominantly controlled by initial pressure and stress heterogeneity which ultimately affect the magnitude of an induced earthquake event

The five-volume set LNCS 11536, 11537, 11538, 11539 and 11540 constitutes the proceedings of the 19th International Conference on Computational Science, ICCS 2019, held in Faro, Portugal, in June 2019. The total of 65 full papers and 168 workshop papers presented in this book set were carefully reviewed and selected from 573 submissions (228 submissions to the main track and 345 submissions to the workshops). The papers were organized in topical sections named: Part I: ICCS Main Track Part II: ICCS Main Track; Track of Advances in High-Performance Computational Earth Sciences: Applications and Frameworks; Track of Agent-Based Simulations, Adaptive Algorithms and Solvers; Track of Applications of Matrix Methods in Artificial Intelligence and Machine Learning; Track of Architecture, Languages, Compilation and Hardware Support for Emerging and Heterogeneous Systems Part III: Track of Biomedical and Bioinformatics Challenges for Computer Science; Track of Classifier Learning from Difficult Data; Track of Computational Finance and Business Intelligence;

Track of Computational Optimization, Modelling and Simulation; Track of Computational Science in IoT and Smart Systems Part IV: Track of Data-Driven Computational Sciences; Track of Machine Learning and Data Assimilation for Dynamical Systems; Track of Marine Computing in the Interconnected World for the Benefit of the Society; Track of Multiscale Modelling and Simulation; Track of Simulations of Flow and Transport: Modeling, Algorithms and Computation Part V: Track of Smart Systems: Computer Vision, Sensor Networks and Machine Learning; Track of Solving Problems with Uncertainties; Track of Teaching Computational Science; Poster Track ICCS 2019 Chapter “Comparing Domain-decomposition Methods for the Parallelization of Distributed Land Surface Models” is available open access under a Creative Commons Attribution 4.0 International License via link.springer.com.

Numerical simulation models have become indispensable in hydro- and environmental sciences and engineering. This monograph presents a general introduction to numerical simulation in environment water, based on the solution of the equations for groundwater flow and transport processes, for multiphase and multicomponent flow and transport processes in the subsurface as well as for flow and transport processes in surface waters. It displays in detail the state of the art of discretization and stabilization methods (e.g. finite-difference, finite-element, and finite-volume methods), parallel methods, and adaptive methods as well as fast solvers, with particular focus on explaining the interactions of the different methods. The book gives a brief overview of various information-processing techniques and demonstrates the interactions of the numerical methods with the information-processing techniques, in order to achieve efficient numerical simulations for a wide range of applications in environment water. This book systematically introduces readers to the simulation theory and techniques of multiple media for unconventional tight reservoirs. It summarizes the macro/microscopic heterogeneities; the features of multiscale multiple media; the characteristics of complex fluid properties; the occurrence state of continental tight oil and gas reservoirs in China; and the complex flow characteristics and coupled production mechanism under unconventional development patterns. It also discusses the simulation theory of multiple media for unconventional tight oil and gas reservoirs; mathematic model of flow through discontinuous multiple media; geological modeling of discrete multiscale multiple media; and the simulation of multiscale, multiphase flow regimes and multiple media. In addition to the practical application of simulation and software for unconventional tight oil and gas, it also explores the development trends and prospects of simulation technology. The book is of interest to scientific researchers and technicians engaged in the development of oil and gas reservoirs, and serves as a reference resource for advanced graduate students in fields related to petroleum. Integrating information from several areas of engineering geology, hydrogeology, geotechnical engineering, this book addresses the general field of groundwater from an engineering perspective. It covers geological engineering as well as hydrogeological

and environmental geological problems caused by groundwater engineering. It includes 10 chapters, i.e., basic groundwater theory, parameter calculation in hydrogeology, prevention of geological problem caused by groundwater, construction dewatering, wellpoint dewatering methods, dewatering wells and drilling, groundwater dewatering in foundation-pit engineering, groundwater engineering in bedrock areas, numerical simulation in groundwater engineering, groundwater corrosion on concrete and steel. Based on up-to-date literature, it describes recent developments and presents several case studies with examples and problems. It is an essential reference source for industrial and academic researchers working in the groundwater field and can also serve as lecture-based course material providing fundamental information and practical tools for both senior undergraduate and postgraduate students in fields of geology engineering, hydrogeology, geotechnical engineering or to conduct related research.
Presents advanced reservoir simulation methods used in the widely-used MRST open-source software for researchers, professionals, students.

