

EAI/Springer Innovations in Communication and Computing

Nguyen Thanh Hai
Nguyen Xuan Huy
Khalil Amine
Tran Dai Lam *Editors*

EAI International Conference on Renewable Energy and Sustainable Manufacturing

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Khalil Amine • Tran Dai Lam
Editors

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Editors

Nguyen Thanh Hai 
Ho Chi Minh City University of Technology
Ho Chi Minh, Vietnam

Nguyen Xuan Huy
Ho Chi Minh City University of Technology
Ho Chi Minh, Vietnam

Khalil Amine 
Argonne National Laboratory
Lemont, IL, USA

Tran Dai Lam 
Vietnam Academy of Science and
Technology
Hanoi, Vietnam

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Preface

The EAI International Conference on Renewable Energy and Sustainable Manufacturing 2023 (EAI ICRESM 2023) was held from December 16–17, 2023, at Ho Chi Minh City University of Technology (HCMUT), Ho Chi Minh City, Vietnam. It provided an opportunity for technical experts to meet and discuss the latest developments in the field of renewable energy and sustainable manufacturing.

The technical program of EAI ICRESM 2023 consisted of 52 full papers, including 3 invited papers in oral presentation sessions at the main conference tracks. The conference tracks were: Track 1—Energy Transition; Track 2—Earth Resources for Sustainable Development; Track 3—Sustainable Logistics; Track 4—Advanced Material Processing; Track 5—Smart Mechatronics; Track 6—Production and Sustainability; Track 7—Internet of Things; Track 8—Low Carbon Technology; and Track 9—Supply Chain and Sustainable Techniques. Aside from the high-quality technical paper presentations, the technical program also featured three keynote speeches, two invited talks, and one technical session. The three keynote speeches were Prof. Dsc. Banh Tien Long from Hanoi University of Science and Technology (HUST), Vietnam, Prof. Dr. Jiwang Yan from Keio University, Japan, and Associate Prof. Dr. Xuan Huy Nguyen from Ho Chi Minh City University of Technology, Vietnam.

Coordination with the steering chairs, Ha Quang Thinh Ngo and Mai-Ha Phan, was essential for the success of the conference. We sincerely appreciate their constant support and guidance. It was also a great pleasure to work with such an excellent organizing committee team for their hard work in organizing and supporting the conference. In particular, the Technical Program Committee has completed the peer-review process of technical papers and made a high-quality technical program. We are also grateful to Veronika Kissova, Conference Manager, for her support and all the authors who submitted their papers to the EAI ICRESM 2023 conference and workshops.

We strongly believe that EAI ICRESM 2023 conference provides a good forum for all researcher, developers, and practitioners to discuss all science and technology

aspects that are relevant to smart grids. We also expect that the future EAI ICRESM conference will be as successful and stimulating, as indicated by the contributions presented in this volume.

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Nguyen Thanh Hai
Nguyen Xuan Huy

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About the Editors



Nguyen Thanh Hai is a distinguished mechanical engineer born on September 7, 1979, in Vietnam. He earned Bachelor of Engineering degree from Ho Chi Minh City University of Technology in 2002 and Master of Science degree from Yeungnam University in 2008. Furthering his academic journey, he completed a Ph.D. in Mechanical Engineering at Chonnam National University in Korea in 2013.

Currently, as an Associate Professor in the Faculty of Mechanical Engineering at Ho Chi Minh City University of Technology, he shares his knowledge and expertise with students while actively contributing to academic research. His prolific publication record reflects his focus on ultrasonic technology, including welding, ultrasonic-assisted processes, X-ray mirror development, and advanced materials processing.

His research encompasses various material joining methods, including ultrasonic welding, rotary friction welding, and friction stir welding. He also explores the application of ultrasonic vibration in metal casting and arc welding during cooling to improve microstructures and mechanical properties while optimizing resource use and reducing waste. Additionally, he actively investigates sustainable 3D printing techniques to minimize material waste and energy consumption in additive manufacturing processes, aligning with the industry's demand for eco-friendly fabrication methods.



