

Seismic Monitoring of the CO₂ Flood at Weyburn Field

**Thomas L. Davis, Martin J. Terrell and Robert D. Benson, Department of Geophysics, and John Fanchi,
Petroleum Engineering Department, Colorado School of Mines,
1500 Illinois Street, Golden, CO 80401 USA**

Summary

Multicomponent, time lapse (4-D) seismology is being used for monitoring the CO₂ flood at Weyburn Field. By monitoring the areal and vertical distribution of CO₂ in the reservoir, the vertical and lateral sweep efficiency in the reservoir can be increased and more oil ultimately recovered.

Introduction

If we can monitor sweep efficiency laterally and vertically in the reservoir by 4-D, multicomponent seismology we can effectively manage the reservoir. The bottom line is to lower costs, and increase recovery. Multicomponent 4-D seismology enhances the accuracy of the reservoir model. An enhanced reservoir model enables improved forecasting which allows for better operational response. Better operations and improved reservoir management positively affects the bottom line. The technology pays for itself through the additional percentage of incremental recovery that can be added by increased recovery efficiency.

Weyburn Field

Weyburn Field is located on the northeast flank of the Williston Basin in southeast Saskatchewan, Canada. Approximately 1000 wells, including 137 horizontal wells with 284 lateral legs, have been used to recover 24% of the 1.4 billion barrels of oil originally in place. Pan Canadian, the operator, has converted 19 patterns of horizontal wells to CO₂ injection. Injection of 3 to 7 mmcf/day/well has occurred since early October 2000. The goal of CO₂ flooding is to increase production by at least 15% incremental oil.

Weyburn Field produces from the Mississippian Midale Beds of the Charles Formation. The reservoir is made up of two parts: the uppermost Marly dolomite and the lowermost Vuggy limestone. The reservoir is overlain by an anhydrite unit that forms the top and updip lateral seal to the reservoir. The combination of the overlying anhydrite and the porous upper part of the reservoir provides an acoustic impedance contrast and a seismic reflector coincident with the

reservoir interval. The reservoir zone generally averages 100 ft (30 m) in thickness, has a temperature of 145° F (63° C), and a pressure of approximately 3000 psia (20.7 MPa).

The most porous unit is the Marly, averaging 26% porosity. The Marly averages 30 ft (9 m) thick in the study area. Permeability of this zone is low, averaging 10 md. Horizontal wells drilled since 1991 in Weyburn Field have targeted the Marly as a zone of bypassed pay. These wells have substantiated the belief that the Marly unit has not been as effectively swept as its underlying counterpart, the Vuggy. The Vuggy averages 70 ft (21 m) in thickness with an average porosity of 11% and permeability of 15 md. The flow capacity of the formation is the product of permeability and net thickness. The Marly has a relatively low flow capacity relative to the Vuggy and correspondingly low sweep efficiency. The potential for bypassed oil in the Marly is greater with CO₂ flooding than it is with waterflooding because of the comparatively high mobility of CO₂.

If seismic data can be used to monitor the CO₂ front in the reservoir, especially in the Marly, significant cost savings could occur. Permeability is the biggest uncertainty in the reservoir modeling thus far. Until permeability can be established, operating strategies devised to maximize recovery based only on waterflood performance are in question. The specific goal of our research is to create a high-resolution measurement system for monitoring the sweep of the Midale reservoir at Weyburn Field.

A baseline survey was acquired in Fall 2000 prior to CO₂ injection. The areal extent of the survey encompasses approximately 3.4 square miles (9 square kms) and monitors at least four injection patterns. The surface data was shot with a fine grid of source and receivers to maximize the quality of seismic data for post-stack and pre-stack analysis of amplitude. These amplitudes will enable determination of attribute volumes of bulk density, compressional and shear wave velocities, and fracture density/permeability on a high resolution basis as input to the dynamic reservoir characterization process. A repeat or monitoring seismic survey is scheduled for Fall 2001. The greatest benefit of monitoring occurs early in the life of the project.

Reservoir Characterization

Baseline multicomponent seismic data reveal the presence of faults with a few meters of offset at the reservoir level. The greatest fracture density occurs in proximity to the faults. The open fracture systems are conduits for fluid movement vertically and laterally in the reservoir. Shear waves are much more sensitive than compressional (p) waves to the vuggy porosity and natural fractures within the reservoir. As a result multicomponent seismic data has been used to map reservoir porosity and permeability into the reservoir model.

Reservoir Simulation Results

If current well rates are maintained, simulation results show that seismic differences should be detectable by Fall 2001.

Injected CO₂ is flowing both vertically and horizontally away from the horizontal injectors. The geologic model obtained from the history match includes a zone of relatively large vertical permeability in the vicinity of the injection well that allows fluid flow between the upper (Marly) and lower (Vuggy) layers. The most detectable timelapse seismic changes may be associated with seismic changes as a function of depth. For this reason surface seismic surveys are being integrated with crosswell seismic surveys.

Discussion and Conclusions

The present study encompasses 4-D multicomponent and crosswell seismic, integrated with reservoir simulation. Monitoring is necessary because CO₂ may flow downward into the Vuggy with a corresponding reduction in sweep efficiency in the Marly. Monitoring will enable important reservoir management decisions to take place early in the tertiary flood and lead to enhanced recovery.