The presence of natural fractures will usually result in a complex fracture network due to the interactions between hydraulic and natural fracture. The reactivation of natural fractures can generally provide additional flow paths from formation to wellbore which play a crucial role in improving the hydrocarbon recovery in these ultra-low permeability reservoir. Thus, accurate description of the geometry of discrete fractures and bedding is highly desired for accurate flow and production predictions. Compared to conventional continuum models that implicitly represent the discrete feature, Discrete Fracture Network (DFN) models could realistically model the connectivity of discontinuities at both reservoir scale and well scale. In this work, a new hybrid numerical model that couples Discrete Fracture Network (DFN) and Dual-Lattice Discrete Element Method (DL-DEM) is proposed to investigate the interaction between hydraulic fracture and natural fractures. Based on the proposed model, the effects of natural fracture orientation, density and injection properties on hydraulic-natural fractures interaction are investigated.

Among the most important and exciting current steps forward in geo-engineering is the development of coupled numerical models. They represent the basic physics of geo-engineering processes which can include the effects of heat, water, mechanics and chemistry. Such models provide an integrating focus for the wide range of geo-engineering disciplines. The articles within this volume were originally presented at the inaugural GeoProc conference held in Stockholm and contain a collection of unusually high quality information not available elsewhere in an edited and coherent form. This collection not only benefits from the latest theoretical developments but also applies them to a number of practical and wide ranging applications. Examples include the environmental issues around radioactive waste disposal deep in rock, and the search for new reserves of oil and gas.

This book solves the open problems in fluid flow modeling through the fractured vuggy carbonate reservoirs. Fractured vuggy carbonate reservoirs usually have complex pore structures, which contain not only matrix and fractures but also the vugs and cavities. Since the vugs and cavities are irregular in shape and vary in diameter from millimeters to meters, modeling fluid flow through fractured vuggy porous media is still a challenge. The existing modeling theory and methods are not suitable for such reservoir. It starts from the concept of discrete fracture and fracture-vug networks model, and then develops the corresponding mathematical models and numerical methods, including discrete fracture model, discrete fracture-vug model, hybrid model and multiscale models. Based on these discrete porous media models, some equivalent medium models and methods are also discussed. All the modeling and methods shared in this book offer the key recent solutions into this area.

This book deals exclusively with naturally fractured reservoirs and includes many subjects usually treated in separate volumes. A highly practical edition, Naturally Fractured Reservoirs is written for students, reservoir geologists, log analysts and petroleum engineers.

This book presents new insights into the development of different aspects of petroleum science and engineering. The book contains 19 chapters divided into two main sections: (i) Exploration and Production and (ii) Environmental Solutions. There are 11 chapters in the first section, and the focus is on the topics related to exploration and production of oil and gas, such as characterization of petroleum source rocks, drilling technology, characterization of reservoir fluids, and enhanced oil recovery. In the second section, the special emphasis is on waste technologies and environmental cleanup in the downstream sector. The book written by numerous prominent scholars clearly shows the necessity of the multidisciplinary approach to sustainable development in the petroleum industry and stresses the most updated topics such as EOR and environmental cleanup of fossil fuel wastes.

Fractal geometry allows the description of natural patterns and the establishment and testing of models of pattern formation. In particular, it is a tool for geoscientists. The aim of this volume is to give an overview of the applications of fractal geometry and the theory of dynamic systems in the geosciences. The state of the art is presented and the reader obtains an impression of the variety of fields for which fractal geometry is a useful tool and of the different methods of fractal geometry which can be applied. In addition to specific information about new applications of fractal geometry in structural geology, physics of the solid earth, and mineralogy, proposals and ideas about how fractal geometry can be applied in the reader's field of studies will be put forward.

This book presents some fundamental concepts behind the basic theories and tools of discrete element methods (DEM), its historical development, and its wide scope of applications in geology, geophysics and rock engineering. Unlike almost all books available on the general subject of DEM, this book includes coverage of both explicit and implicit DEM approaches, namely the Distinct Element Methods and Discontinuous Deformation Analysis (DDA) for both rigid and deformable blocks and particle systems, and also the Discrete Fracture Network (DFN) approach for fluid flow and solute transport simulations. The latter is actually also a discrete approach of importance for rock mechanics and rock engineering. In addition, brief introductions to some alternative approaches are also provided, such as percolation theory and Cosserat micromechanics equivalence to particle systems, which often appear hand-in-hand with the DEM in the literature. Fundamentals of the particle mechanics approach using DEM for granular media is also presented. · Presents the fundamental concepts of the discrete models for fractured rocks, including constitutive models of rock fractures and rock masses for stress, deformation and fluid flow · Provides a comprehensive presentation on discrete element methods, including distinct elements, discontinuous deformation analysis, discrete fracture networks, particle mechanics and Cosserat representation of granular media · Features constitutive models of rock fractures and fracture system characterization methods detaiing

