the ENERGY lab

PROJECT FACTS

Carbon Storage – ARRA - GSRA

Geomechanical Simulation of Fluid-Driven Fractures

Background

The overall goal of the Department of Energy's (DOE) Carbon Storage Program is to develop and advance technologies that will significantly improve the effectiveness of geologic carbon storage, reduce the cost of implementation, and prepare for widespread commercial deployment between 2020 and 2030. Research conducted to develop these technologies will ensure safe and permanent storage of carbon dioxide (CO_2) to reduce greenhouse gas (GHG) emissions without adversely affecting energy use or hindering economic growth.

Geologic carbon storage involves the injection of CO_2 into underground formations that have the ability to securely contain the CO_2 permanently. Technologies being developed for geologic carbon storage are focused on five storage types: oil and gas reservoirs, saline formations, unmineable coal seams, basalts, and organic-rich shales. Technologies being developed will work towards meeting carbon storage programmatic goals of (1) estimating CO_2 storage capacity +/- 30 percent in geologic formations; (2) ensuring 99 percent storage permanence; (3) improving efficiency of storage operations; and (4) developing Best Practices Manuals. Developing and deploying these technologies on a large scale will require a significantly expanded workforce trained in various carbon capture and storage (CCS) technical and non-technical disciplines that are currently under-represented in the United States. Education and training activities are needed to develop a future generation of geologists, scientists, and engineers who possess the skills required for implementing and deploying CCS technologies.

The National Energy Technology Laboratory (NETL), through funding provided by the American Recovery and Reinvestment Act (ARRA) of 2009, manages 43 projects that received more than $12.7 million in funding that focus on conducting geologic storage training and support fundamental research projects for graduate and undergraduate students throughout the United States. The training and projects can be categorized under one or more of the DOE Carbon Storage Program's five Technology Areas: (1) Geologic Storage and Simulation and Risk Assessment (GSRA), (2) Monitoring, Verification, Accounting (MVA) and Assessment, (3) CO_2 Use and Re-Use, (4) Regional Carbon Sequestration Partnerships (RCSP), and (5) Focus Area for Sequestration Science. This project focused its efforts on modeling of fluid induced fractures.

CONTACTS

Traci Rodosta
Carbon Storage Technology Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507
304-285-1345
traci.rodosta@netl.doe.gov

Robert Noll
Project Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236
412-386-7597
robert.noll@netl.doe.gov

Joseph Labuz
Principal Investigator
University of Minnesota
500 Pillsbury Drive SE
Room 122 CivE 0851
Minneapolis, MN 55455
612-625-9060
jlabuz@umn.edu

PARTNERS

None

PROJECT DURATION

Start Date	**End Date**
12/01/2009	11/30/2012

COST

Total Project Value
$299,568

DOE/Non-DOE Share
$299,568 / $0

PROJECT NUMBER

DE-FE0002020

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U.S. DEPARTMENT OF ENERGY

Project Description

The University of Minnesota provided graduate and undergraduate students the opportunity to participate in cutting-edge research related to the modeling of fluid-driven fractures, a challenging geomechanics problem associated with geologic carbon storage. An understanding of fracture propagation provides researchers with the insight to help them maintain the reservoir and caprock integrity critical to any CO_2 geologic storage project. Modeling studies indicate that fractures in the caprock formation (the low permeability formation above the target injection formation) can lead to potential CO_2 leakage into other formations, including drinking water sources.

The difficulties in fracture simulation stem from a number of interacting factors including: (1) the strong nonlinearity in the lubrication equation (which takes into account fluid density, fluid velocity, and normal and shear stress) that governs the flow of fluid inside the fracture; (2) the moving boundary nature of these factors as the crack edge and the possibly distinct fracturing fluid front evolution; and (3) the deterioration of the lubrication equations near the crack front caused by the disappearance of the channel aperture, which is itself responsible for a large fluid pressure gradient in the tip region. In particular, the challenge to accurately capture the near tip pressure gradient (ultimately needed to calculate the velocity of the fracture front) is the major disadvantage of most computational algorithms for hydraulic fracture. Trying to accurately estimate this phenomena requires long calculation times and irreversible errors in the predicted evolution of the fracture footprint.

The research approach for this project included numerical analyses with the boundary element method, and physical experiments for material characterization and predictive model testing. The numerical modeling approach allowed the following conditions and processes to be considered: (1) a piece-wise homogeneous media, i.e. inclusions with different elastic properties, may be incorporated; (2) a system of arbitrary curvilinear cracks; (3) a wide range of boundary conditions, which may include tractions, displacement discontinuities, etc.; and (4) the possibility to take into account different types of poroelastic effects.

Goals/Objectives

The goal of project was to support graduate students working on the geomechanical simulation of fluid-driven fractures, and develop technologies to predict CO_2 storage capacity in geologic formations. The project has the following objectives:

- Devise rock characterization techniques related to laboratory testing of fluid-saturated rock.
- Develop predictive models for the simulation of fluid-driven fractures.
- Establish educational frameworks for geologic carbon storage issues.

