Fracture and Fluid Flow Control

Introduction

Control of subsurface fractures and fluid flow, a major component of "mastering the subsurface," is a grand scientific and technical challenge. If a marked improvement in mastery could be achieved beyond what has been developed up to this time after a century of drilling and fluid production/injection experience, there is the potential to radically transform multiple subsurface energy applications. For example, manipulating subsurface fracture characteristics and associated fluid flow is critical for improving recovery efficiency of unconventional hydrocarbons and geothermal energy. In nuclear waste disposal, minimization of fracturing and fluid flow in the near-field damage zone surrounding emplacement tunnels is needed for ensuring safe long-term storage. For CO_2 sequestration, energy storage (natural gas or compressed air), or large-scale disposal of liquid wastes, fluid flow may need to be enhanced to improve well injectivity, while also sealing potential fracture leakage pathways in the overlying confining layers. At a time when the subsurface is being called upon to provide primary energy resources and storage and disposal solutions for energy and energy wastes, the benefits of addressing this grand challenge now are potentially enormous, including:

- Dramatically improved efficiency of energy resource recovery;
- Robust design of energy/carbon/waste storage solutions;
- Reduced environmental risks and water use associated with subsurface energy strategies;
- Stronger scientific basis and increased public confidence in subsurface energy operations.

The current lack of precise control over fracturing and fluid flow despite decades of industrial practice is testimony to the huge challenges involved, primarily related to the difficulty of characterizing the heterogeneous deep subsurface and incomplete understanding of the coupled processes related to fluid flow, geomechanics and geochemistry over scales from nanometers to kilometers. What is needed is a substantial and sustained research effort focused on the overall theme of fracture and fluid flow control. This whitepaper summarizes research that should be undertaken to "master the subsurface."

Knowledge gaps and Proposed Research

Physicochemical processes in rocks under fracture stimulation including fluid-rock geochemical interactions

High-pressure fluid injection stimulation activates a wide variety of coupled processes involving thermal-hydrological-mechanical-chemical (THMC) effects that play out over a wide range of length and time scales. A better understanding of the stimulation of tight rocks (e.g., carbonaceous shales) is needed to design effective and sustainable fluid flow pathways. There is a need to characterize rock properties, including, textures, mineralogy, composition, and mechanical properties at all relevant scales and their effect on induced fracture characteristics. In addition to rock properties, the effects of fluid properties on induced and natural fractures need to be characterized in order to design and control the stimulation. An underlying need for realizing such control is a set of validated, rate-dependent poro-mechanical models for tight unconventional reservoirs and caprocks.

In addition, there are large uncertainties in predicting and modeling the geochemical interactions between the injectate, pore fluids (e.g. in nanopores) and minerals as well as organics in tight hydrocarbon-bearing rocks and the effect of geochemical interactions on rock's geomechanical response. To remedy this shortcoming, research is needed to improve understanding of fracture-matrix

fluid flow, fluid-organic-mineral, and fracture-tip interactions as a function of stress, temperature, and solution composition. Knowledge about fluids and geomechanics and geochemistry is essential to achieving mastery of control of fracturing (orientation, aperture, and size) from near-well-scale to reservoir-scale for efficient and sustained fluid extraction while minimizing formation damage and environmental impacts.

A sustained research program involving characterization, high resolution imaging, geomechanics, geochemistry, and coupled process experimentation and modeling is needed to address existing gaps in knowledge. Reservoir geologic material from sites such as unconventional hydrocarbon reservoirs, potential nuclear waste repository formations, and caprock from prospective geologic carbon sequestration sites should be used. Studies should be carried out on a range of scales from core, to block, to field scales and laboratory observations should be compared against targeted field observations.

Manipulating (enhancing, reducing, and eliminating) fluid flow

The primary means by which fluid flow can be manipulated is to control the fluid flow path. Some energy applications demand enhancements to fluid flow (e.g., hydrocarbon production), while others demand reducing or eliminating fluid flow (e.g., nuclear waste disposal, and geologic carbon sequestration). While hydraulic fracturing is widely used, and grouting of fast-flow paths is successful in some applications, there is a clear need for improved capabilities in this area as evidenced by rapid declines in production of gas from shale, and concerns about CO_2 and CH_4 leakage through fractures and faults.

In the area of stimulation by hydraulic fracturing, what is needed is the ability to adaptively control fracturing in real time. This demands a coupled injection-monitoring-modeling approach with a short response time. Improved understanding of fracture-matrix fluid flow in tight rocks is needed to enhance production. For reducing or eliminating flow paths, fluids or materials that change properties (e.g., solidify or become more viscous) as a function of natural or applied conditions are needed. This is useful for multi-step stimulations to create pervasive fracture networks in the face of single, large fractures dominating flow. The plugging of leakage pathways through caprock and thermal break through pathways are obvious applications for such technology. Another application is the delivery of fluids/materials to target zones for treatment or flow control.

Novel stimulation methods

While the current stimulation methods have been successfully deployed to produce unconventional fossil and geothermal resources, there is a need to develop environmentally sustainable novel stimulation methods. In some cases, novel stimulation approaches including combinations of approaches could make the difference between an economical and sustainable production well and one that would otherwise be abandoned. Depending on the relevant fracture initiation mechanisms, energetic approaches (e.g. low explosives) may provide advantages. Chemical approaches (e.g., acidization) coupled with mechanical stimulation could also have advantages.

Laboratory and field experiments on new materials, propellants, and energetics are needed to develop the capability to deliver precise stimulation at precise locations with the desired rate of energy release. There is also the possibility of developing green fracturing fluids (less or zero water) all of which need research and development. Finally, we need to develop full-scale simulation codes for fracture propagation with realistic heterogeneity and fluid properties with iterative coupling of models and experiments across scales to optimize effectiveness of stimulation approaches, including extent of stimulation, fracture spacing, fracture surface area, and fracture dynamics.