their significant impacts on the performance and uncertainty of the DEM models
The development of naturally fractured reservoirs, especially shale gas and tight oil reservoirs, exploded in recent years due to advanced drilling and fracturing techniques. However, complex fracture geometries such as irregular fracture networks and non-planar fractures are often generated, especially in the presence of natural fractures. Accurate modelling of production from reservoirs with such geometries is challenging. Therefore, Embedded Discrete Fracture Modeling and Application in Reservoir Simulation demonstrates how production from reservoirs with complex fracture geometries can be modelled efficiently and effectively. This volume presents a conventional numerical model to handle simple and complex fractures using local grid refinement (LGR) and unstructured gridding. Moreover, it introduces an Embedded Discrete Fracture Model (EDFM) to efficiently deal with complex fractures by dividing the fractures into segments using matrix cell boundaries and creating non-neighboring connections (NNCs). A basic EDFM approach using Cartesian grids and advanced EDFM approach using Corner point and unstructured grids will be covered. Embedded Discrete Fracture Modeling and Application in Reservoir Simulation is an essential reference for anyone interested in performing reservoir simulation of conventional and unconventional fractured reservoirs. Highlights the current state-of-the-art in reservoir simulation of unconventional reservoirs Offers understanding of the impacts of key reservoir properties and complex fractures on well performance Provides case studies to show how to use the EDFM method for different needs
This book provides a self-contained introduction to the simulation of flow and transport in porous media, written by a developer of numerical methods. The reader will learn how to implement reservoir simulation models and computational algorithms in a robust and efficient

manner. The book contains a large number of numerical examples, all fully equipped with online code and data, allowing the reader to reproduce results, and use them as a starting point for their own work. All of the examples in the book are based on the MATLAB Reservoir Simulation Toolbox (MRST), an open-source toolbox popular popularity in both academic institutions and the petroleum industry. The book can also be seen as a user guide to the MRST software. It will prove invaluable for researchers, professionals and advanced students using reservoir simulation methods. This title is also available as Open Access on Cambridge Core.

In the past two or three decades, fractured rock domains have received increasing attention not only in reservoir engineering and hydrology, but also in connection with geological isolation of radioactive waste. Locations in both the saturated and unsaturated zones have been under consideration because such repositories are sources of heat and potential sources of groundwater contamination. Thus, in addition to the transport of mass of fluid phases in single and multiphase flow, the issues of heat transport and mass transport of components have to be addressed.

