A Finite Difference Approach to Modelling Hydraulically Fractured Systems

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Modelling a Hydraulically Fractured Well from Stage 1 through Flow Back and into Production

Abstract

This poster presents a holistic process for the simulation of the hydraulic fracturing treatment, flow-back period and the resulting multi-phase production of a well. By modelling the entire life of the well in a single simulation run, it is possible to learn about the properties of a reservoir that would be completely hidden by a modelling process that involved separate simulations for the hydraulic fracturing and the resulting production. Through refinements and iterations, this method has been applied to major unconventional oil plays and other prospects. This presentation summarizes the physics of the simulator that makes it unique for this purpose and shows an example of the results for the Three Forks. This type of simulation work involves numerous unknown variables so an automated history matching process is applied.

Introduction

- The hydraulic fracturing treatment and how the rock responds to the treatment are critical physical processes that add novel complexity to the history matching effort.
- A holistic model that matches measured injected fracture fluid volumes and generates the SRV based on those volumes and rates is presented here.
- Even with a simplified numerical simulation approach the problem becomes extremely complex under the weight of variables, so an assisted history matching algorithm is necessary to achieve a match.
- New physical processes such as bubble point suppression can be identified once the basic problems of hydraulic fracturing are resolved. It is possible to explore fracture design quantitatively using a finite difference model that combines the injection and production processes.
- A commercial simulator with simplified geomechanical capabilities has been used to model several wells in the Wolfcamp, Bakken, Eagle Ford, and Three Forks. The Three Forks is given as an example.

Mechanism

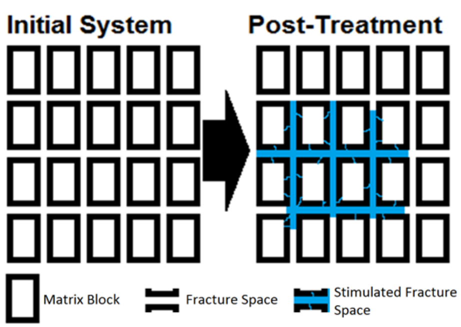
The model's fracturing is driven by effective minimum stress as defined by Terzaghi's law:

$$\sigma_{eff} = \sigma_{\min} - \alpha P_{pore}$$

In which σ_{eff} is the effective stress, σ_{min} is the minimum stress (fracture gradient), α is Biott's coefficient, and P_{pore} is the pore pressure.

Propagation

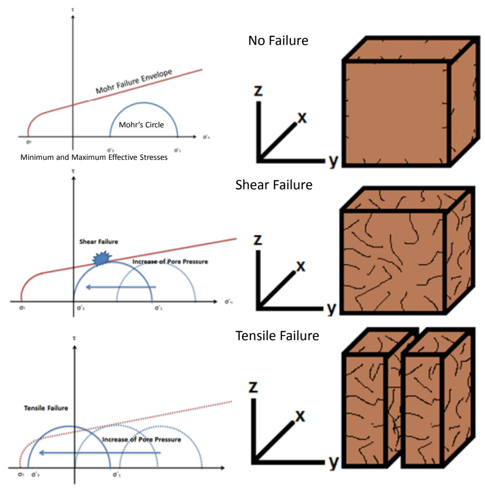
The simulator is used in dual-porosity mode. Each simulation cell is divided into fracture and matrix pore volumes. The matrix can only communicate with the fracture it shares a cell with. The fracture can communicate with other fractures. In the case of the unconventional reservoirs, the fractures are the micro-fractures caused by the over pressuring or structural fractures when appropriate. The hydraulic fracturing treatment is simulated by injecting the measured fluid rates and volumes into the fracture pore volume for each stage. The pore pressure increase alters the effective stress in the simulation cells and enhances the pore volume and transmissibility properties of the cells.



Shear and Tensile Failure

The history matching process uses two failure thresholds. Failure criteria were based on a simple understanding of the Mohr circle. The first threshold is at a low effective stress causing shear failure. Shear failure is represented by a large change to the ability of the fracture and matrix pore volume to communicate.

The second threshold is a lower effective stress and represents the tensile failure. Tensile failure enhances simulation cell to cell communication.



