Howdy! This is the last Crisman newsletter for calendar 2013, a very active year for the Crisman Institute.

In this issue you will find two final reports on an ongoing acid fracturing project written by recent graduates.

As usual we had 2 two-day review meetings during the year, one in early May and the other in early December. Our December reviews featured 23 oral presentations, following the SPE presentation format, on both continuing and new projects. Additionally there were 5 posters on early-stage projects. Based on a request from some of our members, dinner on the first evening of the reviews was a more informal affair in the lobby of Richardson Building, using a lecture hall for seating. This allowed for significantly more informal interaction among company members, students and faculty. Our next reviews will be 30 April – 1 May 2014. We have found that the best dates for reviews are during the reading days between the end of semester classes and the beginning of final exams. This assures that there is parking available for our on-site attendees!

Ten new Crisman projects were funded in September as several others reached completion during the year. The new projects were chosen based on your feedback on 18 proposals submitted by our faculty (see November newsletter online for listing of new projects).

We have received several suggestions from our members on ways we can improve delivery of results to you and on increasing the interaction among our companies, students and faculty. We will be implementing many of these over the coming months—stay tuned for details in upcoming newsletters. One new event that I will describe here is that we intend to hold a series of webcasts in the form of “lunch-and-learn” beginning in the Spring. These will be announced to you by e-mail ahead of time. We are working out details, but the general idea will be to bring subsets of
Crisman projects that are working in similar areas for updates and discussion with you via the web. Two representative topic areas might be “the importance of rock-fluid interactions in source rock well completions and production” or “progress in description of storage and transport of hydrocarbons in organic-rich source rocks.” You may have other topical areas you’d like to see updated by webcast. If so, please let us know your thoughts.

I plan to continue offering and asking for ideas in future newsletters, but please don’t wait to be asked if you have suggestions on improving the way we serve you.

For now, all the best for a safe and restful holiday season. I look forward to further communication in the New Year.

Bob
Introduction

To quantify the cost and benefit of a particular acid fracture stimulation treatment, the practitioner must be able to predict its resulting conductivity profile. Conductivity correlations estimate the amount of conductivity generated by a given treatment and may be based on theoretical or experimental relationships. New conductivity correlations developed by Deng et al. (2012) utilize geostatistical parameters to describe the impact of the small scale arrangement of the acid-etched width on the overall conductivity, so the conductivity is strongly dependent on the etched width generated during an acid fracturing treatment.

Few options exist to predict the dissolved width during an acid fracturing treatment. Some commercial software can estimate the acid-etched width and calculate the Nierode-Kruk (1973) conductivity (StimPlan, MFrac, FracPro, GOHFER). At best, these software packages utilize 2D fluid flow solutions. This approach does not incorporate gridding perpendicular to the fracture surface and fails to capture numerically the process of acid convection and diffusion perpendicular to the fracture plane.

A model that numerically and rigorously resolves the acid-etched width for a given acid fracture treatment is needed to implement published acid fracture conductivity correlations. The acid fracture simulator developed by this project is a general, portable model of acid transport and dissolution in the fracture. The model uses the fracture geometry generated by commercial hydraulic fracture propagation software as the basis for the simulator physical domain. Gridding is fully 3D and includes resolution of the diffusion and convection of acid to the fracture surfaces. The acid fracture simulator yields the amount of dissolution that has occurred in every fracture grid block. With this information and a description of the statistical variations of certain rock properties, the final distribution of created acid fracture conductivity is determined using the new conductivity correlations (Deng et al., 2012).

Objectives

Develop an acid transport and fracture face dissolution model that can be easily coupled with commercial hydraulic fracturing simulators. The acid fracture model uses the fracture geometry generated by a 3D fracture model and numerically solves the equations describing acid transport and reaction. The model yields the etched width of each fracture grid block at the end of acid injection and the fracture conductivity of each grid block after fracture closure.