Hydraulic fracturing is a stimulation technique in which fluid is injected at high pressure into low-permeability reservoirs to create a fracture network for enhanced production of oil and gas. It is the primary purpose of hydraulic fracturing to enhance well production. The three main mechanisms during hydraulic fracturing for oil and gas production which largely impact the reservoir production are: (1) fracture propagation during initial pad fluid injection, which defines the extent of the fracture; (2) fracture propagation during injection of proppant slurry (fluid mixed with granular material), creating a propped reservoir zone; and (3) shear dilation of natural fractures surrounding the hydraulically fractured zone, creating a broader stimulated zone. The thesis has three objectives that support the simulation of mechanisms that lead to enhanced production of a hydraulically-fractured reservoir. The first objective is to develop a numerical model for the simulation of the mechanical deformation and shear dilation of naturally fractured rock masses. In this work, a two-dimensional model for the simulation of discrete fracture networks (DFN) is developed using the extended finite element method (XFEM), in which the mesh does not conform to the natural fracture network. The model incorporates contact, cohesion, and friction between blocks of rock. Shear dilation is an important mechanism impacting the overall nonlinear response of naturally fractured rock masses and is also included in the model--physics previously not simulated within an XFEM context. Here, shear dilation is modeled through a linear dilation model, capped by a dilation limiting displacement. Highly nonlinear problems involving multiple joint sets are investigated within a quasi-static context. An explicit scheme is used in conjunction with the dynamic relaxation technique to obtain equilibrium solutions in the face of the nonlinear constitutive models from contact, cohesion, friction, and dilation. The numerical implementation is verified and its convergence illustrated using a shear test and a biaxial test. The model is then applied to the practical problem of the stability of a slope of fractured rock. The second objective is to develop a numerical model for the simulation of proppant transport through planar fractures. This work presents the numerical methodology for simulation of proppant transport through a hydraulic fracture using the finite volume method. Proppant models commonly used in the hydraulic fracturing literature solve the linearized advection equation; this work presents solution methods for the nonlinear form of the proppant flux equation. The complexities of solving the nonlinear and heterogeneous hyperbolic advection equation that governs proppant transport are tackled, particularly handling shock waves that are generated due to the nonlinear flux function and the spatially-varying width and pressure gradient along the fracture. A critical time step is derived for the proppant transport problem solved using an explicit solution strategy. Additionally, a predictor-corrector algorithm is developed to constrain the proppant from exceeding the physically admissible range. The model can capture the mechanisms of proppant bridging occurring in sections of narrow fracture width, tip screen-out occurring when fractures become saturated with proppant, and flushing of proppant into new fracture segments. The results are verified by comparison with characteristic solutions and the model is used to simulate proppant transport through a KGD fracture. The final objective is to develop a numerical model for the simulation of proppant transport through propagating non-planar fractures. This work presents the first monolithic coupled numerical model for simulating proppant transport through a propagating hydraulic fracture. A fracture is propagated through a two-dimensional domain, driven by the flow of a proppant-laden slurry. Modeling of the slurry flow includes the effects of proppant bridging and the subsequent flow of fracturing fluid through the packed proppant pack. This allows for the simulation of a tip screen-out, a phenomenon in which there is a high degree of physical interaction between the rock deformation, fluid flow, and proppant transport. Tip screen-out also leads to shock wave formation in the solution. Numerical implementation of the model is verified and the model is then used to simulate a tip screen-out in both planar and non-planar fractures. An analysis of the fracture aperture, fluid pressure, and proppant concentration profiles throughout the simulation is performed for three different coupling schemes: monolithic, sequential, and loose coupling. It is demonstrated that even with time step refinement, the loosely-coupled scheme fails to converge to the same results as the monolithic and sequential schemes. The monolithic and sequential algorithms yield the same solution up to the onset of a tip screen-out, after which the sequential scheme fails to converge. The monolithic scheme is shown to be more efficient than the sequential algorithm (requiring fewer iterations) and has comparable computational cost to the loose coupling algorithm. Thus, the monolithic scheme is shown to be optimal in terms of computational efficiency, robustness, and accuracy. In addition to this finding, a robust and more efficient algorithm for injection-rate controlled hydraulic fracturing simulation based on global mass conservation is presented in the thesis.

Tight gas and shale oil play an important role in energy security and in meeting an increasing energy demand. Hydraulic fracturing is a widely used technology for recovering these resources. The design and evaluation of hydraulic fracture operation is critical for efficient production from tight gas and shale plays. The efficiency of fracturing jobs depends on the interaction between hydraulic (induced) and naturally occurring discrete fractures. In this work, a coupled reservoir-fracture flow model is described which accounts for varying reservoir geometries and complexities including non-planar fractures. Different flow models such as Darcy flow and Reynold's lubrication equation for fractures and reservoir, respectively are utilized to capture flow physics accurately. Furthermore, the geomechanics effects have been included by considering a multiphase Biot's model. An accurate modeling of solid deformations necessitates a better estimation of fluid pressure inside the fracture. The fractures and reservoir are modeled explicitly allowing accurate representation of contrasting physical descriptions associated with each of the two. The approach presented here is in contrast with existing averaging approaches such as dual and discrete-dual porosity models where the effects of fractures are averaged out. A fracture connected to an injection well shows significant width variations as compared to natural fractures where these changes are negligible. The capillary pressure contrast between the fracture and the reservoir is accounted for by utilizing different capillary pressure curves for the two features. Additionally, a quantitative assessment of hydraulic fracturing jobs relies upon accurate predictions of fracture growth during slick water injection for single and multistage fracturing scenarios. It is also important to consistently model the underlying physical processes from hydraulic fracturing to long-term production. A recently introduced thermodynamically consistent phase-field approach for pressurized fractures in porous medium is utilized which captures several characteristic features of crack propagation such as joining, branching and non-planar propagation in heterogeneous porous media. The phase-field approach captures both the fracture-width evolution and the fracture-length propagation. In this work, the phase-field fracture propagation model is briefly discussed followed by a technique for coupling this to a fractured poroelastic reservoir simulator. We also present a general compositional formulation using multipoint flux mixed finite element (MFMFE) method on general hexahedral grids with a future prospect of treating energized fractures. The mixed finite element framework allows for local mass conservation, accurate flux approximation and a more general treatment of boundary conditions. The multipoint flux inherent in MFMFE scheme allows the usage of a full permeability tensor. An accurate treatment of diffusive/dispersive fluxes owing to additional velocity degrees of freedom is also presented. The applications areas of interest include gas flooding, CO_2 sequestration, contaminant removal and groundwater remediation.

