PROJECT facts

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
STRATEGIC CENTER FOR NATIONAL GAS AND OIL

Petroleum Exploration and Production

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TIME-LAPSE SEISMIC MODELING AND INVERSION OF CO_2 SATURATION FOR SEQUESTRATION AND ENHANCED OIL RECOVERY

Accurate modeling methods enable high-resolution CO_2 flood front imaging

PARTNERS

4th Wave Imaging Corp.
Aliso Viejo, CA

MAIN SITE

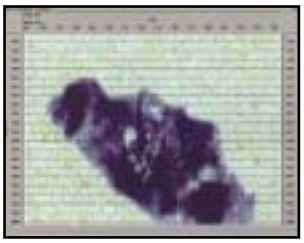
Aliso Viejo, CA

Background/Problem

Time-lapse seismic monitoring during CO_2 injection is still in its infancy. Seismic monitoring requires knowledge of the rock and fluid properties of the oil reservoir to track changes in CO_2 saturation and pressure over time. In addition, the behavior of supercritical CO_2 is complex, and its interaction with brine and oil in porous rock systems is not well understood. Modeling CO_2 behavior often can lead to numerical instabilities that create large artifacts in modeled time-lapse seismic data and in maps of CO_2 saturation and pressure changes.

Project Description

The goal of this project is to improve current methods of rock physics and time-lapse seismic reflection modeling for CO_2 sequestration and miscible CO_2 floods in oil and gas reservoirs, and to develop new strategies to invert such data to estimate changes in pressure, oil saturation, water saturation, and CO_2 saturation over time.



Time-lapse CO_2 seismic data set showing a clear amplitude anomaly caused by increasing CO_2 saturation at this level

The project consists of three phases. In Phase I new ways to calculate fluid properties of oil-water-CO_2 mixtures under varying reservoir conditions are being investigated. A thorough literature search has revealed two major approaches for accomplishing this: using either an equation-of-state (EOS) formulation or molecular dynamics simulations. These two approaches are being compared for robustness and accuracy. A preliminary EOS formulation has been developed that is capable of calculating bulk fluid properties from multiple liquid and gas phases for supercritical CO_2 mixtures.

In Phase II this EOS is being used to perform 1-D time-lapse seismic modeling by calculating changes in well-log velocities and densities under varying CO_2 saturations and pressures. In addition, progress has been made in building a 3-D seismic modeling tool that can be used to predict time-lapse seismic anomalies in 3-D field data.

In Phase III, a method is being developed to invert time-lapse seismic anomalies to yield maps of CO_2 saturation and pressure changes over time. The first step of this method—which generates seismic attributes as a function of CO_2 saturation and pressure changes, including changes in both miscible and free CO_2 levels—has been completed.

Time-Lapse Seismic Modeling and Inversion of CO_2 Saturation for Sequestration and Enhanced Oil Recovery

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TOTAL ESTIMATED COST

$0.8 million

COST SHARING

DOE	$0.6 million
Non-DOE	$0.2 million

WEBSITE

www.netl.doe.gov

Accomplishments

In this project calculations were enhanced to determine rock and fluid properties of CO_2-oil-water mixtures in porous rock systems in order to better predict how CO_2 affects time-lapse seismic data. New tools were developed that use these data to 1) model the time-lapse seismic response of a reservoir during CO_2 injection, and 2) invert time-lapse seismic anomalies to yield estimates of CO_2 saturation and pressure changes.

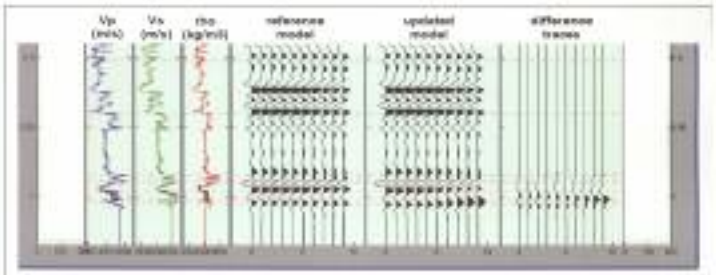
Among other accomplishments, the project participants:

- Investigated new ways to compute fluid properties of oil-water-CO_2 mixtures using both EOS methods and molecular dynamics modeling.
- Developed a 1-D seismic modeling program that uses time-lapse changes in well-log velocities and densities to predict changes in seismic data during CO_2 injection.
- Wrote an algorithm to accomplish the first step of the inversion procedure, namely, the generation of time-lapse seismic attribute changes as a function of changes in CO_2 saturation and pressure.
- Completed a preliminary evaluation of time-lapse seismic anomalies in different vintages of a 3-D data set from Sleipner gas field in the Norwegian North Sea.

Benefits

Miscible CO_2 flooding has become an increasingly important enhanced oil recovery (EOR) technique in the U.S. for recovering residual or bypassed oil. For example, roughly half the CO_2 floods in the world are located in the Permian Basin, producing more than 20% of the area's total oil production.

By developing an accurate approach for tracking CO_2 fronts during EOR operations, this project is expected to help improve recovery rates, optimize well patterns, locate bypassed oil, and minimize the cost of injected CO_2. Project results also will benefit the public by improving current methods for monitoring reservoir leaks and verifying the location and quantity of sequestered CO_2 in order to minimize its impact on the environment. CO_2 sequestration in oilfields is getting more attention because of concerns over the gas's role in purported climate change.



Example of time-lapse seismic modeling of well-log velocities and densities during CO_2 injection.

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