Approach

The first step in resolving the profile of acid in a fracture is to predict the transport of acid along the fracture and to the fracture surfaces. This work utilizes a standard computational fluid dynamic approach called SIMPLE (semi-implicit method for pressure-linked equations). SIMPLE is based on the fundamental Navier-Stokes equations to describe fluid flow. The non-Newtonian simulator option is quantified with the power law fluid model and handled numerically, using the traditional equations for (Continued on page 4)
Newtonian fluids and the apparent viscosity for a power law fluid. The last complication for the 3D velocity and pressure field solution portion of the simulator is to transform the rough physical domain into a smooth computational domain over which the calculations may be accomplished. This is done using the Jacobian to map between the physical and computational domains.

The acid concentration profile is then used to determine the resulting acid-etched width and conductivity. The acid balance requires a large matrix inversion based on the resolved velocity profile. Convection is considered in all three directions, but diffusion is only considered in the direction perpendicular to the fracture surface. The change of each surface due to dissolution by acid transported to the surface defines the acid-etched width. This is used in the new Mou-Deng conductivity correlations to calculate conductivity throughout the fracture both during and at the end of the treatment.

**Accomplishments**

A case based on an actual acid fracture treatment for a West Texas carbonate reservoir is used to demonstrate the simulator output. Four stages of a typical gelled acid fluid are injected via two perforation clusters into a fracture along a vertical well. The geometry for the simulator is created using StimPlan 3D (Smith, 2010). A fracture approximately 80 feet by 200 feet is created with the Fully 3D option at four different times during the treatment and used as input to the acid fracture simulator. The length, width, and height are exported from StimPlan and incorporated as the physical domain for the acid model.

The acid-etched width is distributed non-uniformly across the fracture length (Fig. 1). The gelled acid is modeled using a small effective diffusion coefficient, and this allows high concentrations of acid to reach the fracture extent. The acid-etched width profile follows the profile of the fracture in the center, but the non-uniform, initial fracture width results in relatively large etching at narrow locations within the fracture. The fracture narrows toward the fracture tip in the $x$- and $z$-directions. The narrower width at the tip enables more acid to diffuse to the fracture surface and create etching during the treatment.

The conductivity follows the pattern of acid-etched width across the fracture (Fig. 2).
The same geostatistical parameters are used across the fracture in the Mou-Deng conductivity correlation and represent the characteristics of the formation. These parameters indicate the formation is not strongly layered $\left( \lambda_{b,z} = 1, \lambda_{b,x} = 0.75, \sigma_y = 0.2 \right)$. Acid-etched width is generated across most of the fracture, but most of the conductivity is created in the first half of the fracture and in the vicinity of the perforations. The higher conductivity at the fracture top and bottom portions near the fluid entrance is due to the smaller width, which enables diffusion of the acid to create etching and conductivity where the acid concentration is near its maximum as it enters the fracture. At the end of the treatment any acid still in the fracture is assumed to create etching at the ratio of the user specified fraction of acid to react on the fracture surface before becoming leakoff $\left( f_r = 0.3 \right)$ for this case, which is supported via experimental comparison by Mou [2009]. This generates additional conductivity everywhere along the fracture but mostly where the fracture is the widest as the largest amount of acid is there to create additional etching. This counteracts the effect of narrower width generating the majority of the etching. The arithmetic average of conductivity across the fracture for locations where there is acid-etched width is approximately 4 mD-ft after closure. This suggests that the acid fracture treatment provided a small stimulation benefit.

**Significance**

The model developed in this project is a three-dimensional acid transport and etched width simulator. A standard computational fluid dynamics algorithm is used to determine fluid movement in the fracture. The fluid movement defines how acid is convected through the fracture, and this is coupled to the diffusion of acid to the fracture surfaces. The resolved acid concentration profile determines the acid that is present near the fracture walls, and this is used to calculate the etching that can occur for a specific acid fracture treatment. Lastly, the etching is used to resolve the conductivity by way of newly presented conductivity correlations that incorporate small scale etching effects to describe the treatment performance.