Naturally fractured reservoirs (NFRs) hold a significant amount of the world's hydrocarbon reserves. Compared to conventional reservoirs, NFRs exhibit a higher degree of heterogeneity and complexity created by fractures. The importance of fractures in production of oil and gas is not limited to naturally fractured reservoirs. The economic exploitation of unconventional reservoirs, which is increasingly a major source of short- and long-term energy in the United States, hinges in part on effective stimulation of low-permeability rock through multi-stage hydraulic fracturing of horizontal wells. Accurate modeling and simulation of fractured media is still challenging owing to permeability anisotropies and contrasts. Non-physical abstractions inherent in conventional dual porosity and dual permeability models make these methods inadequate for solving different fluid-flow problems in fractured reservoirs. Also, recent approaches for discrete fracture modeling may require large computational times and hence the oil industry has not widely used such approaches, even though they give more accurate representations of fractured reservoirs than dual continuum models. We developed an embedded discrete fracture model (EDFM) for an in-house fully-implicit compositional reservoir simulator. EDFM borrows the dual-medium concept from conventional dual continuum models and also incorporates the effect of each fracture explicitly. In contrast to dual continuum models, fractures have arbitrary orientations and can be oblique or vertical, honoring the complexity and heterogeneity of a typical fractured reservoir. EDFM employs a structured grid to remediate challenges associated with unstructured gridding required for other discrete fracture models. Also, the EDFM approach can be easily incorporated in existing finite difference reservoir simulators. The accuracy of the EDFM approach was confirmed by comparing the results with analytical solutions and fine-grid, explicit-fracture simulations.

Comparison of our results using the EDFM approach with fine-grid simulations showed that accurate results can be achieved using moderate grid refinements. This was further verified in a mesh sensitivity study that the EDFM approach with moderate grid refinement can obtain a converged solution. Hence, EDFM offers a computationally-efficient approach for simulating fluid flow in NFRs. Furthermore, several case studies presented in this study demonstrate the applicability, robustness, and efficiency of the EDFM approach for modeling fluid flow in fractured porous media. Another advantage of EDFM is its extensibility for various applications by incorporating different physics in the model. In order to examine the effect of pressure-dependent fracture properties on production, we incorporated the dynamic behavior of fractures into EDFM by employing empirical fracture deformation models. Our simulations showed that fracture deformation, caused by effective stress changes, substantially affects pressure depletion and hydrocarbon recovery. Based on the examples presented in this study, implementation of fracture geomechanical effects in EDFM did not degrade the computational performance of EDFM. Many unconventional reservoirs comprise well-developed natural fracture networks with multiple orientations and complex hydraulic fracture patterns suggested by microseismic data. We developed a coupled dual continuum and discrete fracture model to efficiently simulate production from these reservoirs. Large-scale hydraulic fractures were modeled explicitly using the EDFM approach and numerous small-scale natural fractures were modeled using a dual continuum approach. The transport parameters for dual continuum modeling of numerous natural fractures were derived by upscaling the EDFM equations. Comparison of the results using the coupled model with that of using the EDFM approach to represent all natural and hydraulic fractures explicitly showed that reasonably accurate results can be obtained at much lower computational cost by using the coupled approach with moderate grid refinements.

Petrophysical Characterization and Fluids Transport in Unconventional Reservoirs presents a comprehensive look at these new methods and technologies for the petrophysical characterization of unconventional reservoirs, including recent theoretical advances and modeling on fluids transport in unconventional reservoirs. The book is a valuable tool for geoscientists and engineers working in academia and industry. Many novel technologies and approaches, including petrophysics, multi-scale modelling, rock reconstruction and upscaling approaches are discussed, along with the challenge of the development of unconventional reservoirs and the mechanism of multi-phase/multi-scale flow and transport in these structures. Includes both practical and theoretical research for the characterization of unconventional reservoirs Covers the basic approaches and mechanisms for enhanced recovery techniques in unconventional reservoirs Presents the latest research in the fluid transport processes in unconventional reservoirs

Hydraulic Fracture Modeling delivers all the pertinent technology and solutions in one product to become the go-to source for petroleum and reservoir engineers. Providing tools and approaches, this multi-contributed reference presents current and upcoming developments for modeling rock fracturing including their limitations and problem-solving applications. Fractures are common in oil and gas reservoir formations, and with the ongoing increase in development of unconventional reservoirs, more petroleum engineers today need to know the latest technology surrounding hydraulic fracturing technology such as fracture rock modeling. There is tremendous research in the area but not all located in one place. Covering two types of modeling technologies, various effective fracturing approaches and model applications for fracturing, the book equips today's petroleum engineer with an all-inclusive product to characterize and optimize today's more complex reservoirs. Offers understanding of the details surrounding fracturing and fracture modeling technology, including theories and quantitative methods Provides academic and practical perspective from multiple contributors at the forefront of hydraulic fracturing and rock mechanics Provides today's petroleum engineer with model validation tools backed by real-world case studies