Nguyen Xuan Huy born in 1978 in Phu Yen province, Vietnam, is an accomplished professional in the field of geology and petroleum engineering. He completed his Bachelor of Engineering and Master of Engineering degrees at Ho Chi Minh City University of Technology (HCMUT) and Vietnam National University-Ho Chi Minh City (VNU-HCM) in 2001 and 2004, respectively. In 2008, he obtained an MBA degree from HCMUT. To further advance his academic qualifications, Nguyen Xuan Huy pursued a Doctor of Engineering degree at Sejong University in South Korea, which he completed in 2012. Following his doctoral studies, he engaged in postdoctoral research for two years.

Currently, Nguyen Xuan Huy holds the esteemed position of Professor in the Faculty of Geology and Petroleum Engineering at Ho Chi Minh City University of Technology (HCMUT). As a professor, he imparts his knowledge and expertise to students and contributes to the academic community through research and teaching.

Nguyen Xuan Huy has made significant contributions to his field through his research, resulting in numerous papers for publication. His research primarily focuses on geology, petroleum engineering, and the specialty of CCUS in EOR (Carbon Capture, Utilization, and Storage in Enhanced Oil Recovery) with a specific emphasis on CO₂ flooding.

Specifically, Nguyen Xuan Huy has been involved in windfarm projects in Vietnam since 2017, with a specialization in offshore windfarms. Offshore windfarms are an important component of renewable energy infrastructure, harnessing wind power from offshore locations to generate electricity. Nguyen Xuan Huy's involvement in these projects indicates his dedication to promoting sustainable energy solutions and his contribution to the development of renewable energy sources in Vietnam.

His expertise and participation in windfarm projects likely involve various aspects, such as site selection, feasibility studies, environmental impact assessments, project management, and optimization of energy production. By applying his knowledge

and experience in these areas, Nguyen Xuan Huy contributes to the growth and implementation of off-shore windfarm projects, which play a vital role in the transition to cleaner and more sustainable energy sources.

Part I

Energy Transition

Assessing the Fundamental Significance of the PKN Two-Dimensional Model in Hydraulic Fracture Modeling



Hai T. Nguyen , Jang Hyun Lee, Khaled A. Elraies, and Tu V. Truong

Abstract In the field of petroleum engineering, substantial effort has been invested over decades in developing hydraulic fracture models with different levels of accuracy. This paper examines the critical role of the PKN (Perkins-Kern-Nordgren) two-dimensional model in the evolution of hydraulic fracture modeling. First, the analysis of its assumptions showed that the PKN model serves as a base for developing more complex pseudo-three-dimensional (P3D) models. The governing equations of the PKN model were then reformulated, leading to the analytical solutions for the two limiting cases of storage-dominated and leakoff-dominated regimes. A series of simulations were performed for the above analytical solutions for two cases of PKN in storage-dominated and leakoff-dominated regimes at both an early time and a late time. It was indicated that the storage-dominated regime happened at an early time of the hydraulic fracture propagation, and the leakoff-dominated regime happened at a late time of the process. The results also showed the effectiveness of using PKN analytical solutions to validate more complex P3D models.

Keywords PKN · Hydraulic Fracturing · 2D Modeling

H. T. Nguyen (✉)

Laboratory of Applied Physics, Science and Technology Advanced Institute, Van Lang University, Ho Chi Minh City, Vietnam

Faculty of Applied Technology, School of Technology, Van Lang University, Ho Chi Minh City, Vietnam

e-mail: nguyenthihai@vlu.edu.vn

J. H. Lee · K. A. Elraies

Department of Petroleum Engineering, Universiti Teknologi PETRONAS, Persiaran UTP, Seri Iskandar, Perak, Malaysia

T. V. Truong

Drilling and Production Department, Faculty of Petroleum and Energy, Hanoi University of Mining and Geology, Hanoi, Vietnam