The model adds a number of new features to the simulation of acid fracture treatments. The most important feature is that the fracture interior is gridded in all three directions. This allows the severe concentration profile that occurs across the fracture width to be captured as well as changes along the fracture height (e.g., layer mineralogy, layer permeability, and velocity gradients in the vertical direction). In using a computational fluid dynamics approach, the velocity profiles throughout the fracture are resolved instead of assuming the shape of a profile based on an analytical expression. This is the first model to use computational fluid dynamics to describe the three-dimensional profile of acid throughout a fracture to quantify the etching and conductivity that occurs for a specific acid fracture treatment.

**Future Work**

The simulator does not describe all the physics of the acid fracture treatment process.
The simulator only accepts one initial fracture geometry and updates the acid-etched width. No geomechanical effects are considered during the model simulation. The width is a critical parameter that defines the acid concentration in the fracture, however, so changes to the fracture geometry during the treatment should not be ignored.

The next step in improving acid fracture treatment design modeling is to couple the three-dimensional acid concentration solution approach developed here to a fracture geometry model. Most hydraulic fracture models use semi-analytical expressions for the velocity profiles in the fracture. Typically the velocity profile results from the model during a simulation were very similar in shape to the analytical equations used by commercial software. The three-dimensional acid solution portion of the code could use the velocity profile from the commercial fracture simulator and calculate the acid concentration throughout the fracture. This methodology would marry the benefit of modeling the acid concentration throughout the fracture with the stability of commercial fracture geometry models for better acid-etched width and conductivity predictions.

References


Acid Fracture Conductivity Experiments

Objectives

Conduct a series of conductivity experiments using core or outcrop material supplied by sponsoring companies. The goals of these experiments are to examine the acid etching patterns for each formation type, and measure the roughness-scale conductivity that remains when larger channel-like features along the fracture faces have closed. This conductivity is the baseline conductivity that would exist in the absence of channels in the acid fracture conductivity model that is currently being developed under this same project number.

Specific Project Objectives – Experimental Study of Acid Fracture Conductivity of the Austin Chalk Formation

This research work focused on a systematic study to investigate the effect of temperature, rock-acid contact time and initial condition of the fracture surfaces on acid fracture conductivity. While temperature and rock-acid contact are variables normally studied in fracture conductivity tests, the effect of the initial condition of the fracture surface has not been extensively investigated.

Fracture conductivity tests were performed using an experimental facility that properly scale acid injection and leak-off fluxes to those compared in actual acid fracturing treatments. Austin Chalk cores were used as well as a linear gelled acid of extended use in this prolific formation. Two main objectives were identified for the present research work:

- Conduct a systematic study to investigate the effect of temperature and rock-acid contact time on fracture conductivity in Austin Chalk. Formation cooling effects and contact times that match current pumping schedules were considered in the creation of the experimental matrix.
- Determine if there is a substantial difference between the values of conductivity measured for smooth and rough fracture surfaces at the same experimental conditions. The mechanisms of conductivity creation will be characterized for both surface types.

Accomplishments

The experimental results showed that there is no significant difference in acid fracture conductivity at formation closure stress, using smooth or rough fracture surfaces in soft rocks such as Austin Chalk. In addition, we analyzed the mechanisms of acid etching and resulting conductivity creation in the two types of fracture surfaces studied by using surface profiles. For smooth surfaces, the mechanism of conductivity creation seems connected to uneven etching of the rock and roughness generation. For rough surfaces, acid conductivity is more related to smoothness of irregular features and the consequent mismatch of the fracture than by asperities or roughness creation.

Finally, we compared the experimental results with Nirode-Kruk correlation for acid fracture conductivity. Large disagreement was found between the experimental data and the correlation predictions. The discrepancy is due to the low formation strength of
Austin Chalk which causes a drastic reduction of conductivity as the closure stress is increased in the correlation. Our experimental data showed that the conductivity reduction might not be as steep as predicted by the correlation. This suggests that Nirode and Kruk’s correlation may underestimate acid fracture conductivity for soft formations such as Austin Chalk.