The combined finite discrete element method is a relatively new computational tool aimed at problems involving static and / or dynamic behaviour of systems involving a large number of solid deformable bodies. Such problems include fragmentation using explosives (e.g rock blasting), impacts, demolition (collapsing buildings), blast loads, digging and loading processes, and powder technology. The combined finite-discrete element method - a natural extension of both discrete and finite element methods - allows researchers to model problems involving the deformability of either one solid body, a large number of bodies, or a solid body which fragments (e.g. in rock blasting applications a more or less intact rock mass is transformed into a pile of solid rock fragments of different sizes, which interact with each other). The topic is gaining in importance, and is at the forefront of some of the current efforts in computational modeling of the failure of solids. * Accompanying source codes plus input and output files available on the Internet * Important applications such as mining engineering, rock blasting and petroleum engineering * Includes practical examples of applications areas

Essential reading for postgraduates, researchers and software engineers working in mechanical engineering.

A growing demand for more detailed modeling of subsurface physics as ever more challenging reservoirs - often unconventional, with significant geomechanical particularities - become production targets has moti-vated research in coupled flow and geomechanics. Reservoir rock deforms to given stress conditions, so the simplified approach of using a scalar value of the rock compressibility factor in the fluid mass balance equation to describe the geomechanical system response cannot correctly estimate multi-dimensional rock deformation. A coupled flow and geomechanics model considers flow physics and rock physics simultaneously by cou-pling different types of partial differential equations through primary variables. A number of coupled flow and geomechanics simulators have been developed and applied to describe fluid flow in deformable po-rous media but the majority of these coupled flow and geomechanics simulators have limited capabilities in modeling multiphase flow and geomechanical deformation in a heterogeneous and fractured reservoir. In addition, most simulators do not have the capability to simulate both coarse and fine scale multiphysics. In this study I developed a new, fully implicit multiphysics simulator (TAM-CFGM: Texas A&M Coupled Flow and Geomechanics simulator) that can be applied to simulate a 2D or 3D multiphase flow and rock deformation in a heterogeneous and/or fractured reservoir system. I derived a mixed finite element formu-lation that satisfies local mass conservation and provides a more accurate estimation of the velocity solu-tion in the fluid flow equations. I used a continuous Galerkin formulation to solve the geomechanics equa-tion. These formulations allowed me to use unstructured meshes, a full-tensor permeability, and elastic stiffness. I proposed a numerical upscaling of the permeability and of the elastic stiffness tensors to gener-ate a coarse-scale description of the fine-scale grid in the model, and I implemented the methodology in the simulator. I applied the code I developed to the simulation of the problem of multiphase flow in a fractured tight gas system. As a result, I observed unique phenomena (not reported before) that could not have been deter-mined without coupling. I demonstrated the importance and advantages of using unstructured meshes to effectively and realistically model a reservoir. In particular, high resolution discrete fracture models al-lowed me to obtain more detailed physics that could not be resolved with a structured grid. I performed numerical upscaling of a very heterogeneous geologic model and observed that the coarse-scale numerical solution matched the fine scale reference solution well. As a result, I believed I developed a method that can capture important physics of the fine-scale model with a reasonable computation cost. The electronic version of this dissertation is accessible from http://hdl.handle.net/1969.1/151194

This book gathers the latest advances, innovations, and applications in the field of computational geomechanics, as presented by international researchers and engineers at the 16th International Conference of the International Association for Computer

Methods and Advances in Geomechanics (IACMAG 2020/21). Contributions include a wide range of topics in geomechanics such as: monitoring and remote sensing, multiphase modelling, reliability and risk analysis, surface structures, deep structures, dams and earth structures, coastal engineering, mining engineering, earthquake and dynamics, soil-atmosphere interaction, ice mechanics, landfills and waste disposal, gas and petroleum engineering, geothermal energy, offshore technology, energy geostructures, geomechanical numerical models and computational rail geotechnics. Scientific understanding of fluid flow in rock fractures--a process underlying contemporary earth science problems from the search for petroleum to the controversy over nuclear waste storage--has grown significantly in the past 20 years. This volume presents a comprehensive report on the state of the field, with an interdisciplinary viewpoint, case studies of fracture sites, illustrations, conclusions, and research recommendations. The book addresses these questions: How can fractures that are significant hydraulic conductors be identified, located, and characterized? How do flow and transport occur in fracture systems? How can changes in fracture systems be predicted and controlled? Among other topics, the committee provides a geomechanical understanding of fracture formation, reviews methods for detecting subsurface fractures, and looks at the use of hydraulic and tracer tests to investigate fluid flow. The volume examines the state of conceptual and mathematical modeling, and it provides a useful framework for understanding the complexity of fracture changes