1 Introduction

Hydraulic fracturing is a well stimulation method used in the oil and gas industry to improve hydrocarbon recovery in rock formations. It can also be used in mining and drill-cutting disposal [1] or occur naturally under the earth's surface [2]. The Perkins–Kern–Nordgren two-dimensional (PKN 2D) hydraulic fracturing model [3–5] is one of the most well-known employed in the petroleum industry. Later, more sophisticated models such as the pseudo-three-dimensional (P3D) or the planar three-dimensional (PL3D) models were studied and applied for field operations. These models differ in their underlying assumptions for formulating the governing equations, the range of input data and the numerical method of solution. Even though the PKN 2D model is not suitable for field operation owing to its simplified assumptions compared to other P3D and PL3D models, it is still popularly used in research for several critical applications. First, the PKN model serves as a base for developing a more complex P3D model by allowing the fracture height to vary in time and space [6–9]. The inherited assumption of the P3D model, in which the ratio of fracture length to fracture height greater than 1, results in finger-like hydraulic fracture geometries, occurring commonly in hydrocarbon reservoirs. This leads to the wide application range of P3D models in the industry. Furthermore, the analytical solutions of different limiting cases (i.e., storage-dominated, leak-off-dominated regimes) of the PKN model are used as benchmarks to validate more complex P3D and PL3D numerical algorithms [8, 10, 11]. This is necessary because, in many situations, it is not feasible to conduct hydraulic fracturing experiments for validation purposes due to the complicated nature of the tasks.

Therefore, the PKN model still plays an essential role in the development of hydraulic fracture modeling. The following section will present the reformulation of its governing, leading to the analytical solutions for two limiting cases of storage and leakoff-dominated regimes. Then, a series of simulations are performed to illustrate how the PKN model can be used to validate a more complex P3D model.

2 Governing Formulation

The PKN problem is depicted in Fig. 1. It propagates along the horizontal x -axis with a constant fracture height contained in the pay zone layer. Every vertical cross-section is elliptical and under a plane-strain condition, implying the fracture length $\gg$ fracture height and the fluid pressure are unchanged vertically. Here, $w(x, t)$ is the fracture width at $y = 0$, $l(t)$ is fracture length, μ is the fluid viscosity and $q(x, t)$ is the flow rate. Furthermore, $p(x, t) = p_f(x, t) - \sigma_0$ is the net pressure, where p_f denotes the fracturing fluid pressure and σ_0 denotes the minimum horizontal stress. E is Young's elastic modulus and ν is Poisson's ratio of the rock.

Hydraulic fracturing is a physical mechanism essentially coupling the rock elastic response caused by the pressure of fracturing fluid, the viscous flow in the

