An Extended Finite Element Method Based Modeling of Hydraulic Fracturing*

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Abstract

In hydraulic fracturing, high-pressure fluid is injected to the reservoir to create a connected network of fractures. Modeling of the hydraulic fracturing process demands applying a rigorous approach to take into account various mechanisms such as fluid flow inside the fracture, leak-off, rock deformation, and fracture initiation and propagation. Many studies are conducted to analyze each mechanism. These studies have offered different models for each process. However, these models generally failed to capture the essence of each mechanism since they did not examine the process as a whole. Most models are based on analyzing of a two dimensional system in which can be misleading in many circumstances.

Introduction

Hydraulic fracture initiation and propagation is a complex process that involves many mechanisms. Fracture initialization and growth depend on the type and direction of forces acting on fracture as well as type of rock materials and geology of the formation. Theoretical models commonly make many assumptions to reduce the computational space needed for the numerical operation. Therefore, accuracy of the models declines significantly and the models lose their ability to understand different phenomena associated in the process. On the other hand, conventional FEM cannot be applied for a large reservoir because of the expensive computational space needed to deliver an accurate and inclusive prediction.

In this study, we have introduced an innovative approach to model fracture initiation and propagation in a heterogeneous reservoir. We have constructed a workflow that incorporates the main mechanisms in the hydraulic fracturing. The workflow is shown in Figure 1.

Workflow

Our workflow is developed to address several conventional issues associated with hydraulic fracturing modeling. Among many things, the workflow incorporates the effect of fluid pressure at the boundary for the geomechanical model. Geomechanical modeling is performed utilizing an extended finite element method to simulate fracture initiation and growth. We provide a main platform to link all the programs and codes associated with the modeling. This is complemented by a method to model the fluid transfer between fracture and matrix. An example of fluid pressure distribution in a fracture-matrix system is shown in Figure 2. This method is based on solution to the diffusivity equation using Finite Difference technique. We analyze the rock behavior in a simplified model. Newly developed scheme was utilized to determine the crack initiation and growth based on traction-separation law. Maximum principal stress criterion was used to determine fracture initiation. In addition, a layer of shale is added to the reservoir model to study effect the heterogeneity on fracture deviation.

Discussion

As it is shown in Figure 1, first, the model is initialized using the available data. This step involves generating the input file for the modeling. Building the solid model, meshing, and assigning boundary conditions are performed in this step. Eight-node brick element was used for meshing of the model. In addition, pressure in the fracture is calculated considering the effect of leak-off. Then, this model is exported to the analysis section for stress field calculation. Once the stress surpasses the threshold, failure occurs and the fracture starts to grow. In the next step, fluid is allowed to progress in the fracture. At this step, new boundary condition is defined for the model. The loop continues until the fluid injection stops.

Summary

Several preliminary simulation results will be shown to demonstrate the effectiveness of the new approach. The model enables us to observe fracture deviation in the heterogeneous formation and to disprove current assumption of planar fracture propagation. Based on the above workflow, we will describe additional enhancements the new scheme to integrate the fluid flow model and geomechanical model in a single platform. This includes a physical modeling approach, involving only a few assumptions for developing the simulator. The workflow can be used to predict hydraulic fracture propagation under various operational and environmental conditions.