that occur during fluid pumping and other engineering practices. With a practical and multidisciplinary outlook, this volume will be welcomed by geologists, petroleum geologists, geoengineers, geophysicists, hydrologists, researchers, educators and students in these fields, and public officials involved in geological projects.
This monograph on fractures, fracture networks, and fractured porous media provides a systematic treatment of their geometrical and transport properties for students and professionals in Geophysics, Materials Science, and Earth Sciences.
Fractured rock is the host or foundation for innumerable engineered structures related to energy, water, waste, and transportation. Characterizing, modeling, and monitoring fractured rock sites is critical to the functioning of those infrastructure, as well as to optimizing resource recovery and contaminant management. Characterization, Modeling, Monitoring, and Remediation of Fractured Rock examines the state of practice and state of art in the characterization of fractured rock and the chemical and biological processes related to subsurface contaminant fate and transport. This report examines new developments, knowledge, and approaches to engineering at fractured rock sites since the publication of the 1996 National Research Council report Rock Fractures and Fluid Flow: Contemporary Understanding and Fluid Flow. Fundamental understanding of the physical nature of fractured rock has changed little since 1996, but many new characterization tools have been developed, and there is now greater appreciation for the importance of chemical and biological processes that can occur in

the fractured rock environment. The findings of Characterization, Modeling, Monitoring, and Remediation of Fractured Rock can be applied to all types of engineered infrastructure, but especially to engineered repositories for buried or stored waste and to fractured rock sites that have been contaminated as a result of past disposal or other practices. The recommendations of this report are intended to help the practitioner, researcher, and decision maker take a more interdisciplinary approach to engineering in the fractured rock environment. This report describes how existing tools-some only recently developed-can be used to increase the accuracy and reliability of engineering design and management given the interacting forces of nature. With an interdisciplinary approach, it is possible to conceptualize and model the fractured rock environment with acceptable levels of uncertainty and reliability, and to design systems that maximize remediation and long-term performance. Better scientific understanding could inform regulations, policies, and implementation guidelines related to infrastructure development and operations. The recommendations for research and applications to enhance practice of this book make it a valuable resource for students and practitioners in this field.

Porous Rock Failure Mechanics: Hydraulic Fracturing, Drilling and Structural Engineering focuses on the fracture mechanics of porous rocks and modern simulation techniques for progressive quasi-static and dynamic fractures. The topics covered in this volume include a wide range of academic and industrial applications, including

petroleum, mining, and civil engineering. Chapters focus on advanced topics in the field of rock’s fracture mechanics and address theoretical concepts, experimental characterization, numerical simulation techniques, and their applications as appropriate. Each chapter reflects the current state-of-the-art in terms of the modern use of fracture simulation in industrial and academic sectors. Some of the major contributions in this volume include, but are not limited to: anisotropic elasto-plastic deformation mechanisms in fluid saturated porous rocks, dynamics of fluids transport in fractured rocks and simulation techniques, fracture mechanics and simulation techniques in porous rocks, fluid-structure interaction in hydraulic driven fractures, advanced numerical techniques for simulation of progressive fracture, including multiscale modeling, and micromechanical approaches for porous rocks, and quasi-static versus dynamic fractures in porous rocks. This book will serve as an important resource for petroleum, geomechanics, drilling and structural engineers, R&D managers in industry and academia. Includes a strong editorial team and quality experts as chapter authors Presents topics identified for individual chapters are current, relevant, and interesting Focuses on advanced topics, such as fluid coupled fractures, rock’s continuum damage mechanics, and multiscale modeling Provides a ‘one-stop’ advanced-level reference for a graduate course focusing on rock’s mechanics
This thesis focuses on the effective hydraulic transmissivity of two-dimensional fracture networks in rocks. The main simulation tool used in this work is the discrete fracture