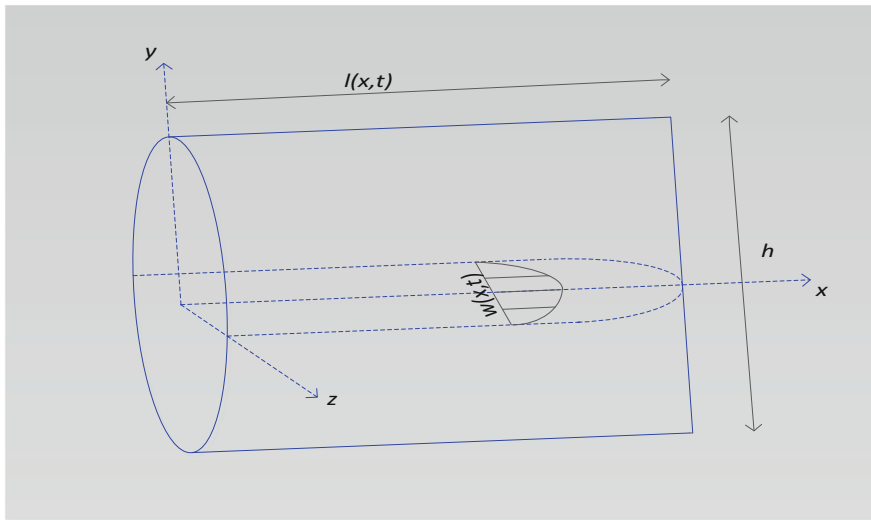


Fig. 1 PKN geometry

fracture, and the fluid leak into the surrounding formation. The governing equations of the PKN 2D model are reformulated based on linear elasticity theory for rock deformation, Poiseuille's law based on lubrication theory for fluid flow in the fracture and Carter's law for the leakoff process.

Particularly, the rock elastic response due to the fracturing fluid pressure inside the crack is expressed by Sneddon's equation for a dry, narrow crack, which describes the local relationship between net pressure and fracture width at every cross-section:

$$w = \frac{2h}{E'} p \quad (1)$$

where $E' = \frac{E}{1-\nu^2}$, denoting the plane strain modulus.

In fluid mechanics, Navier-Stokes's equations describe the motion of incompressible viscous Newtonian laminar fluids. Under the assumptions of lubrication theory-based Poiseuille's law (i.e., fluid flow in geometry has one dimension significantly smaller than the other two) and unchanged vertical fluid pressure for PKN modeling, the Navier-Stokes's equations reduce to the following form for incompressible Newtonian fluid flow:

$$q = -\frac{\pi w^3}{64\mu} \frac{\partial p}{\partial x} \quad (2)$$

The leak from the fracture into the host reservoir is assumed to be a 1D diffusive process in the vertical direction and follows Carter's law [12], described as:

$$q_l = \frac{2C_L}{\sqrt{t - t_0(x)}} \quad (3)$$

where q_l is the fluid leakoff velocity, t is the injection time, $t_0(x)$ is the time at which the fluid arrives at a point x and C_L is Carter's leakoff coefficient.

Finally, the continuity equation is induced from the local mass conservation, written as follows:

$$\frac{\partial q}{\partial x} + \frac{\partial w}{\partial t} + q_l = 0 \quad (4)$$

The system of the governing Eqs. (1), (2), and (4) together with the boundary conditions assuming fracture width and net pressure at the fracture tip equals zero (i.e., $w(x = l, t) = 0$; $p(x = l, t) = 0$) give the solutions for the PKN model. In the limiting case of storage dominated regime (i.e., no leakoff: $q_l = 0$), the governing system gives the analytical solution as follows:

$$l = 0.68 \left[\frac{G q_i^3}{(1 - \vartheta) \pi h^4} \right]^{\frac{1}{5}} t^{\frac{1}{5}} \quad (5)$$

$$w(0, t) = 2.5 \left[\frac{(1 - \vartheta) \mu q_i^2}{G h} \right]^{\frac{1}{5}} t^{\frac{1}{5}} \quad (6)$$

where q_i denotes the injection rate at the wellbore and $G = \frac{E'(1-\nu)}{2}$ denotes shear modulus.

In the limiting case of a dominated regime, meaning storage term in eq. (4) is negligible compared with the leakoff term (i.e., $\frac{\partial w}{\partial t} = 0$), the governing system gives the analytical solution as follows:

$$l = \frac{q_i t^{\frac{1}{2}}}{\pi C_L h} \quad (7)$$

$$w(0, t) = 4 \left[\frac{2(1 - \nu) \mu q_i^2}{\pi^3 C_L G h} \right]^{\frac{1}{4}} t^{\frac{1}{8}} \quad (8)$$

3 Simulation and Discussion

First, two limiting cases of the PKN model of storage-dominated and leakoff-dominated regimes were performed at both an early time $t_1 = 5s$ and a late time $t_2 = 700s$. The input data for the two cases are shown in Table 1, obtained from the literature.