Closure

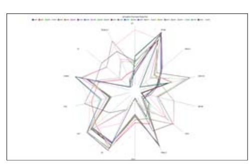
Closing the fractures during pressure depletion is as important as opening them. When the hydraulic fracturing treatment is complete, it has created a system that is capable of absorbing 30+ bbls/minute of fluid, but that is clearly not a sustainable production rate for these wells. Pressure depletion causes the fractures to close. Transmissibility compressibility values are the rate that the fractures close as a function of the pressure:

$$T_{x,1} = T_{x,\max} e^{\Delta P c_{tx}}$$

The maximum transmissibility of any cell is $T_{x,max}$. The current transmissibility of any cell is $T_{x,1}$. ΔP is the difference between the maximum pore pressure that the cell has reached and its current pore pressure. Depending on which pressure thresholds have been reached in the simulation cell during the run, different transmissibility compressibility values can be used. Stimulated but not propped, stimulated and propped, and non-stimulated regions all have different transmissibility closure behavior during depletion.

History Matching

The combination of pseudo-geomechanical and normal unknowns results in a tremendous number of variables to history match. An automated process is necessary to get the final answer.

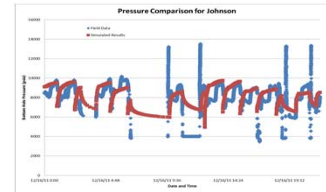


Common matching parameters are:

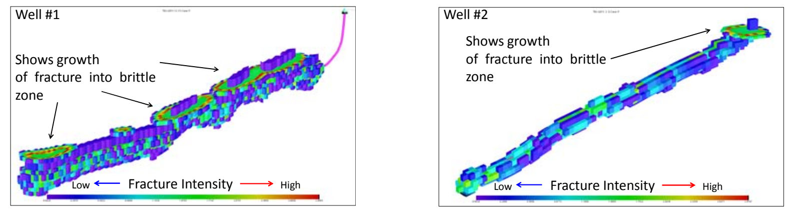
- Natural Fracture Porosity
- Matrix Porosity
- Natural Fracture Permeability
- Initial Pressure
- Default Fracture to Matrix Communication
- Transmissibility Multiplier at Different Stress Levels
- Effective Pore Volume Compressibility at Different Stress Levels

Application

The measured hydraulic fracturing fluid rates and volumes are injected into the model to generate the SRV. BHP pressure can be matched during treatment for history matching purposes. The following example is from Well #1, producing from the Three Forks. The blue points indicate the second-by-second measured BHP. The red points indicate the BHP from the simulation model:



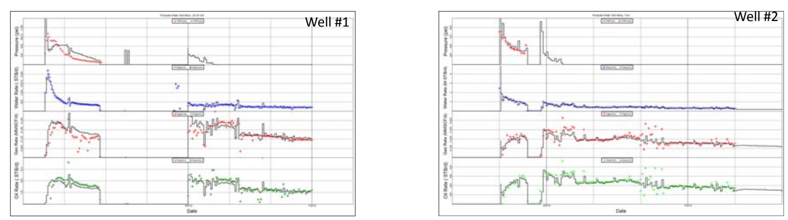
The following two pictures depict the SRV (stimulated rock volume) of two wells from the Three Forks that had surface locations 10 miles apart. Well #1 was history matched using the entire procedure including the assisted history matching of 20 parameters. Once this well was matched the reservoir properties and the hydraulic fracture parameters were used for Well #2. The history match for Well #2 was achieved without any significant effort using these properties.



By generating the SRV with the hydraulic fracturing treatment it is possibly to quantifiably predict how changes to the fracturing treatment will impact productivity

Production History

The production match of the two wells shown below. Black lines are the simulated results and colored points are the observed data. From top to bottom, pressure, water rate, gas rate, and oil rate are plotted. Liquid rate was used as the controlling constraint. The match for Well #2 was obtained with only PI tuning the resulting data set from Well #1.



Advantages

- This approach to history matching hydraulically fractured wells results in the maximum amount of information being used.
- Information gathered from one well can be applied to its neighbors. In the Three Forks examples above, the second well was matched without further effort using the information gathered from the first.
- Alternative scenarios can be run to quantify the impact of different strategies
  - Well placement/spacing
  - Fracture treatment volumes
  - Fracture treatment rates
  - Well orientation
  - Number of stages
  - Placement of stages

Future Improvements

- Proppant transport may be explicitly modelled
- Shear rate dependent fracturing fluid viscosity may be included
- Pressure drop representation through the perforations during fracture treatment can be improved
- More rigorous treatment of geomechanics
- Direct translation of geomechanical properties into flow simulator parameters