network code NAPSAC. There are four main topics in this thesis: (1) estimating permeability from network properties, (2) comparing discrete fracture network with effective continuum models, (3) using DFN for hydro-mechanical coupled modelling, and (4) solute transport simulations. For fracture networks with uniform aperture, the permeability can be estimated using segment density, fracture density, and fracture lengths of the fracture network. For fracture networks with apertures directly proportional to their lengths, the individual conductance of each of the fracture segments was used to calculate an effective conductance for the whole network. The arithmetic mean of the segment conductance gives a good approximation for the effective conductance of the whole network. A series of effective continuum models of a fracture network were created using different element sizes, and their flow behaviours were compared against results obtained from discrete fracture network model. The permeability tensors of each of the elements in the effective continuum meshes were calculated using discrete fracture network methods. It was found that the flow through effective continuum model with any element size gave good agreement with the discrete fracture network results. Hydro-mechanical coupled simulations were carried out using NAPSAC, where the applied far field stresses are applied to each fractures independently. Simulations were then carried out using the distinct element code UDEC to justify the simplified physics used in NAPSAC. It was shown that for random 2D fracture networks under a range of loadings, NAPSAC and UDEC seem to predict similar overall flows. Different ways for modelling the effects of rock matrix diffusion were explored. The significance of rock matrix diffusion, as well as the diffusion distance, was linked to the magnitude of the pressure gradient across the fracture network. A semi-analytical method for estimating the diffusion distance was proposed: using the perimeter and the area of each of the matrix blocks, it is possible to estimate the diffusion distance using the 'shape factor' concept.

This collection of symposium papers covers a wide range of topics on rock fragmentation, from carefully documented case studies to attempts, for example, at fractal representation of the fracture process itself.

Discrete Fracture Network Modeling of Hydraulic Stimulation describes the development and testing of a model that couples fluid-flow, deformation, friction weakening, and permeability evolution in large, complex two-dimensional discrete fracture networks. The model can be used to explore the behavior of hydraulic stimulation in settings where matrix permeability is low and preexisting fractures play an important role, such as Enhanced Geothermal Systems and gas shale. Used also to describe pure shear stimulation, mixed-mechanism stimulation, or pure opening-mode stimulation. A variety of novel techniques to ensure efficiency and realistic model behavior are implemented, and tested. The simulation methodology can also be used as an efficient method for directly solving quasistatic fracture contact problems. Results show how stresses induced by fracture deformation during stimulation directly impact the mechanism of propagation and the resulting fracture network.

Multiphase Fluid Flow in Porous and Fractured Reservoirs discusses the process of modeling fluid flow in petroleum and natural gas reservoirs, a practice that has become increasingly complex thanks to multiple fractures in horizontal drilling and the discovery of more unconventional reservoirs and resources. The book updates the reservoir engineer of today with the latest developments in reservoir simulation by combining a powerhouse of theory, analytical, and numerical methods to create stronger verification and validation modeling methods, ultimately improving recovery in stagnant and complex reservoirs. Going beyond the standard topics in past literature, coverage includes well treatment, Non-Newtonian fluids and rheological models, multiphase fluid coupled with geomechanics in reservoirs, and modeling applications for unconventional petroleum resources. The book equips today's reservoir engineer and modeler with the most relevant tools and knowledge to establish and solidify stronger oil and gas recovery. Delivers updates on recent developments in reservoir simulation such as modeling approaches for multiphase flow simulation of fractured media and unconventional reservoirs Explains analytical solutions and approaches as well as applications to modeling verification for today's reservoir problems, such as evaluating saturation and pressure profiles and recovery factors or displacement efficiency Utilize practical codes and programs featured from online companion website

The 91st London Mathematical Society Durham Symposium took place from July 5th to

15th 2010, with more than 100 international participants attending. The Symposium focused on Numerical Analysis of Multiscale Problems and this book contains 10 invited articles from some of the meeting's key speakers, covering a range of topics of contemporary interest in this area. Articles cover the analysis of forward and inverse PDE problems in heterogeneous media, high-frequency wave propagation, atomistic-continuum modeling and high-dimensional problems arising in modeling uncertainty. Novel upscaling and preconditioning techniques, as well as applications to turbulent multi-phase flow, and to problems of current interest in materials science are all addressed. As such this book presents the current state-of-the-art in the numerical analysis of multiscale problems and will be of interest to both practitioners and mathematicians working in those fields.

This book is a compilation of selected papers from the 10th International Field Exploration and Development Conference (IFEDC 2020). The proceedings focuses on Reservoir Surveillance and Management, Reservoir Evaluation and Dynamic Description, Reservoir Production Stimulation and EOR, Ultra-Tight Reservoir, Unconventional Oil and Gas Resources Technology, Oil and Gas Well Production Testing, Geomechanics. The conference not only provides a platform to exchanges experience, but also promotes the development of scientific research in oil & gas exploration and production. The main audience for the work includes reservoir engineer, geological engineer, enterprise managers senior engineers as well as professional students.