The results were given in terms of fracture length and fracture width, as seen in Fig. 2. The material balance method in the form of volume balance for incompressible fracturing fluids (i.e., fluid density is unchanged) was then used to check the accuracy of the two cases. In particular, in the case of the storage-dominated regime: $Volume_{injection} = Volume_{fracture\ shape}$ and for the case of the leakoff-dominated regime: $Volume_{injection} = Volume_{fracture\ shape} + Volume_{leakoff}$. It is shown that at an early time $t_1 = 5s$, the case of storage-dominated regime provided a better result of 75% accuracy (Fig. 2a). At late time $t_2 = 700s$, the case of leakoff-dominated regime provided better results with an accuracy of 98% (Fig. 2b).

Another simulation was conducted to illustrate the role of the PKN model in the validation of a more complex P3D model. Here the chosen classic P3D model was developed by Adachi et al. in 2010 [7]. Their model was re-validated against the PKN analytical solutions for the storage and leakoff-dominated regimes. The results are shown in Fig. 3. It can be seen that the fracture width solutions of the P3D model agree with the PKN storage-dominated regime at an early time and the leakoff-dominated regime at a late time. The fracture length of the P3D model starts from the storage-dominated PKN solution and closely traces the leakoff-dominated solution at the end of its evolution. This demonstrates the effectiveness of using PKN-limiting solutions in the validation of P3D models. It is a critical application of the PKN model since validating complex models with field or lab experiments is costly and challenging due to the size and complex nature of the rock formations.

Table 1 Input data

Parameter	Symbol	Value	Unit
Shear modulus	G	$2.45 * 10^{10}$	Pa
Poisson's ratio	ν	0.2	
Fluid viscosity	μ	0.2	$Pa \cdot s$
Injection rate	q_i	0.062	m^3/s
Fracture height	h	10	m
Leakoff coefficient	C_L	$9.84 * 10^{-5}$	$m/s^{1/2}$
Early time	t_1	5	s
Late time	t_2	700	s