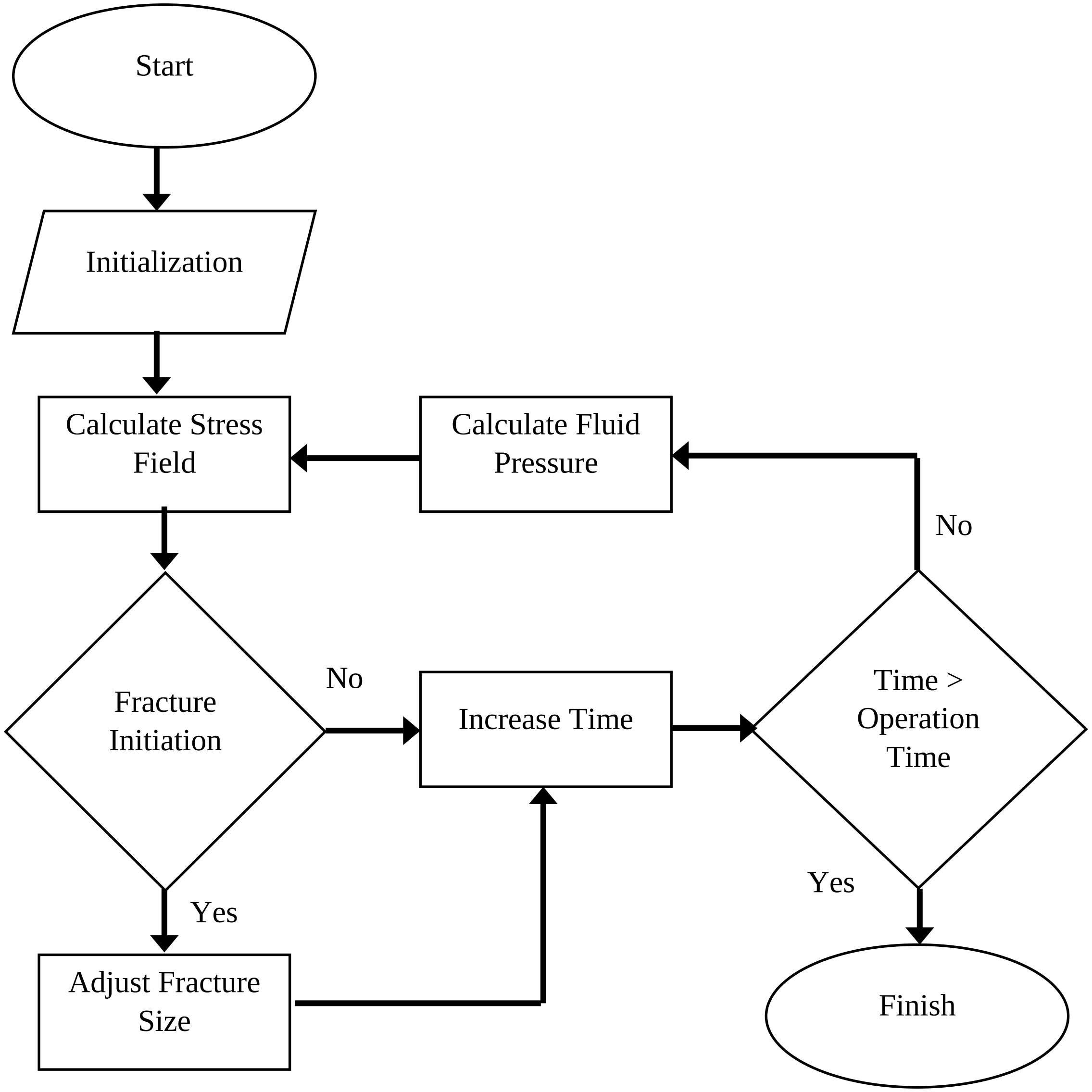
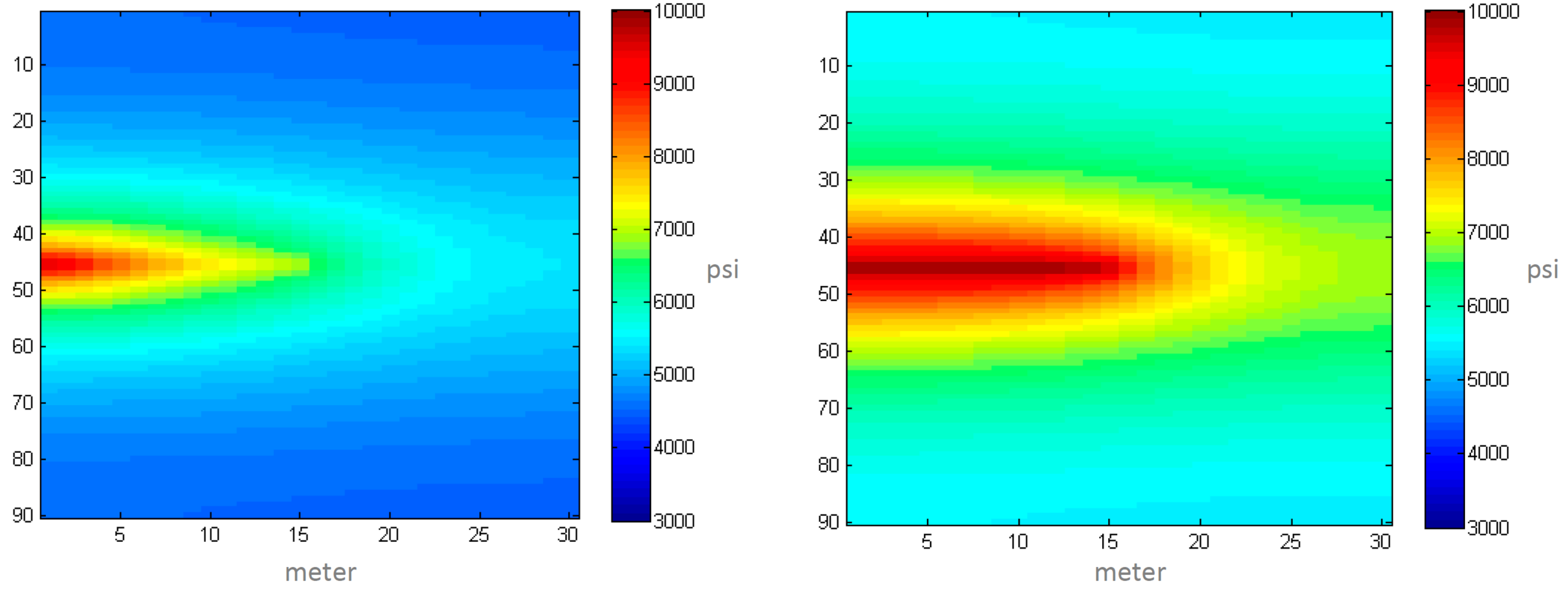


Figure 1. Workflow for the modeling of hydraulic fracturing.



(a) (b)

Figure 2. Pressure distribution around the fracture for different fracture permeabilities, a) 1,260 Darcy, b) 126,000.