Figure 1. A novel apparatus is used to produce failure of fluid-saturated rock and to characterize poroelastic parameters.

These objectives were achieved by: (1) using a novel apparatus to produce failure in a fluid-saturated rock; (2) modeling fluid-driven fractures with the boundary element method; and (3) developing curricula for training geoengineers.

Accomplishments

- By the completion of the project, seven students had accumulated 6,248 training related hours under the program.
- Deformation and damage of a porous, fluid-saturated rock under drained and undrained conditions were investigated. A plane-strain apparatus was modified in order to conduct tests with water-saturated rock specimens and to measure the pore pressure within the rock. Transducers within the apparatus were calibrated at the various loading states and the com-pliances of the system were determined. Plane strain compression and conventional triaxial compression tests were performed at different confining pressures under air-dry (Figure 2), drained, and undrained conditions. Acoustic emissions (AE) were random in nature until a fracture peak occurred. AE events become more localized after the fracture propagated.
- The behavior of the rock was evaluated within the framework of linear poroelasticity. Dilatant hardening and contractant softening was investigated from undrained experiments, where pore pressure was measured throughout the failure process. The parameters that govern the inelastic deformation of fluid-saturated rock, (i.e. dilatancy angle β, friction coefficient μ, poroelastic coefficient Keff, shear modulus G, and inelastic hardening modulus H), were calculated for the drained response. Pore pressure increases as rock samples were compacted, and showed no decrease until the deformation of the specimen became inelastic.
- The constitutive model predicted the undrained inelastic response of the rock with relative accuracy, almost up to the peak load if compared with the undrained test that had the same effective mean stress at the onset of inelasticity. Knowledge of dilatants hardening behavior is essential for the proper assessment of underground structures, such as long-term CO_2 storage facilities
- A final report has been completed and is now available.

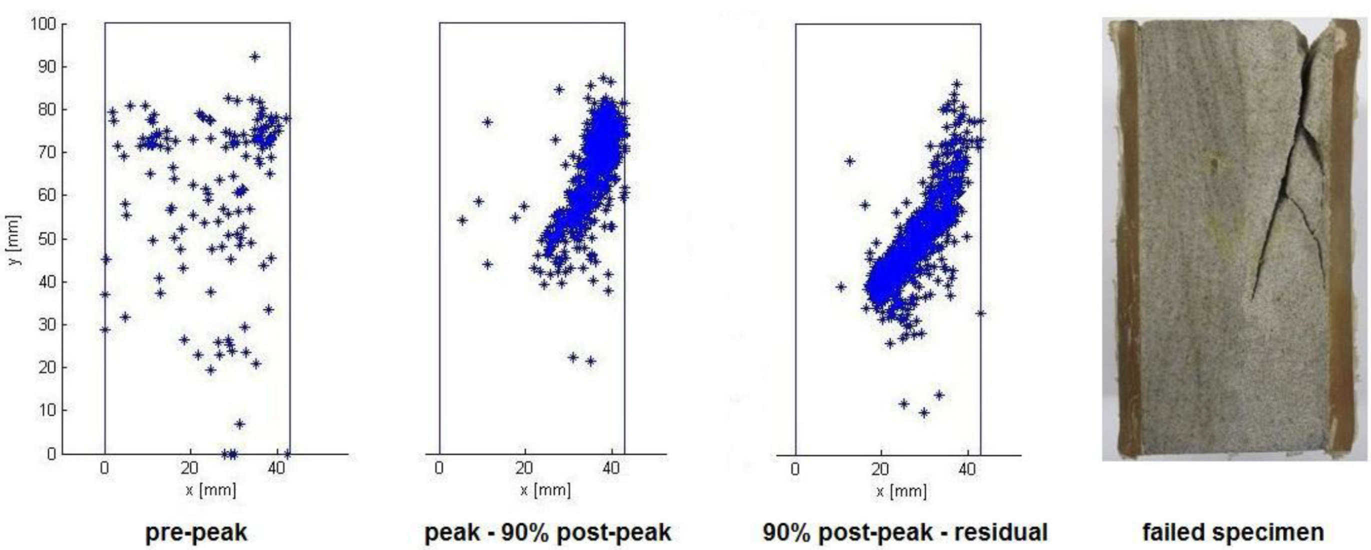

Figure 2. Acoustic emissions (AE) under the dry test. AE events were found to be random throughout the rock sample before a fracture peak occurred. AE events were more localized after the peak resulted.

Benefits

Given the anticipated timeframe associated with the lifetime of geologic carbon storage field project, modeling of fluid-driven fractures is an essential tool for predicting the effectiveness of a reservoir, and modeling provides works toward the Carbon Storage Programmatic goals for ensuring 99 percent storage permanence and improving the efficiency of carbon storage operations. Additionally, the project provided geosciences-based research opportunities for graduate students, in order to build a workforce well-versed in the field of CCS.

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