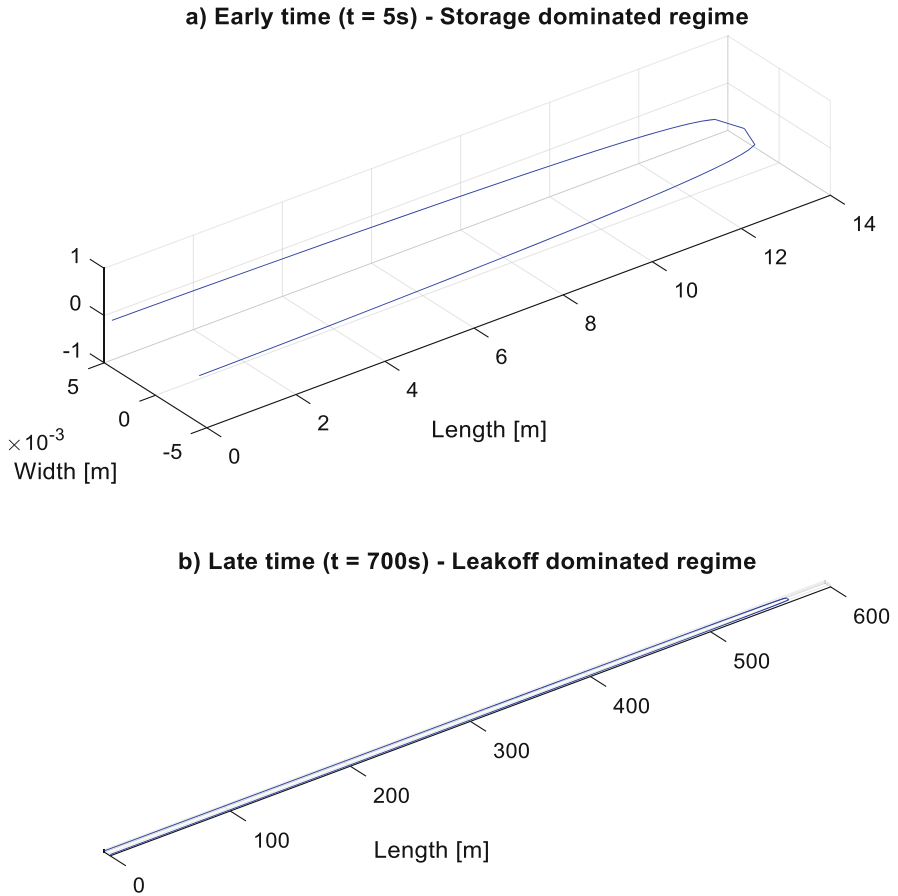


Fig. 2 PKN analytical solutions for two limiting cases: (a) storage-dominated regime happens at an early time and (b) leakoff-dominated regime happens at a late time

4 Conclusion

This work reformulated the PKN governing system and analyzed the vital role of the PKN 2D model in the development of hydraulic fracture modeling. Even though the PKN model is no longer applied for field operations owing to its simplified assumptions, this model is still a focal point in research. It is because the PKN model is a starting point for developing more complex P3D models. Furthermore, the PKN limiting solutions of the storage and leakoff-dominated regimes provide a practical yet convenient tool to validate more complex P3D algorithms. This application is a good alternative for situations in which laboratory or field experiments are not available.

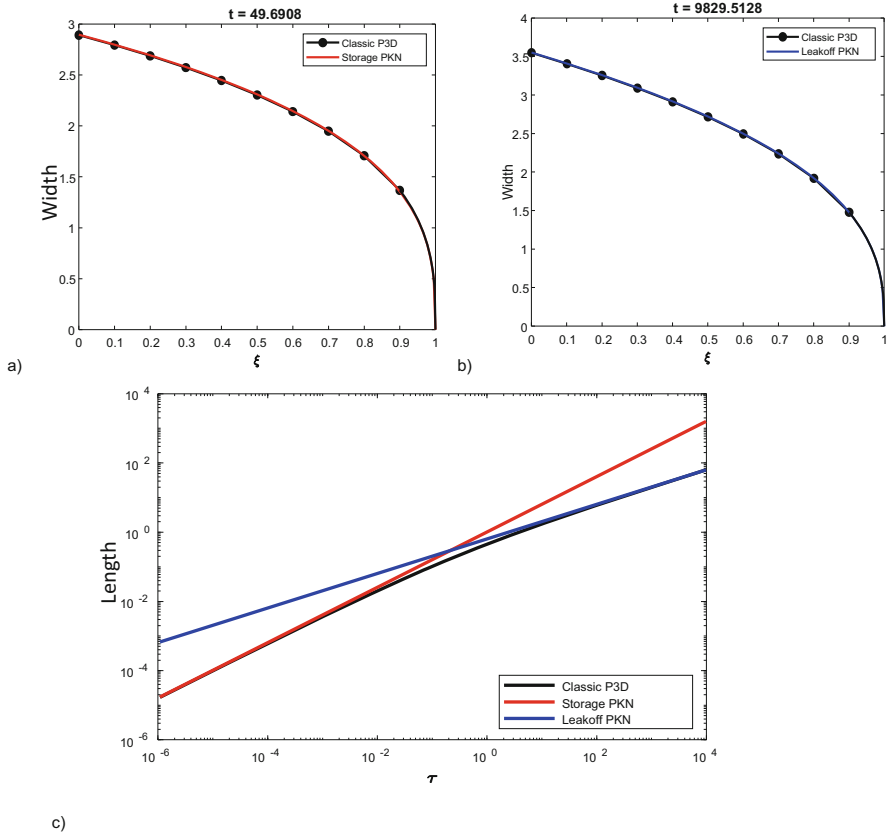


Fig. 3 P3D model validation against the PKN analytical solutions: (a) fracture width at an early time, (b) fracture width at a late time, and (c) fracture length evolution

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